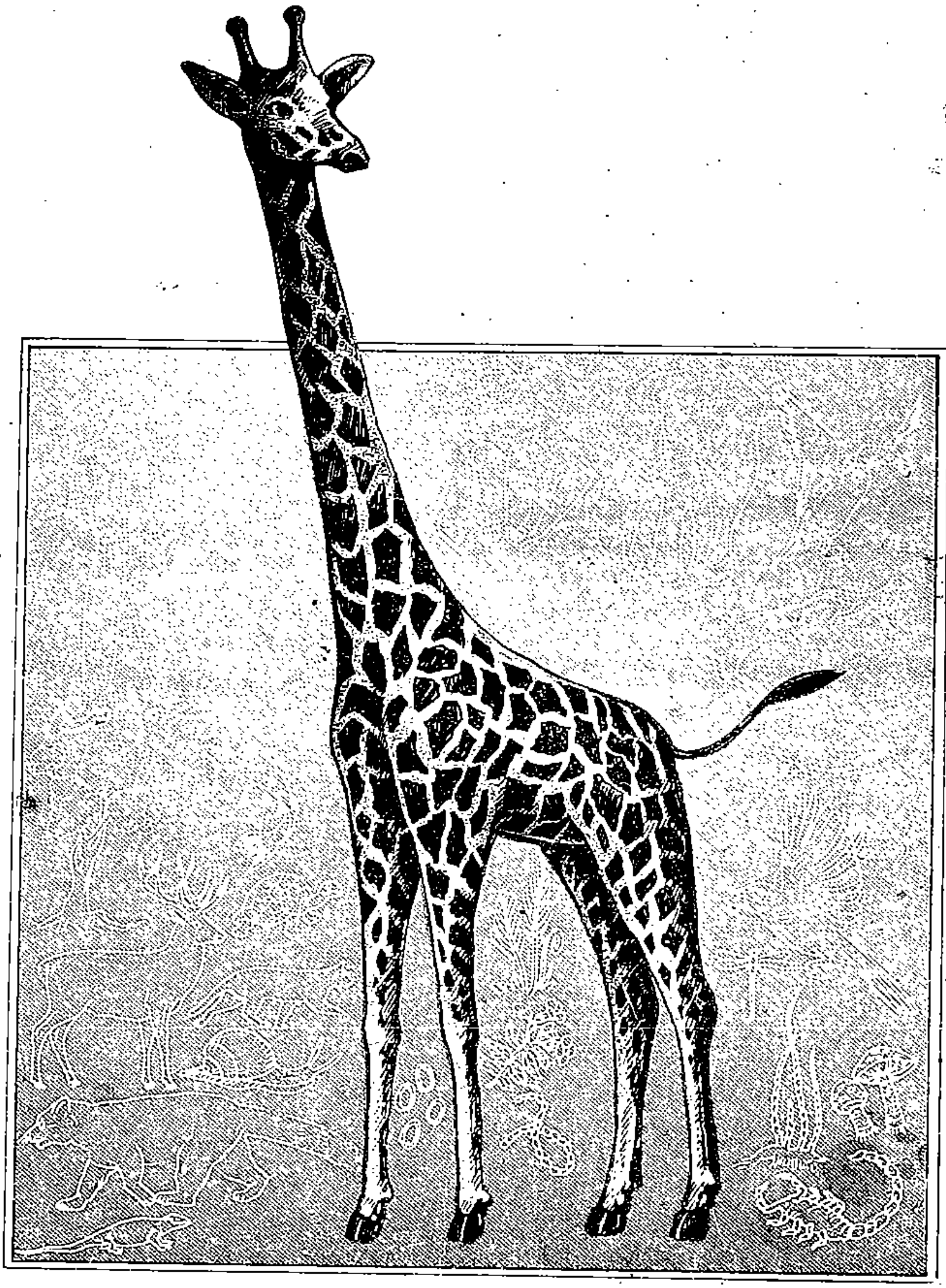
Indira Gandhi National Open University
School of Sciences

U424/B4-10

LSE-07

Taxonomy and Evolution



History and Concept of Taxonomy

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Indira Gandhi
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UGZY/BY-10

Taxonomy and Evolution

Block

1

HISTORY AND CONCEPT OF TAXONOMY

TAXONOMY AND EVOLUTION

Taxonomy and Evolution is a four credit elective course and consists of four blocks. Blocks 1 and 2 are concerned with taxonomy and Blocks 3 and 4 on evolution. There are specific reasons as to why we have clubbed these two subjects together into one course. You may be aware that the seeds for the ideas on organic evolution were sown before the birth of Christ during the period of Greek Philosophers. But it was only during the period of renaissance, beginning with 18th century, more specifically with Carolus Linnaeus (1707-1778) the father of modern taxonomy that evolutionary biology was truly born. Linnaeus contributed the essential tool of taxonomy to the evolutionary science. Besides this significant contribution, he also held the view that all species originated from a common genus and the diversification occurred because of hybridisation. In other words the species of a genus might be genetically related. Thomas Henry Huxley (1825-1891), a contemporary of Darwin and an outstanding spokesman for the cause of evolution (hence earned the nickname "Darwin's bulldog") has this to say on taxonomy: "That it is possible to arrange all the varied forms of animals into groups, having this sort of singular subordination of one to the other, is a most remarkable circumstance." Darwin in fact saw different degrees of genetic relationship among the various taxonomic categories. For instance, although the members of the phylum chordata may be distantly related to each other phylogenetically, the most fundamental chordate characters are found commonly among them. Within a class the degree of relatedness is much closer. This tendency continues even as we go down the taxonomic ladder and finally members of a species share a common inheritance and only differ in minor traits. It is this idea that crystallises in Darwin's definition of evolution—"the descent with modification". Let us look into the details of course.

The Blocks on taxonomy will introduce you to the classification of animals and plants, its objectives and importance. You will learn the need for classifying the animals and plants and the various systems of classification. Here, the emphasis is laid on the significance of the scientific terminology associated with the taxonomical studies and the concept of binomial nomenclature. Taxonomy has spread its wings to the other branches of science and the result is the birth of certain new trends in the study of systematics of animals and plants such as chemotaxonomy, cytotaxonomy, numerical taxonomy etc.

The study of evolutionary biology has gained a lot of importance in the past five decades. The theory of natural selection put forth by Charles Darwin showed that evolution is a simple fact of nature. Darwin was the first one to think evolution in terms of populations. He suggested that evolution could be explained in terms of adaptations and in terms of facts of heredity. The Blocks on Evolution lay a great emphasis on the origin of adaptations through the process of natural selection. Evolutionary biology as a lively branch of science has expanded during the past century, and other disciplines as genetics, palaeontology and molecular biology have made this branch of science a more comprehensive and an all encompassing one.

Broad Objectives

This course should enable you to

- comprehend the objectives and importance of the principles of classification and become familiar with various systems of classification of plants and animals,
- appreciate the importance of the contributions from other fields of biology to taxonomic studies and become conversant with the recent trends in taxonomy,
- discuss as to how the plant and animal populations evolve by adaptations to their environment and have a basic understanding of the evolutionary process, and
- describe the speciation process and have a better understanding of the human evolutionary history.

Study Guide

To get maximum benefit out of this study material please take note of the following points:

i) Read the material slowly and attentively. Spend enough time on figures and tables. This will help you in better understanding of text.

ii) While studying the text, underline the important points in the Block itself. Write down salient points in space provided on each page, or in your notebook if necessary.

iii) After finishing a section or subsection, ask yourself—what have I learnt? Try to list the important points in your notebook and compare them with the text and see if you have missed any.

iv) We have given Self-Assessment Questions (SAQs) within the text after each major concept. The Terminal Questions (TQs) are given at the end of each unit. Attempt all the self-assessment questions and terminal questions. Don't skip any of them as they are designed to assess your understanding of the subject. If you cannot answer, read the text again.

v) The answer to the SAQs and Terminal Questions are given at the end of each unit. Don't get tempted to see the answers before you try them.

vi) If you don't understand any word in the text, consult a dictionary. For scientific and technical words consult the glossary given at the end of each block or a scientific dictionary if necessary.

vii) Some of the ideas and concepts under evolutionary biology may appear to be abstract to you. Therefore, you may have to study certain of the units, more specifically, Units 11, 12 and 13, more than once in order to comprehend them.

viii) To understand the evolutionary concept a basic understanding of the mechanism of inheritance is necessary. You should have taken our course on Genetics (LSE-03) which would be of great help in understanding the evolutionary biology. If you have not opted to do Genetics, get the Blocks and go through them to become familiar with the concepts.

ix) We have suggested a number of books under further reading in each block. These books are available in your study centre. These books will be of help to you in case you require more details.

x) **You will find at the end of each block a questionnaire attached. Fill this questionnaire, tear it off from the block and send it back to us.** The questionnaire relates to any difficulty that you come across while studying the block. Your answers will help us to improve the text by revising it suitably.

BLOCK 1 HISTORY AND CONCEPT OF TAXONOMY

Each one of us is a taxonomist from the cradle to the grave. Each one of us classifies, identifies, names and describes each and everything that we come across in our daily life. Thus taxonomy is the most relevant field of enquiry for modern man. The scientific classification developed to arrange all of the world's plants and animals in related groups is called taxonomy. Latin and Greek words are used in scientific classification because early scholars used these languages.

The classification is based on certain basic guiding principles or guidelines which are followed all over the world. Thus certain classification or systems of classification are formed. Plants and animals are different from each other thus they are dealt separately. In this block you will read about taxonomy, its concepts and principles and their development. You will also come across history of classification and various types of classification.

The first unit deals with history and taxonomic concepts, principles and objectives of taxonomy. You will learn the difference between taxonomy and systematics in this unit. The history of plant and animal classification is given with special emphasis on history of plant classification in India.

The second unit deals with the system of plant classification. It is a descriptive unit and carries three systems of classification.

i) Artificial System – Linnaeus's System

ii) Natural System – Bentham and Hooker's System

iii) Phylogenetic System – Engler and Prantl's System
Hutchinson System
Takhtajan System

Their basis, outline and merits and demerits are described in detail.

The third unit is devoted to animal classification. Various types of classification namely phenetic, natural, phylogenetic, evolutionary and ominspective are described. Taxonomic characters, their selection and taxonomic hierarchy are described so that you will know how to use them and realise their importance. This unit is a lengthy one. The widely accepted Five Kingdom Classification System which is described includes animal as well as plant kingdom.

In unit four, you will study about biological nomenclature. The assignment of names to plants is called nomenclature which was relatively unstructured until the seventeenth century. If a plant is well-known it may have a dozen or more common names. Common or vernacular names are not universal and may be applied only in a single language. These names vary from place to place. This necessitated the use of scientific names, that are universally accepted and are recognised through out the world. The scientific names of plants and animals are based on the genus name and specific epithet. This two-word format **binomial nomenclature** made naming more convenient and is universally accepted. In this unit you will study more about binomial nomenclature.

Objectives

After reading this block you will be able to:

- define and describe taxonomy, the concepts, and their development,
- study about history of plant and animal taxonomy with special reference to the advantage of using any of them.
- describe and know the importance of artificial, natural and phylogenetic classification of plants,

- describe various types of animal classification and their importance, and interpret the advantagge of using any of them.
- describe and use the generally accepted Five Kingdom Classification System including plants and animals, its merits and demerits,
- describe the fundamental principles of nomenclature and its importance in biological world especially taxonomy.

UNIT 1 TAXONOMIC CONCEPTS AND THEIR DEVELOPMENT

Structure

1.1 INTRODUCTION

The history of classification is an exciting aspect of plant taxonomy. The discovery of the use of plants for food and later as medicine began at a very early stage in the history of civilisation. The early hunter-gatherer society eventually gave way to the classification of plants. Plants were classified as edible, poisonous and medicinal. Thus plant taxonomy originated and took its shape The earlier groupings were practical and based largely on their economic uses. They were not based entirely on morphology but also on smell, taste and nutritive value From that period to present day the development of taxonomy has witnessed a series of changes. The ancient concept about plants has undergone an entire change with advance of knowledge and updated versions of earlier work. Plants provide an orderly and comprehensive array of curiosities for their classification.

The history of plant taxonomy is fascinating and full of controversies and is still reshaping itself. Systematised story of plant description dates back to the period of Bock, de l'oble, Brunfels and Fuchs. Philosophical giants like Theophratus, Aristotle, Dioscoroides and Pliny added a more systematic and scientific approach to the subject. The progress in taxonomy was gradual and assisted by all those interested in various aspects of economic plants. Earlier attempts to classify plants from each other were purely artificial and based on external features of the plants alone. But gradually ecological study of plants and usage of environment considerations developed the science of taxonomy. In this unit you will get aquainted with history of taxonomy and will learn about principles of taxonomy. There will be special emphasis on taxonomy in ancient India.

Objectives

After reading this unit you will be able to:

- define and differentiate between taxonomy and systematics,
- describe various principles of taxonomy and systematics,
- discuss aims, objectives and importance of taxonomy,
- describe the history of plant and animal taxonomy, with special emphasis on plant taxonomy in ancient India.

1.2 NEED FOR CLASSIFICATION

Species are groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups.

First of all there is a need to know what classification is? Let us define in simple term. **Classification is placing of a plant (or groups of plants) or animal (or groups of animals) in groups or categories according to a particular plan or sequence and in conformity with a nomenclatural system.** Every species is classified as a member of a particular genus, the genus belongs to a family, family to an order, the order to a class and so on (Fig. 1.1).

Kingdom : Plantae, ANIMALIA, etc.
Phylum : Echinodermata, Arthropoda, Mollusca, Cnidaria, CHORDATA etc.
Class : Aves, Amphibia, Reptilia, MAMMALIA, etc.
Order : Primates, Perissodactyla, Artiodactyla, Insectivora, CARNIVORA, etc.
Family : Canidae, Ursidae, Mustelidae, Viveridae, FELIDAE, etc.
Genus : *Panthera*, *FELIS*, etc.
Species : *Cancolor*, *CATUS*, etc.

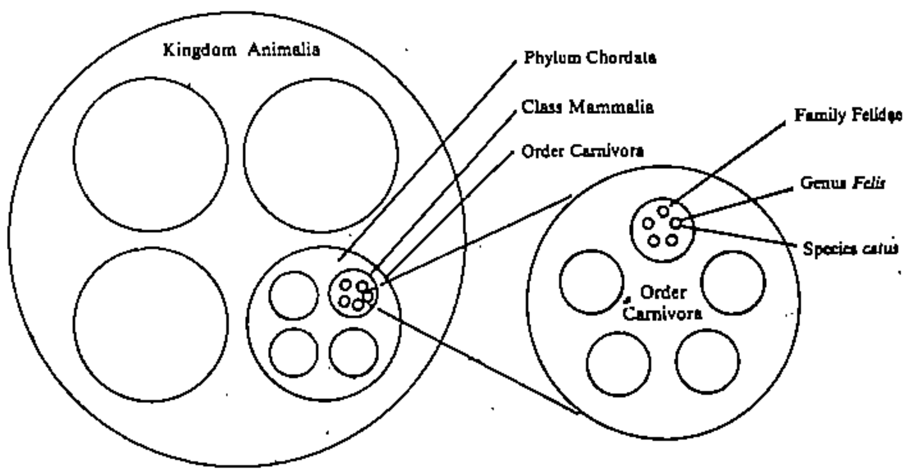

Fig. 1.1 : The Principal categories in classification

In practical terms classification deals more with the placing of a plant group with a selected scheme than the placing of an individual plant in one of several minor categories. Thus a system of classification is necessary to allow us to identify plants and animals and to communicate scientifically with others. Indeed, classification is both an information storage and retrieval system without which scientific communication would be impossible. For instance a plant's name is the key that unlocks the door to its total biology. Ecologists, horticulturists, biochemists, agriculturists and others must have a reference system for the plants, they use in their research. However, the name of plant is not meant only for the scientist, it may be used by other people with varied interests and training, those who are interested in the natural history of plants. The scientific name of a plant communicates the species and genus, and from that the family may be easily determined.

From the time immemorial plants have been known by some name, they are common, vernacular or local names given by different persons. Thus a single plant can bear several names, or several plants can be named by the same name at different places. For example, *Verbascum* has 140 names, *Viola* (pansy) has more than 150 names, *Plantago* (plantain) has about 50 names. Some common names such as 'celar', Foxtail, flame of the forest are being used for variety of plants markedly different from each other. It is, therefore, apparent that in order to avoid confusion some general principles of universal acceptance had to be adopted. Thus professional botanists gradually suggested names to all the known plants and classified them in a scientific way. The scientific names and classification are published and remain unchanged in different languages and are quoted as such universally in botanical literature.

We will take an example and see how classification helps its user. For example, when a forester identifies a white oak *(Quercus alba)*, it can reasonably be assumed that there are other individual white oaks in nature that have similar morphological features, structure and physiology. The knowledge that a plant is *Quercus alba* automatically predicts that much information will be applicable to that plant.

Classification thus enables us to summarise our knowledge about the organisms, and that is one of the most important functions of taxonomy.

1.3 AIMS, OBJECTIVES AND IMPORTANCE OF TAXONOMY

Plants and animals both have a great significance and unparalleled impact on human life. Most of our needs are fulfilled with plants such as foodstuffs, medicinal products, and fodder resources. So the plants whether harmful or beneficial are intimately associated with daily life and that's why it becomes necessary to have an orderly and scientific approach for the study of plants. There are millions of plants in which upto some extent there are differences or similarities but none of them are identical. Thus the individuals showing similarities are placed in smaller groups known as species and these species are placed in larger groups known as genera. The basic knowledge of plants is the first necessity and provides idea about their morphological variations. Various usage of plants in everyday life necessitated formulation of standard terminology for description of various parts as an aid to identification and nomenclature. The systematised study of plants and animals has benefitted all those who are related to forestry, medicine, paper industry and food etc., as it helps them to procure proper material. This is also associated with the study of plant and animal diseases as they affect human economy.

Modern work is saturated with extensive development of hybrid plants since they are more useful for people as providing better fruit, seed and flower products, and without the knowledge of taxonomy **hybridization** is not possible. The study of plants also helps in soil conservation as their special features are employed to minimise the loss of soil, and increase the soil fertility. Next comes agriculture and horticulture. Both are interrelated branches of science and have a direct bearing on taxonomy. Fossil identification is possible only when adequate literature on the living plants and animal is available. Identification of preserved specimens is sometimes difficult because of their fragmentary and ill-preserved nature. But the information about them evolves the evolutionary sequence and helps in furtherance of establishing connecting links amongst various taxa.

Plant taxonomy has a long history. It gave birth to several phases of botany but remains exciting, interesting and important because there is a direct link between fascinating species of plants and its inhabitants. Taxonomic studies have major objective—the learning of the kinds of plants and animal on earth, their names, their distinctions, their affinities, their distribution and habit. In the beginning, the science of taxonomy was the study of small fragments of plants which were collected, labelled and put on record. The information accumulated from these studies is fundamental to the scientific knowledge of the inventory of the earth's plant resources.

A second objective of taxonomy is the assemblage of knowledge gained. This is usually in the form of treatises useful to fellow scientists and to civilisation in general. But the knowledge thus gained is sterile unless it is transferred to others for study. Thus the floras and fauna are published to account for the plants and animals of a given area. Manuals are prepared so that the plants and animal of an area may be more readily identified and named; revisions, and monographs are published so that one may know the extent and delimitations of a particular group and its components. Distributional studies are published so that others may know of range extensions, corrections and interrelationships of the taxa within an area. All the products of taxonomic research add to the resources and are available to scientists. They are essential to any study of the natural resources of raw materials possibly suited to man's needs in a multiplicity of activities, for example, forest products, medicine, food, ornamentals, agriculture and industry.

A taxon (plural taxa) is a groups of organisms defined by the classification scheme, such as particular species or class.

A third objective is the demonstration of tremendous diversity of the plant and animal world and its relation to man's understanding of evolution. An organised reconstruction of the plant and animal kingdom as a whole can be made only after the inventory of its components has been assembled. After assemblage, charting of the degree and character of variation will demonstrate its diversity, and these data can be integrated with other facets of evolutionary knowledge to produce a more accurate phylogenetic scheme.

Let us summarise the objectives of taxonomy:

i) to inventory the world flora and fauna

ii) to provide a method for identification and communication

iii) to produce a coherent and universal system of classification

iv) to demonstrate the evolutionary implications of plant and animal diversity and

v) to provide a single Latin "scientific" náme of every group of plants and animals in the world, both living and fossil.

SAQ 1

State whether the following statements are true or false and indicate by putting T for True and F for False in the given brackets.

1) The basic knowledge of plants provides idea about their morphological variation. [ ]
2) Hybridisation is possible without the knowledge of taxonomy. [ ]
3) Study of plant taxonomy also helps in conservation of soil and to decrease soil fertility. [ ]
4) Fragmentary and ill-preserved specimens sometimes helps in establishing connecting links amongst various taxa. [ ]
5) One of the important objective of plant taxonomy is to give accurate phylogenetic scheme. [ ]
6) One of the most extensive works of taxonomists was to provide a single Latin scientific name. [ ]

1.4 PRINCIPLES OF TAXONOMY AND SYSTEMATICS

Before coming to principles of taxonomy let us discuss the difference between taxonomy and systematics. **Systematics is the science of identifying, naming and classifying all organisms.** The potential económic uses of plants may not be immediately evident, but we must know which plants are related to one another in order to predict their properties. Wild relatives of our cultivated plants often have genes that can provide the desirable qualities, such as disease resistance, needed by plant breeders for crop improvement. Even nonscientists can more readily understand evolution and variation by observing the relationship of form and function that are so conspicuous among flowers. Thus this is the subject which fascinates scientist and nonscientist alike.

Before coming to principles of systematics let us define systematics and know that difference between systematics and taxonomy (Fig. 1.2). For example Systematic botany is the broad field concerned with the study of the diversity of plants and

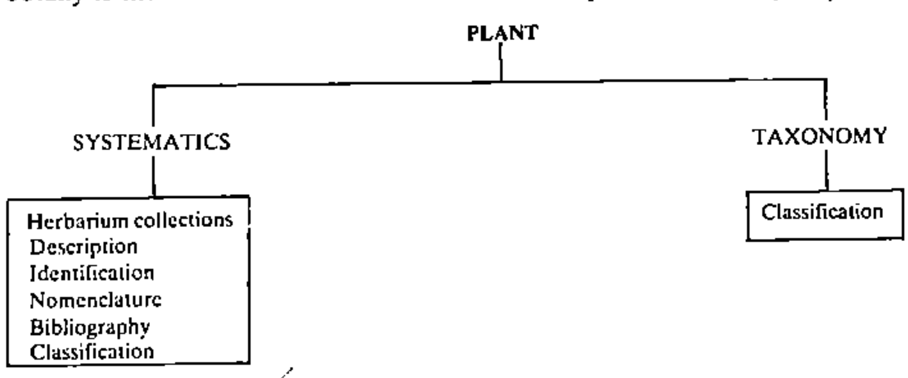

Fig. 1.2 : Difference between plant systematics and taxonomy

their identification, naming (classification), and evolution. Systematics have a broad area of study while taxonomy is restricted to the study of classification. However, taxonomy and systematics are very often considered by many to denote the same thing and the terms are treated as synonymous.

Classification is the arrangement of organisms into groups having common characteristics. These groups are then arranged according to a system. For example similar species of flowering plants are placed into a genus (plural, genera); similar genera are grouped into families; families with common features are arranged into orders, orders into classes and classes into divisions. Classification results in the placing of organisms into a hierarchy of ranks or categories such as species, genera, families and so on. You will study in detail about these concepts in Unit 3.

We will now learn something more about systematic botany. The early recognition of harmful and useful plants was the beginning of systematic botany. When the language was developed it was possible that observation of plants was accumulated and this knowledge could be passed from one generation to the next. Today, the basic recognition and grouping of plants has developed into a highly complex science concerned with classifying plants into groups based on postulated evolutionary relationships. Systematic botany includes all activities that are part of the effort to organise and record the diversity of plants and acquaints us with the fascinating differences among the species of plants. Thus systematics provide an inventory of plants or animals, scheme of identification, their names and a system of classification. Systematics is basic to other scientific fields, but also it depends on other disciplines for information and data useful in constructing classifications. A sound classification bringing related organisms together, may suggest problems worthy of study by ecologists, plant breeders, pharmacologists, horticulturists and biochemists.

SAQ 2

Fill in the blanks with appropriate words:

Systematic botany is broad field concerned with the .... of plants and their ...., and ....
Classification is the arrangement of plants into groups having .... groups are arranged into a .... and Similar plants are placed into a ...., similar genera into ....
Classification results into a hierarchy of .... such as ...., ..., ... and so on.

Now we will discuss the principles of taxonomy which enable us to classify the diversity of organism in different groups.

- The goal of taxonomy is to develop a workable classification that reflects evolutionary relationships and provides identification and nomenclature.
- Species represent lineages produced by evolution and branching genetic relationship exists among the taxa of each group.
- Categories such as species, genera, families and orders are not rigid but are flexible and individually delimited for each group. Hierarchy is established by International Code of Botanical Nomenclature for plants and International Code of Zoological Nomenclature for animals.
- Taxa are based on the correlation of characters and discontinuities in the variation pattern. Any attribute of the plant/animal may be selected as character and they do not have fixed value at all ranks.
- The selected character should be constant and must show little environmental variation for delimiting taxa.
- Taxa should be monophyletic.
- Taxonomic treatments should be practical and consistent in their use of the various categories.
- Taxa may resemble one another because of either convergence or parallelism.
- In the development of classification whenever possible, taxa should be sampled throughout their range and all taxa at lower ranks should be examined.

- Ancestral features and trends of diversity may often be recognised in the structure of living organisms.
- Ancestral organisms should be given careful consideration.
- Evolution may result in reduction or loss of parts which should also be taken into consideration.
- Morphological characters should be given proper importance because they provide guidance to primitive versus advanced features and aid in developing phylogenetic relationships. Thinking should be very flexible so that modifications in classification may be made as soon as new evidence is available.
- In phenetic taxonomy, taxa are organised and classified on the bases of similarities of the phenotypes of the organism.
- The modern taxonomy includes cladistic taxonomy which involves summarising knowledge about similarities among taxa in terms of a branching diagram called a cladogram depicting the hypothetical evolutionary histories of the organisms.
- Biogeography is also an important part of taxonomy because it analyses the pattern of distribution of organisms and relates these to the systematics of the organisms.

Classification thus enables us to summarise our knowledge about the organisms, and that is one of the most important functions of taxonomy. The saving of time and effort is thus one way in which we can define the utility and purpose of classification.

SAQ 3

Strike out the incorrect word (or words).

i) The goal of taxonomy is to develop workable classification that reflects evolutionary/non-evolutionary relationship.

ii) Species represents lineages produced by evolution and branching genetic/nongenetic relationships.

iii) Categories such as species, genera, families are rigid/flexible and individually delimited for each group.

iv) For delimiting taxa selected character should be constant/nonconstant and must show little variation.

v) Taxa should be monophyletic/diphyletic.

vi) In the development of classification taxa of lower rank should/should not be examined.

vii) Evolution may result in only reduction/increase in parts.

viii) Morphological characters should/should not be given proper importance because they provide aid in developing phylogenies.

ix) Modern taxonomy includes/does not include cladistic taxonomy.

x) Cladogram depicts/does not depict the hypothetical evolutionary history of the organisms.

1.5 HISTORY OF PLANT CLASSIFICATION

Before Darwin's theory of evolution and publication of his epoch making work 'Origin of Species' in 1959 no outstanding basis for the classification of plants was used. Therefore, the history of evolution of plant classification can broadly be divided into two eras, the pre-evolutionary and post-evolutionary era.

The pre-evolutionary era can further be subdivided into four important periods for the sake of convenience and better understanding.

I) The Ancient Greeks and Romans

II) The Herbalists

III) The Transition Period and

IV) The Post-Herbal Period

In the present unit we shall tell you briefly about some ancient Greek and Roman naturalists and scholars who made important contributions to plant sciences in general and plant classification in particular in their own classical way. They made observations on living organisms and classified them. The period of those classic ancient Greeks and Romans culminated into a period of descriptive botany when several important herbals were written by several celebrated physicians, naturalists and other scholars. It was a significant departure from the earlier works which were written for utilitarian reasons only and had little academic importance. You will learn about those herbalists of the Middle Ages and their work also in this unit.

1.5.1 The Ancient Greeks and Romans

Hippocrates, "The Father of Medicine" (460-377 B.C.) is reputed to have been one of **Democritus**'s disciples. He lived to an advanced age, being famous as the founder of the Hippocratic School of Medicine which started the study of the causes of disease. It cast new light upon the use of herbs. A list of about 240 plants used in medicine may be found in the writings of the Hippocratic School, but they were mentioned primarily for their medicinal properties, not being described botanically. The Greek rootdiggers (rhizotomoi) and drug merchants (Pharmocopuloi), who engaged in the business of collecting and preparing drug from plants, acquired knowledge which must have been advantageous. Their knowledge of plants was, however, empirical and full of superstitions and would have contributed little to the science of botany.

Aristotle, the Stagirite : The prodigious activity of Aristotle (384-323 B.C.) marks the climax of the Golden Age of Greece. The very existence of his works proves not simply that he had an encyclopedic mind of the highest order, but also that a large amount of research had been accomplished by his predecessors. His deep mathematical knowledge was happily balanced by a very extensive acquaintance with every branch of natural history.

Aristotle was born in 384 B.C., the son of **Nicomachus,** physician to the royal family of Macedonia. Born in Stagira, a small Greek colony on the Macedonian coast, he was sometimes called the Stagirite. His father, Nicomachus, was a member of the guild of the Asclepiads which was composed of physicians using herbs and other remedies known only to members of the guild. At seventeen, Aristotle went to Athens where he met and became a pupil of **Plato.** Aristotle, though essentially a biologist, was closely attached to his master and continued to be a member of his school until Plato's death in 347 B.C.

The plant was an integrated thing to Aristotle; leaves, shoots and roots were not mere appendages of the plant but were members of an organised thing. Each of them had its own characteristics but they had dependencies, relations, and harmonies which interacted to maintain the life of the whole.

Theophrastus of Eresus : The Father of Botany (370-285 B.C.); of all the men who ever lived upon the earth certainly one of the most remarkable was Theophrastus of Eresus who was born about 370 B.C. on the isle of Lesbos (Modern Mytilene) in the Aegean sea and is regarded as the Father of Botany. Botanical science in its broadest aspects received tremendous stimulus in Greece under the leadership of **Theophrastus** and his disciples. Incredibly enough, only about one-twentieth of his voluminous writings were about botany, but his **'Historia Plantarum'** is , the foundation of all we know about plants today, in which he classified and described about 480 kinds of plants, and gave accounts of woodland, marsh, lake, river and other plant associations. In this classic work he also indicated essential differences between dicotyledons and monocotyledons. Theophrastus became a student of Plato at an early age. Plato died when Theophrastus was only 22; after that he became a student and later a close friend and fellow teacher of Aristotle. When Aristotle died he bequeathed his manuscripts, books and botanic garden to Theophrastus who was then 48 years old.

In his works, philosophy of Plato and Aristotle is clearly reflected. He classified all plants on the basis of form or texture; trees, shrubs, undershrubs and herbs, and distinguished between annual, biennial and perennial. He also differentiated between centripetal (indeterminate) and centrifugal (determinate) inflorescences, recognised differences in ovary position, and in polypetalous and gamopetalous corollas. Different types of insertion of floral parts, characteristic of hypogynous, perigynous and epigynous plants were clearly recognised by Theophrastus.

Theophrastus **'Historia Plantarum'** survived the centuries from his death until invention of printing in the mid 15th century. It was among the first books to be printed and, as it began to appear again and again in Greek, Latin, German and English, until by 1866 more than 20 editions had appeared in practically every European language.

Caius Plinius Secundus, also known as **Pliny the Elder** (23-79 A.D.), a Roman naturalist and scholar, born in Como, mentioned nearly a thousand plants in his **'Historia Naturalis'.** This work in 37 volumes is a very elaborate encyclopedia, often critical but of great value, since it contains a wealth of information not to be found elsewhere. Sixteen of these volumes dealt largely with plants, treated such topics as medicinal properties, classification, forestry, plant anatomy, and the practice of horticulture.

Pliny seemed to have little interest in the classification of plant on the basis of their resemblances. He classified trees as forest trees, exotic trees, and fruit trees. He divided forest trees into glandiferous and pitch-bearing; the former including all the catkin bearing trees, the latter most of the Conifers.

Pedanios Dioscorides, a Cicilian Greek, who lived in the first century A.D. was the most important botanist after Theophrastus. He was a military physician under Emperor Nero of Rome. His principal writings were on medical botany. During the Middle Ages his work was far more popular than that of Theophrastus though he knew less about botany. For more than 1500 years he was the alpha and omega of European botany. His chief contribution, **'Meteria Medica'** was description of about six hundred species mainly mediterranean, used for medicinal purposes. Another manuscript, the **'Anicia Juliana Codex'** was prepared for the daughter of a Byzantine emperor about 512 A.D. from material originally compiled by Dioscorides. It contained coloured illustrations of plants and is still in existence.

The most significant aspect of this period of early Greek and Roman naturalists and scholars was that men began to think originally and fundamentally about the universe, supernaturalism and mythology were abandoned in preference to logic. During this time the foundations for scientific study of nature were laid.

1.5.2 The Herbals

During the Middle Ages, following the decline of the Greek and Roman civilisations, little significant botanical progress was made. The early herbals (i.e., old books about plants), such as the **Codex** of Dioscorides, were copied and recopied for centuries with only few additions or improvements. In the first half of the sixteenth century, however, a botanical renaissance developed, and it was greatly stimulated by the still young art of printing.

The herbals of **Brunfels, Bock, Fuchs, Cordus** and others, sometimes referred to as the 'German Fathers of Botany', are representative of this period.

Between the years 1530 and 1536 **Otto Brunfelsius** (Brunfels) (1463-1534) published his **'Herbal'** which consisted of descriptions of a large number of plants, many illustrated by woodcuts. It was the beginning of modern taxonomy. This was soon followed by **Leonardus Fuch's 'De Historia Stripium'** (1542) and **Hieronymus Dock's 'Kreuter Buch'** (1539). Fuchs was primarily a medical botanist. His idea of the flower in general is similar to that given by Theophrastus. He distinguished two kinds of flowers, the leafy and the capillary, but regarded both as being united in flowers like the rose. He arranged the plants in **De Historia Stripium** alphabetically by their Greek names, hence we find no attempt at classification made by him. Inspite of these limitations, the Historia which he produced commands admiration.

William Turner (1515-1568), whose **'A New Herbal'** printed in English apeared in 1551 (first part), 1562 (second part) and 1568 (third part), is often called 'Father of English Botany'. He also arranged plants alphabetically since no thought was then given to plant relationships. Turner gave to many plants English names they bear, with an apparently inborn zeal for reformation he swept out many of the old superstitions about plants.

The Herbal of **Valerius Cordus** published posthumously in 1561; contained not only medicinal plants found in Germany and Italy, but also many foreign woods, barks and fruits, acquired from other countries. His descriptions of plants were more accurate than those of any of his contemporaries. He was the first to draw up botanical descriptions in a systematic form, including details about the type of plants, form of parts, colour, odour, taste etc.

The influence of gardening on the development of botany may be seen in the work of **John Gerard** (1545-1612). Gerard published an account in 1696 which contained over 1033 species of the plants growing in his garden. He published his greatest work **'The Herbal'** or **'General Historia of Plants'** in 1597 illustrated with over 1800 wood-cuts of plants. The plants he described were arranged in three books, the first included grasses, second all herbs for medicine and sweet smelling, the third one dealt with bushes, fruit-bearing plants, resins, and mushrooms. The result of this was a rough classification, based on superficial resemblances and upon the relationship of plant with man.

All of these works, in which the botanical descriptions were subordinated to the medicinal details of the plants, were overloaded with the widest speculations regarding their supposed medicinal virtues, and often contained much that would be dismissed today as pure fantasy. Gradually, however, a crude system came into being, based partly upon rough morphology and partly upon the medicinal characteristics of plants.

A significant contribution to taxonomy was made at this time by **Caspar Bauhin.** His **'Phytopinax'** (1596) described 2700 species, beginning with Graminaceae and ending with Papilionaceae. In Bauhin's **'Prodromus Theatri Botanici'** (1620) and **'Pinax Theatri Botanici'** (1623) we find one of the first attempts to utilise a **'binomial system of nomenclature'** which, however, Bauhin did not use exclusively; you will read about bionomial system of nomenclature in Unit 4. The **Pinax Theatri Botanici** contained description of 6000 species. He attempted a classification by natural affinities proceeding from the grasses through the lilies, dicot herbs, and shrubs and trees. However, he was singularly oblivious to the importance of flowers and fruits.

Handed down from the ancients, and elaborated on by the herbalists, was the **'Doctrine of Signatures',** which was based on features that resembled portions of the human body, must have been so created for the purpose of furnishing remedies for the ailments of those portions of the body. Many plants were given common names that referred to supposed remedial properties, and the origin of many scientific names that are still in use today may be traced to this doctrine. For example, the generic name **Hepatica**, the shape of the leaves in that genus being thought to resemble the shape of the liver, and the leaves, therefore, to be a remedy for diseases of that organ.

1.5.3 The Transition Period

The transition period from the Renaissance to the Modern period produced many notable workers and much literature. Botanists gradually broke away from the traditional doctrines of the ancients and developed new systems of classification, a new terminology of description, and a system of nomenclature that was to become a permanent part of taxonomy. Since the concept of evolution had not yet been developed, the arrangement of plant groups in various system of classification was still more artificial than phylogenetic. You will be given a detailed account of some important contributions made during this period in the following unit.

1.5.4 The Post-Herbal Period

It is difficult to draw a sharp line of demarcation between the transition period, marked by various attempts of classification, all of which were more or less artificial (based on form relationships), and the Modern Period, which progressed steadily in the development of a system based on natural affinities.

You will learn in detail about the workers and their contributions of this period in the following units of the block.

1.6 HISTORY OF ANIMAL TAXONOMY

The beginning of animal taxonomy was made by Aristotle (384-322 B.C.). He extensively studied about anatomy, embryology, habit and ecology. He was able to conclude that animals can be classified according to their way of living actions, habits and body parts. His major study includes: i) distinction of mandibulate from

Aristotle because of his major contribution in taxonomy was known as 'Father of Biological Classification'.

haustellate types, ii) winged from wingless forms among insects, iii) monitoring other animals like birds, fishes and whales. Orders like Coleoptera, Diptera and Psychae (now Lepidoptera) were created by him.

Fig 1.3

John Ray (1627-1705) a native of Motly, Essex, and a fellow of trinity, Cambridge. His most interesting systematic work was **Synopsis Methodica Animalium Quadrupedum et serpentini Generis** Published in 1963.

Fig. 1.4

Due to Linneaus, January 1, 1758 is of great importance in Zoological taxonomy because nomenclature was started on this day.

The development of systematics was adversely affected for several decades due to extensive opposition to Darwinism.

The publication of the book New Systematic became a landmark in the history of taxonomy.

The first important work on both animal and plants was initiated by John Ray (1627-1705) Fig. 1.3 He followed Aristotle and divided animals those with blood and those apparently without blood. The former were further divided into those with gills and those with lungs. He also used other characteristics like the production of eggs or living young ones, the possession of broad hooves or narrow claws, the existence of two or more incisor teeth, and so on. Thus, he covered almost the entire animal kingdom. This system of classification was appreciated because, the system was logical, practical and easy to follow. He produced the first rudiments of our hierarchical classification and the first good definition of the species as a reproducing unit.

Then, in 18th century, the work of Linnaeus (Fig. 1.4) and his followers (Haartman, 1751, 1764, Kolreuter, 1761-66) helped systematics to advance further. Linnaeus—was first to introduce the hierarchical system both in animal and plant kingdom. He followed four categories (class, order, genus and species) for the animal world.

He also used the name **Mammalia** instead of **Quadrupeda** in 1758. He presented the first character-based classification which serves as basis for the arrangement of specimens in the collections and the binomial nomenclature for information storage and retrieval system for the great bulk of biological data. He was called "Father of Taxonomy"

The criticism and improvements of the Linnean system continued but the first serious attempt to improve it was made by Lamarck. He divided the animal kingdom into three section on the basis of their mental capacities. His division of animals into four major types was—vertebrates, molluscs, arthropods and radiates.

Lamarck's taxonomy was mainly static in nature and his classification does not show its true value to the development of modern taxonomy. His most important support to the systematics was his preciseness in the diagnosis of various taxa. Many of his generic and other names are still in use. He displayed the groups of animals in form of a branching tree, which was the beginning of the use of phylogeny in systematics.

Cuvier (1769-1832) was critical of Lamarck's evolutionary concept which thereafter remained in oblivion for half a century. Cuvier's outright criticisms of Lamarck greatly affected the progress of animal taxonomy during that period. And the following decades were known by **emergence of three great ideas** which influence a lot of progress in animal taxonomy. The first of these was 'Von Baer's Law' which was put forward by Von Baer. The theory states that "The younger the embryo the more closely did it resemble other embryos of the same stage of development."

The second idea was an explanation of this rule by Ernst Hackel, which is known as Recapitulation theory or "Ontogeny repeats phylogeny"

The third theory of evolution through natural selection was put forward jointly by Darwin and Wallace in 1859. This theory supported the idea of both Lamarck and Cuvier. Thus, this theory gave the greatest support to systematic zoology.

By the 19th century Darwin's ideas had been widely accepted. The Naturalists started searching for missing links between seemingly unconnected taxa and finally reconstructed the "primitive ancestors". Phylogenetic trees were proposed by Hackel which also stimulated several empirical workers and large number of species were discovered and described.

Then came the modern taxonomy and with its development workers realised that the Linnean species based on one or two specimens are not as perfect as those which are based on population studies. After these studies Mayr considered species as groups of interbreeding natural population. This idea of population taxonomy was useful in establishing "polytypic concept".

New terms like New Systematics and biosystematics were added. The taxonomists then realised the importance of other characters in sound classification. Then the scientists started searching for characters from field studies and various characteristics of living animals, namely behaviour, ecology, genetics, zoogeography, physiology, biochemistry. Thus, taxonomy got a new name 'biological taxonomy' in its true sense. The taxonomists came to know their dependence on new characteristics in solving species complexes and by about 1955 a state of **'taxonomic explosion'** was reached.

Thus, present day taxonomic works include all available differences and similarities, phylogenetic adaptations, embryological patterns, biochemical variations, genetical similarity and behavioural characteristics etc. The general concordance of the data from all such diverse source mutually support the basic validity of the scheme of classification.

1.7 PLANT TAXONOMY IN ANCIENT INDIA

In India, history of botanical science dates back to the Vedic period (approx. 1500 B.C. to 600 B.C.). It started with the development of agriculture when people undertook cultivation of various food crops. In the literature of that period, several technical terms are available which were used for the description of plants and plants parts. Details on classification, morphology and anatomy of important economic plants are available. Plants were studied in relation to medicine, agriculture and horticulture. The early treatise on botany like **'Ayurveda'**, **'Charka-Samhita'** and **'Sushruta-Samhita'** were, therefore, primarily utilitarian. It is said that more than 2500 years ago Bhikshu Atreya, a well-known teacher at the University of Taxila asked one of his pupils Jivaka to collect, identify and describe the properties of all the plants growing within a distance of four 'Yojanas' of the University. Dignitaries like Dhanvantari, Nagarjun, Agnivesh Jatukarna, Bhela Harita etc., had an intimate knowledge of the characteristics of medicinal plants.

One of the earliest works dealing with plant life in a scientific manner is **'Vrikshayurveda'** compiled by **Parashara** even before the beginning of the Christian era, and which formed the basis of botanical teachings and medical studies in ancient India. The book deals with the categorisation, morphology and anatomy of plants, nature and properties of soil types, distribution and description of forests in the country. A system of classification based on comparative morphology of plants is also available in this work.

This system of plant classification was considered much more advanced than any other system proposed anywhere in the world before eighteenth century. Many families ('ganas') were clearly distinguished as to be recognisable today. The present day family **Cruciferae** was called **'Swastikaganiyam'** because the arrangement of sepals and petals resembled a 'Swastika', and the flowers were further characterised by a superior ovary, four free sepals, four free petals, six stamens—two of which are shorter, and four longer two carpels fused and form a two-locular fruit. The present day **Cucurbitaceae** was called **'Tripusaganiyam'** and was characterised by having flowers which were epigynous, sometimes bisexual with five sepals, five fused petals, three stamens and a unilocular ovary with three rows of ovules. This clearly shows that Parashara's work was not only utilitarian but a compilation of scientific studies too. It shows that here in India, classification of plants was attempted in that remote period on scientific lines.

SAQ 4

Match the words given in column A with column B.

Column A	Column B	
1. Origin of Species	Dioscorides	[ ]
2. Father of Medicine	Theophrastus	[ ]
3. The Stagirite	Parashara	[ ]
4. Founder of First Botanical Garden	Cruciferae	[ ]
5. Father of Botany	Charles Darwin	[ ]
6. *Historia Plantarum*	Democritus	[ ]
7. *Historia Naturalis*	Cucurbitaceae	[ ]
8. *Anicia Juliana Codex*	Aristotle	[ ]
9. Vrikshayurveda	Aristotle	[ ]
10. Swastikaganiyam	Pliny	[ ]
11. Tripusaganiyam	Theophrastus	[ ]

1.8 SUMMARY

- Taxonomy is the science of naming and classifying organisms.
- There is need for classification of living organisms because scientific name of a plant communicates the species and genus and from that family can also be determined. The scientific name also predicts much information that will be applicable to that plant.
- The three major objectives of taxonomy are :
  1) learning of all kinds of plants and animals,
  2) assemblage of knowledge gained,
  3) demonstration of diversity of living kingdom and its relation to man's understanding of evoution.
- The main goal of taxonomy is to develop a workable classification that reflects evolutionary relationships and gives a nomenclature and identification.
- History of plant classification is very old, starting from ancient Greeks and Romans. The herbalists, the transition period to post-herbal period. In India history of botanical sciences dates back approximately 1500 B.C. to 600 B.C.

1.9 TERMINAL QUESTIONS

1) List the main objectives of taxonomy.

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2) Write any 10 principles of taxonomy?

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3) Write a brief note on history of plant classification.

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1.10 ANSWERS

Self-assessment Questions

1) 1) T, 2) F, 3) F, 4) T, 5) T, 6) T

2) study of the diversity; identification, classification, evolution; common characteristics; system; genus; families; ranks; species, genera, families

3) 1) non evolutionary, 2) non genetic, 3) flexible, 4) non constant, 5) diphyletic, 6) should not, 7) only reduction, 8) should not, 9) does not include, 10) does not depict.

4) Match the words given in column A with column B.

	Column A	Column B
1.	Origin of Species	Charles Darwin
2.	Father of Medicine	Democritus
3.	The Stagirite	Aristotle
4.	Founder of First Botanical Garden	Aristotle
5.	Father of Botany	Theophrastus
6.	*Historia Plantarum*	Theophrastus
7.	*Historia Naturalis*	Pliny
8.	*Anicia Juliana*	Dioscorides
9.	Vrikshayurveda	Parashara
10.	Swastikaganiyam	Cruciferae
11.	Tripusaganiyam	Cucurbitaceae

Terminal Questions

1) i) The first and major objective is the learning of the kinds of plants and animals on earth, their names, distinctions, affinities, distribution and habit characteristics.

   ii) The second objective is the assemblage of the knowledge gained.

   iii) The third objective is the demonstration of vast diversity of the plant world and its relation to man's understanding of evolution.

2) Student can write any 10 principles given in Section 1.4.

3) For the answers you should look into Section 1.4.

UNIT 2 SYSTEMS OF CLASSIFICATION : PLANTS

Structure

2.1 INTRODUCTION

In Unit 1, you have studied about history and concept of taxonomy. Now, you will study about the development of classification of angiosperms. The development of angiosperm classification has been one of the most fascinating subject. A study of sequential events led to various classifications from time to time by several eminent scholars, botanists and thinkers. Plants have been known from times immemorial and remained intimately associated with human life. As the number of plant known to men increased, the necessity to organise them was felt and perhaps earliest classification came into existence. The knowledge of morphology, embryology, palynology, cytology, biochemistry, physiology, and phylogeny have added steps to the concept of classification. The story of classification has also served in evolution of various allied branches of botany. Linnaeus promulgated an artificial system of classification based on one or few characters. Thus, classification is the basic method which man employs to grip with and organise the external world. As a matter of fact, plants and animals are classified basically in the same way as the non-living objects that is on the basis of various characters. For example, one can classify library books by the colour of their bindings or by authors. In the same manner one can classify plants by the colour of their flowers or some other characters.

On this basic unit you will study about various types of plants classification, their basis, merits and demerits in detail.

Objectives

After studying this unit you would be able to:

- understand the importance of classification of plants,
- differentiate between artificial, natural and phylogenetic systems,
- describe the historical background, outline, basis of classification, merits and demerits of the various systems of classification.

2.2 TYPES OF CLASSIFICATION

It is practically impossible for any one to study all the plants of the world, even if one spends whole life. Thus, it is necessary to place them into small or large groups on the basis of their similarities and differences. These groups are then arranged according to their rank, such as order, family, genus, and species etc. For example, similar individuals are grouped or classified under a species, similar species under a genus, similar genera under a family and similar families into an order and so on (Fig. 2.1 and Fig. 2.2).

Category	Groups
Kingdom	Plantae
Division	Tracheophyta
Class	Angiosperm Gymnosperm
Sub-class	Dicotyledon Monocotyledon
Orders	Solanales etc.
Family	Solanaceae etc.
Genus	Solanum etc.
Species	Tuberosum nigrum
	Individuals

Fig. 2.1 : Various groups in classification.

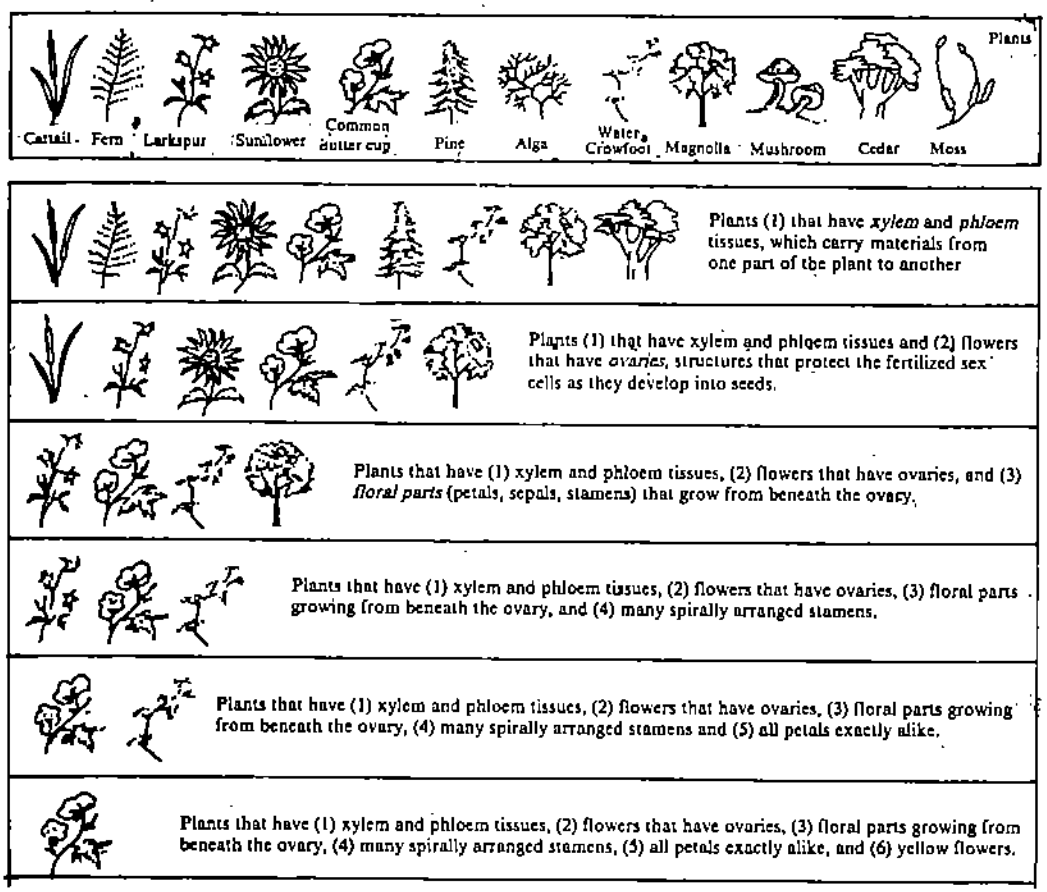


Fig. 2.2 : Diagramatic representation of classification.

Basically there are three kinds of classification : **artificial, natural** and **phylogenetic.**

Artificial Classification

When plants are classified for the sake of convenience only, using some arbitrary or easily observable characteristics the classification is called **artificial.** One of the most familiar artificial system is that of Linnaeus, where he employed number of stamens as one of the important characters in his system of classification.

Natural Classification

Natural systems of classification reflect the situation as it might have existed in nature. This clearly means that all the plant existing today are related and should be grouped together to form a natural group. The system of Bentham and Hooker is a good example of Natural System of Classification.

Phylogenetic Classification

Important Work of Linnaeus

Genera Plantarum (1752)
Supplements Mantissae,
Species Plantarum (1753)
Hortus Uplandicus (1732)
Systema Naturae, Flora
Lapponica; Horitus cliffortianus
and Critica Botanica (1727)

Phylogenetic systems of classification are those where the plants are classified according to their evolutionary tendencies. It may be pointed out clearly that due to incomplete fossil records it is not possible to claim a system as a perfect phylogenetic one. The phylogenetic classification is usually designed on the basis of natural classification. Thus there is an overlaping in practice. The systems of classification proposed by Engler and Prantl (1887-1915), Hutchinson (1926-34), (1959 and 1973) and Takhtajan (1964, 1969, 1973 and 1980) are the excellent examples of phylogenetic classification.

2.3 LINNAEUS ERA : ARTIFICIAL SYSTEM OF CLASSIFICATION

Carolus Linnaeus (1707-1778) popularly known as Carl Von Linne was born on May 1707 at Reshult, a small village in Smaland, Sweden. He took keen interest in the collection of plants, animals and minerals and for this purpose he travelled long distances. Based on the huge collection of plants during the exploration, he classified the plants and proposed a system of classification which is as a matter of fact artificial system or sexual system of classification. The most important publications of Linnaeus related to his system of classification are **systema naturae** (1735), **Flora Lipponica** (1737), **Genera Plantarum** (1737) and **Species Plantarum** (1735).

2.3.1 Basis of Classification

Linnaeus mainly employed the characters of stamens and carpels and that is why the system is called as **Sexual system** of classification. Further he took into account the number of stamens for classification and so the system is also named as **numerical classification.** The basis of classification proposed by Linnaeus are as under:

i)	Number of Stamens	(I-XII classes)
ii)	Size of Stamen	(XIV-XV classes)
iii)	Cohesion of filaments into bundles	(XVI-XVIII)
iv)	Cohesion of anthers	(XIX)
v)	Stamens adnate to ovary	(XX)
vi)	Distribution of sex in plants	(XXI-XXIII)
vii)	Plant without flower	(XXIV)

2.3.2 Outline of the System

Linnaeus classified the plant kingdom into 24 classes in his famous work 'Genera Plantarum' (1737) and 'Species Plantarum' (1753). In species plantarum, he diagnosed nearly 6000 species under 1000 genera. This work is still considered to be the most important in the botanical world. It would not be out of place to mention that Linnaeus proposed **Binomial Nomenclature** in this book and that is why **Species Plantarum and the date 1 May 1753 have been chosen by the modern botanists as the starting point of the present day botanical nomenclature.** For the first time he used two names in Latin for an individual organism i.e. ***a generic name*** and ***a specific name.*** This was the foundation stone in development of binomial system of nomenclature.

The outline of the classification proposed by Linnaeus is as under:

Class I	Monandria	—	One stamens e.g. *Canna, Salicornia*
Class II	Diandria	—	Two stamens e.g. *Olea, Veronica*

Class III	Triandria	— Three stamens e.g. many grasses
Class IV	Tetrandria	— Four stamens e.g. *Protea, Galium*
Class V	Pentandria	— Five stamens e.g. *Ipomoea, Campanula*
Class VI	Hexandria	— Six stamens e.g. *Narcissus, Lilium*
Class VII	Heptandria	— Seven stamens e.g. *Trientalis, Aesculus*
Class VIII	Octandria	— Eight stamens e.g. *Vaccinium, Dirca*
Class IX	Enneandria	— Nine stamens e.g. *Laurus, Butomus*
Class X	Decandria	— Ten stamens e.g. *Rhododendron, Oxalis*
Class XI	Dodecandria	— Eleven to Nineteen e.g. *Asarum.*
Class XII	Icosandria	— Twenty or more stamens attached to Calyx e.g. *Opuntia*
Class XIII	Polyandria	— Twenty or more stamens attached to receptacle e.g. *Tilia, Ranunculus*
Class XIV	Didynamia	— 2 stamens short and 2 long, e.g. *Mentha* (Mint)
Class XV	Tetradynamia	— 2 stamens short and 4 stamens long e.g. *Brassica* (Mustard)
Class XVI	Monadelphia	— Stamens forming one bundle only, e.g. *Hibiscus*
Class XVII	Diadelphia	— Stamens forming in 2 bundles, e.g. *Pisum* (Pea)
Class XVIII	Polyadelphia	— Stamens forming many bundles, e.g. *Bombax*
Class XIX	Syngenesia	— Anthers are fused but filament are free (Syngenesious condition) e.g. Many composites such as sunflower
Class XX	Gynandria	— Stamens adnate to the gynoecium e.g. Orchids
Class XXI	Monoecia	— Plants monoecious Male and Female flowers are borne on the same plant e.g. *Cucurbita, Morus*
Class XXII	Dioecia	— Plants Dioecious Male and Female flowers are borne on different plants e.g. Papaya
Class XXIII	Polygamia	— Plant Polygamous, male female and bisexual flowers are borne on the same plant e.g. Mango
Class XXIV	Cryptogamia	— Flower concealed e.g. Algae, Lichen, Fungi, Musci (Moss), Filicinae (Fern) etc.

Linnaeus followed Tournefort in arrangement of plants in the classification and introduced further modifications and ideas of his own. But his classification was artificial because he has considered only one major character as an aid for delimitation of taxa from each other irrespective of their relationship. By using only one criterion different families of monocotyledons and dicotyledons have come together in one class. He also knew this and pointed out that such artificial system has been followed in order to simply present a practical and easy method to identify and place all known plants of that period. Linnaeus, therefore, never asserted that system proposed by him is perfect and natural. Later in his life he started pointing out that instead of one, group of characters should be taken into consideration.

The evolutionary concept was not clear during Linnaeus period and Darwin's theory of evolution was brought to light nearly a century later than Linnaeus. Despite several limitation Linnaeus has contributed excellent knowledge of living kingdom.

SAQ 1

List three basis of Artificial Classification proposed by Linnaeus.

....

....

....

SAQ 2

Give one word for the following botanical term.

a) When 2 stamens are short and 2 are long ....

b) When 2 stamens are short and 4 are long ....

c) When all the stamens grouped in one bundle ....

2.4 NATURAL SYSTEM OF CLASSIFICATION

After Linnaeus the interest of botanist was the expansion of taxonomic knowledge through the exploration of vegetation and they had started realising the existence of natural affinity amongst plants. Several approaches were made towards the construction of natural system of classification reflecting the natural relationships of individuals. One of the best natural system of classification was proposed by George Bentham (1800-1884) and Joseph Dalton Hooker (1807-1911).

2.4.1 Bentham and Hooker's System

Our National herbarium (Central National Herbarium) is also arranged according to Bentham and Hooker system.

Bernard de Jussieu (1699-1776) tried to classify the plants in Royal Garden, Paris. During this exercise he developed a system of classification which is, in fact, the first natural system of classification. Soon after, A.P. de Candole (1778-1841) proposed a system of classification which was nothing but the modified form of de Jussieu's system.

Based on the general principle of **Form-relationships,** the most popular of the natural systems of classifications was proposed by two British Botanists George Bentham (1800-1884) and Sir Joseph Dalton Hooker (1817-1911). Hooker being the Director of Royal Botanic Gardens, Kew, had all the facilities at his disposal. Bentham and Hooker published the monumental work **"Genera Plantarum"** (1862-1883). This work includes names, accurate description and classification of all the seed plants known at the time (nearly 97,205 species). The term family was designated as order and the term **"Order"** was named as Cohort. This system of classification is adopted in most of the common wealth countries including our country. In all 202 families were recognised in this system. The starting family being Ranunculaceae and Poaceae as the ending family.

2.4.2 Outline and Basis of Classification

As pointed out earlier, this system is mainly based on **Form-relationship** principle. Thus the various genera were grouped under orders and different orders under Cohorts were based on the overall similarities and differences. A few orders which could not be satisfactorily accommodated in any Cohort, were treated as an anomalous orders (**Ordines Anomali**) such as *Moringa,* common name Sajna, Drumstic tree under Moringeae.

The outline and basis of classification are given below:

1) Phanerogams (Flowering plants or seed plants) were classified into 3 classes namely, i) Dicotyledons, ii) Gymnosperms and iii) Monocotyledons.

   This division is based on reticulate venation versus parallel venation, 4-5 merous flowers versus 3-merous flowers, 2-cotylodons versus 1-cotyledon in seed in Dicotyledons and Monocotyledons respectively. They have placed Gymnosperm in between the Dicots and Monocots as the group Gymnosperms possess naked seeds.

2) Dicots are further splitted into 3 subclasses:

   a) Polypetalae,

   b) Gamopetalae, and

   c) Monochlamydeae

This division is based mainly on the presence or absence of petals, and their fusion. For example, in Polypetalae the petals are present but free whereas in Gamopetalae the petals are fused. On the other hand in Monochlamydeae, no distinct petals are present but perianth is present which may be 1 or 2-seriate.

3) Polypetalae is further classified into 3-series
 a) Thalamiflorae,
 b) Disciflorae, and
 c) Calyciflorae

 This splitting is mainly based on the position of ovary in relation to thalamus.

4) Thalamiflorae has 6 Cohort (present day's Orders and 34 orders (present day's families). The starting order is Ranales and Ranunculaceae as the starting or the first family. The last or the sixth order is Malvales with Tiliaceae as the last family of this series.

5) Disciflorae which possesses a well developed disc with superior ovary has 4 orders and an anamolous order namely Ordines Anomali. The total number of families in this series are 23. The starting order is Geraniales with Linaceae as the starting family where as Ordines Anomali is the ending order and Moringaceae as the last family.

6) In Calyciflorae perigynous or epigynous flowers are found which have 5 orders and 27 families. The starting order being Rosales with Connaraceae as the starting family where as the last or the ending order is Umbellales and Cornaceae as the ending family.

7) The sub class Gamopetalae where the petals are fused is divided into 3 series, namely: i) Inferae, ii) Heteromerae, and iii) Bicarpellatae

 This splitting is mainly based on the number and position of carpels. For instance in the series, Inferae, as the name indicates, bicarpellary, syncarpus, inferior ovary is present, while in the case of Heteromerae, the carpels are always more than two. On the other hand in Bicarpellatae, it is always bicarpellary, syncarpous with superior ovary. The total number of order in Gamopetalae is 10, 3 in Inferae, 3 in Heteromerae and 4 in Bicarpellatae. Where as the families are 45 in all, 9 in Inferae, 12 in Heteromerae and 24 in Bicarpellatae.

8) Inferae has 3 orders namely Rubiales, Asterales and Campanulales. The starting family is Caprifoliaceae while the ending or terminating family is Campanulaceae

9) Heteromerae also has 3 orders viz. Ericales, Primulates and Ebenales. The starting family is Vacciniaceae where as the last family is Styraceae.

10) Bicarpellatae has 4 order namely Gentianales, Polemoniales, Personales and Lamiales. Further, the first 2 orders i.e. Gentianales and Polemoniales have actinomorphic flowers while Personales and Lamiales are characterised by zygomorphic flowers. The starting family is Oleaceae while the last or ending family is Labiatae or Lamiaceae. The family Plantaginaceae has been accommodated under Ordines Anomali.

11) The subclass Monochlamydeae is divided into 7 series and one series as Ordines Anomali. The starting series being curvembryeae with Nyctaginaceae as the starting family where as the ending series being Ordines Anomali with Ceratophyllaceae, a hydrophytic family, as the ending family.

12) The Class Gymnospermae is placed in between the Dicots and Monocots with 3 families namely Cycadaceae, Coniferae and Gnetaceae.

13) The Class Monocotyledons is divided into 7 series. The starting one being Microspermae with Hydrocharitaceae as the starting family. The family Orchidaceae is also included in the series, whereas the last series being. Glumaceae with Gramineae (Poaceae) as the last family.

The outline of the system can also be represented graphically.

OUTLINES OF THE SYSTEM OF CLASSIFICATION OF BENTHAM & HOOKER (1862-1883)*
SEED PLANTS OR PHANEROGAMS

- DICOTYLEDONS
  - Polypetalae
    - Series I Thalamiflorae: Order 1. Ranalaes; Order 2. Parietales; Cruciferae; Order 3. Polygalineae; Order 4. Caryophyllineae; Order 5. Guttiferales; Order 6. Malvales; Malvaceae
    - Series II Disciflorae: Order 1. Geraniales; Order 2. Olacales; Order 3. Celastrales; Order 4. Sapindales
    - Series III Calyciflorae: Order 1. Rosales; Leguminosae; Order 2. Myrtales; Order 3. Passiflorales; Cucurbitaceae; Order 4. Ficoidales; Order 5. Umbellales
  - Gamopetalae
    - Series I Inferae: Order 1. Rubiales; Order 2. Asterales; Compositae; Order 3. Campanales
    - Series II Heteromerae: Order 1. Ericales; Order 2. Primulales; Order 3. Ebenales
    - Series III Bicarpellatae: Order 1. Gentianales; Order 2. Polemoniales; Solanaceae; Order 3. Personales; Order 4. Lamiales
  - Monochlamydeae: Series 1. Curvembryeae; Series 2. Multiovulate aquaticae; Series 3. Multiovulatae terrestres; Series 4. Microembryeae; Series 5. Daphanales; Series 6. Achlamydosporeae; Series 7. Unisexuales; Ordines anomali
- GYMNOSPERMAE
- MONOCOTTYLEDONS
  - Series 1. Microspermae; Series 2 Epigynae; Series 3. Coronarieae; Liliaceae; Series 4. Calycineae; Series 5. Nudiflorae; Series 6. Apocarpae; Series 7. Glumaceae

2.4.3 Merits

The merits of this system are as under:

- Careful observation and original description of the genera from living specimens or from herbarium sheets form a fine taxonomic judgement and set a standard for generic description.
- The system is easy to work out and most suitable for all practical purposes or in other words it is quite easy to identify the plants upto family level with the help of this system.
- The geographical distribution of most of the genera included in the system is given.
- Upto date and authentic information is given in the system. Further, Royal Botanic Garden, Kew, is keeping it upto date by the publication of Index Kewensis regularly at the intervals of 5 years.
- Although the system is not phylogenetic, but the position of Ranales (as the starting order of the system) is according to the modern concept of evolution.
- The position of Monocots after Dicots is also logical and in accordance with the modern concept of evolutionary trends.

2.4.4 Demerits

There are several demerits or shortcomings of the system namely:

- The position of Gymnospermae in between Dicots and Monocots is not at all logical and appropriate.
- The establishment and demarcation of Polypetalae and Gamopetalae as natural groups creates confusion in some cases. For example, certain members of Cucurbitaceae have gamopetalous conditions but in this system Cucurbitaceae has been placed in Polypetalae. In the treatment of Gamopetalae, Asteraceae, the highest evolved family has been placed in the beginning of the group and thus the position of Asteraceae is not at all justified according to modern evolutionary trends.

- The consideration of Monochlamydeae as a separate and reduced group is not logical because by doing so the closely related families such as Chenopodiaceae could not be placed near Caryophyllaceae.
- Similarly, the inclusion of Orchidaceae in Microspermae, the starting series of Monocot is not in accordance with the recent evolutionary trends. The family Orchidaceae is considered as one of the highest families in Monocots and so it should not be placed as the starting family.

SAQ 3

Fill in the blank with appropriate words.

a) .... families were recognised by Bentham and Hooker in their system of classification.

b) The starting family of Bentham and Hooker's system is .... and the terminating family being ....

c) Gymnosperms are placed in between .... and ....

2.5 PHYLOGENETIC SYSTEMS OF CLASSIFICATION

As already pointed out earlier that in Phylogenetic system, the plants are classified according to their evolutionary relationships. It is very difficult to claim that a phylogenetic system is perfect on the basis of evolutionary affinities due to incomplete fossils records and in such a situation the plants are classified on the basis of available data. The systems of classification by Engler and Prantl (1887-1915), Hutchinson (1926, 1934, 1969 and 1973) and by Takhtajan (1954, 1964, 1973, 1980) are Phylogenetic systems. We shall discuss these systems one by one in details.

2.5.1 Engler and Prantl's System of Classification

Adolf Engler, Professor of Botany, University of Berlin, Germany, proposed a phylogenetic system of classification in a book entitled Syllabus (1892). Soon after, Engler in collaboration with Karl A.E. Prantl, another German Botanist, published a monumental work entitled **"Die-Nuturlichen Pflanzenfamilien"** (1887-1915) having 23 volumes. Hans Melchior published the revised edition of syllabus in 1964 with a number of modifications in this system.

As a whole 303 families of flowering plants were recognised in this system.

Outline and Basis of Classification

Unisexual, naked flowers arranged in Catkin and wind pollinated were considered as the lowest grade of floral organisation by Engler and as such is called **Englerian concept.** The next stage of evolution in flower is followed by the appearance of 1-seriate perianth leading to 2-seriate condition alongwith bisexual condition.

The outline and basis of classification of Engler and Prantl's system are given below:

1) Plant Kingdom has been divided, into XIII Divisions but according to recent modifications by Melchior (1964) the total Divisions are XVI.
2) Division I to XII dealing with Bacteria, different types of Algae, Fungi, Bryophytes, and Pteridophytes.
3) The XIII Division is named as Embryophyta Siphonogamia. It is divided into 2 sub-division based on the naked and enclosed ovules, that is
   i) Gymnospermae (naked ovules)
   ii) Angiospermae (enclosed ovules)
4) The sub-division Gymnospermae has been divided into 7 orders, the starting one being Cycadofilicales, the most primitive one where as the ending order is Gnetales, an advanced group of Gymnosperms.
5) The sub-division Angiospermae has been splitted into two
   i) Monocotyledonae, and
   ii) Dicotyledonae

This division is mainly based on the striking differences between Monocots and Dicots such as the venation of leaf, 3-merous flowers in Monocots where as 4-5 merous flowers are present in Dicots.

6) Monocots are further divided into 11 Orders and 45 Families (14 Orders and 53 Families after the revision by Hans Melchior, 1964). The first or the starting Order is Pandanales which possesses naked, unisexual flowers with Typhaceae as the starting family. The last order is Microspermae with orchidaceae as the last family.

7) Dicots are divided into 2 subclass namely:
   i) Archichlamydeae, and
   ii) Sympetalae

   This division is mainly based on the condition of perianth, 1-seriate or 2- seriate and their fusion. For example, in Archichlamydeae the flowers may be naked or 1-seriate followed by 2-seriate condition but the petals are mostly free that is polypetalous condition. While in the case of sympetalae, as the name indicates, the petals are fused that is gamopetalous is found in this group.

8) Archichlamydeae has 33 Orders and 206 Families (37 Orders and 227 Families after the revision by Hans Melchior, 1964). The first or the starting order being Verticillatae and Casuarinaceae as the starting family, followed by some other order and families without perianth or reduced perianth, then 1-seriate perianth and lastly 2-seriate perianth. The last order being Umbelliflorae with Cornaceae as the last family.

9) Sympetalae which is also named as Metachlamydeae has 11 Orders in all with 52 Families (11 Orders and 64 Families after revision of Hans Melchior, 1964). The first or the starting Order being Ericales with Clethraceae as the starting family. The last or ending order of Sympetalae is Campanulales with Asteraceae or Compositae as the last or ending family and that is very rightly placed because this family is considered as the highest evolved family among Dicot families.

The outline of the system can also be represented in the form of a chart.

System of Classification Engler and Prantl
PLANT KINGDOM

Division I
II
III
–
–
XII Embryophyta Siphonogamia

Gymnospermae	Angiospermae		
1. Cycadofilicales	Monocots	Dicots	
	11 Orders 45 Families	44 Orders 258 Families	
	1. Pandanales Typhaceae		
		Archichlamydeae	Sympetalae
	2.	33 Orders	11 Orders
	3.	206 Families	52 Families
	4.		
	5.	1– Verticillatae	1. Ericales
	6.	2–	– Cletheraceae
	7.	3–	–
	8.	4–	–
	9.	5–	–
	10.	–	–
	11. Microspermae	–	–
		–	–
		–	–
		–	11. Campanulales Asteraceae
		–	
		32 – Umbelliflorae Cornaceae	

Merits

After going through the details of the system of classification proposed by Engler and Prantl we are in a better position to discuss the merits of the system, which are as follows:

1) Although, Engler himself did not consider the system as a true phylogenetic one but the arrangement of order and families in the system is mostly according to evolutionary tendencies.
2) The system deals with all groups of Plant-Kingdom ranging from Bacteria, Algae, Fungi, Bryophyta, Pteridophyta, Gymnosperms and Angiosperms. The system provides modern keys for the identification of each group of plants.
3) The position of Gymnosperms before Angiosperms is very accurate and is in perfect accordance to the modern concept of evolution.
4) The position of Asteraceae (Compositae) as the ending family of Dicot is very logical and acurate because it is proved beyond doubt that this family is the highest evolved family of Dicot and thus its position is fully justified.
5) Similarly, the position of Orchidaceae as the ending family of Monocot is also very accurate as this family is considered as one of the highest evolved family of monocots.
6) Anatomical data were taken into consideration in this system of classification for the first time.

Demerits

There are some shortcomings or demerits of the system. The important demerits are as under:

1) The corcept of primitive flower (unisexual, naked, catkin) is against the modern concept of evolution.
2) Monocots are regarded more primitive than Dicots. This concept is not in agreement with modern concept of evolution.
3) Amalgamation of Apetalous families with Polypetalous families to form Archichlamydeae is not desirable as it has resulted in the formation of a unmanageable large group 33 Orders and 206 families.
4) The system is not of much practical utility.

2.5.2 Hutchinson's System of Classification

John Hutchinson, a renowned British Botanist proposed 24 phyletic dicta or principles and based on these dicta he published a phylogenetic system in 2 volume book entitled "The Families of Flowering Plants" (1926-1934). The volume I deals with Dicots while the Volume II having Monocots. The revised and detailed treatment of the system was published in 1959 and the most recent revised system appeared in 1973.

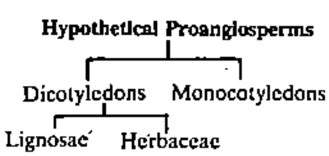
Outline and Basis of Classification

As pointed out earlier, the system is mainly based on 24 phyletic dicta. Thus, it seems proper to give a brief account of these phyletic dicta.

1. Evolution is both upwards and downwards, the former tending towards preservation and the latter to their reduction and suppression (of characters). Examples of former are towards the sympetalous condition and epigyny and of latter towards the apetalous state of many flowers and unisexuality in flowering plants.
2. Evolution does not necessarily involve all organs of the plant at the same time. One organ or set of organs may be advancing while another set may be stationary or retrograting.
3. Evolution has generally been consistent, and when a particular progression or retrogression has set in, it is persisted into the end of the phylum e.g., strong tendency to zygomorphy of the corolla coupled with the reduction in the number of stamens in Engler's hypogynous **Metachlamydeae** and the vast tendency to perigyny and epigyny in **Archichlamydeae** and **Metachlamydeae** as seen in the families **Umbelliferae** and **Rubiaceae** respectively.
4. In certain groups, trees and shrubs are probably more primitive than herbs e.g., **Mimosaceae** and **Caesalpiniaceae** (trees and shrubs) as compared with the derived family **Papilionaceae (Fabaceae)** (often herbaceous).
5. Trees and shrubs are older than climbers in any one family or genus, the latter habit being acquired through particular environment.

6. Perennials are older than biennials, and from them annuals are derived e.g., there are only a few annuals in the primitive family **Ranunculaceae** while there are many more in the more advanced and natural family **Cruciferae.**
7. Aquatic flowering plants are derived from terrestrial ancestors, Epiphytes, saprophytes and parasites are more recent than plants of normal habit.
8. Dicotyledones with collateral vascular bundles arranged in a cylinder are more primitive in origin than Monocotyledones with scattered vascular bundles, although it does not necessarily follow than Monocots are directly derived from Dicots.
9. The spiral arrangement of leaves on the stem and of the floral leaves is more primitive than the opposite and whorled arrangement.
10. Simple leaves are usually more primitive than compound leaves.
11. Unisexual flowers are more advanced than bisexual and dioecious plants are more recent than monoecious.
12. Solitary flowers are more primitive than those in inflorescence, the highest forms of the latter being the umbel and capitulum (**Umbelliferae** and **Compositae).**
13. Spirally imbricate floral parts are more primitive than whorled and valvate. Example-*Magnolia* and *Clematis*.
14. Many-parted flowers (polymerous) precede, and the type with few parts (oligomerous) follows from it, being accompanied by progressive sterilisation of reproductive parts. Examples-*Magnolia* and *Cheiranthus*.
15. Apetalous flowers are derived from petaliferous ones, the former condition being as a result of reduction.
16. Polypetaly (free petals) is more primitive than gamopetaly (fused petals).
17. Actinomorphy is more primitive than zygomorphy.
18. Hypogyny is the most primitive structure and from it perigyny and epigyny have been derived.
19. Apocarpy (free carpels) is more primitive than Syncarpy (connate carpels). Sometimes, however, when the carpels have remained loosely united during evolution, they may again become quite free, e.g., **Asclepiadaceae.**
20. Polycarpy (many carpels) precede oligocarpy (few carpels) e.g., *Ranunculus* and *Nigella*.
21. Endospermic seeds with small embryo are older than non-endosperimic seeds having a large embryo, *e.g.*, **Ranunculaceae** and **Rosaceae.**
22. Indefinite stamens indicate greater primitiveness than an androecium with a few stamens only (exception **Malvaceae**) e.g. *Ranunculus* and *Cheiranthus*. This condition may however, be reversed within the confines of a single family, e.g., **papaveraceae,** where bees feed on the pollen.
23. Separate stamens precede connate ones e.g., **Tiliaceae** and **Malvaceae, Campanulaceae** and **Lobeliaceae.**
24. Aggregate fruits are more highly evolved than single fruits. Generally, capsule precedes berry or drupe.

Based on these above mentioned 24 phyletic dicta, Hutchinson proposed the phylogenetic system of classification. The outline of this system are given below:



1) Hutchinson believed in Monophyletic origin of Angiosperms from a hypothetical group, which he named as **Proangiosperms.**
2) He traced 2 main lines development of Dicots viz.
   i) Lignosae (woody)
   ii) Herbaceae (herbaceous)
3) Lignosae has 54 Orders and 251 Families. The starting order is Magnoliales with Magnoliaceae as the starting family passing through Annonales—Rosales—Malvales Rubiales and terminating at Verbenales with Phrymaceae as the terminating family.
4) Herbaceae has 28 Orders and 100 Families. The starting order is Ranales with Paeoniaceae as the starting family passing through Rhoedales—Caryophyllales—Umbellales—Asterales and terminating at Lamiales with Lamiaceae (Labiatae) as the ending family.

5) The Monocots have 29 Orders and 69 Families.

As a whole, Monocots have been subdivided into 3 distinct groups based on the nature of Perianth viz.
i) Calyciferae
ii) Corolliferae
iii) Glumiflorae

The starting order of Calyciferae is Butomales with Butomaceae as the starting family. The climax (ending) order is Zingiberales with Marantaceae as the ending family.

The starting order of Corolliferae is Liliales with Liliaceae as the starting family. The terminating order of this group is Orchidales with Orchidaceae as the ending family.

In the case of Glumiflorae the starting order is Juncales and Juncaceae as starting family. The climax order is Graminales and Gramineae (Poacea) as the last or terminating family.

The outline of the monocots can be represented in the form of chart as given below:

Verbenales	Lamiales	Graminales	Glumiflorae
Rubiales	Solanales	Cyperales	
Apocynales	Asterales	Juncales	
Malvales	Umbellales	Orchidales	Corolliferae
Leguminales		Liliales	
Rosales	Caryophyllales	Zingiberales	
Annonales	Brassicales	Alismatales	Calyciferae
Magnoliales	Ranales	Butomales	

Merits

The merits or achievements of the system are as follows:

- The standard of the family description is of high order and valuable features are given in the keys for identification.
- The system of classification is of much practical value.
- The treatment of Monocots is more adequate, logical and acceptable.
- The data from Floral Anatomy and Embryology are taken into consideration during the classification of Monocots in particular and Dicots in general.
- Geographical distribution of most of the genera is included in this system.
- The system of classification is phylogenetic one.

Demerits

A number of shortcomings and criticism have been put forward to expose the demerits of the system.

- More stress is given on Monophyletic origin of Angiosperm from a hypothetical proangiosperm.
- Due to special emphasis on Herbaceae and Lignosae, some very closely related families have been put apart. For example, Ranunculaceae and Magnoliaceae under Ranales (Herbaceae) and Magnoliaceae (Lignosae) are separated just because of demarcation between Herbaceae and Lignosae. Similarly, the family Lamiaceae and Asteraceae (Herbaceae) are put apart from Verbenaceae and Rubiaceae (lignosae).

However, in the opinion of most taxonomists, Hutchinson has contributed an excellent service by his most careful and critical appraisal of family and ordinal limitations. His classification has been a greater stimulant to phyletic thinking during the past decade or two than any other similar contribution.

2.5.3 Takhtajan's System of Classification

Another important phytogenetic system was proposed by Takhtajan, the famous Russian Palaeobotanist working at Komarov Botanical Institute, Leningrad, U.S.S.R. For the first time he proposed the system in 1942 mainly based on the structural types of Gynoecium and placentation. Afterwards, he put foward a modified system in 1954 in Russian language and then the translated version of English in 1958. This modified system was mainly based on phylogenetic principles. Soon after he made another attempt to revise the system in the light of evolutionary trends in Angiosperms, which appeared in 1964. This, too, was not the last word but Takhtajan again revised and updated version of his system appeared in 1980.

Before we take into account the outline of the system it seems proper to point out the important and significant points of the system as new terms were employed by Takhtajan in his system:

i) Magnoliophyta (Angiosperms) are regarded to be monophyletic in origin.
ii) Magnoliopsida (Dicots) are considered as a primitive group than Liliopsida (Monocots).

Outline of Takhtajan's System of Classification

(Takhtajan. 1980)

1) Mognoliophyta (Angiosperms) has 419 Families and is divided into 2 classes viz.
   i) Magnoliopsida (Dicots) and
   ii) Liliopsida (Monocots)
2) Magnoliopsida (Dicots) is further divided into 7 subclasses, 20 super orders, 71 Orders and 342 Familes.

   The 7 subclasses with some important orders and families (starting and ending) are as follows:

Subclass

I) Magnolidae
   Super order — Magnolianae
   Order — Magnoliales (1)
   Family — Magnoliaceae (1)

II) Ranunculidae
   Order — Ranunculales
   Family — Ranunculaceae

III) Hamamelididae
   Order — Trochodendrale

IV) Caryophyllidae
   Order — Caryophyllales
   Family — Caryophyllaceae

V) Dilleniidae
   Order — Dilleniales
   Family — Dilleniaceae

VI) Rosidae
   Order — Rosales
   Family — Rosaceae

VII) Asteridae
   Order Asterales — 71st, the last or ending order
   Family Asteraceae — 342nd, the last or ending family

3) Liliopsida (Monocots) is divided into 3 subclasses, 3 super order 21 Orders and 77 Families. The 3 subclasses of Liliopsida with important orders and Families (Starting and ending) are given below:

Subclasses

I) Alismatidae
   Order — Alismatales
   Family — Butominaceae

II) Lilidae
   Order — Triuridales
   Family — Triuridaceae
   Order — Orchidales
   Family — Orchidaceae
   Order — Poales
   Family — Poaceae

III) Arecidae

Order	— Arales
Family	— Arecaceae
Order	— Typhales
Family	— Typhaceae
Order	— Arales — 21st (The last or ending order)
Family	— Araceae — 77th (The last or ending family)

The outline of the system can also be represented in the form of a chart:

Magnoliophyta (Angiosperm)

Magnoliopsida (Dicots)
342 Families

I) Magnolidae
Magnoliales (Starting Order)
Magnoliaceae (Starting Family)

II) Ranunculidae
Ranunculales

III) Hamamelididae
Trochodendrales

IV) Caryophyllidae
Caryophyllales

V) Dilleniidae
Dilleniales

VI) Rosidae
Rosales

VII Asteridae
Asterales — 71 Order (Terminating order)
Asteraceae — 342 Family Last or ending family.

Liliopsida (Monocots)
77 Families

I) Alismatidae
Alismatales (Starting Order)
Butominaceae (Starting Family)

II) Lilidae
Triuridales
Orchidale
Poales

III) Arecidae
Arales 21 Order
(The last or terminating order)
Arecaceae –77th family
(the last or ending family)

Takhtajan has accepted main divisions and sub-divisions as classes and sub-classes almost similar to classification given by Bentham and Hooker. In the Hooker's system the larger taxa are natural since their status is ascertained on the basis of large number of characters. But so far as further sub-groupings like series (Thalimiflorae, Disciflorae, and Calyciflorae etc. and several orders and families; are concerned—one can easily spot out that more or less only one character is chosen as basic criterion in categorization making it more artificial. Takhtajan introduced modifications at such levels. A critical examination of Takhtajan's classification shows that it is of considerable merit since he has made use of maximum data available through morphology, cytology, Palynology, Anatomy, Embryology, Cytogenetics, Biochemistry and Palaeobotany in the construction of taxa of various ranks.

SAQ 5

Insert the correct information in the space provided for:

a) Syllabus was written by .... in the year ....

b) The monumental book entitled .... with 23 volume was written by .... and .... during 1887-1915.

c) .... families were recognised in Engler and Prantl's system.

SAQ 6

Name the 2 subclasses of Dicots in Engler and Prantl's system:

i) ....

ii) ....

2.6 SUMMARY

In this unit you have learnt that:

classification of organisms is the basic method, employed by us to organise the external world.

- The various systems of classification are grouped into artificial, natural and phylogenetic ones. The system proposed by Linnaeus is one of the best examples of artificial system. In all, Linnaeus recognised 24 classes in his system.
- In natural system of classification, two British Botanists namely Bentham and Hooker proposed a system of classification, which is chiefly based on the Form—Relationship. In all 202 families were recognised in this system. The starting family being Ranunculaceae and Poaceae (Graminae) being the ending family of the system.
- Phylogenetic system of classification are those where plants are grouped according to their evolutionary and genetic affinities. The most popular systems under this category are the systems of classification by two German Botanists, Engler and Prantl, British Botanist, John Hutchinson and Russian Botanist, Takhtajan.
- In the case of Engler and Prantl system of classification, unisexual, naked flowers in catkin are considered as the most primitive type of flowers. In this system the position of Gymnosperms just before the Angiosperms is an important point of merit. As a whole 303 families of flowering plants are recognised in this system.
- Hutchinson system is mainly based on 24 phyletic dicta. He traced 2 lines of development of Dicots viz Lignosae (Woody Plants) and Herbaceae (Herbaceous plants). As a whole 111 orders and 420 families are included in this system.
- Takhtajan proposed the system of classification in 1942 and then revised and modified several times. The most recent version of the system appeared in 1980. He coined new terms for Dicots and Monocots and named them Magnoliopsida and Liliopsida respectively. He recognised 419 families of flowering plants in his system of classification.

2.7 TERMINAL QUESTIONS

1) Give the historical background, basis of classification and outline of the sexual system of classification.
2) Give the outline of Bentham and Hooker's system of classification. Point out the merits and demerits of the system.
3) Draw a scheme to classify Polypetalae of Bentham and Hooker.
4) Draw a chart to show the outline of Engler and Prantl system of classification.
5) On how many phyletic dicta Hutchinson's system of classification is based? Enumerate atleast 15 dicta.
6) Draw a scheme to show the outline of Hutchinson's system of classification. Point out the starting and climax orders in each group.
7) Give the outline of Takhtajan's system of classification in the form of a chart.

2.8 ANSWERS

Self-assessment Questions

1) i) Number of stamens
   ii) Size of stamens
   iii) Cohesion of anthers
2) a) Didynamous
   b) Tetradynamous
   c) Monadelphous
3) a) 202
   b) Ranunculaceae, Poaceae
   c) Dicots, Monocots
4) a) The position of Asteraceae is not at all correct and logical in Bentham and Hooker system as it has been placed in the beginning of Gamopetalae. As a matter of fact this family is one of the highest evolved family and it should occupy the climax position.

b) The position of Orchidaceae in Bentham and Hooker system is not justified because it has been placed just in the beginning of Monocots under Microspermae, where as the family Orchidaceae is one of the highest evolved family of Monocot and thus it should be placed in the end of Monocots.

5) a) Adolf Engler 1892
   b) "Die Naturlichen Pflanzenfamilien", Adolf Engler and Karl A.E. Prantl.
   c) 303

6) i) Archichlamydeae
   ii) Sympetalae

Terminal Questions

1) Refer to the text (2.2 and 2.2.1)
2) Refer to the text (2.3).
3) Refer to the Graphic Representation of Bentham and Hooker's System.
4) With the help of graphic representation of Engler and Prantl system, draw the chart.
5) In all there are 24 phyletic dicta. Select 15 out of these, selecting few from different morphological features i.e. Symmetry of flower, Zygomorphic verses Actionmorphic, Number of Stamen, Carpels etc.
6) Consult the graphic representation of Hutchinson's system and then draw a scheme to show the outline of the system as well as the starting and climax orders.
7) Refer to Section 2.5.3.

UNIT 3 SYSTEMS OF CLASSIFICATION— ANIMALS

Structure

3.1 INTRODUCTION

Today, we have almost overwhelming riches in species diversity. The total number is unknown—but estimates run as high as 10 million living species. Zoologists have named more than 1.5 million species of animals and a thousand more are added every year. Yet, some zoologists believe that species named so far make up less than 20% of all living animals and less than 1% of all those that have existed in the past. This diversity has attracted the attention of people. At first, the study of diversity was motivated by purely practical reasons, to determine which animal might be an useful source of food, medicine and other products. The motivation continues till today.

To communicate with each other, about the diversity of life, biologists have found it very necessary to name and classify the organisms. The primary method of classification depended on the grouping of the animals on the basis of the similarities among them. The classification is not static but changes continually in the light of new information and ideas as well as the addition of new species. There are two distinct processes in the classification which are frequently carried out at the same time i.e. the establishment of equivalent features of the objects to be classified and their grouping on the basis of the features.

The main purpose of the classification is to keep track of diversity and numbers of more than one million species, and provision for the discovery of new ones. It is a communication system which provides greatest information content with greatest ease of information retrieval. The passion of classification led to the complex systems that we use today, and the efforts of those biologists stimulated important developments in many fields of biology including ethology, ecology, biogeography, embryology and physiology.

In Unit I and Unit II you have read about various plant classification now in this unit you will know about animal classification. After reading this unit you will be able to know:

- the importance of zoological classification,
- the goals of biological classification,
- various methods of classification used in animal taxonomy,
- the merits and demerits of various methods of classification described.

3.2 THE GOALS OF BIOLOGICAL CLASSIFICATION

The world of animal diversity is quite complex and it requires an ability to recognise similarities and differences among organisms. Classification systems have four important roles. First, they are an aid to memory. It will be impossible to remember the characteristics of a large number of different animals unless we can group them into categories all members of which share many features. Second, classification systems greatly improve our predictive powers. If, for example, you know that mammals of all species have mammary glands with which they produce milk for their offspring, we can be quite certain that a newly discovered mammal will have this method of provisioning its offspring even if the first specimens we happen to find are males. Third, classification system improves our explanatory power about relationships among animals. For biologists, this is especially an important role as they attempt to reconstruct the evolutionary pathway that has produced the diversity of organisms. The animals are named according to binomial nomenclature as you will read in coming unit. If the names are changed, the system provides a means of tracing those changes. There are two types of names, scientific names and common names. Common names are very unreliable and often confusing. For example, the pickerel is prized as an edible fish in the large lakes of central Ontario, whereas to the south, in Great Lakes, it is regarded as a relatively undesirable table fish. Thus, definite scientific name is necessary for a species.

Classification systems are based on features whose utility depend on what we hope to accomplish with the system. Classification of animals was made from several points of view, such as type of reproduction, habitat and mode of life, usefulness to people in ancient time, but now we use much more evolved classification. Thus, a classification should fulfil all the four important roles that you have read. From time to time, different classification have been proposed and we can classify them into following five categories.

3.3 TYPES OF CLASSIFICATION

There are several biological classification of animals which were suggested from time to time but they belonged to one of the following types. There are:

i) Phenetic Classification
ii) Natural Classification
iii) Phylogenetic Classification
iv) Evolutionary Classification
v) Omnispective Classification

3.3.1 Phenetic Classification

This system is based exclusively upon face value of observed characters without direct reference to phylogeny. The taxa are either classified on the basis of a few characters or overall characteristics. When based on a few characters, the groupings are subjected to change on the discovery of natural affinities of the taxa.

The greatest weakness in phenetic approach is that it demonstrates a false claim in establishing natural groups as products of the human mind rather than of evolution. It is now a well recognised fact for all natural taxa, especially species with their reproductive isolation, that they are not an arbitrary, subjective, man-made phenomena. This approach is quite useful for groups with immature classification and to those with numerous non-redundant characters. It is of no use when applied to higher organisms. The use of computer methods of pheneticists can be of great help in taxonomy if combined with philosophy of evolutionary taxonomy together with the proper weighting of characters.

3.3.2 Natural Classification

Natural classification is based on the natural characters of the taxa. Some consider natural classification a phylogenetic one reflecting the evolutionary relationships among the groups that comprise it. Some oppose this concept on the ground that phylogeny is not known but merely hypothesised. It is not an attribute but only a guess at an attribute and it is based on previous classification. The animals are placed into as many groups and subgroups as are the similarities and dissimilarities. They define "natural classification" as one in which the groups are recognised by having a maximum number of attributes in common, with their limits set by discontinuities in the diversity, and capable of yielding the maximum number of correct deductions about correlations of other features.

3.3.3 Phylogenetic or Cladistic Classification

Phylogeny plays a great role in classification. It is the appropriate theoretical background for taxonomy and is quite essential in explaining all the associations involved in classification. Some people believe phylogenetic and evolutionary classification are similar to each other since they both are based on the features derived from a common ancestor while some other consider as different approaches. Cladistic classification is exclusively based on phylogenetic branching. Cladistics phylogeny, in opposition to numerical phenetics, includes an attempt to map the sequence of phyletic branching through a determination of characters that are shared primitive (symplesiomorphic) and shared derived (synapomorphic) (Fig 3.1). But, to date there is no true phylogenetic classification for any group of animals except (to some extent) that of horses. This is due to incomplete fossil record and also because the comparative data collected through other approaches fail to possibly give a clear picture by itself. Thus, cladistic taxonomic system attempts to communicate only genealogy. There is no attempt to express the degree of overall similarity of the organisms in such classification systems.

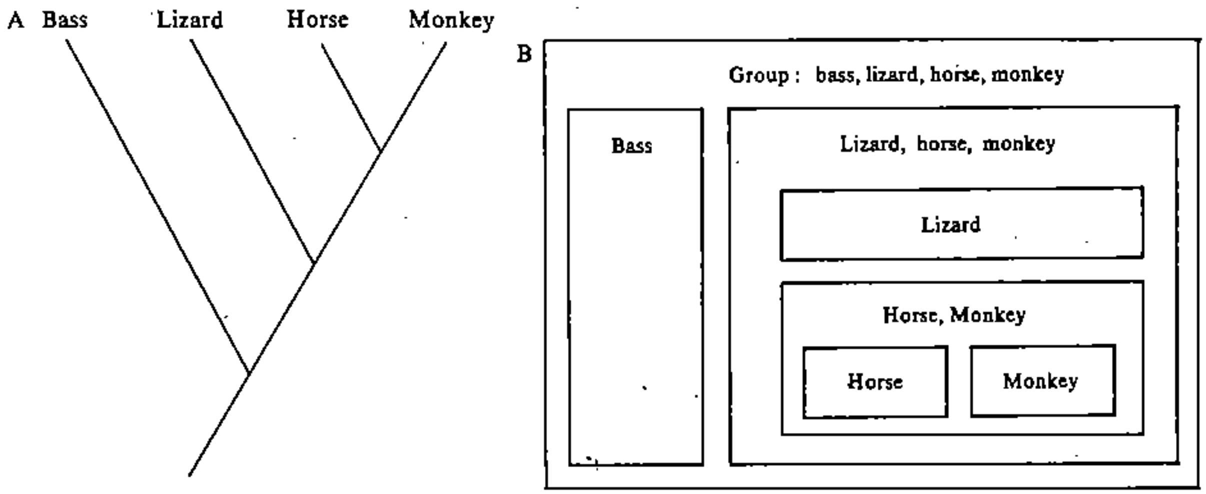


Fig. 3.1 : a) A simple cladogram. The bass is the outgroup, and monkey, horse and lizard are closely related groups. Cladogram, unlike traditional phylogenetic trees, carries no time to scale because it is meant to show only relative degree of relationship not actual historical events.
b) The "nested sets" of the cladistic hierarchy, constructed from the cladogram.

3.3.4 Evolutionary Classification

Evolutionary classification combines aspects of both phenetic and cladistic systematics. Evolutionary taxonomists attempt to show in their classification both the evolutionary relationships and the degrees of similarity among organisms. It is impossible, however, to represent both similarities and genealogies accurately in a single classification system because rates of evolution among groups of organisms and among different traits within groups of organisms are often highly variable. Therefore, evolutionary taxonomists must compromise between their two goals. This need not be confusing as long as the nature of the compromise is clearly indicated so that users of the system know how the taxonomic categories were constructed. With a simple and hypothetical example we can illustrate how different approaches lead to different classification of organisms even when they use the same data (Fig 3.2). Six characters have been measured, and each one can have either the ancestral state (0) or a derived one (1). In this example, evolutionary reversal of character states are not found but in real life some reversals may occur. Given these character states, we can compare the four species phenetically and cladistically. The phenetic similarity calculation is based on the number of shared characteristics that are in the derived state. The phenorograms and cladograms of these four species are quite different (Fig. 3.3).

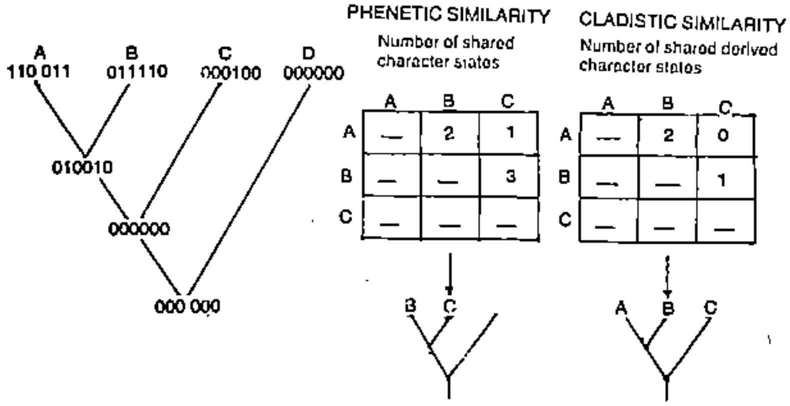


Fig. 3.2 : Different systems give different classifications

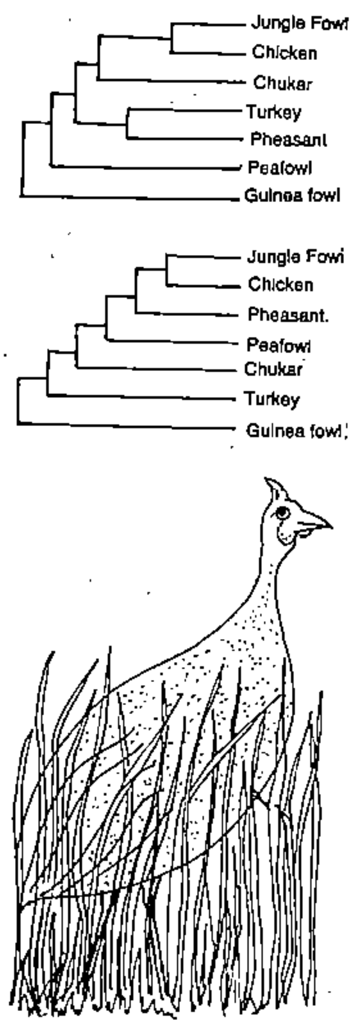


Fig. 3.3 : Phylogeny of phasianoid birds. Phasianoid (pheasant-like) birds are now placed in several different families, including the Numinidae (guinea fowl), Meleagrididae (turkeys) and Phasianidae (pheasants, partridges, chickens). Phylogenetic tree a) depicts the relationships suggested by nuclear gene maps. Phylogenetic tree b) is the branching order implied by the study of the general morphological features of these birds. Both schemes agree that guinea fowl c) are most distinct from the others, and that jungle fowl and chickens are very closely related, but the schemes differ in other significant respects. Nuclear gene data suggest that convergent evolution in morphology has occurred in the group.

To take a real example, we may consider the classification of pheasants and their relatives. The species of phasianoid birds are well known and have been intensively studied in terms of their gross morphology. Three regions of the chicken's nuclear genome have been intensively studied: those containing structural genes for lysozyme C, those for three different "α like globins, and those for four "β like" globins. Each of these regions is located on a different chromosome. These parts of the genome have also been measured for jungle fowl (the ancestor of modern domesticated chickens) chukar, turkeys, pheasant, peafowl and guinea fowl. A phenogram for the phasianoid birds based on genetic information can be converted into a cladogram (phylogenetic tree) if we assume constant rates of evolutionary changes in the globin molecules. This classification differs in significant ways from the one based on traditional morphological evidence (Fig. 3.3). In this case, the genetic evidence is particularly compelling because the extent of differences among the birds is roughly the same for all three gene regions. Taxonomists have evidently been misled by considerable convergent evolution among the phasianoids. Current classification will probably be changed as a result of new genetic evidence.

Currently, the most commonly used classification are evolutionary ones, and they continue to be used partly because they are so familiar. For example, crocodiles are generally grouped with reptiles because of their morphological similarities with lizards and other reptiles (aphenetic classification) even though they share a more recent common ancestry with birds than with other reptiles. In a purely cladistic classification crocodiles would be grouped with birds rather than with reptiles.

3.3.5 Omnispective Classification

This is the extension of the concept of natural classification put forward by Black Welder (1967). The approach seems quite realistic and pragmatic. Here, an experienced taxonomist includes all the readily available features of the organism but only those are used for classificatory purposes, which are helpful in establishing groupings and distinctions. This practice is currently used by most of the animal taxonomists.

SAQ 1

State whether true or false by placing T for True and F for False in parenthesis.

i) Phenetic classification is directly based on face value of observed characters. [ ]

ii) Phenetic approach is that have claim in establishing natural group as product of evolution. [ ]

iii) Natural classification is based on the natural characters of taxa. [ ]

iv) In natural classification minimum number of attribute are in common with their limits set by discontinuities in the diversity. [ ]

v) Cladistic classification is exclusively based on phylogenetic branching. [ ]

vi) To date no true phylogenetic classification for any group of animal is formed. [ ]

vii) Cladistic and phenetic together form evolutionary classification. [ ]

viii) Recently most commonly used classification are evolutionary onces because they are so familiar. [ ]

ix) Omnispective classification is the extension ot the concept of natural classification [ ]

3.4 TAXONOMIC CHARACTERS

Classification is done on the basis of information we have. More information gives better classification. Modern taxonomy is developed by incorporating contributions made by various branches of biological sciences. Thus, sometimes there are important revision in the classification systems. Several types of characters are used in classifying organisms. From centuries the characteristics of organisms have been measured, and most species descriptions are based on gross morphology, that is, size and shapes of body parts. The morphology can be revealed from the fossils and it is the best direct source of information about the ancestors of living organisms. Sophisticated methods are now available for making morphological measurements and for comparing the amount of variability among individuals, populations and species.

The early developmental stages of many organisms reveal similarities with other organisms that are lost by the time adulthood is reached. For instance, larval, but not adult, sea squirts (tunicates) have a dorsal supporting rod, the notochord, that reveals their evolutionary relationship to other chordates. Examination of the adults would not suggest such a relationship.

Although fossils tell us little about the behaviour of organisms of the past, living organisms often reveal their close affinities by similarities in their behaviour. This information is most useful for detecting relationships among rather closely related organisms. The German ethologist Konard Lorenz showed that close similarities in behaviour patterns supported other evidence suggesting that species of ducks with quite different plumages are nonetheless very closely related. Many species of ducks can cross and produce fertile hybrid offspring, showing that they are genetically similar. Successful hybridization sometimes reveals that organisms that look very different may be very similar genetically. The sequence of amino acid in proteins provide information about genetic similarities and differences that is relatively free of environmentally induced changes. A direct measure of genetic distance is given by the number of amino acid replacements that have occurred since the taxa from which the proteins are obtained shared a common ancestor. An important taxonomic character is the structure of the genes themselves, the nucleotide sequences. These are being determined in several ways, the most important of which is the cleavage of DNA and RNA into short sections by the use of enzymes that recognise specific nucleotide sequences. These sections are then separated electrophorically and their sequences are determined. Thus these are some important taxonomic characters which should be taken into considerations. Let us look into as to how the selection of characters should be made.

3.5 SELECTION OF TAXONOMIC CHARACTERS

Eventually classification systems may be based almost entirely on direct study of the genes themselves, but for a long time we will continue to use information for many sources. Characters useful for classifying organisms must be **measurable, describable, and relatively invariable, regardless of the environment** in which the organism grows. For a plant whose leaves have different shapes depending upon whether they grow in water or in air, leaf shape would not be a good taxonomic character. For groups with good fossil records, direct measures can be made of the rates at which different features have evolved. Nucleic acid analyses and amino acid sequences in proteins, especially when combined with fossil evidence (of the splitting of groups) provide very accurate estimates of the average rate of change in genes and their direct consequences. Although the same procedures are used with all organisms, the characters upon which classification is based differ and only those characters which vary strikingly among organisms are measured. Flowering plants offer branching patterns, leaf shapes, specialised cells, reproductive structures and so on. Many invertebrates have shells that are readily preserved as fossils and can be measured long after the animal has died. Thus taxonomic character is a feature which is present in all appropriate specimens at appropriate times. One should be very cautious in selecting useful characters. The choice of character is directly based on the accumulated experience of the taxonomist. One should select only those characters which are stable within species or groups, easily studied and quite distinctive in its easy separation from other closely related taxa. Thus a taxonomist has to search for good characters which are most effective in making the distinction and separation of the species or other taxa, quick and easy. He has to keep in mind that these characters should not show wide variation among known specimens as well as intrinsic genetic variability. Also characters should not be influenced readily by the environment but must be consistent and easily seen in the specimen.

One of the important criteria in selecting a character is its analogy or homology with characters of other organs. Let us know what does it means. Homology is defined as a correspondence between two structures due to inheritance from a common ancestor. The homologus structures usually retain certain basic features that betray their common ancestry. For example, the leaves of vascular plant, as you know there are several modification of leaves but they are all homologies of one another. Similarly, the forelimbs of horses, bats, whales and humans, all have the same framework of bone structure, yet function differently (Fig. 3.4).

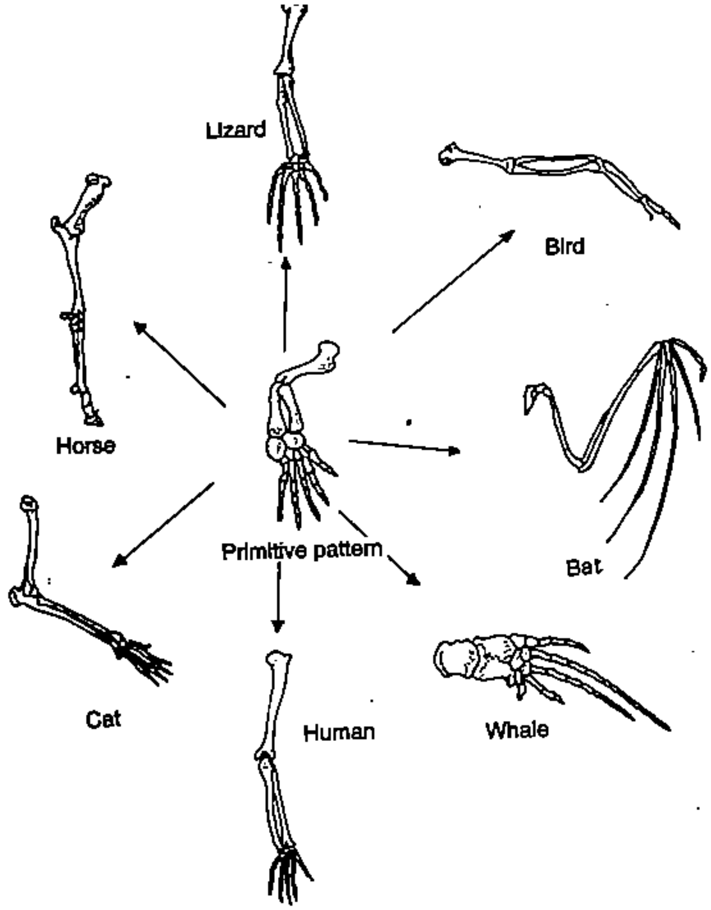


Fig. 3.4 : Structural homology. In spite of different uses, the forelimbs of a number of very different vertebrates all have the same framework of bone structure, modifications of a primitive skeletal pattern in an ancient ancestor from which they all descended.

However, often, structures that do not come from a common ancestry converge to become more similar than they formerly were, because they perform similar functions. Such resemblance in function due to convergent evolution is defined as analogy and such structures are said to be analogous. For instance, the wings of both butterflies and birds function as flight organs but specifically they are different and do not have a common origin. Analogous structures often pose problems for taxonomists because their similarities may suggest common ancestry unless a very close examination is made to reveal which original structures were actually modified. Thus, selection of taxonomic characters is very important task and should be done very cautiously.

3.6 TAXONOMIC HIERARCHY

The sheer complexity of oganisms seems so bewildering that some people believe life to be unfathomable by the rational mind. Biologists constantly chip away at this notion by exploring and discovering real explanation for phenomena. Our ability to solve these natural mysteries would be severely handicapped, however, without another hierarchy of organisation that creates meaningful order out of the overwhelming variety of organisms to be studied. This orderly system enables us to distinguish clearly between different types of organisms. Also it allows us to classify and assign names to the almost two million known types of living organisms as well as their extinct ancestors.

Most classification systems group smaller units into successively larger ones. The number of features shared by members of small units. For instance, ostriches, owls, hummingbirds, and sparrows are quite different animals, but they share more features with one another then they do with whales, cats, mice or deer. By calling them birds, and the second group mammals, we direct attention to certain significant features that serves to unite members of the group and distinguish them from members of other groups.

In the system used today, based on the work of the great Swedish biologist Carolus Linnaeus (1707-1778), each species is assigned two names, one identifying the species itself and the other the genus to which the species belongs known as binomial nomenclature. A genus is a group of species that are closely related (the plural of genus is genera and its adjectival form is generic).

In the Linnean system, the species are grouped into higher taxonomic categories. The number and limits of these categories are somewhat arbitrary, but there are some guiding rules. One is purely practical; if every species were put into its own genus, or conversely, all were lumped into one genus, the genus would not carry any information not already present in the designation of species. A second consideration is the relative amount of similarity or dissimilarity among the organisms. A higher taxonomic category may have a single species in it if that species is very different from all other species. Some genera, on the other hand, have hundreds of species in them. Similarly, a family the next higher unit, can contain a single genus or many of them. A family can contain only a single species if that species is judged to be sufficiently different from all other species. But again families must contain, on the average, a number of genera if they are to be useful in describing a different level of similarity among organisms than that expressed with genera. In animal classification the names of families are identified by idea endings. Thus Formicidae is the family that contain all ant species, while Hominidae contains humans and few of our fossil relatives. Family names are based on a member genus. Formicidae is based on *Formica* (remove the a and add idae), and Homindia is based on *Homo* Families are in turn grouped into orders, orders into classes, classes into phyla (singular phylum) and divisions (for plants) and phyla and divisions into kingdom. Thus various units of classification—kingdom, phylum, class and so on—are called taxonomic categories and together they make up the taxonomic hierarchy (Fig. 3.5). Let us take an example and see how three well known organisms fit into the system (Table 3.1).

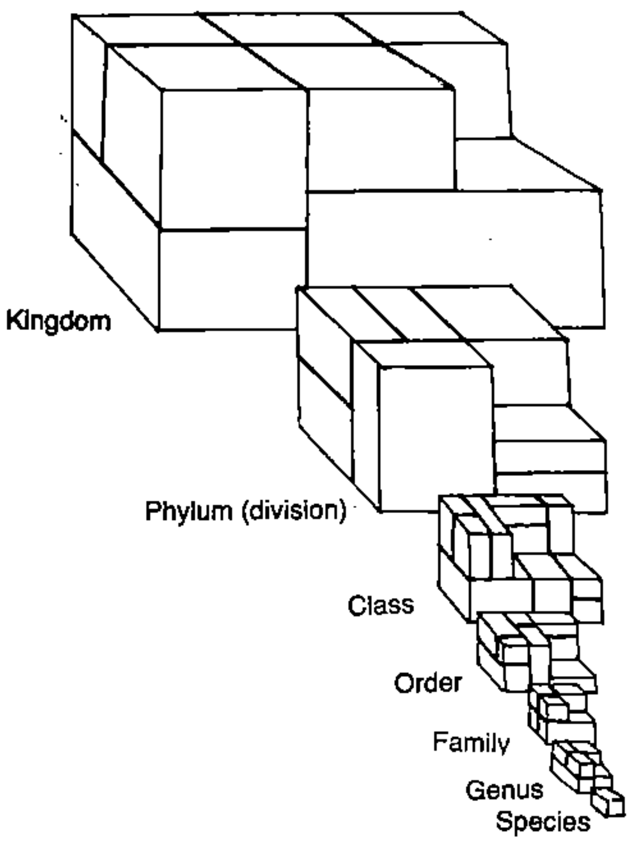


Fig. 3.5 : Taxonomic levels in the classification of life. Members of the same group at a particular level (taxon) are more related to each other than they are to members of the other groups in the same taxon. For example, all the organisms in the same genus resemble each other more than they do members of the other genera in that family. The smallest group, the species, consists of the most closely related organisms. At the other end of the spectrum are the kingdoms, the largest, most encompassing groups that contain the greatest number of organisms.

Table 3.1 : Examples of Animal and Plant Classification

Taxonomic group	Animal Examples		Plant Example
Kingdom	Animal	Animal	Plant
Phylum	Annelida	Chordata	Tracheophyta
Class	Oligochaeta	Mammalia	Angiospermae
Order	Terricolae	Primates	Ranales
Family	Lumbricidae	Hominidae	Ranunculaceae
Genus	*Lumbricus*	*Homo*	*Ranunculus*
Species	*L.terrestris*	*H. sapiens*	*R.acris*
Common name	earth worm	Human	meadow buttercup

SAQ 2

2 a) Put appropriate word/words in the blanks.

i) Characters used for classifying organisms must be:

a) ....

b) ....

c) .... invariable

d) .... of environmental change.

ii) Very accurate estimate in the rate of change in genes can be measured by:

.... analyses

.... sequence in protein

....

iii) Characters of flowering plant which are to be measured are :

....

....

....

....

iv) The characters which are to be chosen by a taxonomist for a particular Plant group should be :

i) ....

ii) ....

iii) ....

2 b) In which of the following list are the levels of the taxonomic hierarchy not arranged in correct descending order?

i) Phylum, order, family
ii) Class, family, genus
iii) Class, family, order
iv) Order, family, genus

3.7 HOW MANY KINGDOMS?

Until quite recently living organisms were divided into two kingdoms—the animal and plant kingdom. The animal kingdom contained mainly motile organisms which fed heterotrophically and the plant kingdom contained mainly static organisms which fed autotrophically by photosynthesis. Unicellular heterotrophs (protozoa) were put in the animal kingdom, and unicellular autotrophs (protophyta) were kept under the plant kingdom with the algae. Fungi were regarded as plants which have lost their chlorophyll and taken up a heterotrophic mode of nutrition. Bacteria were also put in the plant kingdom mainly on the ground that they possessed a cell wall.

There are three main problems with having only two kingdoms. The first problem concerns the unicellular flagellates such as *Euglena* and its relatives. These were put with protozoa in the animal kingdom. However, some euglenoids for example, *Euglena* itself, contain Chlorophyll and feed autotrophically by photosynthesis. With only two kingdoms we have to content with the embrassing fact that these organisms can, in effect hop from one kingdom to the other.

The second problem concerns the fungi. Although fungal hyphae bear a superficial resemblance to the filaments of simple multicellular algae like *Spirogyra,* fungi are really very different from green plants. Not only do they lack chlorophyll and feed heterotrophically but in several structures differ from those of the plants.

The third problem is posed by bacteria. In electron microscope we can see that bacteria have simple prokaryotic cell structure, and same feature is also found in blue-green algae. They appear to be similar to each other, and markedly different from all other organisms which are eukaryotic. To solve this problem new five kingdom system was proposed.

3.8 THE FIVE KINGDOM SYSTEM

To cope up with above discussed problem a number of alternative classificatory schemes have been suggested with more than two kingdoms. The one which has gained most support was put forward in 1969 by the American biologist R.H. Whittaker. Whittaker's scheme divides living organisms into five kingdomes. The animal kingdom is reserved for multicellular motile organisms which feed heterotrophically, the plant kingdom for multicellular organisms which feed by photosynthesis. The protozoa and unicellular algae are brought together into a separate kingdom, the Protista kingdom and the bacteria with blue-green algae, unique amongst living things in being prokaryotic, are combined together in the Monera Kingdom (Fig 3.6). Though five kingdom system solves many difficulties but it also creates some. For example, separating the unicellular algae from the simpler multicellular algae is not entirely satisfactory as they have certain features in common. This has led some biologists to suggest that all algae, unicellular and multicellular, should be included in the protista kingdom. In this scheme even quite complex organisms such as seaweeds would find themselves with the protists, traditionally associated with unicellular organisms. Some biologists feel that the name protist should not be used for this expanded group and it has been suggested that this

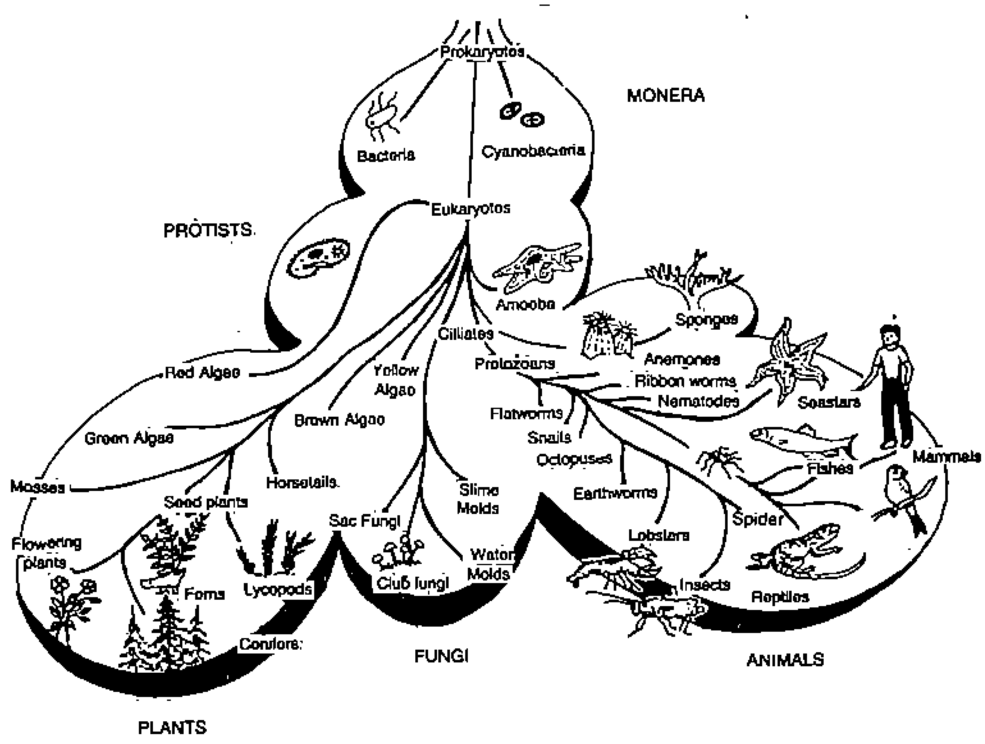


Fig. 3.6 : The modern five kingdom scheme of biological classification. This diagram shows the relationship between the five kingdoms and the relative numbers of species that each contains. The animal kingdom, with its 1.3 million species, is the largest kingdom, in other words, it contains the greatest diversity.

kingdom should be called the protoctista. This modification of Whittaker's original five kingdom system has certain advantages but it will not be dealt here and Viruses also are not included in this system.

In grouping living things into kingdoms, there are bound to be anomalies, whatever scheme one adopts. If we look at Fig. 3.6 we will see that kingdoms are really the trunk and main branches of an evolutionary tree. Splitting the tree into kingdoms is an arbitrary process and depends whereabouts along the trunk and branches you make your cut.

SAQ 3

What is the five kingdom system as distinguished by Whittaker, and on what basis did he distinguish them?

....

....

....

....

....

Whittaker Five Kingdom System

Table 3.2 : The Five Kingdom of Organisms

Kingdom	Representatives	Characteristics
Monera	Bacteria and cyanobacteria (formerly called blue-green algae) 16 phyla 2000 species	Prokaryotic (no nucleus or cellular organelles) Unicellular Cell wall of polysaccharides and polypeptides Autotrophic (chemosynthetic and photosynthetic) or Heterotrophic Reproduction mainly asexual by binary fission. Rare sexual reproduction by conjugation
Protista	Algae, protozoans, slime moulds, water moulds 27 phyla 60,000 species	Eukaryotic Unicellular, or simple colonies of cells. No tissues Aquatic Various types of cell walls present in some Autotrophic (photosynthetic) or Heterotrophic
Fungi	Bread moulds, yeasts, truffles, puffballs, mushrooms, lichens 5 phyla 100,000 species	Eukaryotic Multicellular Cell Wall of chitin or other polysaccharides Heterotrophic. Excretes digestive enzymes and absorbs externally digested nutrients Sexual reproduction and production of asexual species No embryological development
Plantae	Mosses, liverworts, hornoworts club mosses, horsetails, ferns, cycads, conifers, gnetophytes, flowering plants 9 phyla 400,000 species	Eukaryotic Multicellular, forming simple and complex tissues Cell walls, made primarily of cellulose Autotrophic (photosynthetic) Distinct alternation of haploid and diploid generations Embryological development
Animalia	Sponges, coelenterates, flatworms, segmented worms, nematodes, and other wormlike animals. Rotifers, mollucs, arthropods (crustaceans, spiders, insects), mammals, birds, fish, amphibians, reptiles 32 phyla 1,300,000 species	Eukaryotic Multicellular, forming simple & complex tissues Heterotrophic, ingests food & digests it internally Sexual reproduction Embryological development Nervous system, sometimes complex

Kingdom Monera

The monerians are structurally the simplest of all living things. They have apparently changed little since they first appeared on the earth. Their structure is very simple and they lack nuclear membrane, membrane-bound organelles, and flagella with microtubules having characteristic 9 + 2 structure. Because of this simplicity they are believed to be ancestors of Eukaryotes.

Phylum-Bacteria (Eubacteria)

Eubacteria, the true bacteria, are extremely small and they exist in vast numbers virtually everywhere on earth. They range from the upper atmosphere to hot springs, polar ice caps, raw petroleum, the deepest reaches of the sea and animal guts. **It is believed that their mass will outweight that of all plants and animals combined.**

They are unicellular (Fig. 3.7), but the cells may be grouped together in clumps or chains. They have varied method of nutrition i.e. autotrophic by chemosynthesis or photosynthesis and heterotrophic by absorption. Some are important parasites. The asexual reproduction is by **binary fission** and **sexual** by a simple type of conjugation. Bacteria can be divided into groups according to their shapes (Fig. 3.8):

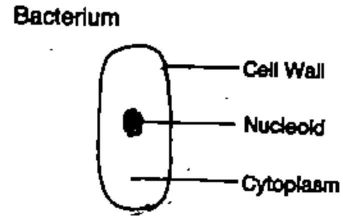


Fig. 3.7 : Bacterium

Staphylococcus	— Cell is spherical and can exist in clumps
Diplococcus	— pair of spherical cells
Streptococcus	— chain of spherical cells
Bacillus	— rod-shaped cells, may occur in chain, some have flagella
Vibrio	— cells shapaed like a bent rod with a single flagellum
Spirillum	— spirally coiled cells with a tuft of flagella

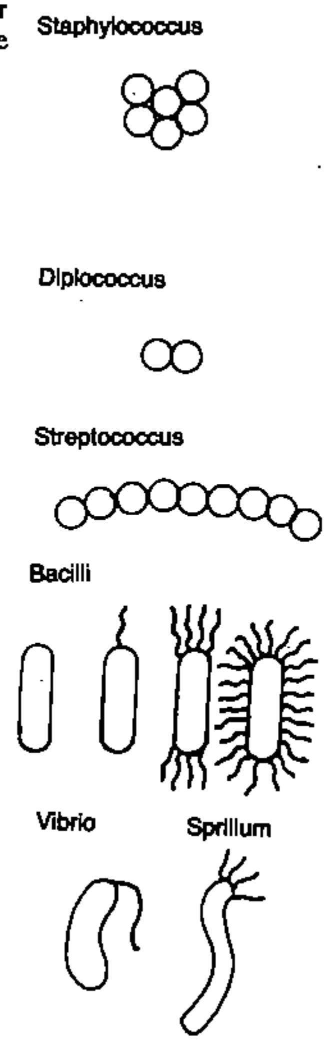


Fig. 3.8 : Types of bacteria

Phylum Cyanobacteria

Cyanobacteria are prokaryotes, but they are not like bacteria in the usual sense of the word. The cyanobacteria lack chloroplasts, and their light capturing pigment is scattered over highly folded inner membrane lamellae. However, their photosynthetic mechanism differ from that of other bacteria. Like plants, they derive their required electrons by breaking apart water molecules. The blue-greens have an important ability to 'fix' nitrogen.

1) Unicellular or filamentous, some of the filamentous forms bear branches.
2) Autotrophic, the photosynthesis is carried out on membranes round the periphery of the cells.
3) Photosynthetic pigments include chlorophyll plus red pigment (phycoerythin) and blue pigment (phycocyanin).

Some examples *Chroococcus, Anabaena* (Fig. 3.9).

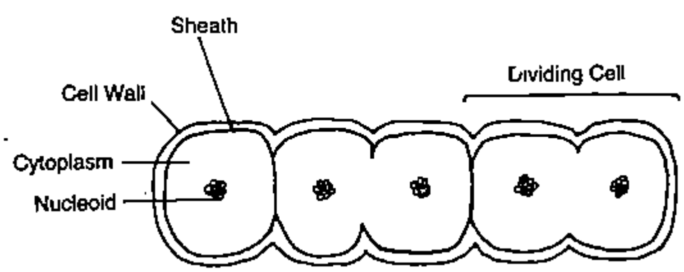


Fig. 3.9 : Anabaena

Kingdom Protista

The protistans are a complex and diverse group of organisms that are placed together simply because they are all single celled eukaryotes but some form rather specialised colonies.

Phylum Phytofagellata

(Plant flagellates)

1) At some stage of life cycle they have one or more flagella. The flagella are used for locomotion.

2) Photosynthetic protistans have chlorophyll.
3) **They form major part of phytoplankton.**

Some examples : *Euglena, Chlamydomonas, Volvox.* (Fig. 3.10)

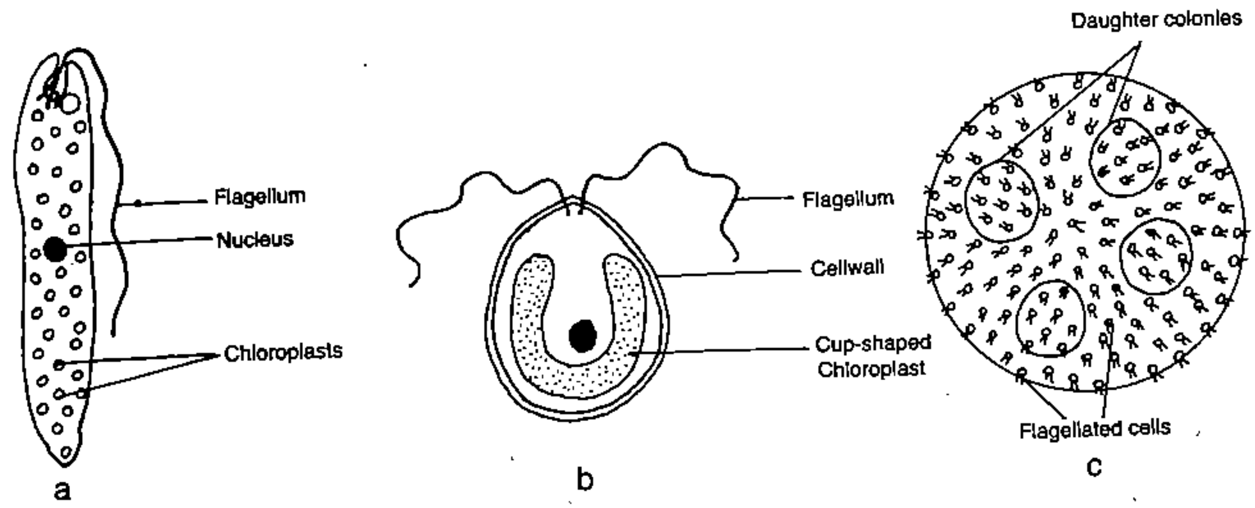


Fig. 3.10 : Plant Flagellates

Other related phyla which have photosynthetic but non flagellated organism: *Pleurococcus,* (Fig. 3.11), *Acetabularia,* Diatoms & Desmids.

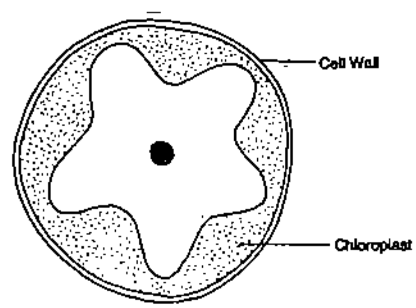


Fig. 3.11 : Pleurococcus

Phylum Zooflagellata

(Animal Flagellates)

1) At some stage of life-cycle they have one or more flagella.
2) They feed heterotrophically by absorption or phagocytosis, and have no chlorophyll.

Some examples : *Trypanosome,* Collar flagellate.

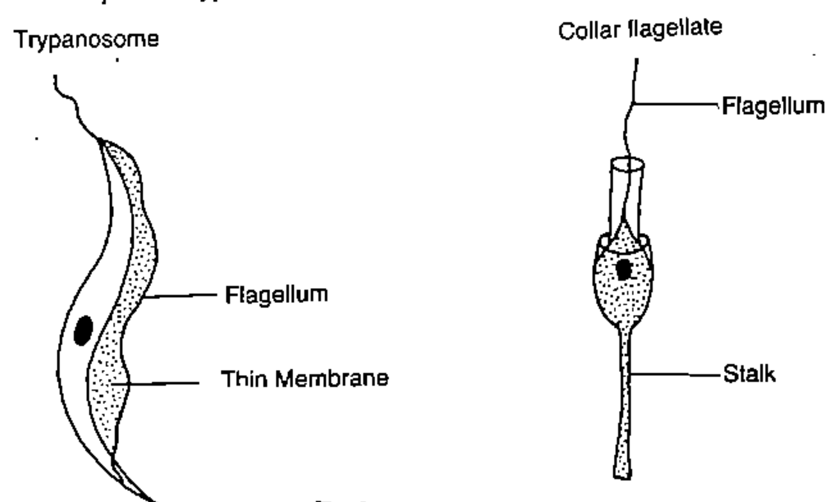


Fig. 3.12 : Animal Flagellates

Phylum Sarcodina

1) They move by means of pseudopodia (false feet) or similar structures.
2) They feed heterotrophically by phagocytosis.

Some examples : *Amoeba (Fig. 3.13), Entamoeba, Elphidium, Actinospherium.*

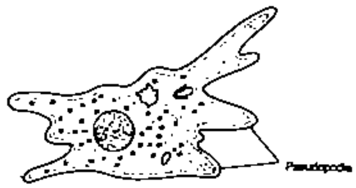


Fig. 3.13 : Amoeba

Phylum Ciliophora

1) They have cilia at some stage in the life-cycle. The cilia are used for locomotion or creating a feeding current.
2) They feed heterotrophically usually by phagocytosis.
3) They have two nuclei, i) meganucleus and ii) micronucleus. The former concerned with vegetative functions of the organisms and the latter with reproductive functions.

Some examples : *Paramecium, Stylonichia, Vorticella, Suctorians* (Fig. 3.14).

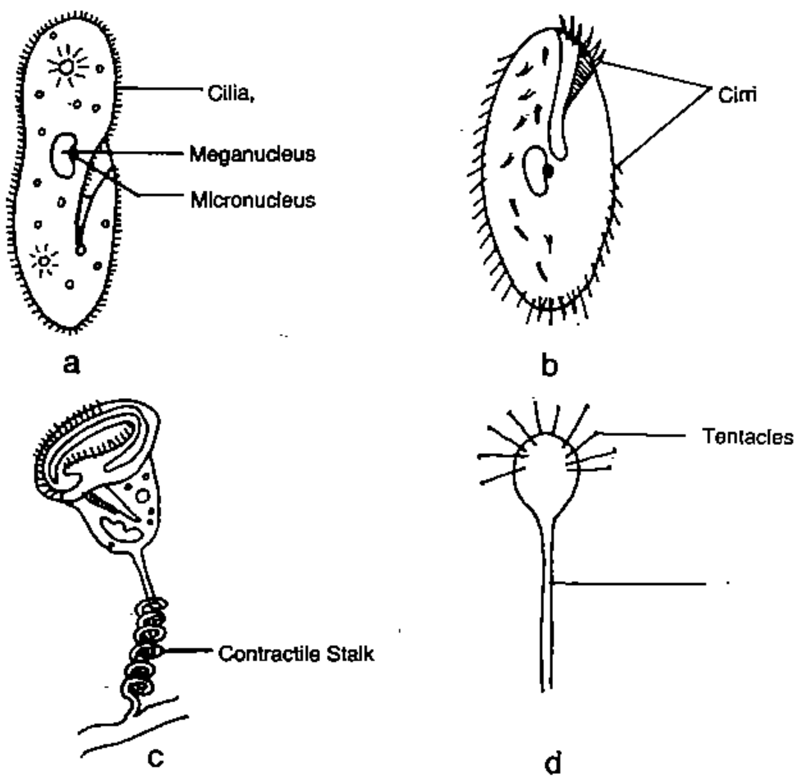


Fig. 3.14 : a-Paramecium, b-Stylonichia, c-Vorticella, d-Suctorian.

Phylum Sporozoa

1) They do not have any external locomotory device and move by wriggling.
2) Reproduction by producing numerous spores.
3) All are parasites of animals, feeding heterotrophically.

Some examples : *Plasmoduim, Monocystis* (Fig. 3.15).

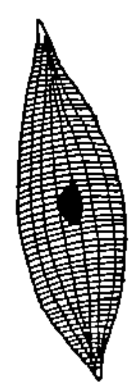


Fig. 3.15 : Sporozoan

Kingdom Fungi

Fungi was earlier placed with the true plants and are still largely considered so in the domain of botanists yet they are quite different. They are multicellular eukaryotes with absorptive heterotrophic nutrition. Body usually consists of a network (mycelium) of thread-like hyphae with cellulose or chitinous wall. In some forms the hyphae are divided into multinucleate compartments by cross wall (septa); in other forms the hyphae are undivided. There are no plastids. They reproduce by spores produced asexually, or by simple sexual conjugation.

Phylum Zygomycetes

1) Asexual reproduction by non-motile spores produced from a stalked spore case which is known as **sporangium.**

2) They reproduced by **conjugation** between neighbouring hyphae.

Some examples : 'Pin mould' lives saprotrophically on jam, bread etc. **(Fig. 3.16).**

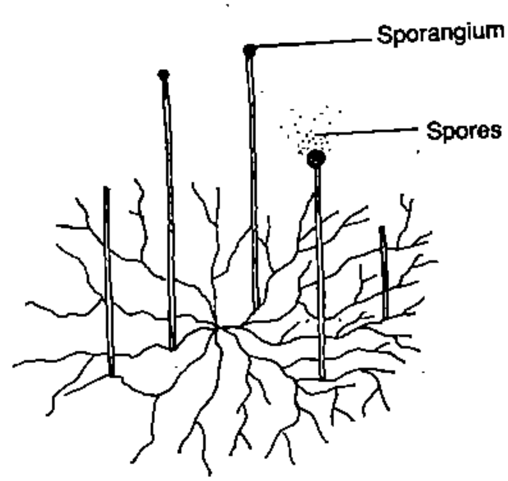


Fig. 3.16 : Mucor

Phylum Oomycetes

1) They reproduced asexually by non-motile conidia and/or mobile flagellated zoospores.
2) The sexual reproduction is by fusion of a male gamete with an egg contained inside an oogonium.

Some examples *Peronospora* (Fig. 3.17), *Phytophthora,*

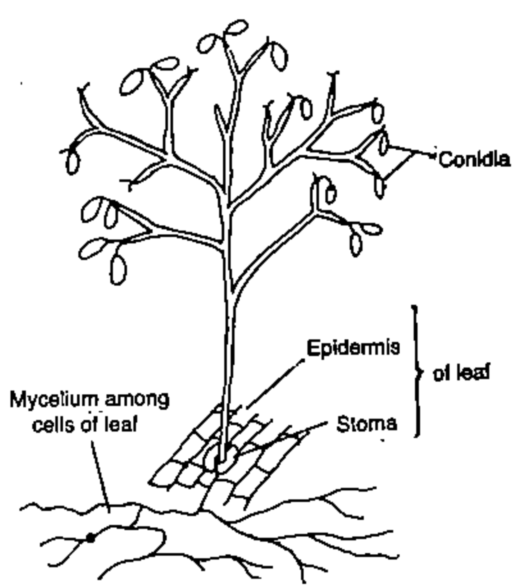


Fig. 3.17 : Peronospora

Phylum Ascomycetes

1) Sexual reproduction is by conjugation and is followed by the formation of ascospores inside a sac called **ascus.**

2) The asci may be grouped together to form a cup-shaped structure known as **Perithecium.**

Some examples : *Sordaria* (Fig. 3.18), *Neurospora, Penicillium.*

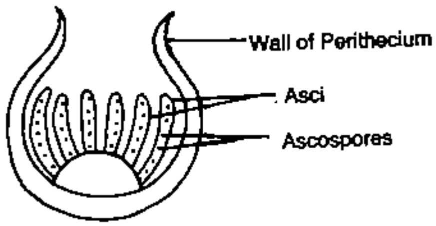


Fig. 3.18 : Sordaria

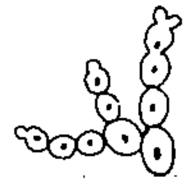


Fig. 3.19 : Yeast

Yeast

They are unicellular fungus which feed saprotrophically on sugars. They can respire anaerobically and reproduce by budding or fusion. Ascospores, formed after sexual reproduction tell us that they belong to ascomycetes (Fig. 3.19).

Phylum Basidiomycetes

1) The asexual reproduction is by means of basidiospores which are produced on a microscopic, club-shaped **basidium.**

2) The basidia are found in a fruiting body made up of densely packed hyphae.

Some examples : Mushroom (Fig. 3.20), *Puccinia.*

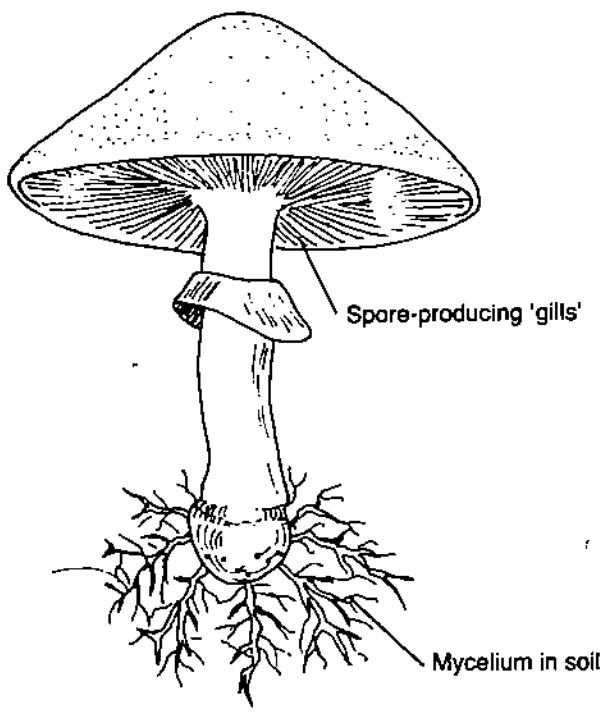


Fig. 3.20 : Mushroom

Phylum Myxomycetes

1) They are known as cellular slime moulds mostly grow in damp places e.g. soil and rotting tree trunks.

2) They have a curious life-cycle in which free living 'amoebas' aggregate into slimy multinucleate 'slug' which forms a spore producing sporangium, the spores develop into a new generation of 'amoebas'.

Example : *Dictyostelium* (Fig. 3.21).

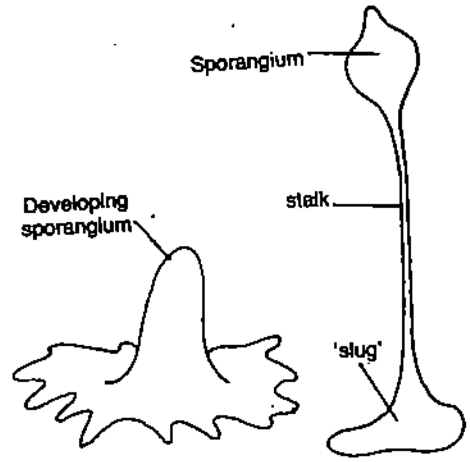


Fig. 3.21 : Dictyostelium

Kingdom Plantae

The kingdom plantae includes multicellular eukaryote organisation with photosynthetic nutrition. Typically cell has cellulose wall, sap vacuole, plastids and several photosynthetic pigments which always include chlorophyll. They have varied methods of reproduction including sexual and asexual.

Phylum Chlorophyta (green algae)

1) The chlorophyll is the main photosynthetic pigment.
2) There is little or no cell differention in thallus. Thallus is usually filamentous or flattened.

   Some examples : *Spirogyra* (Fig. 3.22), *Oedogonium.*

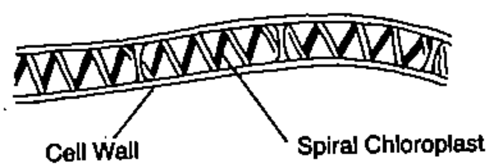


Fig. 3.22 : Spirogyra.

Phylum Rhodophyta (Red algae)

1) The photosynthetic pigments include red pigments (phycoerythrin) and blue pigment (phycocyanin) apart from chlorophyll, of which red pigment predominates. However, the range of colour is from green to red, purple or greenish black.
2) They can be single-celled and filamentous, or may be large with apparently a more usual plant like body.

   Example : *Rhodomela.*

Phylum Phaeophyta (brown algae)

1) They are brown algae, apart from chlorophyll they have brown pigment i.e. **fucoxanthin** which predominates.
2) They are one of the most complex algae and unlike flowering plants, their cells contain centrioles.
3) The common rockweed, *Fucus,* is in this group, as are the giant kelps along the pacific coast.

Some examples : *Fucus* (Fig. 3.23) *Laminaria.*

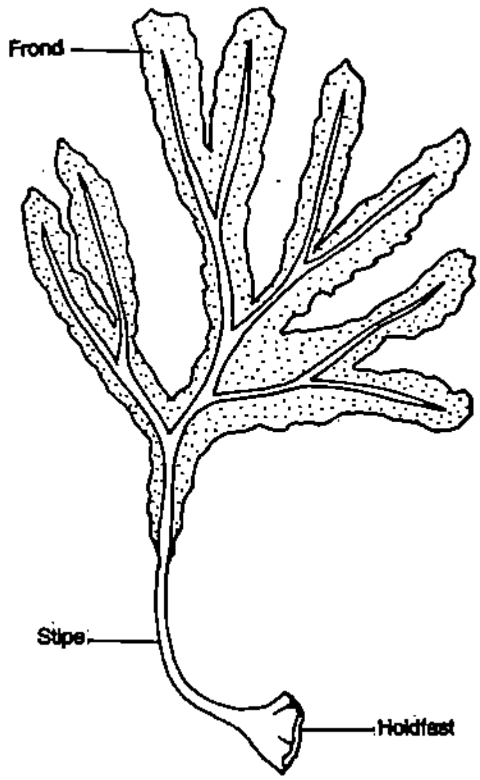


Fig. 3.23 : Fucus.

Phylum Bryophyta

The Bryophytes include the mosses and their close relatives. They are widely diverse and grow in a variety of place.

1) Life cycle shows **alternation of generation** between haploid, gamete-producing, **gametophyte** and a more prominent phase, **the sporophytes**, the diploid spore producing phase.
2) The gametophyte is without vascular tissue but is differentiated into stem and leaves; **rhizoids** are filamentous and used as anchorage.
3) Sporophyte is attached to gametophyte and derives nourishment from it. The most important feature of sporophyte is **spore capsule** (sporangium) which is carried at the end of a slender stalk above the gametophyte.

Hepaticae (Liverworts)

The gametophyte is thalloid body or simple stem and leaves, with aquatic or semi-terrestrial habit. Rhizoids are multiceillular.

Some examples : *Marchantia, Riccia, Funaria* (Moss) Fig. 3.24.

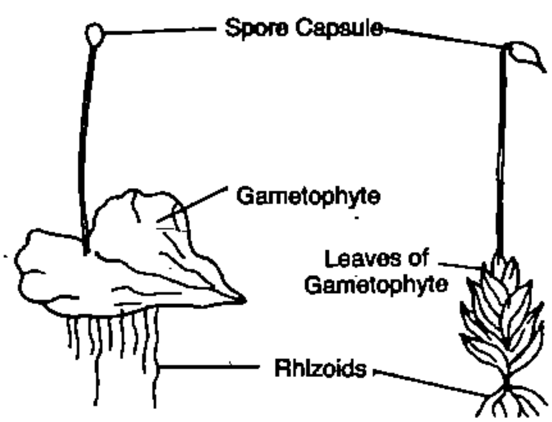


Fig. 3.24 : Liverwort and Moss.

Phylum Tracheophyta

Tracheophytes mean vascular plants. Tracheophyta includes ferns, the gymnosperms and the flowering plants. They have appeared some 400 million years ago, and within only 50 million years or so, they had through divergence formed the major evolutionary lines of land plants.

1) Similar to bryophytes they also show alternation of generation, but in this case the sporophyte is more prominent phase.
2) Sporophyte is differentiated into roots, stem, leaves and vascular tissues.
3) Lignified tissue present.

Subphylum Pteridophyta

Gametophyte is reduced to small simple prothallus.

Class Filicales (Ferns)

Large prominent leaves (fronds) bearing spore-capsules (sporangia) on undersides

Some examples : *Dryopteris*, **Hart's tongue** (Fig. 3.25).

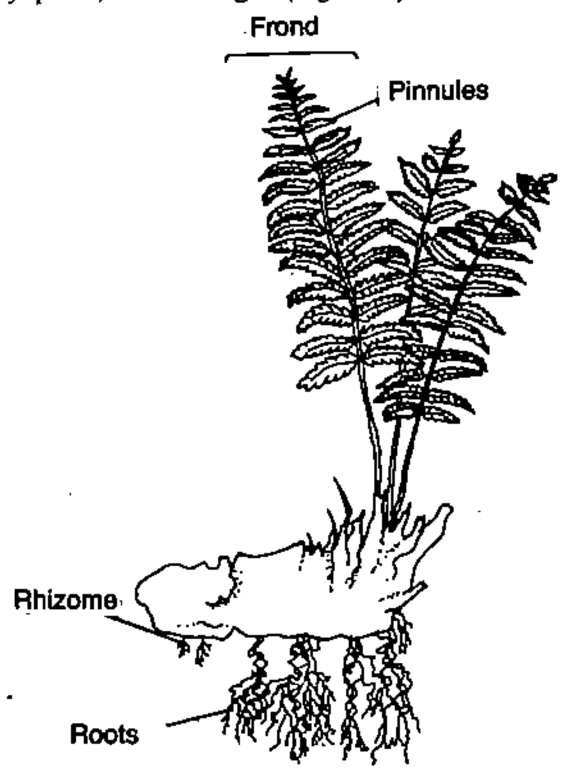


Fig. 3.25 : Fern

Class Equisetales (Horsetails)

Upright stem bears whorls of small leaves at nodes and spore-producing 'cane' at apex.

Example : *Equisetum* (Fig. 3.26).

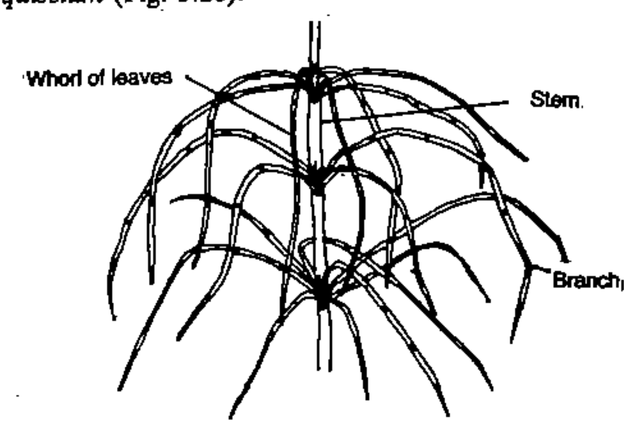


Fig. 3.26 : Equisetum

Class Lycopodiales

(Not mosses at all) small-leaves pteridophytes. Leaves generally densely arranged on branching.

Some examples : *Lycopoduim* (Fig. 3.27), *Selaginella* (Fig. 3.28).

Fig. 3.27 : Lycopodium.

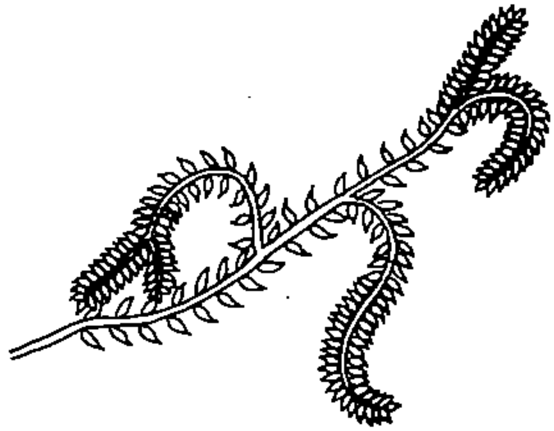


Fig. 3.28 : Selaginella

Subphylum : Spermatophyta (seed plants)

Gametophyte develops within sporophyte tissue. Male and female spores are produced, Microspores are produced within pollen grains. Female gametophyte develops into embryo within seeds.

Class : Gymnospermae (naked seeds)

The leaves are palm like, the reproductive structures are carried together into cones, ovules are unprotected. Pollens are dispersed by wind. Vascular tissues consist only of tracheids, xylem absent (Fig. 3.29).

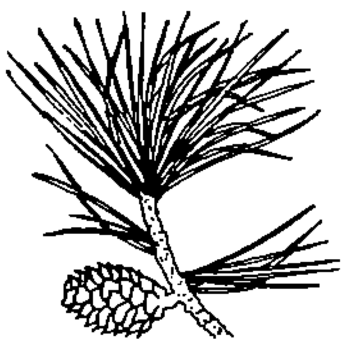


Fig. 3.29 : Pine.

1) Cycas : (100 species, the cycas) the leaves are palm like. Flagellated sperm within pollen tube.

2) Ginkgos/(Species Ginkgo)

   Trees are with fan shaped leaves, the seeds are exposed, pollen are dispersed by wind mobile sperm with pollen tube.

3) Conifers

   Usually large trees with leaves, needles like or scale like. They are evergreen, seeds are exposed and borne upon cones, sperms are non motile sperms.

4) Gynetophytes : (7 species)

   Gymnosperms having angiospermic characters i.e. xylem vessels. Pollens are cone shaped, seeds are exposed sperm is nonmotile.

Class angiospermae (Flowering plants)

Flowers are the reproductive structures. Ovules are protected within ovary, xylem vessels are present. After fertilisation the ovary develops into fruit.

Dicotyledons (2,00,000 species)

The dicot's are of diverse nature.

The leaves are net veined, stem contains ring of vascular bundles, cambium tissue is present so secondary growth occurs. Floral parts are present in four, five or multiples of these seed contains two cotyledons.

Examples : Ranunculaceae, Leguminosae, Crucierae (Fig. 3.30 a). Compositae, Euphorbiaceae, Labiatae, Umbellieferae (Fig. 3.30 b).

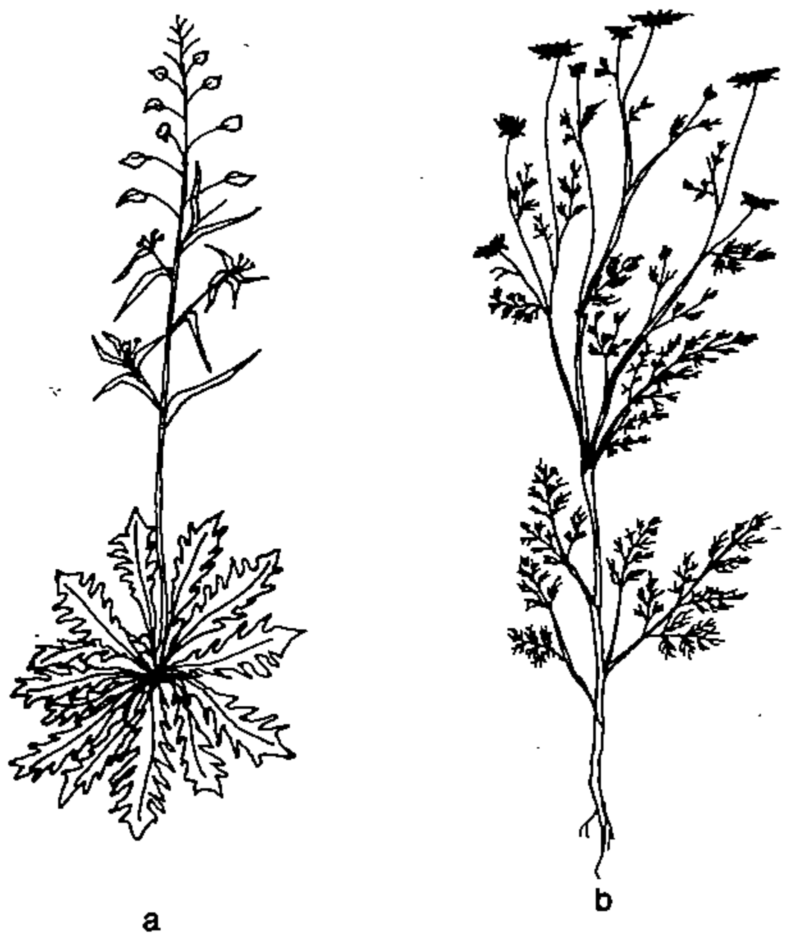


Fig. 3.30a : Cruciferae b) Umbelliferae

Monocotyledons (50,000 species)

They are also diverse in nature. Leaves are parallel veined. Secondary growth is rare. Floral parts are multiples of three or three. Vascular bundle scattered. Seed contains single cotyledon. Most of them do not achieve great height (Fig. 3.31).

Examples : Liliaceae, Graminae, Palmaceae, Orchidaceae.

Fig. 3.31 : Monocot family.

Kingdom Animalia

Multicellular, heterotrophic, eukaryotes, tissues are specialised and most of them have organs, mostly highly responsive. Only gametes are haploid, fertilisation occurs without intervening of haploid cycle. Sperm is flagellated. An egg is large, typical and stationary.

Subkingdom Parazoa : Animals of flagellate origin, simple development progression

Phylum Porifera : (5,000 species)

They have cellular grade of organisation. The adult is nonmotile and always sessile. Feeding habit is filter feeding. The skeleton is made up of calcium carbonate, silicon dioxide or spongin. Asexual reproduction is by budding while sexual reproduction is by fertilisation of internalised egg (Fig. 3.32).

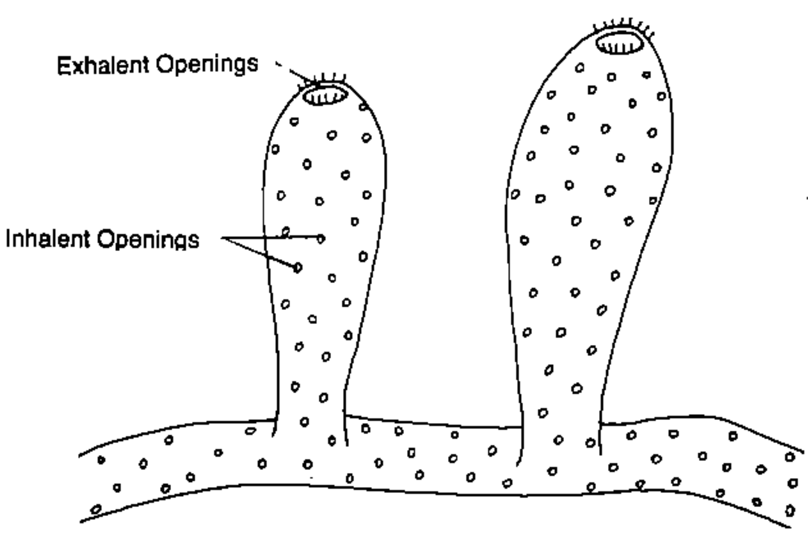


Fig. 3.32 : Sponge.

Subkingdom Metazoa : Animals of ciliate origin, includes all animals except porifera

Radiate, Acoelomic phyla
Radial symmetry, no coelom, diploblastic

Phylum Coelentrata : (9,000 species)

The body is radial and made up of two cell layers. Gastro-Vascular cavity is saclike, tentacles and stinging cells are present. They may exist in two forms medusa and polyps or may pass entire life in one form :

Three classes.
Hydrozoa (hydra, obelia Fig. 3.33 a,b)

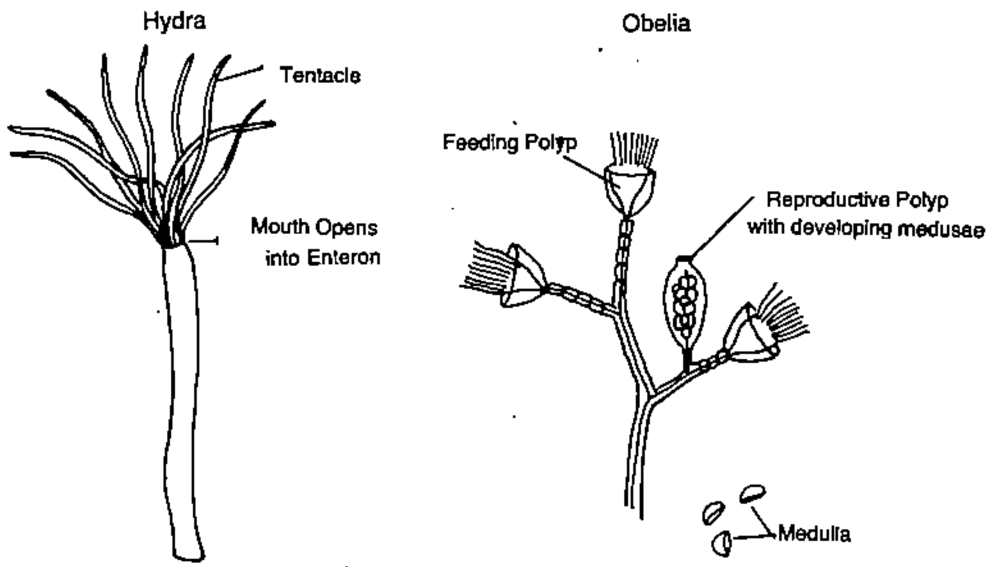


Fig. 3.33 : A-Hydra **B-Obelia**

Schyphozoa (Jellyfish Fig. 3.34).

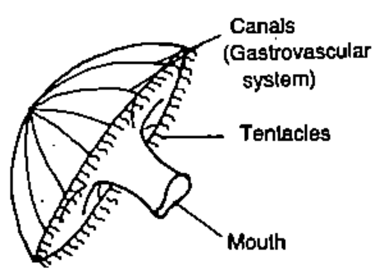


Fig. 3.34 : Jelly fish

Anthozoa (Corals & anemones Fig. 3.35 a,b)

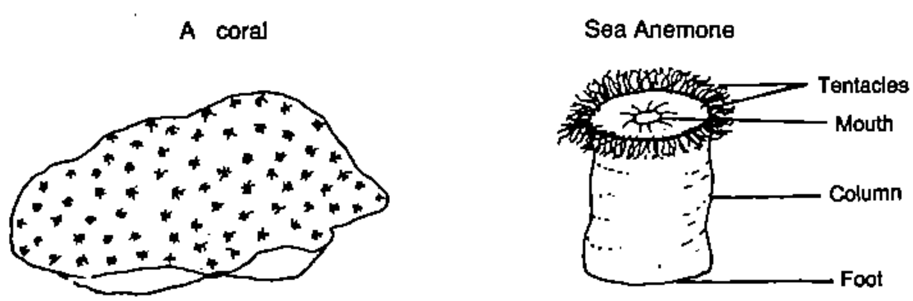


Fig. 3.35 : A-Coral B-Sea anemone

Phylum Ctenophora (90 species, Comb-jellies)
Body is radial with two cell layer, tentacles are with glue cells

Bilateral, Acoelomate phyla
Bilateral symmetry, nocoelom, Triploblastic

Phylum platyhelminthes (13,000 species Flatworm)

The body is flattened. Gastrovascular cavity is branched, dense bodies with many cell layers, mouth but no anus. Hermaphrodite often with elaborate precautions for minimising self-fertilisation. Phylum contains many important parasites. Three classes:

Turbellaria (free-living planarians Fig. 3.36).
Trematoda (parasitic fluke Fig. 3.37).
Cestoda (Parasitic tape worm Fig. 3.38).

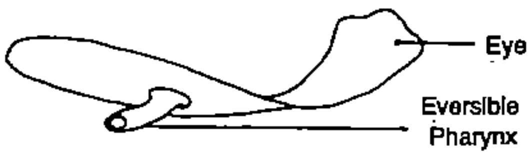


Fig. 3.36 : Planarian.

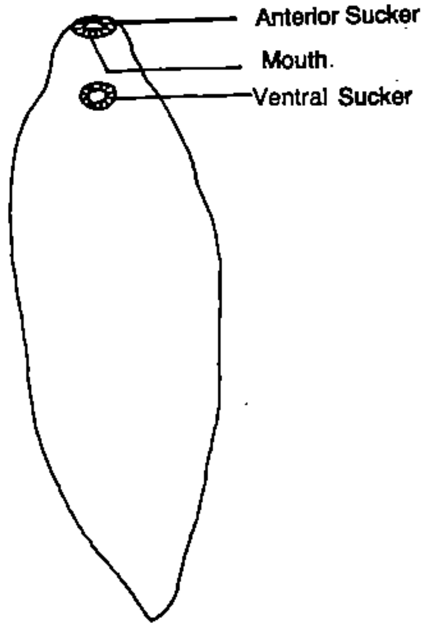


Fig. 3.37 : Liver fluke

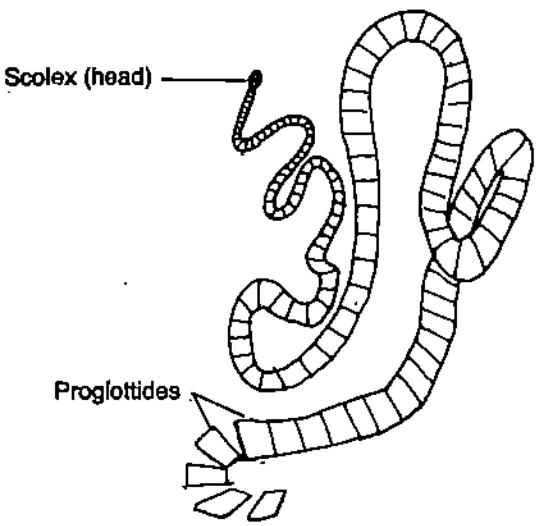


Fig. 3.38 : Tapeworm

The Bilateral, Pseudocoelomate phyla

Bilateral symmetry, pseudocoelom

Phylum Nematoda (12,000 species named and half million are estimated unnamed; the roundworms

Nematodes include both free living and parasitic species. The body is slender and body plan is tube within a tube (Fig 3.39).

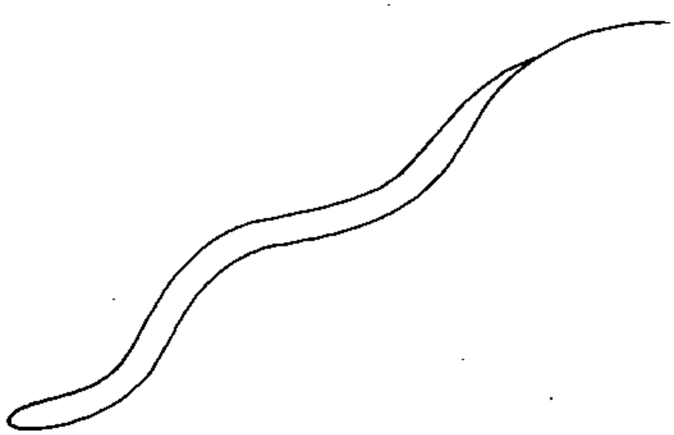


Fig. 3.39 : Ascaris

Phylum Rotifera : (wheel animalcules)

They are free living minute and have very complex organ system. Its members are common inhabitants of freshwater ponds Fig. 3.40.

Phylum Nematophora (230 species horsehair worms Fig. 3.41).

Phylum Rynchocoela : (650 species)

Proboscis or ribbon worms.

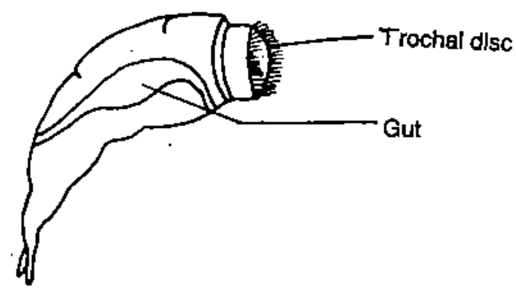


Fig. 3.40 : Rotifer.

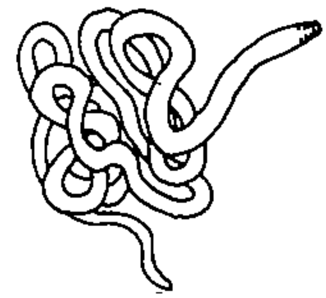


Fig. 3.41 : Nemertinea

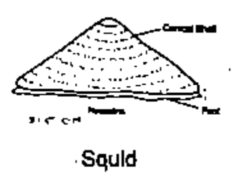
The Bilateral, Coelomate, Protostome phyla

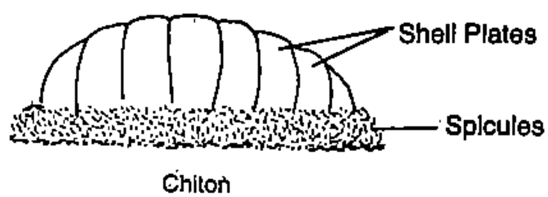
The bilateral symmetry, true coelom, embryologically "mouth first" animals.

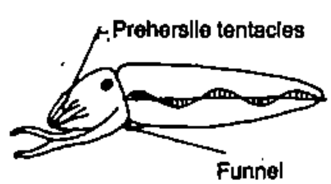
Phylum Mollusca (47,000 species)

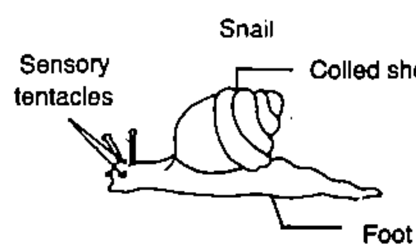
The segmentation and coelom may not exist. Diversification through modifications of head, foot, mantle and radula for feeding. Visceral organs generally protected by a shell, the phylum includes seven classes (Fig. 3.42).

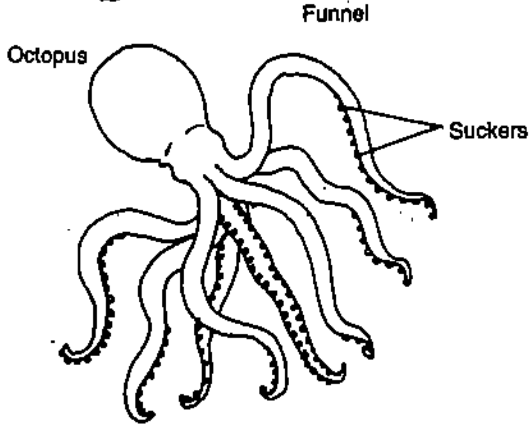
Aplacophora	–	solenogasters-worm like, radula only clear characteristic.
Monoplacophora	–	*Neopilina*, deep-sea form, believed to be extinct.
Scaphopoda	–	Tusk shells.
Polyplacophora	–	*Chitons*.
Bivalvia	–	bilavalves : two shells, clams.
Gatropoda	–	snails & slugs
Cephalopoda	–	octopus, squid-rather intelligent, fast predator, foot subdivided into tentacles, covering mantle, large brain, keen eyesight

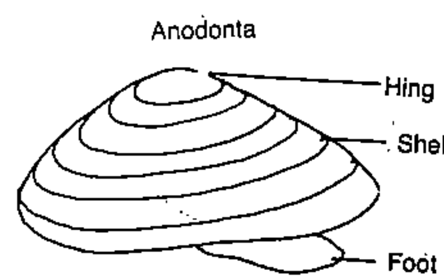












Phylum Annelida (9,000 species, segmented worms)

Body subdivided into repeating segments, true coelom, well developed digestive system, closed circulatory system.

Three classes

Oligochaeta – (earthworms Fig. 3.43).

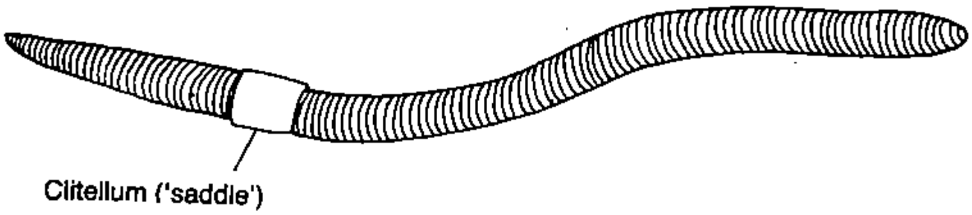


Fig. 3.43 : Earthworm.

Hirudinea – (leeches Fig 3.44)
Polychaeta – (marine worms Nereis Fig 3.45)
Phylum Priapulida (9 species : proboscis worms)
Phylum Pogonophora (100 species : beard worms)
Phylum Sipuncula (300 Species : peanut worms)
Phylum Tardigrada (350 species : water bears)

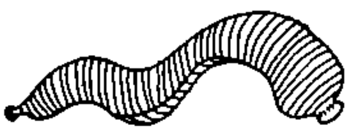


Fig. 3.44 : Leeches

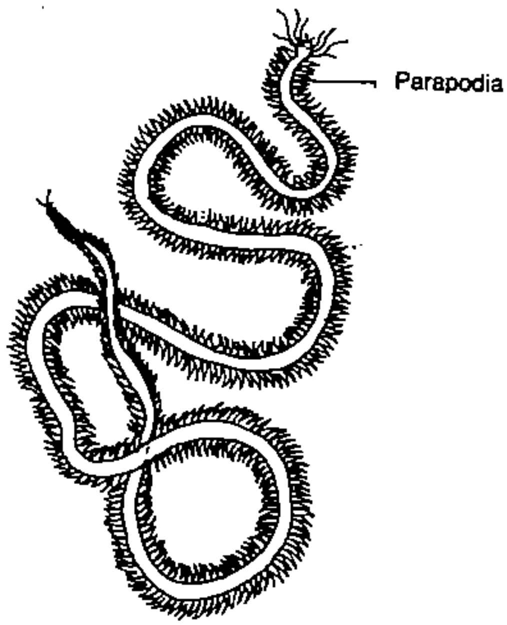


Fig. 3.45 : Nereis.

Phylum Arthropoda : (8,00,000 to 10,00,000 species)

They are known as 'jointed footed' animals. The appendages are paired, and jointed with chitinous exoskeleton, varied and wide segmentation, wide distribution.

Subphylum Chelicerata

Six pairs of appendages, four pairs being legs, with paired chelicerae (fangs). There are three classes in this phylum.

i) Xiphosura – horseking crabs (Fig 3.46)

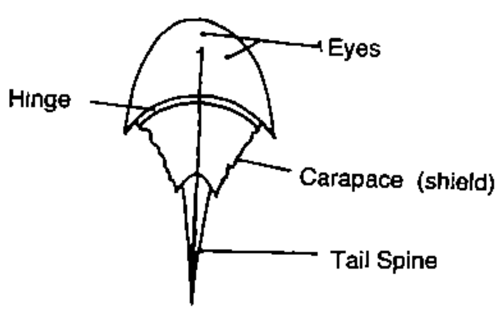


Fig. 3.46 : King Crab.

ii) Arachnida – spiders, ticks, scorpions, mites (Fig 3.47).

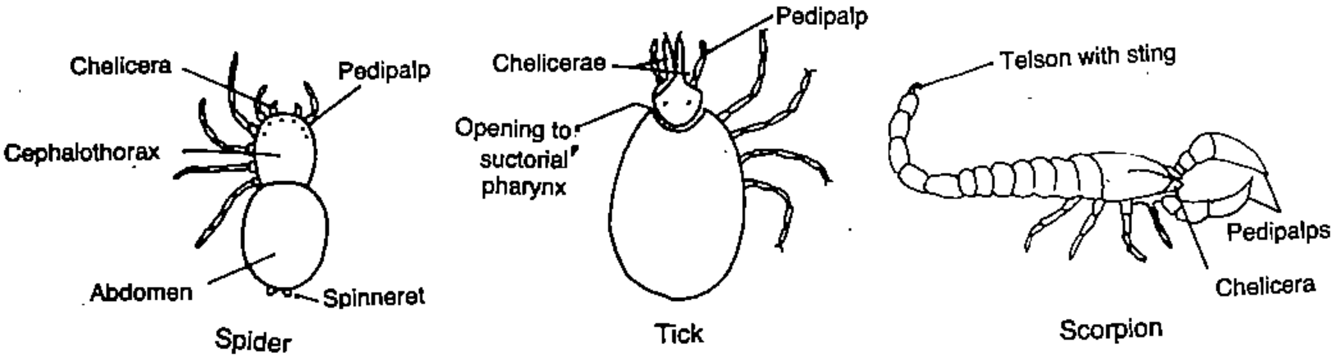


Fig. 3.47 : Various members of class Arachnida

iii) Pycnogonida – Sea Spiders

Subphylum Mandibulata

Most of them have three pairs of walking legs, mandibles, compound eyes, antennas, some with wings. There are four classes.

Crustacea – aquatic with crusty exoskeleton, gills

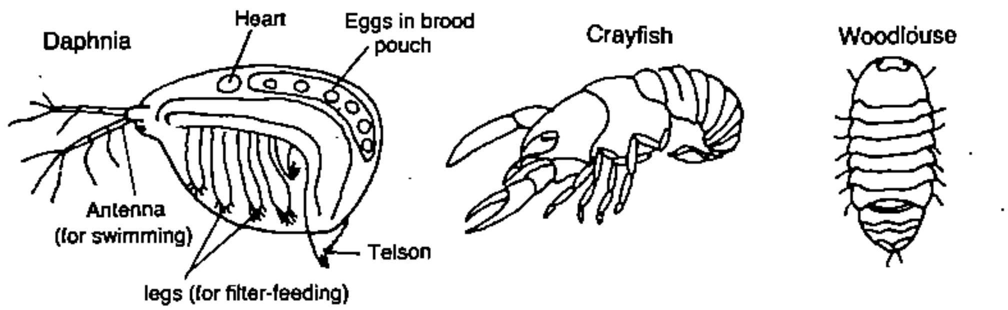


Fig. 3.48 : Various Crustaceans

Chilopoda – centipedes (Fig 3.49)
Diplopoda – millipedes (Fig. 3.50)

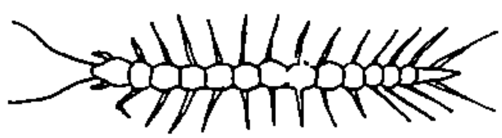


Fig. 3.49 : Centipede

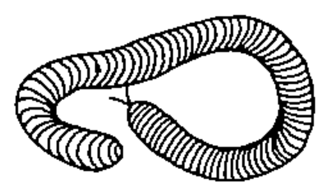


Fig. 3.50 : Millipede

Insecta – Commonly found with 3 pairs of legs, wings at some time in life cycle. body divided into three parts, mouth parts are specialised (Fig 3.51).

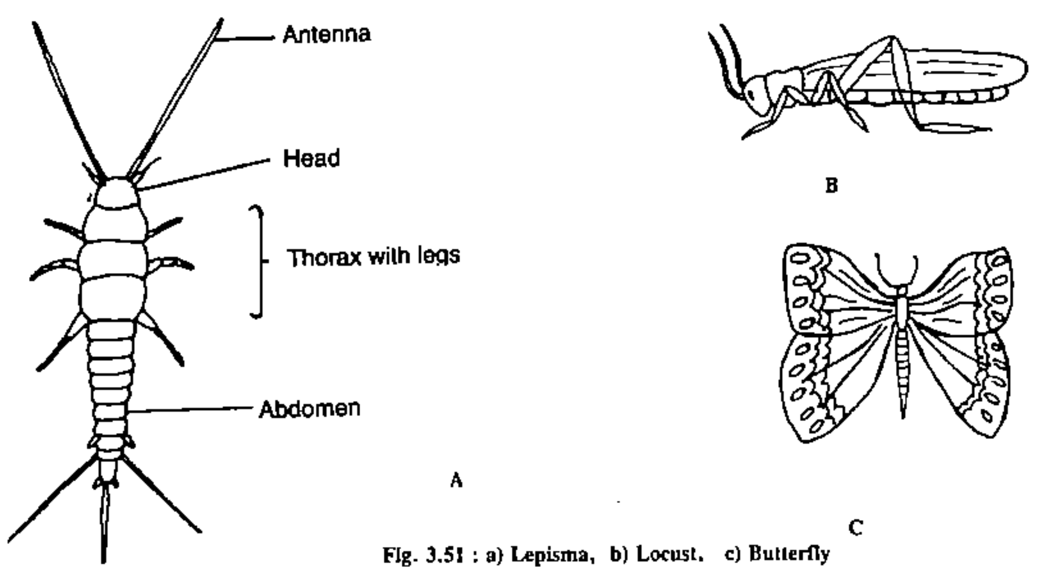


Fig. 3.51 : a) Lepisma, b) Locust, c) Butterfly

Possessing both annelid and arthropod characteristics.

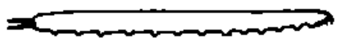


Fig. 3.52 : Peripatus.

Phylum Brachiopoda : (250 species)
They are similar to bivalves, but shell in mounted differently lopophore (ring of ciliated tentacles present).

Phylum Phoronida : (18 species)
Lopophore present.

Phylum Ectoprocta : (4,000 species)
Moss animals lopohore present.

The Bilateral, Coelomate, Deuterostome Phyla

Bilateral symmetry, true coelom, embryologically, "moth second"

Phylum Echinodermata : (6,000 species)
They are spiny, skinned animals, adults have five part radial symmetry, the larvae is bilateral. Endoskeleton is present. Water vascular system is present.

There are five classes in this phylum:
Class Crinoidea (sea lilies)
Class Holothuroidea (sea cucumbers Fig 3.53 A)
Class Echinoidea (sea urchins sand dollars Fig 3.53 B)
Class Asteroidea (sea stars, basket stars Fig 3.53 C)
Class Ophiuroidea (serpent stars, brittle stars Fig. 3.53 D)

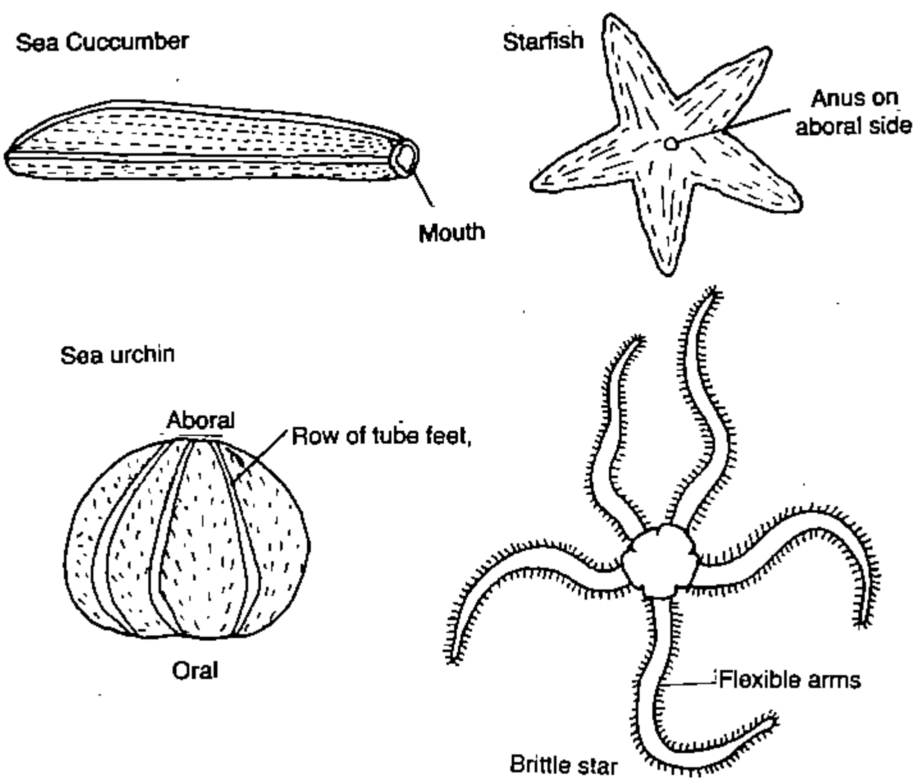


Fig. 3.53 : Various Echinoderms.

Phylum Chordata Dorsally situated notochord, which give strenght to body, hollow, dorsal nerve tube (central nervous system) Pharyngeal clegts. Segmented muscle blocks, Post-anal tail. Circulation in which blood flows forward ventrally and backwards dorsally.

Phylum Hemichordata : (80 species)
The gill slits are present. Notochord, postanal tail, dorsal hollow nerve cord all present at some time in life cycle (Fig 3.54).

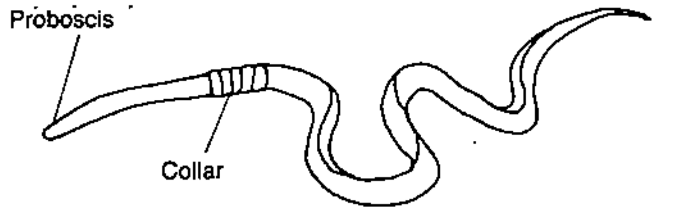


Fig. 3.54 : Acorn worm

Subphylum Urochordata : (13,000 species, sea squirts)
Notocord is dorally situated, nerve tube dorsally situated and is hollow, chordate characteristics seen mainly in bilateral larva.

Subphylum Cephalochordata : (28 species, lancelet)
The animal body is fishlike, notochord and gill slits are permanent. Filter feeders (Fig 3.55).

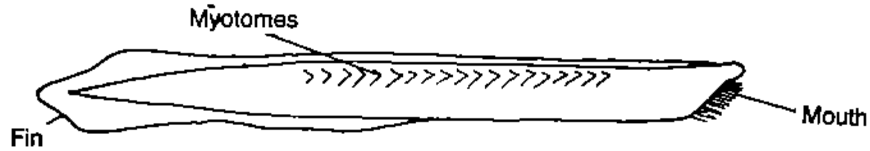


Fig. 3.55 : Amphioxus.

Subphylum Vertebrata : (41,700 species, the vertebrates)
Vertebral column of bone or cartilage, head is well developed, heart is ventrally situated dorsal aorta, two pairs of limbs. The phylum contains six classes (Fig 3.56 - Fig 3.61).

The phylum contains six classes which are :

Class Cyclostomata

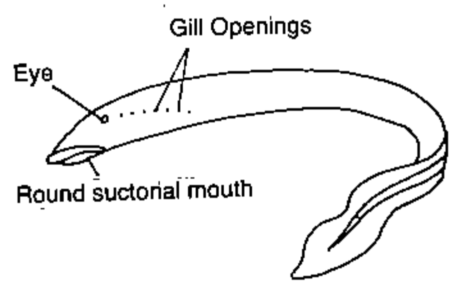


Fig. 3.56 : Lamprey

Class Pisces

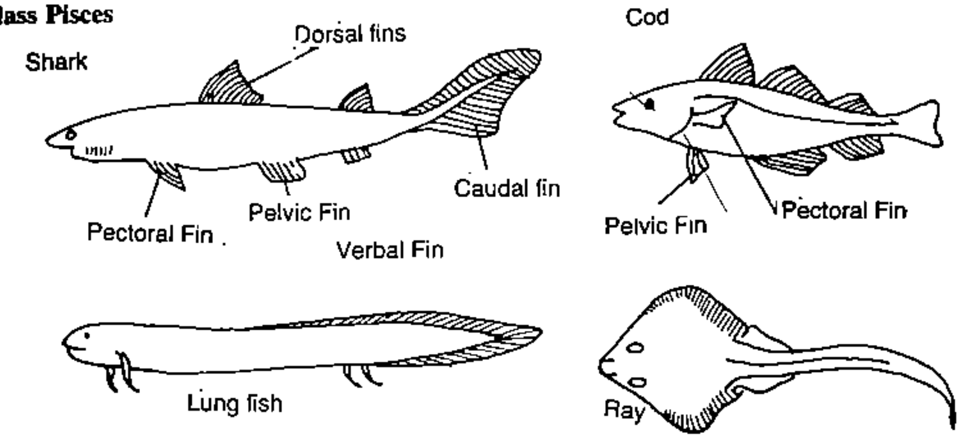


Fig. 3.57 : Fishes.

Class Amphibia

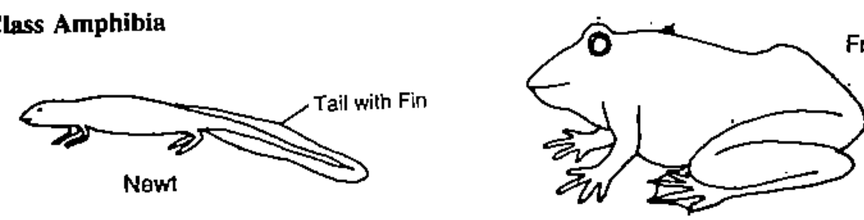


Fig. 3.58 : Amphibians.

Class Reptilia

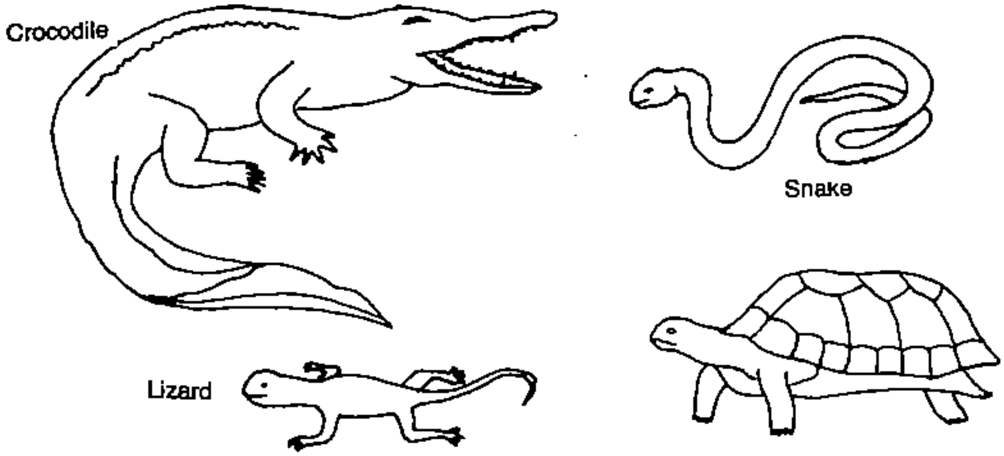


Fig. 3.59 : Reptilians.

Class Aves

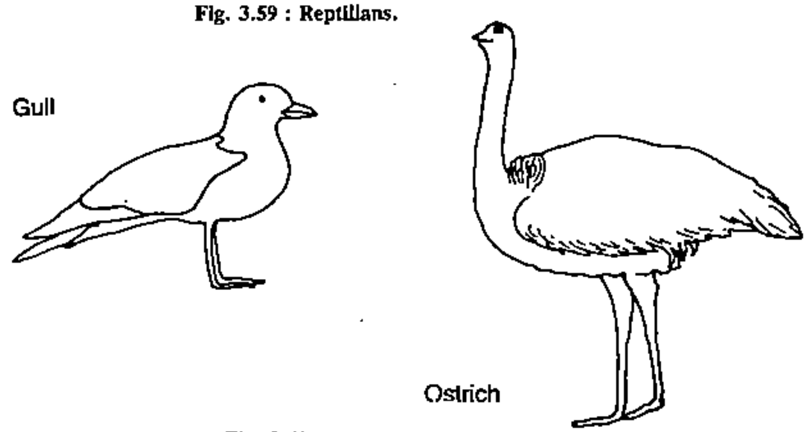


Fig. 3.60 : Birds.

Class Mammalia

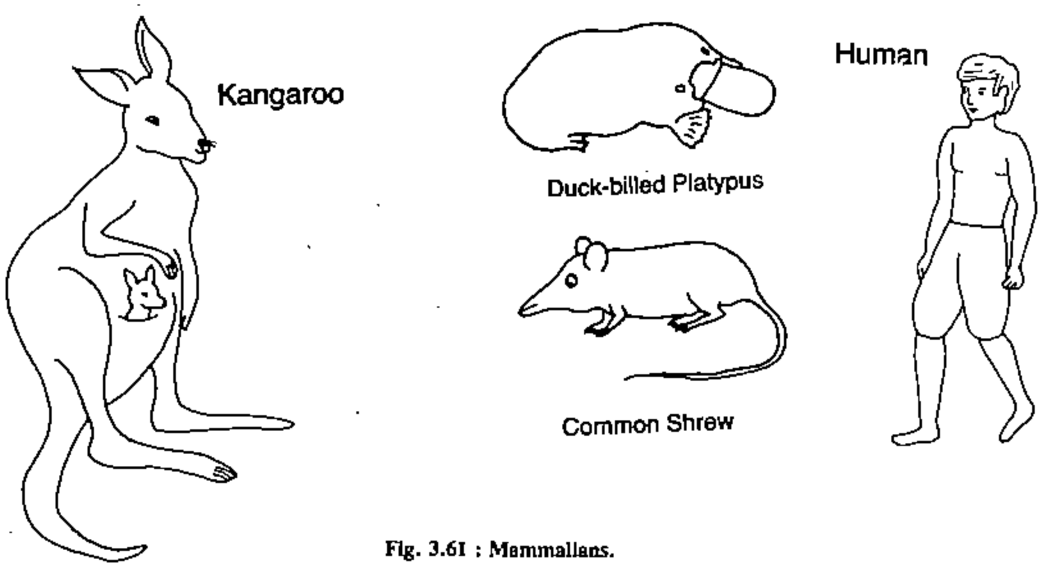


Fig. 3.61 : Mammalians.

The detail study of various class in the classification dealt in Animal Diversity I and II.

In this survey only the main groups and subgroups are included.

3.9 SUMMARY

- Classification is a basic and vital necessity and this orderly arrangement of organisms enable us to distinguish clearly between different types of organisms and allow us to classify and assign names to the almost two million known types of living organisms.
- The important classifications are i) Phenetic classification, ii) Natural classification, iii) Phylogenetic classification, iv) Evolutionary classification, v) Omnispective classification.

- Among the characters used in classifying organism are morphology, development patterns, behaviours and information revealed by variety of molecular techniques.
- One of the most important features in classification is selection of characters. Characters useful for classifying organisms must be measurable, describable and relatively invariable regardless of the environment in which the organism grows.

Biologist classify organisms in the following hierarchy of categories:

Kingdom	organisms per group	Low
(or Phylum)	↑	↑
Class		
Order		
Family		
Genus	↓	↓
Species	organism per group	High

Presently, five kingdom system is followed and it has gained most support. Though this system helps to solve many difficulties, it also creates some.

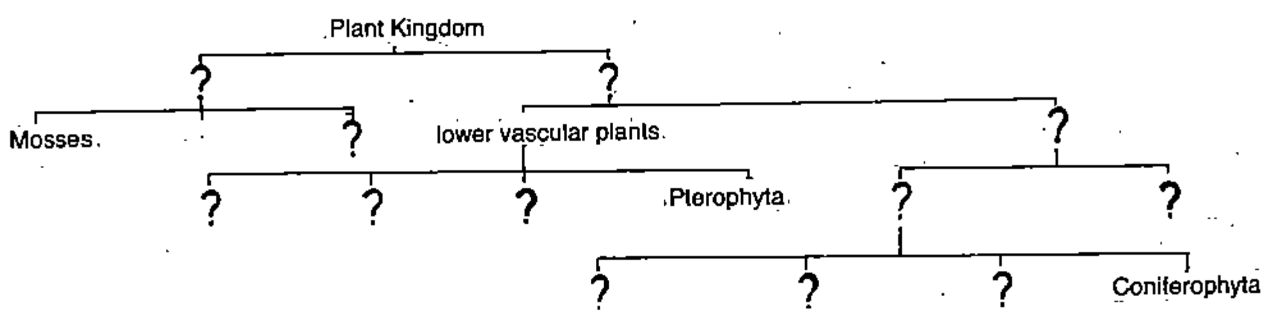
3.10 TERMINAL QUESTIONS

1) Match the structure with the appropriate plant group:

a) Gymnosperm	i) Prothollus
b) Angiosperm	ii) Strobilus
c) Ferns	iii) Rhizoids
d) Mosses	iv) Fruits & Flowers
e) Clubmosses	v) Naked seed

2) Complete the given plant classification by using the following terms :

Higher Vascular Plants	Bryophyta	Gymnosperms
Hornworts	Tracheophyta	Angiosperms
Sphenophyta	Lycophyta	Psilophyta
Cycadophyta	Ginkgophyta	Gnetophyta



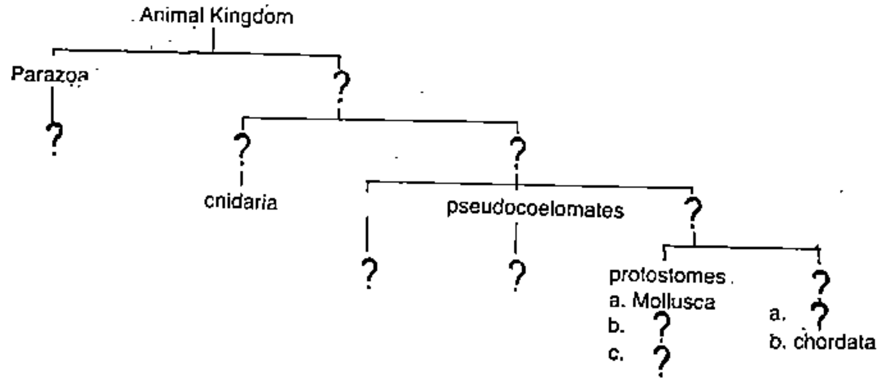
3) Match the following structure with the appropriate phylum:

i) Vertebral column	a) Cnidaria
ii) Cnidocytes	b) Chordata
iii) Vesceral mass	c) Porifera
iv) Choanocytes	d) Mollusca
v) Exoskeleton	e) Annelids
vi) Setae or parapodia	f) Arthropoda

4) Describe main problems in having two kingdoms of living organisms.

5) Complete a classification scheme for the Animal Kingdom by inserting the following in the appropriate place:

Eumetazoa	Radial symmetry	Platyhelminthes
Coelomates	Nematoda	Bilateral symmetr
Porifera	Deutorostomes	Annelida
Arthopoda	Echinodermata	



3.11 ANSWERS

Self-assessment Questions

1) i) T, ii) F, iii) T, iv F, v) T, vi) F, vii) T viii) T, ix) T

2) a) i) a) measurable b) desirable c) relatively d) regardless

ii) Nucleic acid analyses
Amino acid

iii) branching patterns
leaf shape
specialised cell
reproductive structure

iv) i) stable within a species or groups
ii) easily studied
iii) qui'ˀ distinguish and easily separable from closely related taxes

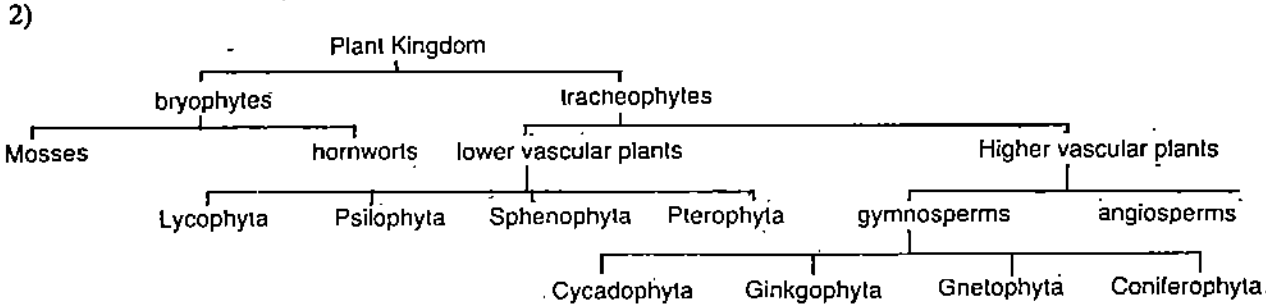
2) b) iii

3) Students should consult Section 3.8.

Terminal Questions

1) a) v b) iv, c) i, d) ii, e) iii

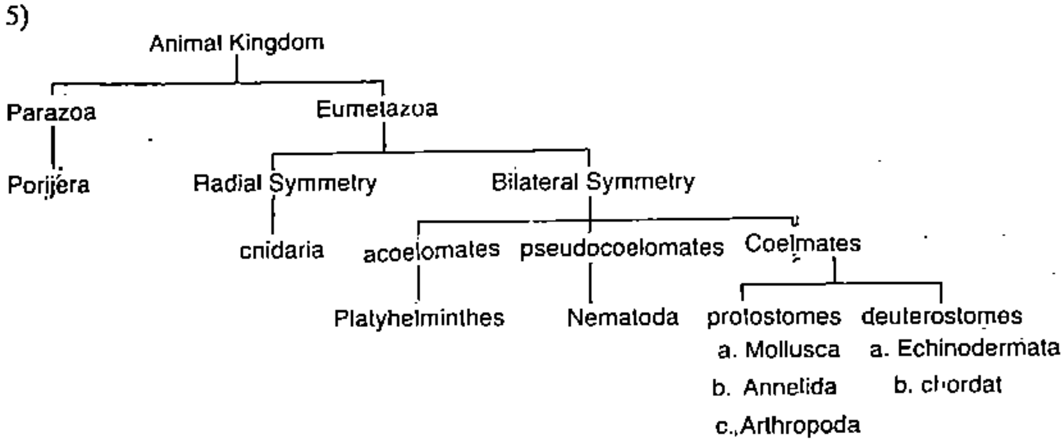
2)



3) 1) B, 2) A, 3) D, 4) C, 5) F, 6) E

4) Refer to Section 3.8

5)



UNIT 4 BINOMIAL NOMENCLATURE

Structure

4.1 INTRODUCTION

In Units 2 and 3 you have read about classification of plants, animals, the process of establishing and defining systematic grouping. In this unit we will discuss Binomial Nomenclature which is unique in Biological Sciences. Binomial nomenclature is the naming of the individual entity and the group so produced through classification, according to the international rules. These rules are published in the form of international codes. Like all other branches of science the field of biology is ever changing in all its contents like characters, circumscriptions and knowledge. Under the heading of binomial nomenclature we will discuss (1) its concepts and principles, (2) binomial systems as put forth by Bauhin and Linnaeus and (3) units of classification like species, genera and families. It is important to mention here that the international codes have no hand in deciding the scientific interpretation but whichever decision you follow the code should guide as to which name or names are to be applied to the entities under study.

Objectives

After reading this unit you should be able to:

- Explain the concepts of binomial nomenclature
- Apply the principles of binomial nomenclature to the naming of plants and animals
- Justify the importance of scientific names
- enlist international codes of nomenclature.

4.2 DEVELOPMENT OF CONCEPTS

Name is a conventional tool to act as means of reference. For example, when we say chimpanzee, sparrow, paddy, virus, we mean to refer certain wild animal, bird, cultivated plant and virus respectively. Thus the words mentioned above are the names. Let us have an example to give the concept of nomenclature. Suppose a farmer with half a dozen cows might refer to each animal by descriptive phrases as the long horned red cow and short horned white cow etc. But when his herd of cows increases he might have more than one long horned red cow and he would be more inclined to designate each cow with a short individual name, not necessarily descriptive in character.

You should know that there are two trends in naming organisms. The one for the convenience of the layman termed as vernacular or common name and the others are scientific names. Virus, sparrow, chimpanzee, man and paddy are examples of common names and turnip yellow mosaic *virus, Passer domesticus, Macacus* *macaque; Homo sapiens* and *oryza sativa* are the scientific names for virus, sparrow, chimpanzee, human and paddy respectively (Fig. 4.1).

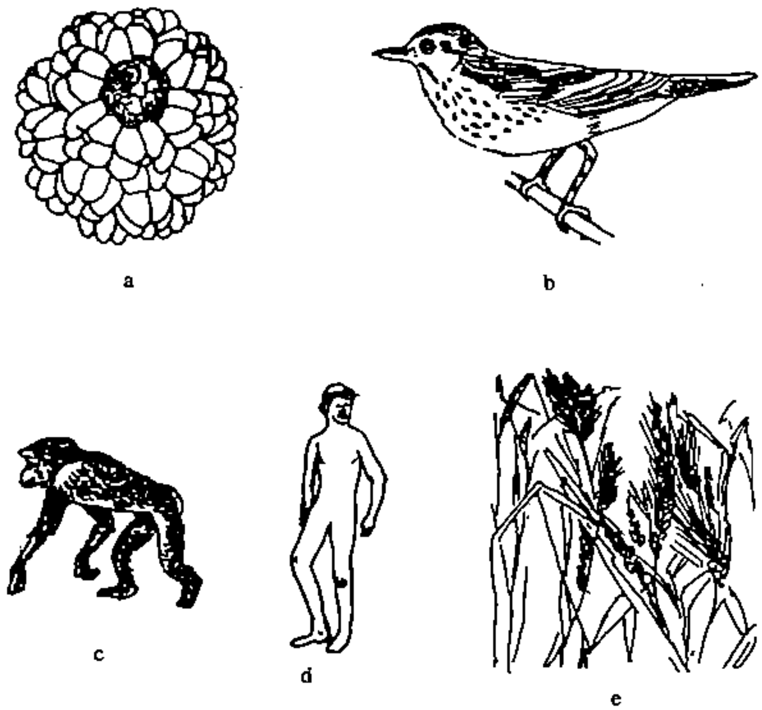


Fig. 4.1 : Some examples of common-as well as scientific names
a) Virus (Turnip yellow mosaic virus TYMV) b) Sparrow *(Passer domesticus)*
c) Chimpanzee *(Macacus macaque)* d) Human *(Homo sapiens)* e) Paddy *(Oryza-sativa)*

Common or vernacular names are convenient in general discussion, but these are seldom used in more than one language and differ district to district, state to state and country t- country. These are applied arbitrarily and there is no conscious attempt to in. ate relationship between organisms. For example, "Tamala" is a beautiful flowering evergreen tree and is known by common names like Dample, Otor and Tamala in Hindi. Dampel, Oth and Osth in Marathi and Kamal and Ota in Gujarati. Paddy is commonly known as Chaval in Bihar, Uttar Pradesh and Madhya Pradesh, as Dhana in Orissa, as Nellu in Madras and Bhatta in Mysore Similarly, House-sparrow is known as Moineau in France, Gorrion in Spain, Pardal in Portugal, Passer in Italy and House-operling in Germany. In order to overcome the deficiencies and uncertainties arising from the use of local expressions the concept of technical designation or scientific name developed. This is now known as Binomial Nomenclature and is applied to biological organisms both plants and animals. This nomenclature is followed world-wide. For example "House-sparrow" is universally known by its only scientific name *Passer domesticus* Linn. The advantage of scientific name is its definiteness as compared to the varieties found in common names.

In Unit 1 you have read Taxonomic hierarchy of biological classification like taxonomic ranks, taxonomic groups, taxonomic units etc. A taxon is defined internationally as a taxonomic group or category of any rank. Names applied to different rank of hierarchial categories constitute the nomenclature of taxonomy. The concept of scientific name is the initial step at standardizing binomial nomenclature. You should also know that with the change in concept of relationship and as communication increased among the biologists of the world the concept of codes of nomenclature developed. This was based on universal set of rules to govern the application of names of biological organisms.

4.2.1 International Codes

In 1753 Linnaeus suggested a system of binomial nomenclature where each individual is denoted by two epithets, the first denoting generic name and the second representing specific name. Such scientific names were very convenient and the idea was universally accepted by the botanists. In order to have international agreements on the issues, international congresses have been organized from time to time and rules adopted are published in the form of international code of Botanical, Zoological, Bacteriological and Viral nomenclature systems. The formation and usage of the scientific names of animals are governed by International Code of Zoological Nomenclature (ICZN). Organisations responsible at an international level for preparation of the Zoological codes are divisions of Zoology of International Union of Biological Sciences (IUBS). For naming plants including fungi and lichens there is International Code of Botanical Nomenclature (ICBN). Besides, there is a commission on the nomenclature of plants and the International Association of Plant Taxonomy (IAPT). For naming bacteria there is the International Code of Nomenclature of Bacteriology (ICNB). Viral Nomenclature is governed by the International Code of Viral Nomenclature (ICVN). There is a separate code of nomenclature for cultivated plants, International Code of Nomenclature for Cultivated Plants (ICNCP).

Code provides classification and registration besides nomenclature for cultivated rules complementary to the ICBN. Each code has different rules of naming of hybrid The Zoological and bacteriological code makes no provision for the naming of hybrids. No separate code is yet available for the breed names of domesticated animals in Zoology.

Although each code differs in approach, format and in some other aspects from the others, each attempts to provide solution for the same basic problems in its respective field. Thus working principles of each, form the basis of the system of nomenclature, accompanied with a series of numbered rules that denotes the articles. Some of the rules are supplemented by a series of more extensive recommendations which deal with subsidiary points to bring greater uniformity and clearness specially in future usage.

4.2.2 Principles of Binomial Nomenclature

There are certain basic principles of binomial nomenclature which are as follows:

i) Different nomenclatural systems are independent of each other e.g. though "CORYDALIS" is a genus name of plants in the family Fumaricaceae, "CORYDALIS" is a genus name of insects in the order Megaloptera. Although it is permissible in the code it is not desirable to employ the same name for different kinds of organisms of same status of two different systems. This might constitute an obstacle to interdisciplinary understanding.

ii) Within each nomenclature each taxon with a particular definition, position and rank can bear only one correct name except in unusual or specified cases.

iii) No two taxa may bear the same name.

iv) Scientific names of taxa are treated as Latin names regardless of their derivation.

v) The correct name of a taxon except above the rank of family is based upon priority of publication.

vi) For the categories of order (in Botany) or super family (in Zoology) and lower categories in both, the application of name of taxa is based on type specimens, type species or type genera except in specified cases.

SAQ 1

a) What do you mean by binomial nomenclature.

....

....

....

b) List some important aspects of binomial nomenclature.

....

....

....

5) What is the advantage of scientific names over common names?

....

....

....

4.3 IMPORTANT RULES OF NOMENCLATURE

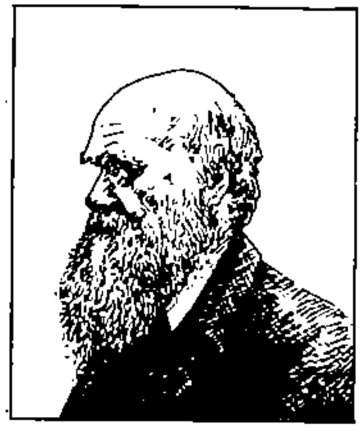


Fig. 4.2 : Charles Robert Darwin

Nomenclature is allied to taxonomy as it deals with the determination of the correct name to be applied to a known taxon. The use of scientific names rather than of common or vernacular names has much to commend. In the days of Linnaeus by common accord no two genera could have the same generic name and no two species within a given genus could have the same specific name.

In biological literature there are numerous examples of different nomenclatural codes drafted and followed simultaneously by different groups of workers. However, such practice became less prevalent. To achieve stability and universality in the name of animals, first Zoological Code "The Stickland Code" was developed in 1842 by a Committee that included Darwin (Fig 4.2), Hanslow, Water house and Westwood. However, a truly cosmopolitan set of rules was not adopted until 1898.

Fig. 4.3 : Augustin de Candolle

You should know that for Botany first code was presented in 1813 by Augustin de Candolle (Fig. 4.3) in his "Theorie elementaire de La botanique" and the organisation established in 1867. International code in Bacteriology was first adopted in 1947. Similarly, awareness of universal viral nomenclature was indicated first by the virus-subcommittee of the International Commission on Bacteriology established in 1951. Since then, there have been many schemes put forth but till date only a few has been universally accepted. The first report on classification and nomenclature of viruses was published in 1971.

It is important for you to know that it is only after a long history that Botanical, Zoological and to some extent Bacteriological Codes have achieved a rather stable position today. The Virological Codes are most recent and insufficient, subject to major revisions before being finalised. You should also know that Zoological nomenclature is independent of botanical nomenclature. Every effort should be made to avoid the introduction of those generic names in Zoology which are already in use in Botany. T , scientific names of animals from sub-genera and above are uninomial. The names of species are binomial and those of sub-species are trinomial.

For example,		Genus	sub genus	species
Sub species	Author	*Dacus*	*Afrodacus*	*aberrans*
nigritus	Hardy 1955			

The first (genus) and the third (species) words formed the binomen. The second word is the sub genus. The first, the third and the fourth together forms the trinomen. The first, the Second, the Third and the fourth word forms the Polynomial nomenclature. Hardy is the original author of this taxon published in 1955.

The International Code for Zoological Nomenclature also brings out declaration that the commission is empowered to implement the provision for the modifications of the code. The official indexes of rejected and invalid names and works and the official tests of validated names and approved ones, although published by the trust separately are considered to be integral parts of the Zoological Code.

SAQ 2

a) Fill in the blanks using appropriate terms from the text.
   i) The basic language of scientific names is ....
   ii) A group of organisms fundamentally alike is treated as a.....................
   iii) .... are aggregates of closely related species.
   iv) A Genus consisting of a single species is ....
   v) A family is said to be natural when all its members are derived from .... stock.

b) Differentiate between Polynomial and Binomial nomenclature.

....

....

....

....

4.4 BINOMIAL SYSTEM

In the previous sections we have outlined the concepts of binomial nomenclature at International level and the current principles that we adopt today for naming the organisms. You should know that these have been evolved through a long historic process of refinement.

After having gone through the previous sections of this unit you must have understood that biological classification is centred on the primary groups of individual organisms, i.e. the species. Before the 17th century, learned biologists had no method of designating any species they wished to discuss except by writing descriptions. Thus we find "Mocking bird" was designated at that time in Latin phrase as "*Turdus minor Cinero-albus* non maculatus" (means, Thrush small grayish-white without spot, Similarly, a species of mint designated with the Latin phrase: "*Prunella maguna flore albo*" (i.e. purnella with the large white flower). These were polynomial names composed of several words in a series. These were cumbersome and often difficult to interpret. The first steps in developing modern nomenclature were those leading to binomial system of nomenclature. Binomial is a Latin term used to denote a combination of two words constituting a name also called binomen, binomial or binary. The system of naming species by means of a generic name plus a specific epithet (often termed trivial name) is known as binomial system of nomenclature. For example we can recollect the scientific name of sparrow i.e., *Passer domesticus* Linn. In this binomial the first word *(Passer)* designates the genus to which the bird belongs and the second word *(domesticus)* to a particular species of that genus. The two words in combination only constitute the species name of sparrow.

Epithet:
Adjective or descriptive phrase that refers to the character or most important quality of subject. It is the ultimate designation of a member of a group.

There is an obvious demerit in tagging specific epithet with the genus to form species name. With the transfer of a species to a different genus on taxonomists decision, its name is inevitably changed which in turn disturbs the free flow of information. To overcome the confusion so produced the code lays certain provisions which should be strictly observed. We can summarise the merits of binomial system as follows:.

1) It provides a summary of affinities for us which acts as an aid to the memory and provides basic information about organisms unknown to us;
2) It facilitates talking about groups of species that have certain features in common.

4.4.1 Bauhin

We got the first reference of binary use of species name in **Pinax** (1623), a publication of a Swiss physician and botanist Casper Bauhin (1560-1624). In this publication attempts have been made to distinguish nomenclaturally between species and genera of plants. This device helped to simplify the situation of expressing a species but it lacked a system. The generic name often comprised two or three words and the specific epithet was often a long phrase. Caspar Bauhin classified plants on the basis of texture and form. The binary nomenclature with which Linnaeus is usually credited was founded by Bauhin more than a century before its use by Linnaeus. In the next subsection we are going to discuss the works of Linnaeus.

4.4.2 Linnaeus

Almost a century after Bauhin the great Swiss naturalist Carolus Linnaeus (1707-1778) published the two monumental works the "**Species Plantarum**" (1758) on animals. In these books binomial system of naming of plants and animals was established as a regular practice with certain definite regulations. The scientific name of each species is restricted to two Latin words, no matter in what country it was first found or in what language it was first described. This use of a universal language of nomenclature helped to avoid ambiguity of meaning for varied local or vernacular names and conveyed the same information about the species in question to scientists throughout the world.

Linnaeus is regarded as the father of Taxonomic Botany and Zoology. His works are the official starting points for most animal and plant. The Latin or Latinised form of scientific names that has been universally used is a direct result of the fact that most publications of natural history were written in Latin. Latin is known as the language of the scholar of the day. It is a rich source of the roots of words from which scientific names (that would be specific and exact in meaning) can be made.

SAQ 3

a) Explain how biologists designated any species before 17th century.

b) Differentiate between species, genera and families.

c) Fill up the blank spaces using appropriate words from the text.
   i) First reference of binary use of species name was available from the publication of ....
   ii) Casper Bauhin classified plants on the basis of ....
   iii) The publication of Linnaeus (1753) was named .... in plants.
   iv) .... is regarded as the father of taxonomic botany and zoology.
   v) .... is known as the language of the scholar of the day.

4.5 UNITS OF CLASSIFICATION

The Rules of Nomenclature prescribed the categories into which plants should be classified. These categories constitute the units of classification. Their sequence and order of importance is fixed by the Rules. The units of classification are arranged below regressively in descending order from units of greatest magnitude to units of least magnitude. In this unit we will discuss only three units of classification namely, Family, Genera and Species.

Family

The first and foremost step in the classification of plants and animals is the grouping together of individual organisms on the basis of relationships or associations among them. These groups constitute families. The family name is a plural adjective used as substantive ending—aceae for plant families and—idae for animal families to the stem of generic name of the included generic names. For example, Rosaceae (from *Rosa*), Geraniaceae (from *Geranium*) Lamiaceae (from *Lamium*) (Fig. 4.4)

Fig. 4.4 : Some examples of family names derived from their forms
a) Rosaceae (*Rosa*), b) Geraniaceae (*Geranium*), c) Lamiaceae (*Lamium*).

The family name suggested on the basis of illegitimate stem name isconserved to be illegitimate unless conserved according to the recommendations of the international code. You should know that some family names are agreed to because of long usage e.g. Palmae (Arecaceae type *Areca* L), Leguminosae (Fabaceae type *faba* Mill), Gramineae (Poaceae type *Poa* L), and Ranidae (*Rana tigrina)* (Fig. 4.5).

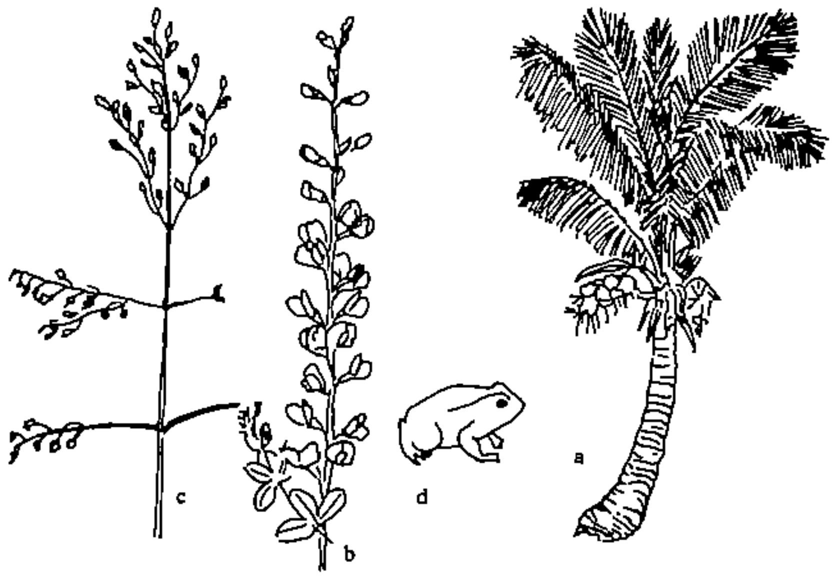


Fig. 4.5 : Various families derived from their types
a) Palmae (Arecaceae Type *Areca* L) b)-Leguminosae (Fabaceae Type *Faba* MILL)
c) Gramineae (Poaceae Type *Poa* L) d) Ranidae (*Rana Tigrina*)

The increase in the number of known species together with the degree of relationship between them facilitates the inclusion of organisms into different families. In Units 2 and 3 you have read about artificial system of classification of plants and animals. You should know that the family is said to be natural when all its members are derived from common ancestral stock i.e. of monophyletic origin. Furthermore this is for your information and understanding, that the families of higher plants are separated from one another by features such as inflorescence type, ovary position, placentation type, number of carpels, ovule type and the disposition of sexes as in dioecism and monoecism. A family is not of any particular size. You can include any number of organisms depending upon the similarity and the relationship between them. When a family is large and comprised of many components you can divide it into units called sub-families. These should bear Latin names terminating by the ending-oideae. For example, the family Papaveraceae (opium family) has been splitted into three sub-families namely Papaveroideae, Fumaroideae and Hypecoideae. Thus you must have noticed that in all these sub-families, there is an ending or suffix-oideae.

Genera

Like species the genus represents a concept. Genera (Plural) are aggregates of closely related species. There is no size requirement for a genus. Name of the genus is a substantive noun in singular number. You should always write name of the genus with capital initial letter and keep only one generic name for one kind of plant. Either underline these words or you should write them in italics. A Genus consisting of a single species is monotypic, e.g. *Leitneria* consisting of a single species *L. Floridana*, is monotypic. If a genus contains two or more species it is polytypic. You should know that this concept has greatly simplified the classification of well-known groups like birds, mammals, snails, butterflies and other insects.

Species

A group of individual plants and animals that are fundamentally alike is treated as a species. Species is a part of the name of the plant and an animal. Species are separated by distinct morphological differences from other closely related forms. A species is a concept that is not defined in exact terms and is not absolute and inelastic. In developing concepts of species specimens are regarded as samples of living, reproducing populations of genetically related individuals. Names of species are binary combinations consisting of the name of the genus followed by a single specific epithet. If the epithet consists of two words you should either unite them or join them by a hyphen. You should know that symbols forming part of specific epithets as proposed by Linnaeus are transcribed, e.g. *Pinus* is the scientific name of a particular genus, *Pinus nigra* the name of a species of that genus and *Pinus nigra* var *caramanica* is the name of a variety of that species. Similarly *Dacus* is the scientific name of a particular genus, *Dacus aberrans* the name of a species of that Genus. *Pheretima* is the scientific name of a particular genus, *P. Posthuma* the name of a species of that genus and *P. posthuma L* is the complete name indicating that Linnaeus is the original author. The basic language of the scientific names is Latin and names from other languages are Latinised. Many different kinds of species have developed by diverse evolutionary and genetic mechanisms. One thing about species concept you should remember is that many species are sexual, a few are asexual. Some have arisen by polyploidy, changes in chromosome number and mechanisms which need not to be emphasised at this level.

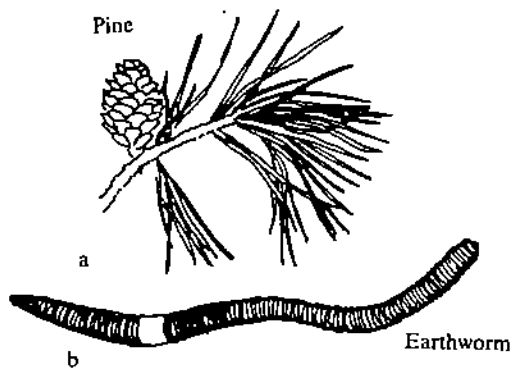


Fig. 4.6 : Binomial names of some plants and animals
a) Pinus nigra var Caramanica b) Pheretima posthuma L.

4.6 SUMMARY

What we have learnt in this unit can be summarised as follows:

- Binomial nomenclature is the allocation or determination of names to the individual entity—living, reproducing.
- The names of species are binary combinations consisting of the name of the genus followed by a single specific epithet.
- A family comprises of organisms grouped together on the basis of relationships and associations among them.
- The concept of scientific names developed to overcome the deficiencies and uncertainties arising from the use of local expressions.
- The first reference of binary use of species name was available from a publication of Casper Bauhin.
- Linnaeus is regarded as the father of Taxonomic Botany and Zoology.

4.7 TERMINAL QUESTIONS

1) Explain why the field of biology is ever changing unlike other branches of science.
2) Write a brief note on Development of Concepts of naming (nomenclature).
3) Give some examples of binomial names.
4) Define a Taxon.

5) Expand the below mentioned abbreviations:
IUBS, ICBN, IAPT, ICNB, ICVN, ICNCP

6) List some important rules of nomenclature.

4.8 ANSWERS

Self-assessment Questions

1) a) Binomial nomenclature is the allocation or determination of name to the individual entity and the group so produced through classification in accordance with the conventions of international rules.

   b) Important aspects of binomial nomenclature are its concepts and principles, binomial systems, units of classification and international codes.

   c) The concept of scientific names is the initial step in standardizing binomial nomenclature. These are world-wide in application e.g. *Homo sapiens* is the scientific name for man and is applied everywhere. Common names are convenient in general discussion but these are seldom used in more than one language, and differ from district to district, state to state and country to country e.g. Paddy is commonly known as "Chaval" in Bihar, U.P. and M.P. as "Dhana" in Orissa and "Bhatta" in Mysore.

2) a) i) Latin
   ii) Species
   iii) Genera
   iv) Monotypic
   v) Common ancestral

   b) Polynomial names are composed of several words in a series e.g. *Prunella magna flore albo;* i.e. *Prunella* with the large white flower. These are cumbersome and often difficult to interpret. Binomial is a Latin term used to denote a combination of two words constituting a name e.g. scientific name of sparrow is *Passer domesticus* Linn. *Passer* designates the genus to which the bird belongs and *domesticus* is a particular species of that genus and Linn is the name of the author.

3) a) Before the 17th century biologists designated species by writing descriptions, e.g. "Mocking bird was designated at that time in Latin phrase as "*Turdus minor* Cinero-albus non maculatus" means "thrush small grayish white without spot" and a species of mint designated with Latin phrase "*Prunella magna* flore albo i.e. "Prunella with large white flower"

   b) **Species**

   A group of individual plants and animals that is fundamentally alike is treated as a species. Species is a concept.

   Genera

   Like species genus is a concept. Genera are aggregates of closely related species and genus is a substantive noun in a singular number.

   Family

   A group of organisms (Plants or animals) showing some relationships and associations among themselves is a family. The family name is a plural adjective used as substantive ending-*eae* to the stem of generic names in plant families while *-idae* is the ending in animal families.

Terminal Questions

1) The field of biology is ever changing with all its contents—like characters, circumscriptions, knowledge etc; because of its dependence on the findings of related sciences like morphology, anatomy, embryology and cytology. The product of modern taxonomic research is rapidly becoming one of synthesis rather than of individual conclusion.

2) The concept of naming originate from its importance. In order to overcome the deficiencies and uncertainties arising from the use of local expressions the

concept of technical designation or scientific names developed. As communication increased among the biologists of the world the concept of codes of nomenclature developed. This is based on a universal set of rules to govern the application of names of biological organisms.

3) Pinus : *Pinus nigra* var. Caramanica
Sparrow : *Passer domesticus* Linn.
Dacus : *Dacus aberrans* Hardy.
Taenia : *Taenia solium* Linn.
Man : *Homo sapiens*
Rose : *Rosa indica* Linn.
Paddy : *Oryza sativa* Linn.

4) Taxon is defined internationally as a taxonomic group or category of any rank and name applied to different rank of hierarchical categories constitutes the nomenclature.

5) IUBS International Union of Biological Sciences
ICBN International Code of Botanical Nomenclature
IAPT International Association of Plant Taxonomy
ICNB International Code of Nomenclature of Bacteriology
ICVN International Code of Viral Nomenclature
ICNCP International Code of Nomenclature for Cultivated Plants.

6) Some important rules of nomenclature are:

i) Scientific names should be used in place of common names.

ii) No two genera should have the same generic name.

iii) Zoological nomenclature is independent of Botanical nomenclature.

iv) Avoid the introduction of those generic names in Zoology which are already in use in Botany.

v) The names of species are binomial and those of sub species are trinomial.

vi) Always write name of the genus with capital initial followed by species name with small initial and name of the original author.

vii) Either underline these words or write them in italics.

GLOSSARY

apetaliferous: Flower without petals as opposed to petaliferous—where petals are well developed

apocarpus: when carpels are separate and not united as opposed to syncarpus—where carpels are united

berry: fleshy fruit with a succulent endocarp e.g. *Vitis*

capitulum: a dense inflorescence comprised of an aggregation of usually sessile flower

capsule: a dry fruit resulting from the maturing of a compound ovary (of more than one carpel), usually opening at maturity by one or more lines of dehiscence

catkin: a scaly-bracted, usually flexuous spike or spikelike inflorescence of cymules; prominent in willows, birches and oaks

dioecious: when staminate and pistillate flowers are on different plants as opposed to Monoecious where staminate and pistillate flowers on the same plant

drupe: a fleshy fruit with stony endocarp as in *Prunus*

electrophoresis: the separation of molecular entities by electric current

epigyny: the condition in which the sepals, petals and stamens are attached to the floral tube above the ovary with the ovary adnate to the tube or hypanthodium. Another condition is hypogyny: where sepals, petals and stamens are attached below the ovary. There is another condition which is known as Perigyny : where sepals, petals, and stamens are attached to the floral tube or hypanthium surrounding the ovary with the tube or hypanthium free from the ovary.

hybridization: the process in which an individual results from a cross between two genetically unlike parents

inferior ovary: an inferior ovary is one that seemingly is below the calyx leaves or other floral organs attached above ovary in opposed to superior ovary where other floral organs attached below ovary

monophyletic: derived from a single ancestral line as opposed to polyphyletic—that is, the result of evolution along two or more lines having different origins

perianth: an aggregation of tepals or combined calyx and corolla

synandrium: an androecium coherent by the anthers as in some aroids as opposite to syngenesious when anthers are connate

umbel: an indeterminate—often flat—topped inflorescence whose pedicels and peduncles (rays) arise from a common point, resembling the stays of an umbrella. Umbels are characteristic of the umbelliferae.

FURTHER READINGS

An Introduction to Plant Taxonomy—C. Jeffrey, J and A Churchill Ltd., London.

Principles of Angiosperm Taxonomy—V.H. Heywood. Academic Press, London, New York.

Taxonomy of Vascular Plants—George H.M. Lawrence, Mac Millian, New York.

An Introduction to Taxonomy of Angiosperm—Priti Shukla, Shital P. Misra. Vani Educational Books, A division of Vikas Publishing House Pvt. Ltd.,

Fundamentals of Plant Systematics—Albert F. Radjord, Harpen and Row Publishers, Inc.

Plant Taxonomy—Dr. Ravindra Nath, Metropolitan, New Delhi.

Principles of Animal Taxonomy—George Gaylord Sinpson Oxford & IBH Publishing Co, Calcutta, New Delhi, Bombay.

Dear Student,

While studying these units you may have found certain portions of the text difficult to comprehend. We wish to know your difficulties and suggestions in order to improve the course. Therefore, we request you to fill and send us the following questionnaire, which pertains to this block.

QUESTIONNAIRE

LSE-07
Block 3

1) How many hours did you need for studying the units?

Unit Number					
No. of hours					

2) How many hours (approximately) did you take to do the assignments pertaining to this block?

Assignment Number		
No. of hours		

3) In the following table we have listed 4 kinds of difficulties that we thought you might have come across. Kindly tick (✓) the type of difficulty and give the relevant page number in the appropriate columns.

Page Number	Types of difficulties			
	Presentation is not clear	Language is difficult	Diagram is not clear	Terms are not explained

4) It is possible that you could not attempt some SAQs and TQs.
In the following table are listed the possible difficulties. Kindly tick (✓) the type of difficulty and the relevant unit and question numbers in the appropriate columns.

Unit No.	SAQ No.	TQ No.	Type of difficulty			
			Not clearly posed	Cannot answer on basis of information given	Answer given (at end of Unit) not clear	Answer given is not sufficient

5) Were all the difficult terms included in the glossary? If not, please list in the space given below.

6) Any other suggestion(s)

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To

The Course Coordinator
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UGZY/BY-10

Taxonomy and Evolution

Block

2

TOOLS AND TRENDS IN TAXONOMY

BLOCK 2 TOOLS AND TRENDS IN TAXONOMY

In the previous block you have studied history and concept of taxonomy, its aims and functions, systems of classification and binomial nomenclature. In this block, you will study tools and trends in taxonomy, laying emphasis on laboratory work, library documentation, keys to the identification of plants and animals and herbarium ethics. Also, you will study about modern trends in taxonomy.

This block comprises four units. In Unit 5, we have discussed ecological and phyto-sociological aspects of taxonomy vis-a-vis field observations and herbarium methodology. You will study about Botanic Garden, Kew (London), Botanic Garden, Sibpur (India), and wild life sanctuaries and national parks of India.

In Units 6, we have discussed the laboratory oriented taxonomic information as gathered from other disciplines of biology, library documentation, keys to the identification of plants and animals and herbarium ethics.

In Units 7 and 8 we have explained to you the importance of using other modern scientific approaches in addition to morphology in identifying organisms. These approaches have been specially useful in the identification of very closely related species and sibling species.

In Unit 7, we have explained how taxonomists nowadays identify plants more reliably by using data from electron microscope studies, anatomy, embryology, cytology, breeding behaviour, chemotaxonomy and numerical taxonomy in addition to data from morphology. Such a synthesis of information helps the taxonomists in preparing keys of identification for plants, in working out their interrelationship and subsequently their evolutionary history in a more scientific manner.

While in Unit 8, we have explained to you how newer approaches or methods like scanning electron microscope studies, embryology, ethology, cytology, biochemistry and numerical taxonomy have supplemented morphological data in identifying animals, in preparing their keys and working out their relationships and evolutionary history in a more reliable manner.

Objectives

The study of this block should enable you to:

- classify organisms on the basis of the information collected from field and the laboratory,
- preserve the specimens for museums and herbaria,
- identify diverse life forms in botanic garden and zoological parks,
- construct different types of keys to the identification of plants and animals,
- describe the new approaches used in plant taxonomy — electron microscope studies, anatomy, embryology, cytology, behaviour patterns, chemotaxonomy and numerical taxonomy,
- describe the modern approaches employed in animal taxonomy — electron microscope studies, embryology, ecology, ethology, cytology, biochemistry and numerical taxonomy,
- explain how in plant and animal taxonomy (systematics) the synthesis of relevant data from the newer approaches, help in identification, of organisms, in preparing keys, and in working out the evolutionary history in a systematic and scientific way.

UNIT 5 TOOLS OF A TAXONOMIST — I

Structure

5.1 INTRODUCTION

Taxonomy is dependent on many sciences and they in turn are equally dependent on it. The activities of a taxonomist are basic to all other biological sciences because it provides an inventory of flora and fauna, schemes to identification, names and a system of classification of plants and animals. Not only is taxonomy basic to other scientific fields but also it depends on other disciplines like ecology, plant breeding phytosociology, pharmacology and biochemistry. While dealing with taxonomic problems we have to understand the distribution of plants and animals. The scores of thousands of plants known today as species have been established by the application of the existing and established principles of taxonomy. You should know that the accumulated knowledge of Earth's flora is far from perfect and will become more perfect only by exploration of its areas, collection of its components, their study and classification. Once names and classification systems have been provided there must be methods for us to identify a taxon as being similar to another known entity. We will discuss keys to the identification of plants and animals in Unit 6. In this unit you will study the ecological and phytosociological aspects of taxonomy, herbaria, botanic gardens and green house. You will be given brief information about Royal Botanic Garden, Kew (London) and Botanic Garden Sibpur, Howrah (India). We will also discuss the conservation of biological resources with special reference to wildlife sanctuaries and national parks.

Objectives

After reading this unit you should be able to:

- list the contributions of ecology to systematic interpretation,
- preserve specimens for herbaria and museums,
- specify the role of botanic gardens,
- identify diverse forms of plants and animals in botanic gardens and zoological parks.

5.2 FIELD OBSERVATIONS: ECOLOGICAL-PHYTOSOCIOLOGICAL

Field studies are desirable for an understanding of the relationship of any group of plants. If it is not possible to study the plants in the field you should grow these plants in one or more test gardens. Seeds and plants for this purpose could be obtained from indigenous source. While making an ecological study in the field record the season of flowering and of fruiting and collect material in all stages of development. Make a note of precise locations of collections, habitat types and of soil characteristics. Make a detailed study of characters often lost in the dried specimens like colouration of foliage and floral parts, smell, presence or absence of latex, corolla vernation, corolla colour and anther colour before and after dehiscence. Also, make a note of viscidity of parts especially nectariferous organs. Look for pollinating agencies and record the time of pollination. Texture of foliage and perianth parts is of great importance and also colour of freshly matured fruits. You should remember that root stock characters often provide immense information and should not be overlooked. While making a phytosociological study, determine the natural variation within and between populations. Assign a different collection number to specimens from different colonies within the same general area. If the material is growing in abundance prepare four or five sets of duplicate collections and on completion of the study you can distribute it to important herbaria. You will learn more about herbaria in next section. Mass collection will also provide a means of determining relationships with greater accuracy and whether a variation is one associated with or restricted to colonies, to habitats or to regions. From this information you can determine that a population represents a sub species, variety or forma. Collect those parts that are significant for their characters and also random samples. Collect about 50 samples of a population after proper selection and this will constitute the material for study and permanent herbarium record compiling information on frequency of variation, discontinuity of variation and correlation between variables.

SAQ 1

a) Briefly differentiate between ecological and phytosociological characters.

....

....

....

b) Why is mass collection of specimen essential? Write your answer in two lines.

....

....

....

5.3 HERBARIA AND MUSEUMS

A herbarium is a collection of pressed and dried plants arranged according to some valid system of classification and available for reference. All research and educational institutions related to plant species have their own specimens collected locally and also millions of gradually accumulated specimens which document the flora of one or more continents. Harbaria began early in the sixteenth century in Italy as collections of dried plants sewn on paper. Linnaeus popularised the current practice of mounting specimens on single sheets of paper and storing them in stacks. Herbaria are the permanent repositories of plant specimens and are sources of information about plant and vegetation (Fig. 5.1).

In the following subsections we will discuss the methodology you should adopt while going on a field trip for collection of plant and animal specimens. Also, you will be given some information on National Botanical Research Institute, Lucknow (India).

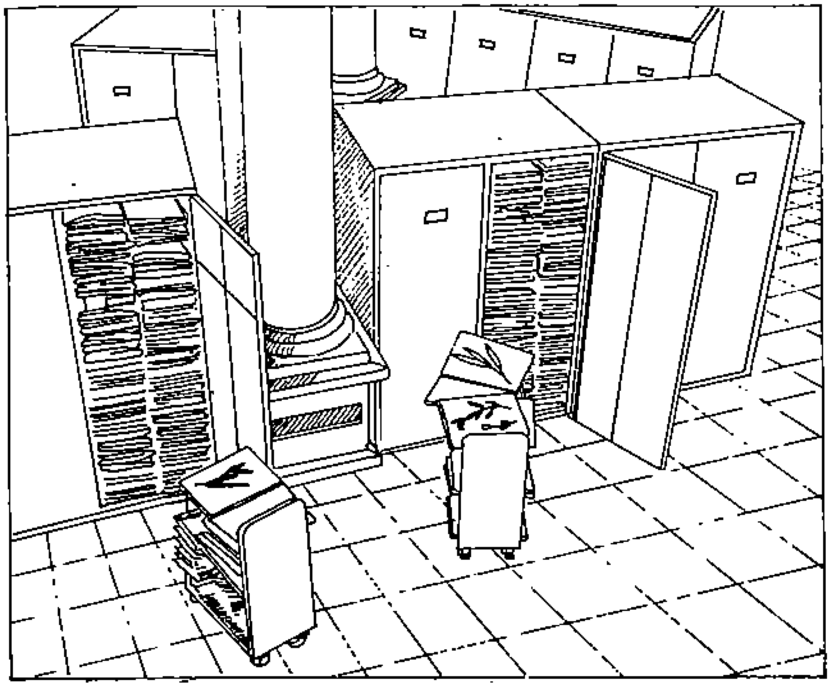


Fig. 5.1 : A herbarium in use.

5.3.1 Field Methodology

Before you plan for a field trip decide the tools and equipment required. Certain equipments are necessary for plant collection. A collecting pick is required for digging up roots and rhizomes. A strong knife is required for cutting branches and other plant parts. A pair of pruning shears is needed for cutting woody and hard material. A pair of forceps is needed for opening the flower bud to study the stamens and carpels. A vasculum is needed for accommodating collected specimens to be studied and pressed (Fig. 5.2). A plant press together with blotters or newsprint for pressing and keeping the collected specimens (Fig. 5.3). Also, you should carry with you a field book for

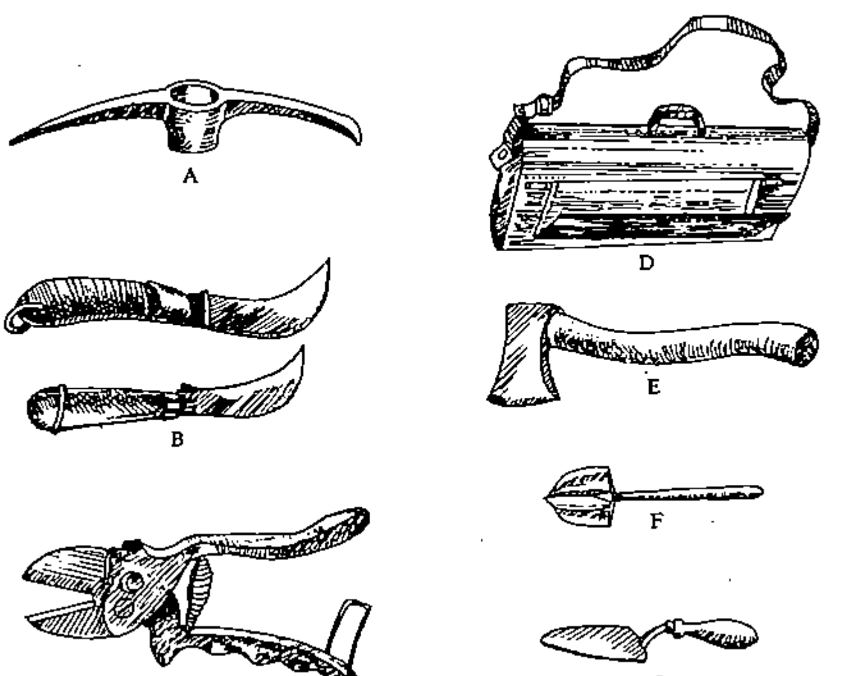


Fig. 5.2 : Equipments used in collection. A, Collecting pick; B, Knives; C, Secateur; D, Vasculum; E, Hatchet; F, Spade; G, Trowel.

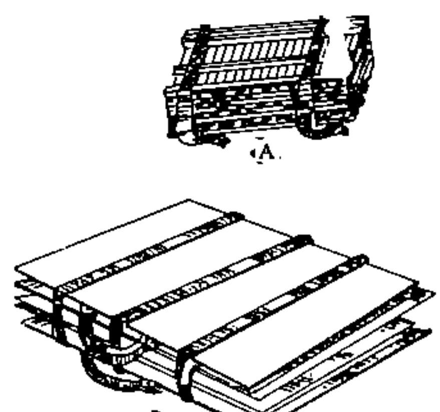


Fig. 5.3 : Plant press.
A. Perforated plant press;
B. Wire-netted plant press.

noting down the details of collected specimens. Polythene bags in good number are also needed for keeping fresh plant specimens. After storing plants in these bags the mouth of bags should be tightly closed to avoid wilting. For collecting aquatics from ponds and lakes, carry a long rope, and for collecting cones, fruits and fungi specimens carry bottles. Obtain necessary permission from the authorities concerned to visit a forest. Ask for forest guide or any other official assistance. Always keep a copy of all essential documents in your camp. Make proper arrangements for your stay, food, clothing and wear field shoes.

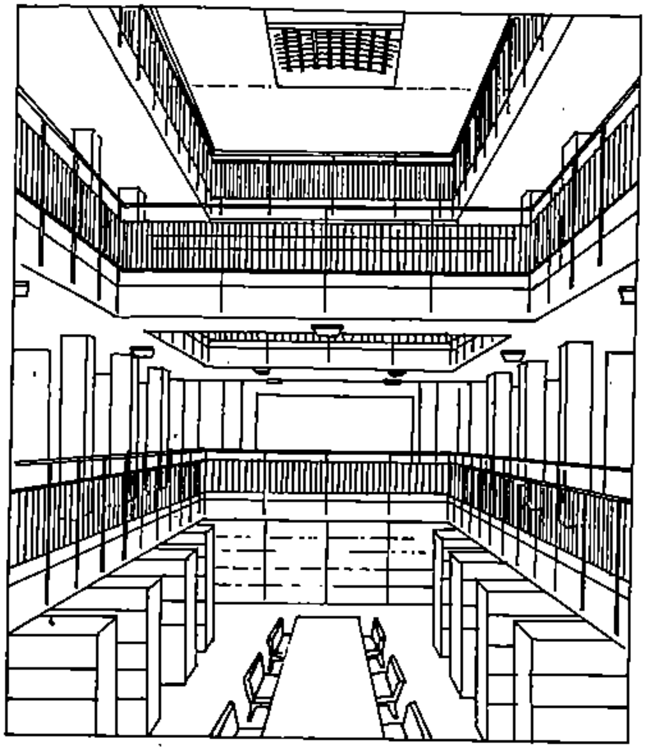
Best period of collection of plants is from February to September. You should know that our motherland is rich in flora and fauna. Look for plants in rocky crevices, sand dunes, marshy regions, mountains, calcareous regions and even on dead and fallen trunks. Observe the nature of the plant, its association with other plants and substrate. Collect complete and perfect material with flowers and fruits. While collecting medicinally valuable plants, collect sufficient quantities of root, shoot, seed and plant part which is of medicinal value. Later on you can sow these seeds in the garden and raise plants to add to your collection. If the size of the plant exceeds the size of mounting board or herbarium sheet bend it in N or U form, but do not break the stem. Collect phytoplanktons by slowly towing a fine net (180 meshes/unit). The small funnel container at the tip collects organisms. Now, preserve the catch in iodine (0.5 g), potassium iodide (0.1 g), glacial acetic acid (4.0 ml), formalin (24.0 ml), and water (400 ml). Collect sea weeds in polythene bags, properly numbered and preserve these in 2.5% formalin alcohol. Collect fungi specimens as a whole, fresh and healthy alongwith the substratum or host. While collecting lichens note the name of the plant serving as substrate. Preserve liverworts and mosses by drying and cacti and other succulents in liquid preservative. If you collect small fleshy fruits prick them at several places and dip in hot water till whole juice exudes out. Now, you press these specimens. Wrap aquatic plants in damp newspaper and keep them in vasculum until they are pressed. You will also find some economically important algae, both marine and fresh water and also diatoms. Collect these with a pipette consisting of a glass tube and a large suction bulb. Dry blue green algae on paper, spread chara species on newspaper and then shift to herbarium sheet. Prepare a preservative fluid of 50% alcohol and 5% formalin and keep the specimens in the fluid. This will prevent the growth of mould on the plants. If you collect tree ferns and other land plants first keep them in polythene bags and then press these between the folds of newspaper. Keep cones, fruits and needles of gymnospermic plants in polythene bags.

For collecting insects carry bottles and some killing agents like ethyl acetate and chloroform with you and kill the insects immediately without affecting their colour. Label the bottles as "poison" because all these killing agents are deadly poisonous. Do not leave insects in the bottles for longer time and there should be no over crowding of specimens in the killing bottles. First kill the larvae of insects in boiling water and later on place them in liquid preservative. Use separate killing bottles. Do not keep tough and fragile specimens in the same bottle as these will be damaged by one another.

5.3.2 National Botanical Research Institute, Lucknow

National Botanical Reserach Institute was earlier known as National Botanic garden. Prior to this name the garden was known as Sikkander Bagh, Prof. K.N. Kaul was the founder Director of this garden. The general plan and lay out of the garden is ample proof of his aesthetic taste and creativity. Dr. T.N. Khosoo took over as the second Director of the garden.

The garden is situated on the banks of Gomiti in the heart of the city. It grows and preserves a rich collection of diverse plants. The specialities of the garden are palms, ferns, medicinal plants, orchids, cacti, and other ornamentals. The experimental research station, Banthra, about 20 km from Lucknow is a part of this Research Institute and is devoted to research on reclamation of usar lands and other applied aspects. There is a huge herbarium, library and a number of green houses in the garden and also laboratories devoted to cytology, palynology, physiology, tissue culture, algology and morphology. The garden is funded by Central Scientific and Industrial Research (CSIR). It is a temple of learning and research in India (Fig. 5.4 a, b).



a)

Fig. 5.4 (a) : A Floor-to-Ceiling view of the Library-cum-Herbarium Block of NBRI

b)

Fig. 5.4 (b) : Interior view of the Cactus House

SAQ 2

a) What is a herbarium? Give definition.

....

....

....

b) Why is collection of specimens essential?

....

....

....

c) Who popularised the current practice of mounting specimens?

....

....

....

5.4 GARDENS AND GREEN HOUSE

Public parks and gardens are centres of aesthetic beauty and serve as places of recreation. Botanic Garden is a living respository of plants arranged and maintained on scientific basis with accurate taxonomic identification of plants. A good botanic garden explains:

The earliest botanic garden was established in 1545-1550 with a collection of medicinal plants.

- importance of afforestation,
- evolution of cultivation of plants,
- horticultural practices for a layman,
- housewives to get interested in gardening, and
- distributes guides to go around the garden to look for plants of our liking.

As housewives we may look for a Jasmine suitable to grow in our house. As a farmer we may look for a bamboo suitable to cultivate in our land after judging the suitability of soil and available water source.

The word green house was coined by John Evelyn in the 17th century.

Green House is a place to grow plants in desired environment. In temperate countries plenty of air and light is provided to the plants but in tropical countries it is meant for shade loving plants. The essential elements of a successful green house environment are heat, humidity, ventilation, light and managed in the method of arranging plants. The heating, humidifying, watering and introduction of nutrients are all done automatically. Green house soil is lighter and better aerated, richer in nutrient than garden soil and well made to compost, sand, vermiculite to avoid pasturisation. In tropical green house we can grow ornamental foliage plants, palms, ferns, orchids and shade loving plants. The glass roofing of the green house is substituted by split-bamboos, plaiting matting of coconut or date palm leaves supported by a strong frame. For permanent roofing creepers are grown while walls of the house are made with brick.

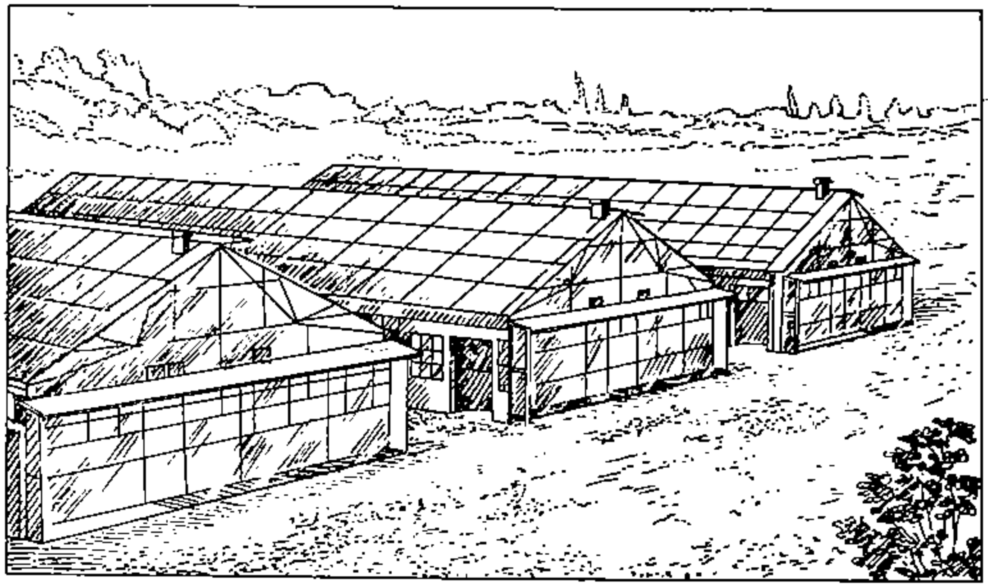


Fig. 5.5 : Rigid plastic (fiberglass) covered greenhouse.

5.4.1 Botanic Garden, Kew (London)

Royal Botanic Gardens, Kew, is a monumental institute in the world. It has most modern and well equipped laboratories and collection of rare plants. The garden extends over 200 acres of land which is beautifully planned. This is one of the chief attractions of the world and is regarded as very precious. Recently it has been felt that the garden is suffering due to pollution in England and also the soil is not suitable enough for the growth of several rare plants. The Government of Britain has paid immediate attention to the problem and about 400 acres of land near Kew with improved soil, topographic condition and mild temperature has been sanctioned under the name "Kew Satellite" through National Trust". This land is not exposed to severe winter due to long excessive low temperature and is away from London's pollution and noise. Actual period of the foundation of this monumental garden dates back to 1759. William Aiton took over as its superintendent. Before Aiton, W.B. Turill worked as keeper of the herbarium and Library at Royal Botanic Gardens. Sir William Chambers, and Sir John Hill brought glory to the garden through the publications of the accounts of plants growing in the garden under the title "The Royal Botanic Garden Kew" (Turill W.B.) and preparation of catalogues "**Hortus Kewensis**" of the plants grown during that period. Aiton following Linnaeus system published "**Hortus Kewensis**" second in the series spread over 5,500 species. Sir Joseph Banks introduced plants from expeditions and spent his personal funds. This itself is enough proof of his keen interest, enthusiasm and devotion towards development of the garden and herbarium. In 1841, Sir William Jackson Hooker took over as the Director of Kew Garden. He built palm house of exotic beauty and established a vast herbarium. His son J.D. Hooker added Rhododendrons which added excellence to Kew. He published "Flora of British India" and was the editor of Botanical Magazine. Thisleton Dyre published Kew Bulletin and "**Index Kewensis**". He also added Alpine house, Rose garden, Bamboo garden and a lily pond.

The layout at Kew includes the collection of willows, oak, elm, cedar, liliacs, pine, sweet chest nut, Tulip, Dafodills, Hazel, Sweet gum, poplar, Filmy ferns, Thuja, cypress, Japanese cedar, Roses, Pears, Prunus, Indian bean, Japanese cherries, Horse Chest nut, Crab apples, Acacia, Lime, Hibiscus, Magnolias, and Walnut.

Special gardens at Kew comprise Rhododendrons collection, Bamboo garden, chalk garden, rock garden, shrub garden, heath garden and rosary.

The splendid green houses in Kew include Palm house, ferneries, water lily house, alpine house and temperature house.

5.4.2 Botanic Garden, Sibpur (India)

Botanic Garden, Sibpur, Howrah, (Bengal) is the largest and oldest in South East Asia. It was established in 1770 by Col. Robert Kyd as East India Company Garden. Dr. William Roxburgh, described as the father of Indian Botany, took charge of the garden in 1793. It spreads over 310 acres serving as repository of over 15,000 trees and shrubs representing 2,350 species in addition to thousands of herbaceous species. It is now maintained by Botanical survey of India. Ministry of environment, Forestry and Fisheries, Govt. of India. Several economically important plants viz. *Cinchona*, Jute, flax, hemp, Indian rubber, *Eucalyptus*, papermulbery, cloves, cinnamon, pepper, tomato, tobacco, coffee are cultivated. Various subsidiary food species were introduced in 1787 when Bengal was worst hit by famine.

Several trees in the garden were destroyed by the great cyclone in 1864 and 1867. The great banyan tree about 250 years old with a circumference of 400 meters and 1600 aerial roots, is the greatest attraction of the garden. The natural orchidarium contains orchids with everlasting beauty. The medicinal plants garden grows about 450 species used in Ayurveda, Unani, Homeopathy and modern Allopathy. These days research is carried out on Plant introduction, breeding and conservation. "Red Data Book" and "Flora India" in 24 volumes are the latest contribution of the publication division of the garden.

5.4.3 Role of Botanic Garden

A botanic garden makes us to simply enjoy the beauty and variety of nature. The pleasure of admiring turns us into good naturalists. We can also appreciate the beauty of foliage and flowers. The role of botanic gardens is to:

- cultivate and maintain plants of interest on scientific basis,
- show vegetation of the world on geographical characteristics i.e. Himalayan flora, Alpine flora,
- maintain plants which are in danger of extinction and save species,
- plan germ plasm collection,
- serve as research centres in various fields,
- facilitate taxonomic studies by preserved and live plants,
- promote educational programmes and research in experimental botany and ornamental horticulture,
- exchange of materials — live, dried and "Index Semidum" i.e. list of seeds offered for exchange.

SAQ 3

Fill in the blanks with appropriate words form the text:

i) Public parks and Gardens serve as places of ....

ii) Green house is a place to grow plants in desired ....

iii) The word green house was coined by .... in the 17th century.

iv) The earliest botanic garden was established in .... with a collection of medicinal plants.

v) The role of botanic garden is to facilitate taxonomic studies by .... and ....

5.5 ZOOLOGICAL PARKS

Zoological park has two faced aspects, the relationship between man and beast. There is awe and there is slaughter. There is worship and there is destruction. The feeling for wild animals is still there, but there is no opportunity to give vent to that feeling. For the vast majority of people alive today there is only one place to come close to wild animals — The Zoo.

The facts and figures tell only part of the story but it bring us to a question as why do people go to the zoo. It will not surprise you to learn that almost a third of all zoo visits are promoted by children or putting it in other words nearly two thirds go to the zoo because it is a good place to take children. However, it is believed that people visit zoos because there is something very rewarding about being in the presence of wild animals. Respect for animals, contempt for animals, oneness with animals, all are feelings that we need to express and we can do so at the zoo. Also, it is interesting to look not at the animals, but at the people to really understand the lure of the zoo.

Extinction is a fact of life. More than 99 per cent of all species that have ever lived are alive no longer. Those that exist at present will not last forever. According to Dr. Norman Myers, the noted conservationist, "It is not unreasonable to suppose that we are losing at least one species per day." The rate of extinction is important because it offers zoos their justification. Zoos can save species from extinction. In the following sub-sections we will study more about wild life sanctuaries and national parks of India.

5.5.1 Wild Life Sanctuaries

You must have seen how some of the parks are fenced. The intention is to keep the animals from wandering out and not to destroy neighbouring farms. The fence insulates the park further. The problem is not keeping the animals in but keeping the people out. The most important thing to realise about wildlife today is that in most places there are not enough predators. The reasons for this are complex. Mankind by his use of agriculture has had more impact on wild life than anything else. Predators need a more space than their prey. This is the reason why big fierce animals are rare. They are rare everywhere, but when they are both rare and restricted to small islands the dangers are immense.

By declaring some areas as wild life sancturies the natural community alongwith its ecosystem is preserved. In a wild life sanctuary killing, hunting, shooting or capturing of any species of birds and mammals is prohibited except by or under the control of the highest authority in the department responsible for the management of the sanctuary. Vagaries in the climate have always resulted in fluctuations in populations. If there is not enough food in one place the animals move to another area where it is more plentiful. Also, the animals succumb to other animal predators, they fall ill, they starve, and ultimately die. Death is a way of life. What Charles Darwin called the "checks to increase" keeps numbers down both by removing animals from the population and by ensuring that few animals survive beyond their reproductive prime. In captivity most of the checks to population growth are removed.

Wild life conservation includes all human efforts to preserve wild animals from extinction. The progress of man throughout has been beneficial for the human race but it is the wild life that has suffered through the years. You should know that wild life represents the result of many years of evolution and constitute an environmental heritage of the past, a world which once surrounded our ancestors. We are responsible to the coming generation to leave as an inheritance an unspoiled world intact with living beauty and richness. In India, several laws have been passed and wild life sanctuaries and national parks have been established for the protection of the dwindling wild life. The wild birds and animals protection act was passed in 1812 and repealed in 1887. Indian Board for Wild Life was established in 1952 and this was followed by setting up of wild life boards in different states in India. In 1972, a new Wild Life Protection act was passed. Under this act, possession, trapping, shooting of wild animals alive or dead are controlled and watched by Chief Wild Life Warden and authorised officers. Conservation projects for individual endangered species like deer (1921), Crocodiles (1947), hangul (1970), Lion (1972), and tiger

(1973) were initiated. Wild life sanctuaries are places where the killing and capturing of any animal is prohibited except under orders of the authorities concerned. Today India has 412 Wild Life Sanctuaries and 80 National Parks. There is one gene sanctuary each for Citrus and pitcher plants both located in north east India. You should bear this thing in mind that plants are critical to the very existence of all life on the surface of earth.

SAQ 4

a) Define Wild Life Sanctuary and a National Park.

....

....

b) Fill in the blanks with appropriate words from the text :

i) Total number of wild life sanctuaries in India is ....

ii) Total number of national parks in India is ....

iii) The project tiger was launched in the year .... and and financed by ....

Some well known wild life sanctuaries of India are:

Kaziranga Wild Life Sanctuary : It was established in 1926 in the district of Sibsagar, sub division Jorhat (Assam) on the southern bank of the Brahmputra river. It covers an area of 430 sq. kms. of forest grass lands and swamps and supports a fauna of Rhinoceros, besides elephant, wild buffalo, bison, tiger, leopard, sloth bear, Sambuar, Swamp deer, hog deer, barking deer, gibbon and birds like pelicon, strock, and ring-tailed fishing eagles.

Manas Wild Life Sanctuary and Tiger Reserve : It is located in the district of Kamrup in Assam, covering an area of 540 sq kms and is situated at an altitude of 2,000 masl. The river Manas runs through the sanctuary. It contains the following wild animals: tiger, panther, wild dog, buffalo, sambuar, swamp deer and golden langur.

Jaldapura Wild Life Sanctuary : It is situated in the Jalpaiguri district of West Bengal and covers an area of 65 sq. kms. of grassland. Wild life fauna includes animals like rhinoceros, gaur, elephant, tiger, leopard, deer and a variety of birds and reptiles.

Point Calimer Wild Life Sanctuary : This is situated at the southern tip of the Thanjavur district of Tamil Nadu. Its back water and lagoon is visited by flamingoes and pelicans. It is close to the vedaranyam forests which has a fauna of numerous black bucks, chitals and wild boars.

Periyar Wild Life Sanctuary : Situated in the state of Kerala, this sanctuary covers an area of 777 sq. kms. It was established in 1949 around the artificial lake which arose behind the dam built across the Periyar river in 1990. This sanctuary supports a fauna of wild elephants, gaurs, leopards, sloth dogs, wild boars, black Nilgiri, langur and water birds like grey hornbills.

Mudumalai Wild Life Sanctuary : This wild life sanctuary was established in 1940 in North western part of Nilgiris in Tamil Nadu. It is known for its rich forests and diversity of fauna that includes wild elephants, gaur, sambuar, chital, barking deer, mouse deer, four-horned antelope, tiger, panther, bonnet monkey, langur, wild cat, sloth bear, porcupine, pangolin, flying lizard, rat, snake, python and various birds.

Bandipur Wild Life Sanctuary : This sanctuary was established in 1941 by the then ruler of Mysore (Karnataka state). It is situated 80 kms south of Mysore city enroute to Ootacamund. It has an area of 874 sq. kms. and is at an altitude of 1,454.4 masl. Its forest is very thick and has plenty of rain fall. Its wild life fauna includes plenty of gaurs and animals like elephant, leopard, sloth bear, wild dog, chital, panther, barking deer, porcupine and langur.

Sesan Gir : This famous wild life sanctuary for the Asiatic lion is situated in Gujarat state, 468 kms from Ahmedabad and 43 kms from Veraval. It has an area of 1295 sq. Kms. of semi arid country with patches of thorn scrub and deciduous trees. Its fauna includes Asiatic lion, spotted deer, blue bull, four-horned antelope, striped hyena, wild boar, porcupine, langur, python, crocodiles and birds like pigeon, patridge, rock grouse etc.

Dachigam Wild Life Sanctuary : It was established in 1951 in Kashmir, 26 kms away from Srinagar. It has an area of 29 sq. kms. and has two levels: upper Dachigam at 3,692.3 masl altitude and lower Dachigam at 1,246.2 masl altitude. It mainly preserves hangul or Kashmir stag, musk deer, leopard, black buck, black beer, brown beer and babboon.

Annamalai Sanctuary : This sanctuary was established in 1972 in the southern part of Coimbatore district in Tamil Nadu. It has an area of 958 sq. kms. and supports rich fauna of animals like elephant, gaur, sambuar, spotted deer, barking deer, nilgai, nilgiri langur, lion tailed macaque, tiger, panther, sloth bear, porcupine and pangolin.

5.5.2 National Parks

National Park is an area dedicated to conserve environment, natural and historical objects and to conserve the wild life therein. National parks also provide for enjoyment from animals in such a manner and by such means as will leave them unimpaired for the enjoyment of future generations. In national parks all private rights are non-existent and all forestry operations and other usages such as grazing of domestic animals etc. are prohibited.

Some well-known national parks of India are:

Hazaribagh National Park : This national park was established in 1954 in Bihar. It has an area of 184 sq. kms. of thick tropical forests. The typical fauna of this park includes wild boar, sambuar, nilgai, tiger, leopard, sloth bear, hyena and gaur.

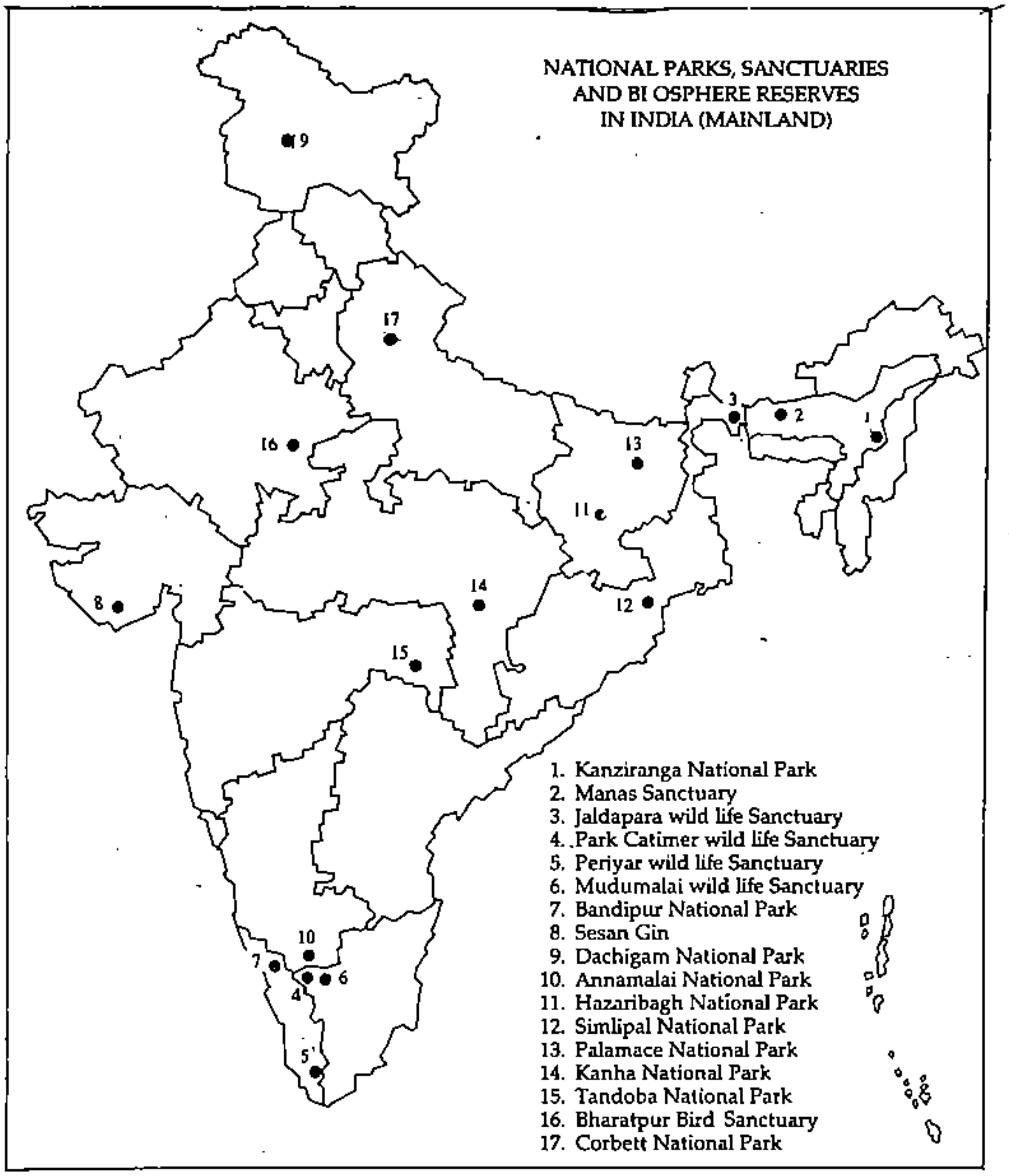


Fig. 5.6. : National Parks, Sanctuaries and Biosphere Reserves in India (Mainland).

Simplipal National Park : It is situated in the district of Mayuri Bhanj in Orissa and has an area of 2,750 sq. kms. It is covered with dense sal forests and has been chosen for project tiger. Its typical fauna includes tiger, elephant, deer, pear fowl, talking mynas, chital, sambuar, panther, gaur, hyena and sloth bear.

Palamau National Park : It is situated in the Dalton Ganj district of Bihar and has an area of 345 sq. kms. The fauna of this national park includes tiger, panther, sloth bear, elephant, chital, gaur, nilgai, tiger, chinkana and mouse deer. The flora is thick tropical forests.

Kanha National Park : This national park was established in 1955 in Madhya Pradesh. This park has an area of 939.94 sq. kms. and includes hilly terrain and streams. It is 175 kms away from Jabalpur and has forests of sal trees. Its typical fauna includes animals like tiger, chital, panther, sambuar, black buck and barasingha.

Tandoba National Park : It is located in Chandrapur district (Maharashtra) and has an area of 116 sq. kms. Its fauna includes tiger, sambuar, sloth bear, bison, chital, chinkara, barking deer, blue bull, four-horned deer, langur, pea fowl and a few crocodiles.

Bharatpur Bird Sanctuary : It is located in Bharatpur district in Rajasthan, has an area of 29 sq. kms. and harbours all kinds of indigenous birds like nesting water birds, water side birds and migratory birds. More than 328 varieties of birds including cormorants, spoonbills, white ibis, Indian darters, egrets, painted storks, open billed storks, black necked storks etc. live there. Many migratory birds like ducks, geese, siberian cranes, etc. regularly visit this sanctuary. Drier parts of this marshy sanctuary have animals like spotted deer, black buck, sambuar, blue bull, wild boar and python.

Corbett National Park : It is one of India's famous wild life sanctuaries and was constituted in 1935 as the first national park of India. It is situated between Nainital and Gharwal districts in Uttar Pradesh. It has an area of 525 sq. kms. and is located within west-south bend of the river Ramganga. It supports a rich and diverse fauna of the following: tiger, pather, sloth bear, hyaena, elephant, blue bull, swamp deer, barking deer, Indian antelope, porcupine, birds like bulbul, wood pecker, barbet, bee-eater and reptiles like crocodile, python etc. (Fig. 5.6).

5.5.3 Collection, Labelling, Mounting, Identification, and Care of Taxonomic Collections

Collection of plant specimens is essential for taxonomic research. Herbarium specimens become a permanent record. Select the plant material carefully. The specimens collected should always be in flowering and fruiting stage. At least five specimens of each element should be collected preferably in different stages of flowering and fruiting. Preserve the specimen by pressing it an soon as it is collected from the sight. Observe the patterns produced by hybridisation, changes in soil, moisture, slope and light. For collecting specimens in their different stages of flowering and fruiting it is necessary to visit the locality several times during a year. The leaves, flowers, fruits and seeds of flowering plants are important. These will make the identification of specimens easy. Similarly collect insects flying towards a torch light in the evening by picking by using ultraviolet lamps and also use mist nests for collecting birds, and follow other methods of collection as already discussed under herbarium and field methodology. While collecting the specimens use good judgement and do not collect rare or uncommon plants. You should know that some species have become extinct at particular sites because of thoughtless collection.

Now, press the plant specimens either by using a plant press that you have to purchase from a biological supply house or you construct it out of plywood sheets cut into 12/18" pieces to be used for either end of the press. Best plant press has ability to hold plant material under a constant and firm pressure. Use newspaper for pressing the specimens. After arranging the specimens tightly close the press with ropes or straps to prevent the wrinkling of the specimens. Keep the press for drying. While collecting specimens note down the necessary data like date of collection, habit, habitat, flower colour, locality. Local name, smell, presence or absence of latex, pollinating mechanism etc. in the field book. Now, prepare herbarium labels carefully and neatly in a legible hand. Include the information regarding collection number, locality, habitat, date of collection, name of collector, and scientific name. Mount

The most effective fumigant is cyanide gas. It is exceedingly poisonous to all forms of life and is used exclusively at the Kew, the World's largest herbarium.

the specimen by attaching it to a sheet of mounting paper. Select good quality herbarium sheet for mounting the specimens as these should last long and not get spoiled by insects. Apply glue to the back of the specimen and press it slowly onto the mounting sheet. The flowers and fruits are the bulky parts of the plants. Fasten these with the strips of transparent linen tape. Now, store these sheets in wooden or steel cabinets and use repellents and fumigants. Repellents will keep insects away from the herbarium specimens while fumigants will kill insects. Be careful about the use of chemicals as these are extremely dangerous. Use only approved ones. Commonly used fumigants include — Cyanide gas, paradichlorobenzene (PDB), carbon disulfide. The much simpler way is to spray DDT liquid application to the interior of herbarium cases. The DDT liquid preparation is available in the market.

You can also protect your specimens in the herbarium cases by providing adequate heating arrangements. If it is not possible to mount all plant material directly on herbarium sheets, preserve them in wooden boxes. Preserve dry fruits in envelops, and label them. Preserve succulent material in liquid preservative made of 5% aqueous solution of the commercial formaldehyde. It will prevent decomposition of the material. Keep these containers in museums. For preserving the specimens for morphological study you can use 50% or 70% alcohol. This will prevent the specimens from decomposition. Store the collection of both plants as well as animals in fire proof and dust proof buildings. If possible store museum specimens in air conditioned buildings because these will provide uniform temperature throughout the year.

Arrange plants in the herbarium according to a selected classification, keep all the specimens — both plants and animals, that you have collected from one locality together. If collection is large arrange it in a predetermined geographic sequence because it will later on help you in understanding the geographic distribution of the species. If you have not been able to identify some species keep them separately and try for identification. After you collect specimens (plants and animals) of a particular area it is essential to identify them. Prepare an artificial key to the identification of families, generas and species. You will read about "keys to identification" in Unit 6 of this block.

By identification, you will determine as to what kind of specimen you have collected. If you want to gain proficiency in identification try to go upto the species level. Try for identification only after classifying the specimens and it is important to have knowledge of taxonomic methods, taxonomic characters and current terminology. Make use of the pertinent literature and keep it for reference. Prepare a key to the main groups of plants and animals. This will facilitate the task of identification.

5.6 TYPE SPECIMENS

The specimens on which the names of the species are based are kept as type specimens. Do not replace these specimens because these will serve as reference material for the species identified. Store these specimens in safe and standard museums separately from other general collection and handle them with great care. If you receive a request from other coworkers, loan these specimens to qualified specialists and label them properly. Send them by safe and efficient means of transport. If you gift the type collection to other workers or to any museum, you still retain control and possession over this collection for your life time. You can also label type specimens as "holotypes". If all the original specimens and even their duplicates (isotypes) are lost or destroyed by fire or some other accident, you can collect the specimens afresh and name them as "neotypes". You should remember that type specimen is the nucleus of a taxon and foundation of its name. Because of their value type are given special care by curators of herbaria, and they do not permit their being sent out on loan to other botanists or institutions.

While examining the herbarium specimen every care is to be taken in shifting the herbarium sheet. It should be lifted with the hands so that it does not bend. Do not turn over the herbarium sheets like the pages of a book. It should be lifted with both the hands and kept over the other. If you do not handle these sheets properly there is every chance of damage to specimen.

Important Herbaria

The herbarium is a place where dried and mounted specimens are stored according to any recognised system of classification. Special attention is paid towards the protection of specimens and also type specimens from all sorts of insects, dust, moisture and other external injuries. Herbaria provide information about collected plants in various forms viz. recorded notes, photographs and hand drawn designs. All the herbaria are associated with Botanic Gardens.

For your information some important herbaria are mentioned below:

1) Herbarium of Royal Botanic Gardens, Kew, Richmond, Surray, Great Britain.
2) Herbarium of British Museums (Natural History), London, Britain.
3) Herbarium of New York Botanical Garden, New York, U.S.A.
4) Herbarium of Missouri Botanical Garden, St. Louis.
5) Central National Herbarium (Herbarium of Indian Botanic Garden) Calcutta, India.
6) Herbarium of Forest Research Institute, Dehradun, India.
7) Southern Circle Herbarium Coimbatore, India.
8) Western Circle Herbarium, Poona, India.
9) Eastern Circle Herbarium, Shillong, Assam, India.
10) Herbarium of National Botanical Garden, Lucknow (India).
11) Herbarium of Indian Agricultural Research Institute, New Delhi, India.

5.7 SUMMARY

In this unit we learnt that:

- Ecological and phytosociological studies are important for understanding the vegetation of an area.
- Herbaria are permanent repositories of plant specimens and are sources of information about plants and animals.
- Royal Botanic Garden, Kew, London, is a monumental institute in the world.
- Botanic Garden Sibpur, Howrah (Bengal), is the largest and oldest in South East Asia.
- Zoological parks save species from extinction.
- By declaring some areas as wild life sanctuaries or national parks the natural community alongwith its ecosystem is preserved.
- Identification and care of plants and animals is essential for taxonomic research.

5.8 TERMINAL QUESTIONS

1) Discuss briefly the importance of field observation for taxonomic study.

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2) Outline the role of botanic gardens.

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3) Explain what you understand by "Checks to Increase" as put forth by Charles Darwin.

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4) Define a type specimen.

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5.9 ANSWERS

Self-assessment Questions

1) a) Ecological observations help in understanding the location of collections, habitat types and soil characteristics. While phytosiological observations determine the natural variation within and between populations.

   b) Mass collection of specimens provide a means of determining relationships with greater accuracy and whether a variation is one associated with or restricted to colonies, to habitats or to regions. This information will help u to determine if a population represents a sub species, variety or forma.

2) a) A collection of pressed and dried specimens and arranged according to some valid system of classification and available for reference is called as herbarium.

   b) Collection of specimens is essential because these are the permanent repositories and are sources of information about plants and animals (flora and fauna).

   c) Carl von Linnaeus popularised the current practice of mounting specimens on single sheets of paper and storing them in stacks.

3) i) recreation

   ii) environment

   iii) John Evelyn

   iv) 1545-1550

   v) Preserved, live.

4) a) In wild life sanctuary the natural community alongwith its ecosystem is preserved and killing, hunting, shooting or capturing of any species of birds and mammals is prohibited. A national park is an area dedicated to conserve the environment, natural and historical objects and to conserve the wild life therein.

   b) i) 412
      ii) 80
      iii) April 1, 1973, World Wide Fund for Nature.

Terminal Questions

1) While dealing with taxonomic study we have to understand the distribution of taxa, variation within taxa and the adaptations of plants. This is possible when we go out for field observations. Morphological features are correlated with environment factors such as light, moisture and soil fertility. Information on ecotypic variation, edaphic specialisation, pollination mechanism, the effect of habitat on hybridisation, plant herbivore interactions and seed dispersal mechanism is also derived from field observations.

2) The role of botanic garden is to:
   - Cultivate and maintain plants of interest on scientific basis.
   - Maintain plants which are in danger of extinction.
   - Facilitate taxonomic studies by preserved and live plants.

3) What Charles Darwin called the "Checks to Increase" keep numbers down, both by removing animals from the population and by ensuring that few animals survive beyond their reproductive prime. There are two ways to regulate an animal population, prevention and removal. Prevention is essentially birth control while removal of surplus animals means killing them.

4) Type specimens are the specimens on which the name of an element has been based. It is the nucleus of a taxon and foundation of its name. Once designated, the type cannot be changed. Because of their value types are given special care by curators of herbaria. Type specimens should not be handled any more than essential. Curators of many herbaria do not permit their being sent out on loan to other botanists or institutions.

UNIT 6 TOOLS OF A TAXONOMIST — II

Structure

6.1 INTRODUCTION

In Unit 5 you have studied ecological and phytosociological aspects of taxonomy and herbarium methodology. In this unit you will learn about the taxonomic information collected from morphology, embryology, anatomy, physiology, ecology and other disciplines of biology. You will learn about the documentation of available taxonomic literature, key to the identification of plants and animals and get familiar with the herbarium ethics. You should understand that a systematic approach to taxonomic literature is necessary for identification and familarity besides other interests of morphological, economical and academic values. After reading this unit the vast treasure of literature concerned with taxonomy and future scope of its growth will be visualised.

Objectives

After reading this unit you should be able to:

- infer taxonomic information from various disciplines of biology,
- compute taxonomic literature for the identification of plants and animals,
- contruct keys to the identification of plants and animals, and
- describe herbarium ethics.

6.2 TOOLS OF A TAXONOMIST : LABORATORY ORIENTED

Modern classification systems are based on many types of evidence. A truly natural classification is obtained from analysis and harmonisation of evidence from all organs and parts like root types, stem types, inflorescence etc. Gross morphology provides the foundation for taxonomy and it should be supplemented by the information from anatomy, palynology, embryology, cytology, paleobotany, physiology and ecology. In the following sub-sections we will discuss each aspect one by one. (Fig. 6.1).

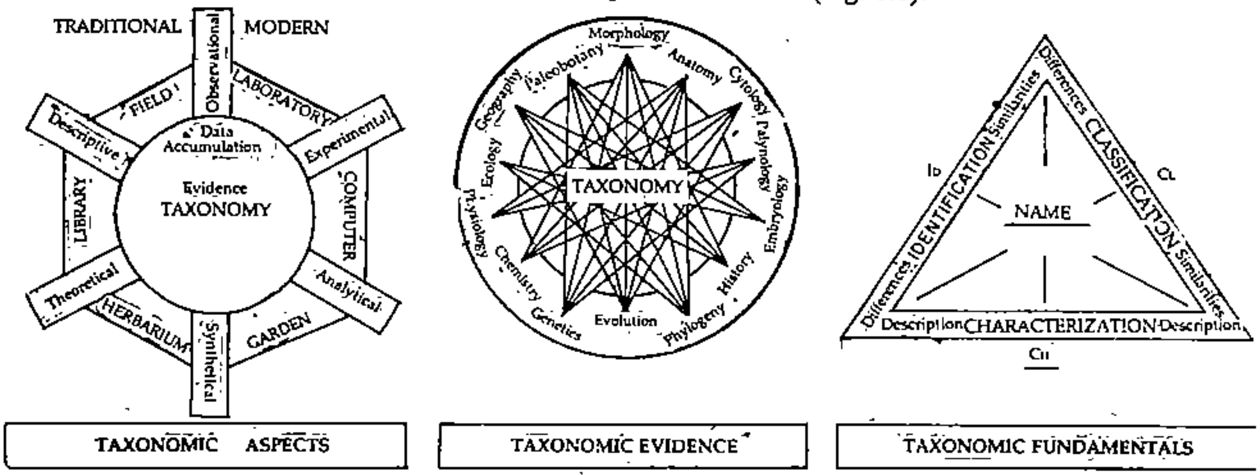


Fig. 6.1 : Systematics: Basic procedures and systems. All interrelated and related to the name.

6.2.1 Morphological Evidence

Morphology is the study of structure and form of plants and animals usually dealing with the organism and its component organs. Morphological evidence provides the basic language for plant characterisation, identification, classification and relationship. Morphological data are easily observable and obtainable, and thus most frequently used in taxonomic studies. The growth habit of herbaceous or woody plants is useful in classification. The root structural types like tap root system (Fusiform, Napiform) and adventitious root systems (Fascicled, Fibrous) classify plants into two major groups namely monocots and dicots. In monocots the number of cotyledons is one (corn) and these are characterised by adventitious roots while in dicots the number of cotyledons is two (Lima Bean, Castor Bean) and these are characterised by tap root system. (Fig. 6.2).

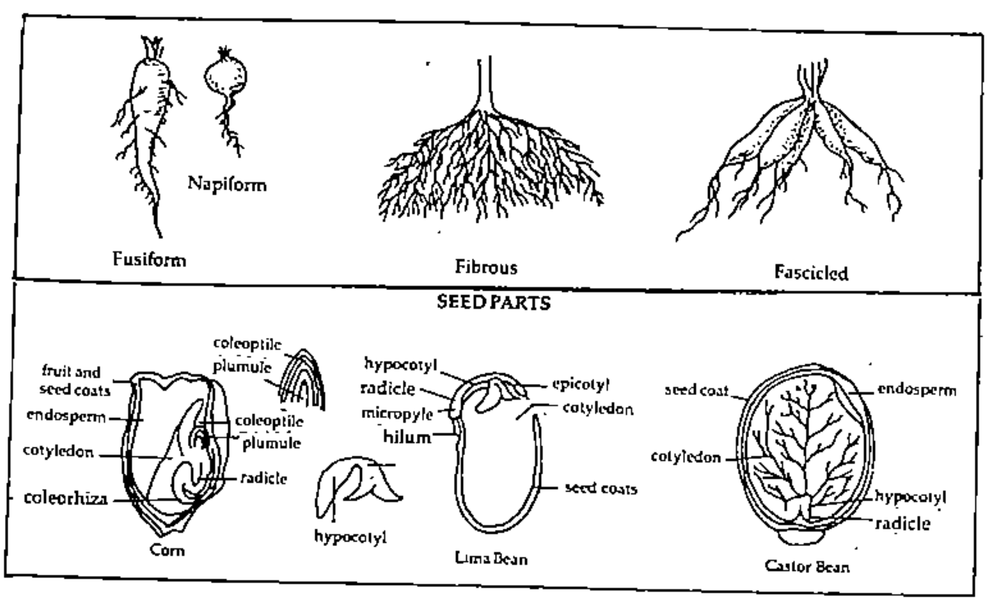
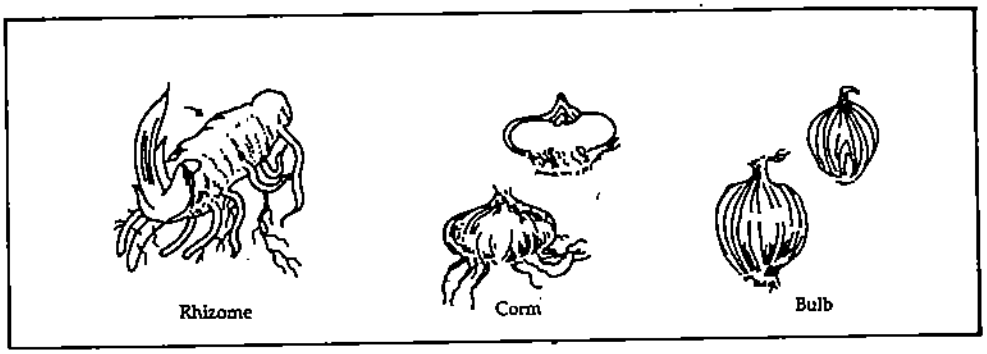
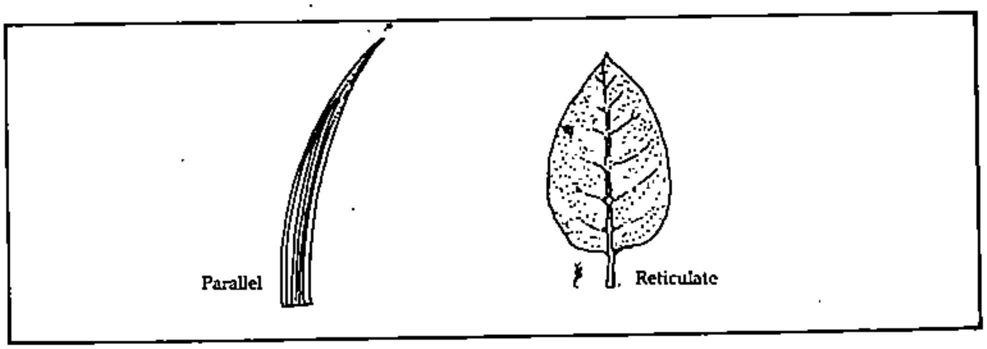


Fig. 6.2 : a) Root structural types (fusiform, napiform, fascicled, fibrous).

b) Seed Types: i) Monocot (Corn) ii) Dicot (Lima Bean, Castor Bean)

Vegetative underground structures such as rhizomes, corms, and bulbs also characterise a group. Also the classification of plants into two groups namely dicots and monocots is based on the arrangement of leaves and their venation. Monocots are characterised by parallel venation, while dicots are characterised by reticulate venation. (Fig. 6.3).





(b)

Fig. 6.3 : a) Stem structural types (Rhizome, Corm, Bulb).
b) Venation Types:
i) Parallel
ii) Reticulate

Natural selection associated with successful reproduction maintains a basic similarity of the reproductive feature of flowers, fruits and seeds within the various species, genera and families. We have already discussed these concepts in Unit 5. This general constancy makes the structures ideal for characterising taxonomic groups. You should know that floral feature of a plant are fundamental in defining natural groups, because of being more constant than vegetative features. Dicots have tetramerous and pentamerous flowers, while monocots have trimerous flowers. Reproductive characters are numerous and provide more features to differentiate taxa. Modifications in floral morphology can be related to the mode of pollination or specialised reproduction. Wind pollinated taxa frequently have unisexual reduced flowers that are individually inconspicuous. Corollacolor, pollinator guides and structure of floral whorls, stamen number, anther position, ovary position, number of carpels, number and position of perianth parts, type of inflorescence and fruit and seed type contribute to the reproductive features of the plants. The mature fruits of the mustard species (Cruciferae) and carrot species and their relatives (umbelliferae) have diagnostic character. In cruciferae the fruit is silique or silicle and in umbelliferae the fruit is a Schizocarp.

These families should include mature fruits to insure identification. Similarly flower type and fruit are important in the classification of the Rosa species (Rosaceae). The flowers are usually actinomorphic, perigynous to epigynous and fruit are fleshy pome (Fig. 6.4). The carollas and stamens of the figworts (Scrophulariaceae) provide much information for classification at various taxonomic ranks within the family. The corolla consists of bilabiate 4-5 connate petals and androecium commonly of 4 didynamous epipetalous stamens that are alternate with the lobes. (Fig. 6.5).

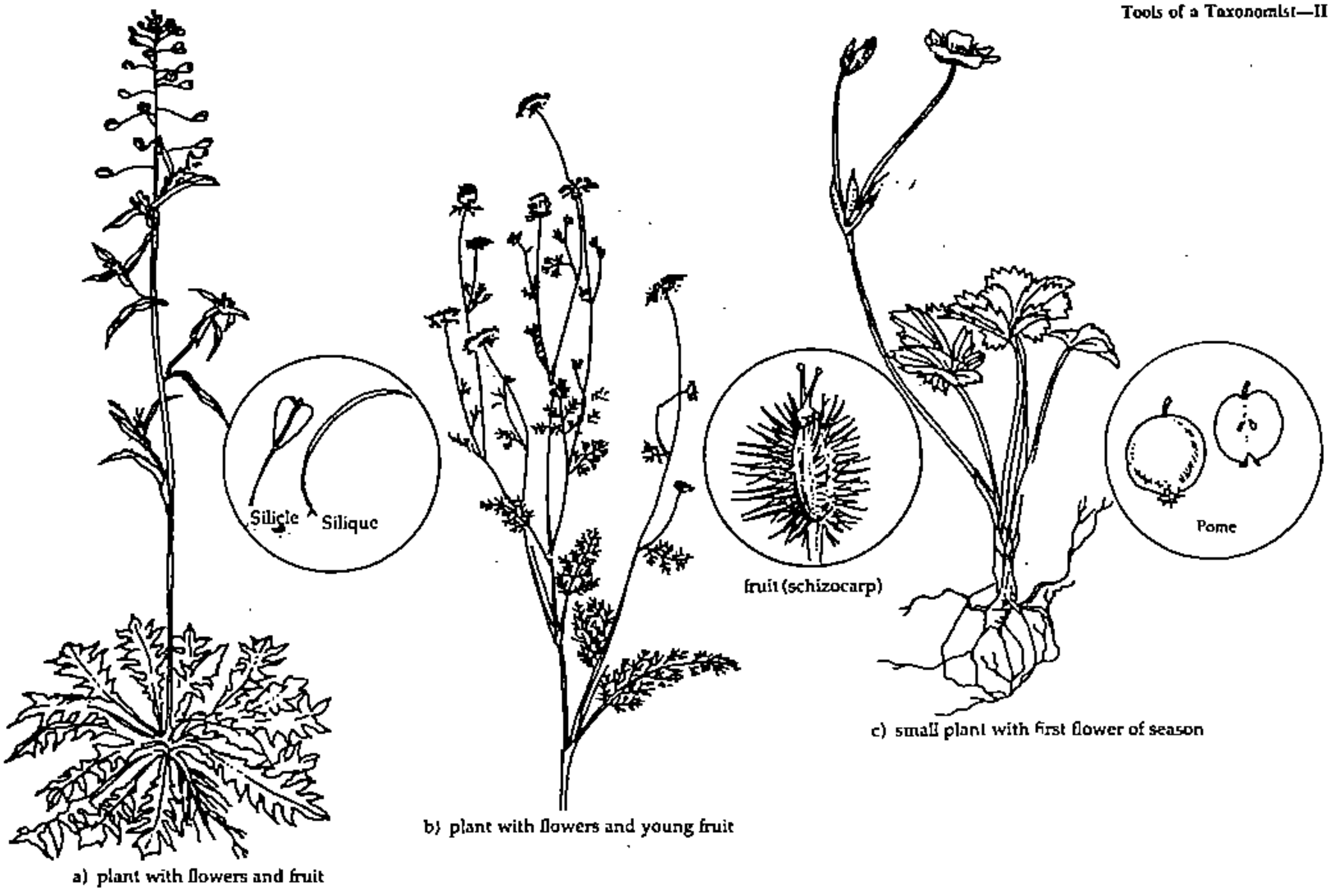


Fig. 6.4 : Fruit structural types:
a) Silique (Cruciferae)
b) Schizocarp (Umbelliferae)
c) Pome (Rosaceae)

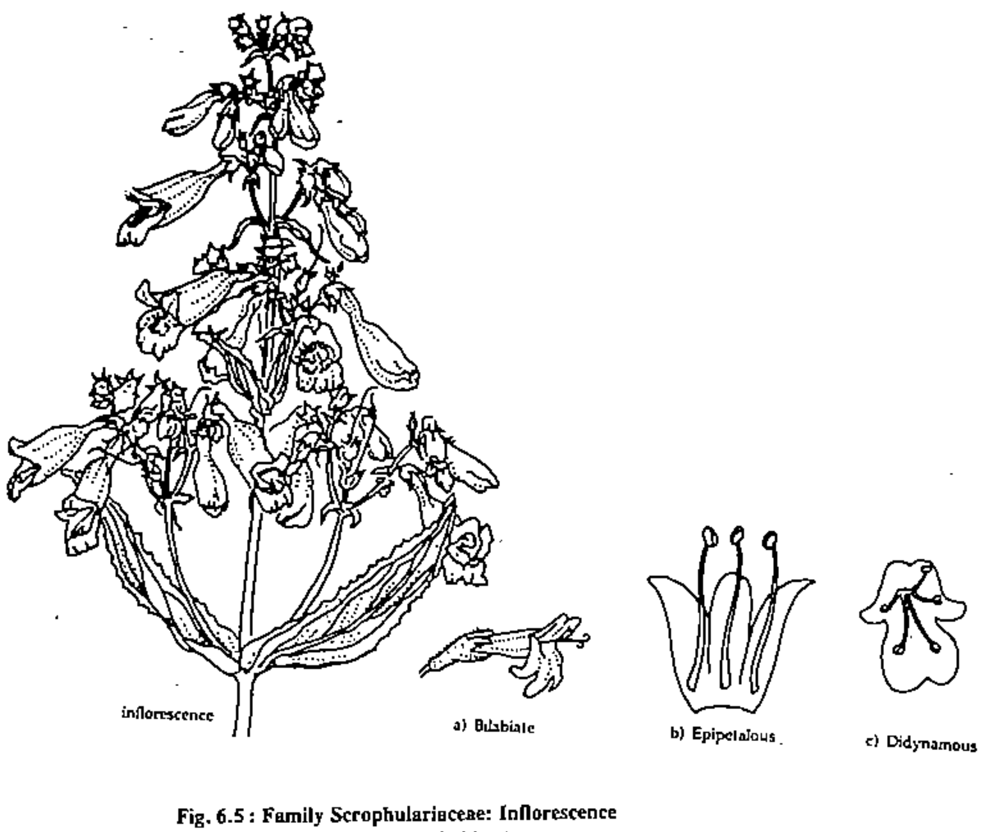


Fig. 6.5 : Family Scrophulariaceae: Inflorescence
a) Corolla shape (bilabiate)
b) Stamen position (Epipetalous)
c) Stamen arrangement (Didynamous)

6.2.2 Anatomical Evidence

Anatomy is the study of the structure, organisation and development of cells and tissues of plants and animals. For over a century taxonomists have used comparative plant anatomy as an aid in classification. The anatomical features of stems and roots are important in separating Gymnosperms from angiosperms and monocotyledons from dicotyledons. In monocot stem the vascular bundles are scattered throughout the parenchyma, whereas in dicot stem the vascular bundles are more orderly and form a definite concentric ring. In some dicots vascular cambium will form between the bundles eventually connecting throughout and forming a solid ring of conducting tissue (Fig. 6.6).

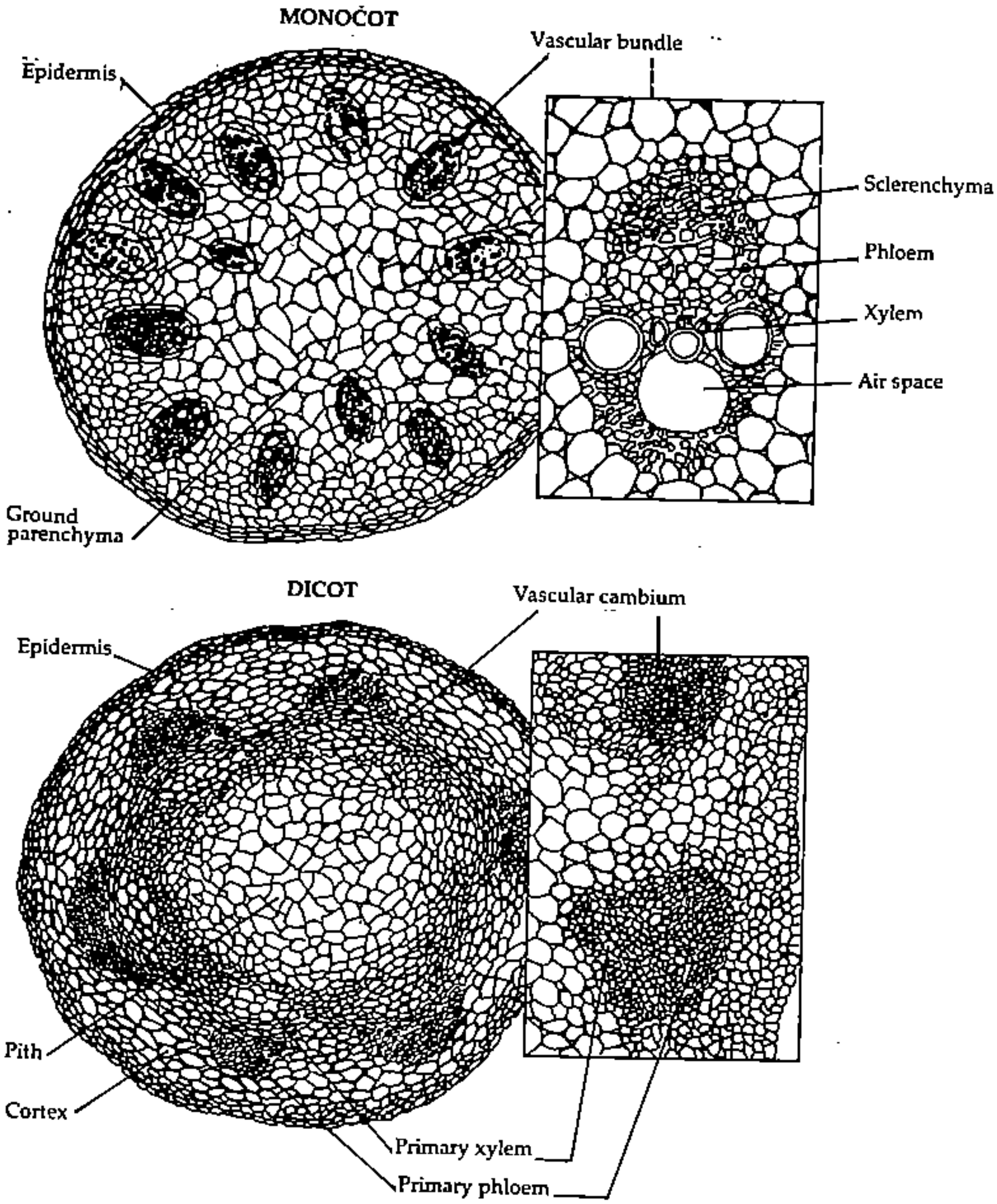


Fig. 6.6 : Diagrams showing the anatomy of a monocotyledonous and a dicotyledonous stem. In the monocot stem, the vascular bundles are scattered throughout the parenchyma, whereas in the dicot stem the vascular bundles are more orderly and form a definite concentric ring. In some dicots, vascular cambium will form between the bundles eventually connecting throughout and forming a solid ring of conducting tissue.

Progressive series from tracheids commonly found in the gymnosperms to specialised vessel elements occur in the secondary xylem of angiosperms. All stages of specialisation from veselles wood to highly specialised vessel elements are found in contemporary flowering plants. Angiosperms with vesselles wood are regarded as primitive (Fig. 6.7).

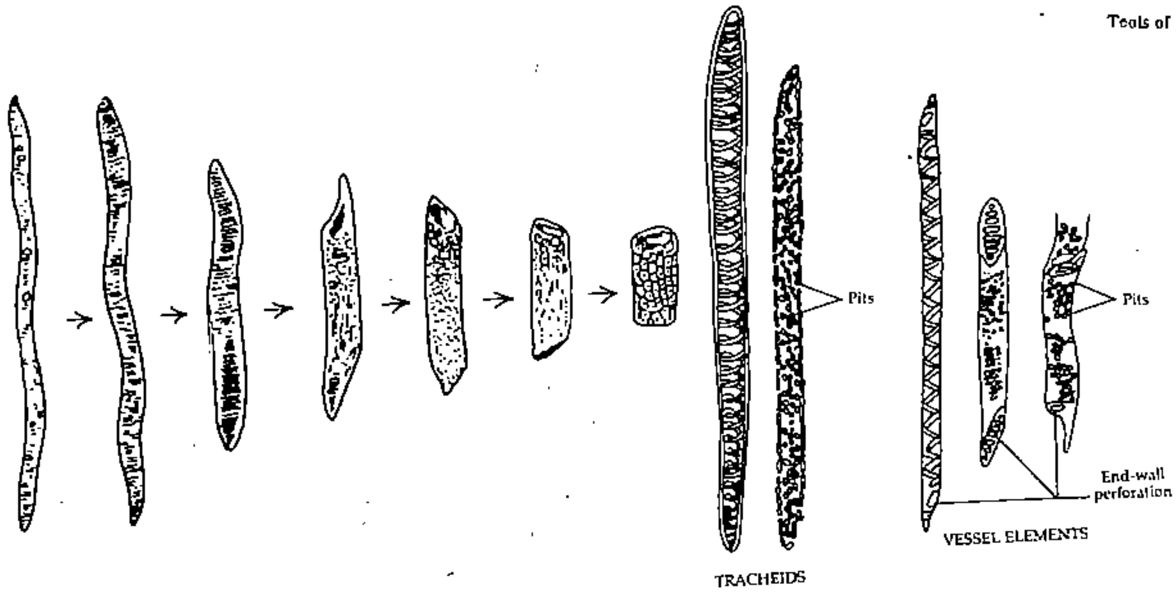


Fig. 6.7 : Morphocline of tracheary element types, representing a presumed evolutionary series. Note transformation from an imperforate gymnospermous tracheid with circular-bordered pits (left) to an angiospermous tracheid with scalariform pitting to an elongate vessel with scalariform pitting and numerous scalariform bars to progressively shorter, wider vessels with alternate or opposite simple perforation plates and transverse end walls.

The presence and structure of trichomes as well as their distribution patterns among taxa are taxonomically important. Variation pattern of trichomes also provides characters for classification. Stomatal types are of taxonomic use. Stomata of dicotyledonous plants have kidney shaped guard cells and stomata of monocotyledonous plants have dumbell shaped guard cells (Fig. 6.8).

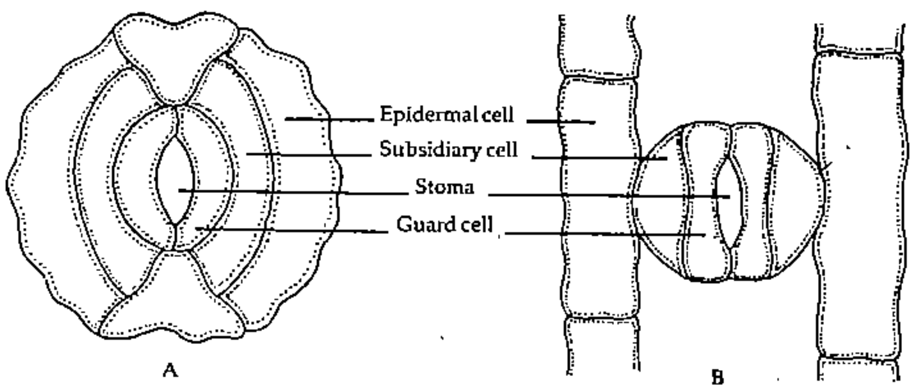


Fig. 6.8 : Drawings to illustrate the typical kidney-shaped guard cells of dicotyledonous plants (A) and the dumbell-shaped guard cells of monocotyledonous plants (B).

In animals the study of anatomical parts provide enough describable characters and classification based on them lead to certain conclusions as has been shown to be true for hard parts as against skin in a test case for lower taxa among mammals. A first step is to extend anatomical data beyond those traditional forms of museum specimens in mammals to the baculeum, to the ear ossicles and then to the soft parts and the second step is to push anatomical observation to deeper levels to cytology and especially karyology.

6.2.3 Palynological Evidence

Palynology is the study of pollen and spores. The taxonomic characters of pollen grains include wall structure, polarity, symmetry, shape and grain size. In angiosperms pollen grains are of two kinds viz. monocolpate and tricolpate. Monocolpate pollen grains are boat shaped, have one long germinal furrow and one germinal aperture. This is characteristic of primitive dicotyledons and majority of monocotyledons. According to some palynologists the first flowering plants had monocolpate pollen grains. Tricolpate grains are globose, symmetrical, have three germinal apertures and are characteristic of advanced dicotyledons (Fig. 6.9).

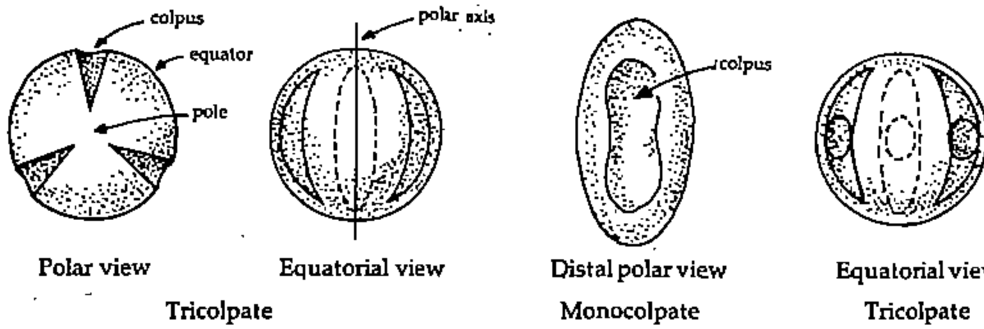


Fig. 6.9 : Pollen Morphology.

6.2.4 Embryological Evidence

Embryology is the study of the successive stages of sporogenesis , gametogenesis and the growth and development of the embryo. The number of nuclei in the pollen grains at the time of pollen dispersal is either two or three. Double fertilisation is an example of embryological unity through out the angiosperms. Based on the number of cotyledons, monocotyledons are separated from dicotyledons. The binucleate pollen is derived. Embryology has had systematic significance in the grass family, where with several other characters it has been used to revise the family's classification. In animals the embryological evidence is of great significance, e.g. the *Anopheles maculipennis* complex is broken into a number of sibling species on the basis of their egg structure. In *Dacus oleae* and *ceratitis capitata* (fruit flies) the whole eggs are separated on the basis of the character of anterior pole and the whole classification of white flies is primarily based on the structure of their pupae (Fig. 6.10).

EMBRYO SAC TYPES IN ANGIOSPERMS

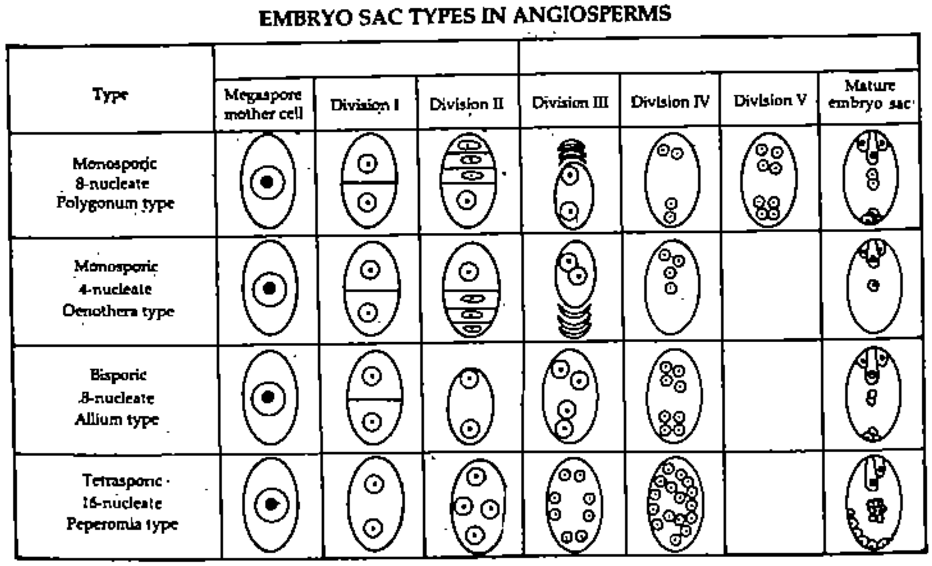


Fig. 6.10 : Embryo sac types in angiosperms.

6.2.5 Cytological Evidence

Cytology is the study of the morphology and physiology of cells. The information about the chromosome number, shape and pairing at meiosis is used for classification purpose. Cytotaxonomy refers to the use ofchromosome number and morphology as data for classification. Cytogenetics includes those studies dealing with observations of chromosome pairing or behaviour at meiosis. In angiosperms haploid number of chromosomes ranges from n=2 in *Haplopapus gracilis* (compositae) to around n=132 in *Poa littoroa* (Gramineae). Most angiosperms have chromosome numbers ranging between n=7 and n=12. About 30 to 40 per cent of flowering plants are polyploids. Polyploids are organisms that have higher chromosome numbers because of multiplication of chromosome sets. In flowering plants there are several kinds of polyploid number relationship. *Pinus* (Pinaceae) is homoploid with n=12, while in compositae family the different species having n=90, 18 and 27 are present. There are still other genera with numbers that show no simple numerical relationship to one another (aneuploids) e.g. *Brassica* (Cruciferae) with n=6, 7, 8, 9 or 10. Base number and chromosome size is useful in understanding relationships in the grass family. Because relatedness of taxa is often reflected in homology of the chromosomes, pairing at meiosis in hybrids of two species helps in understanding relationships of closely related species. You should know that higher the percentage of pairing at meiosis in hybrids of two species the more closely the plants are presumed to be related. In animals there are now more reliable karyotypes for about 1,000 species of mammals, birds and insects.

About 16 species of the genus Drosophila are differentiated on the basis of number and shape of chromosome.

6.2.6 Paleobotanical Evidence

Paleobotany deals with the study of fossil records of plants and animals. New techniques and approaches to the study of fossil flowering plants provide taxonomic information. Paleobotany uses microfossils such as pollen or macrofossils of leaves, stems and other plant parts as source of data. Recent collection of well preserved angiosperm flowers from Eocene sediments of the southern United States and from kansas confirm the presence of diversified representatives of the present day "Amentiferae line" by middle Eocene time and their adaptation for wind pollination. Flowers and inflorescences with structural features allowing pollination by beetles, flies, beas, and butter flies were still in existence by middle Eocene. An extraordinary data source has been provided by the organic chemical profiles of miocene leaf specimens of *Acer, Celtis, Ouercus, ulmus* and *zelkova*. A high degree of correlation between chemical compounds of the fossils and those of modern species was found. Data provided by Paleobotany allow taxonomists to deal with the facts of the fossil record about angiosperms and their possible progenitors. However, the available data is still too limited for the construction of a valid general phylogenetic scheme.

6.2.7 Physiological Evidence

Physiological,and biochemical evidence is providing data of increasing importance to plant systematics. Recently, it has become apparent that a syndrome of anatomical and physiological features related to a high efficiency carbon fixation process occurs in a large number of plants. This syndrome has been called the Kranz syndrome or C_4 photosynthesis. In algae, mosses, most ferns, gymnosperms and many families of flowering palnts C_3-photosynthesis is the only known carbon fixation cycle. C_4-photosynthesis occurs in approximately 10 unrelated families of monocotyledons and dicotyledons. Kranz syndrome has proved useful in characterising *Panicum* and other taxa in the grass family. In the dicotyledon genus *Euphorbia* (Euphorbiaceae) C_3, C_4 and CAM (Crassulaceas Acid Metabolism) species are known. Both C_3 and C_4 carboxylation occurs in zygophyllum (zygophyllaceae) and in Atriplex (chenopodiaceae) (Fig. 6.11).

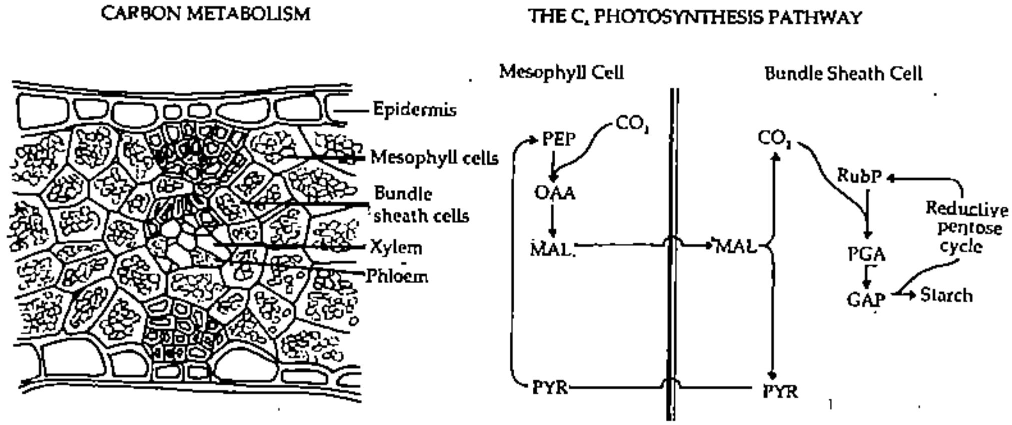


Fig. 6.11 : Kranz anatomy indicative of C_4 species. The drawing shows the typical arrangement of chloroplast containing bundle sheath cells and relatively undifferentiated mesophyll cells. The chloroplasts of bundle sheath have a lamellar arrangement. The chloroplasts of the mesophyll cell have typical grana.

6.2.8 Ecological Evidence

Ecology is concerned with organisms in relationships to their environment. These relationships may be classified as biotic, abiotic, spatial and temporal. Ecological studies demonstrate that the character states of many morphological features are correlated with environmental factors such as light, moisture, and soil fertility. The distribution of taxa both plants and animals, the variation within taxa and adaptations of organisms provide much information about the systematic position of various plant and animal species. As ecologists we should examine ecotypic variation. Edaphic specialisation, pollination mechanisms, the effect of habitat on hybridisation, plant herbivore interactions, seed dispersal mechanisms and ecology of seedling establishment. In plants the ecological information has implications for classification below the level of genus. These features are important in adaptation of populations to their environment. You can perform transplant experiments and grow under control the plants in order to study and describe the life histories and evaluate many characters (Fig. 6.12).

In animals every species has its nearest relatives in food preference, breeding season, tolerance to various physical factors etc. You should know that when two closely related species coexist in the same general habitat they avoid fatal competition by their species-specific niche characteristics. Though the larvae of *Drosophila mulleri* and *Drosophila aldrichi* live simultaneously in the decaying pulp of the fruits of the cactus *(Opuntia lindheimerii)* yet both have specialities in their preferences for certain yeasts and bacteria.

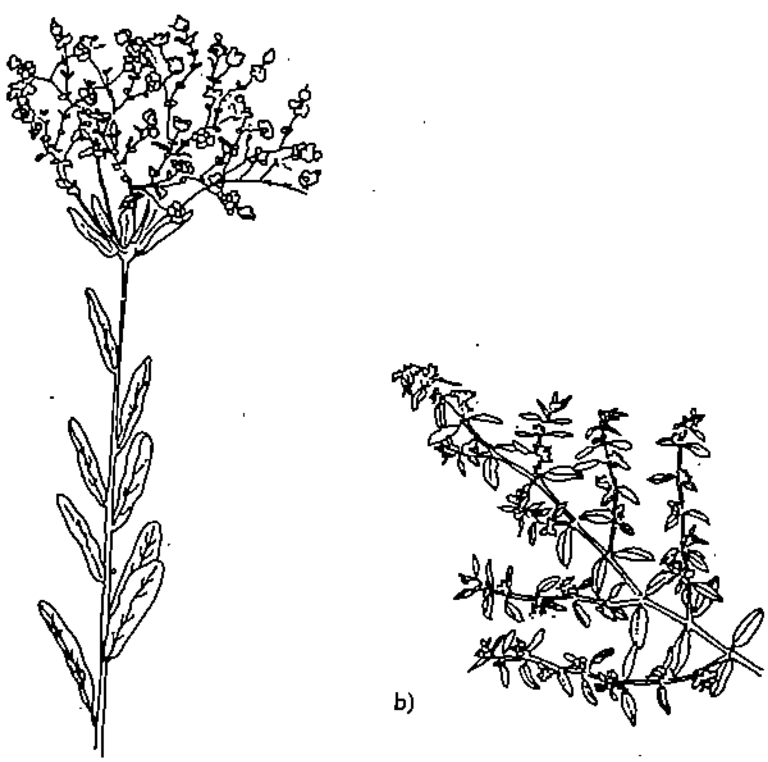


Fig. 6.12 : Ecotypic variation in Euphorbia species:
a) Part of erect plant
b) Part of prostrate plant

SAQ 1

a) How is truly natural classification obtained.

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b) Why is morphological evidence essential in systematic research?

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c) Fill in the blank spaces with appropriate words from the text.

i) Dicots have .... and .... flowers, while monocots have .... flowers.

ii) In cruciferae the fruit is .... or .... and in umbelliferae the fruit is a ....

iii) In monocot stem the vascular .... are ...., whereas in dicot stem the .... bundles are .... are .... in a ....

iv) The pollen grains in monocots are ...., and tricolpate pollen grains are characteristic of ....

v) Paleobotany deals with the study of .... records of .... and ....

6.3 TAXONOMY LIBRARY DOCUMENTATION

Taxonomy is fundamentally a descriptive and highly documented science. For this reason its literature is voluminous and constitutes a vital part of its structure. There is no complete nor even adequate bibliography dealing exclusively with taxonomic literature. In the following sub-sections we will discuss about the literature available for taxonomic research.

6.3.1 General Taxonomic Indexes

The indexes serve as an aid to locate quickly the source of original publications of a name, to learn if a particular name has been applied to a plant or to which order, family subfamily or tribe a plant of a given name may belong. The important indexes to vascular plants are as follows:

i) Index Kewensis Plantarum Phanerogamarum 2 vols. 18 suppl. Oxford, 1893-1985

This work is a corner stone to the literature on the systematics of flowering plants. The compilation of original work was made possible by a gift of money by Charles Darwin. It was compiled at the Royal Botanic Gardens, Kew by B.D. Jackson and his clerical assistants under the direction of J.D. Hooker. Index Kewensis is the reference employed to determine the source of the original publications of a generic name or Binomial of a seed plant. .

ii) Gray Herbarium Card Index. Cambridge, Mass : USA. A Card Index issued quarterly to subscribers accounting for all new names and new combinations applied in any category to the flowering plants and pteridophytes of the Western hemisphere.

iii) Genera Siphonogamarum : Berlin 1900-1907. This work edited by C.G. Dalla Torrey and H. Harms, accounts in one volume for the names published for families and genera of spermatophytes. Orders and families are arranged essentially according to Engler System and under each family name are given the names of sub families, tribes etc. together with the names of genera assigned to each; under each genus is indicated the number of species described in it. With the names in each category are given the appropriate author citation source and date of publication and synonyms.

6.3.2 Floras

A flora provides an inventory of the plants of an area and is often restricted to the vascular plants. Floras contain description of plants and key for identification. In flora plants are arranged according to one or another of the available systems of classification (Bentham & Hooker, Engler & Prantl, Bessey, Hutchinson, etc.). There is no single world flora that accounts for every species, even of the spermatophytes on the earth. A few important floras are cited below:

1) **World Floras :** Baillon, H. The Natural History of Plants. 8 vols. London, 1871-1888. Bentham, G, and Hooker, J.D. Genera Plantarum, 3 vols. London 1862-1883.

   Engler, A. and Prantl, K. This is a glorified book in German language entitled, "Die Naturalichen Pflanzenfamilies". 23 vols. Leipzeg 1887-1915 and other important contribution is of Hutchinson, J., "The families of flowering plants" 2 vols. London 1926, 1959, 1973.

2) **Asian Floras :** Some important Asian Floras are listed as under:

   i) Babu, C.R. **Herbaceous flora of Dehradun**, New Delhi, CSIR 1977.

   ii) Bhandari, M.M. **Flora of Indian desert**, Scientific publishers Jodhpur, 1978.

   iii) Duthie, J.F. **Flora of Upper Gangetic Plain** and **of the adjascent Swalik and sub Himalayan tracts**. Reprinted, Dehradun.

   iv) Hooker, J.D. **Flora of British India** (New Flora of India) 7 vol. London 1876-1897 Reprinted Dehradun.

   v) Kachroo, P. **Flora of Ladakh,** Bishen Singh, Mahindra Pal Singh 1977, Dehradun.

   vi) Kirtikar, K.R. **Indian Medicinal plants**, Dehradun, 1975.

   vii) Maheshwari, J.K. **Flora of Delhi** 2 vols. New Delhi CSIR.

   viii) Nair, N.C. Flora **of Himalayas**, Hissar International Bio Science Publication, 1977.

   ix) Royle, J. Forbes. **Illustrations of the Botany and other branches of the Himalayan mountains and the flora of Kashmir**. New Delhi Today and Tomorrow, 1970 (reprint).

6.3.3 Monographs

A monograph is defined as "the complete account as can be made at a given time of any one family, tribe or genus, nothing being neglected of it". It is worldwide in its scope and application. It reviews and evaluates all taxonomic treatments that have been made of that taxon. It takes care of and synthesises in so far as possible all cytological, genetical, morphological anatomical, paleobotanical, and ecological studies of the taxon by its author, co-workers or others. All elements of the treatise are accounted for by dichotomous keys, full synonymies, complete descriptions, precise designations of types together with notes as to where the types are deposited, citations of specimens examined, distributional ranges, notes on habitats and discussions of taxonomic and nomenclatorial considerations.

6.3.4 Revisions

Revision accounts for only a section of a genus or for the elements as restricted to a continent or smaller geographical area. Some revisions are based solely on herbarium studies and make no attempt to review all previous work on the taxon or to take care of the interrelated sciences of taxonomy, genetics, ecology etc.

It should be noted that there are no modern bibliographies devoted to the subjects of monographs and revisions of the world. The bibliographies by Pritzel, Jackson, Rehder and Merrill and Walker list several thousand monographs and revisions.

6.3.5 Manuals

A manual is a book that contains information on the area of coverage and keys and descriptions to the families, genera and species including the accepted scientific name, followed by the author of that name, major synonyms, information on intraspecific taxa if any, ecological and distributional data and common names. Many manuals have been revised and reprinted numerous times. For example Grays (1950)

Manual of Botany is now in its eight edition. Such manuals become the standard reference for the flora of a particular area of coverage. Recent trends in taxonomy require much attention to detail and documentation of the taxa by means of herbarium specimens deposited in recognised herbaria. A modern floristic researcher diverts much attention to typification, nomenclature, distribution and ecology, in addition to the basic comparative morphology.

6.3.6 Periodical

A periodical is a publication appearing at regular intervals. Each issue is called a number and collectively these numbers comprise a volume. Sponsors of periodicals often publish more than one serial. A society may publish a monthly serial to provide a source of publication for a variety of relatively short papers contributed by its members, together with records of its own proceedings. Such a periodical is usually entitled Journal, Annal, Bulletin or Proceeding. Botanists generally use the abbreviated form of the titles in citations and bibliographies and for this reason it is necessary to know the full title as catalogued. Libraries widely differ in the method of cataloguing titles of periodicals and too often fail to cross index titles under the various possible headings. In general if a periodical is published by a government or municipal institution it is catalogued under the name of the sponsoring country or city; likewise if by a society, academy or educational institution it is catalogued under the title of the organisation which is in turn placed under the name of the city where it has its seat.

Periodicals most frequently used in taxonomic studies of plants are as follows:

1) **Annals of Royal Botanic Gardens**, Calcutta.
2) **Journal of Linnean Society.**
3) **Records of Botanical** Survey of India.
4) **Journal of Indian Botanical Society.**
5) **Tropical Ecology Bulletin.**
6) **Indian Bulletin of the Torrey Botanical Club.**

Taxon is a bulletin published periodically by the International Association of Plant Taxonomy, Netherlands.

6.3.7 Dictionaries

Dictionaries of plants are often encyclopaedic in scope and are so few in number that any accounting of them is not limited to those written in English. Most of the data available in dictionaries is of plant names and is the source for the etymology of Latin or vernacular names for biographical data of persons for whom plants have been named, and for vernacular names in various languages.

Some of the important dictionaries are mentioned below:

1) Anderson, T.H. (1865) **Catalogue of plants cultivated in Royal Botanic Gardens**, Calcutta (1861-1864), Calcutta.
2) **The Wealth of India : A dictionary of Indian raw materials and industrial products.** C.S.I.R. (1948-).
3) Jackson, B.D. (1928). **A glossary of botanic terms with their derivation and accent**, London.
4) Lloyd, D. (1950), **A Dictionary of Botanical terms**, Oxford University Press, London.
5) Watt, G. (1889-96) **Dictionary of Economic products of India**, Calcutta, 6 vols.
6) Willis, J.C. 1911, **A dictionary of flowering plants and terms**, Cambridge (6th ed).

6.3.8 Reference Works in Animal Taxonomy Biological Abstracts

Its publication was first started by biosciences information service. It is bimonthly and the taxonomic information is abstracted in systematic biology part. It also contains a brief abstract of the paper and is of great use in giving the exact material of the paper.

Dissertation Abstracts

These are also useful and published monthly in United States. This contains abstracts of all dissertations by contributing institutions in the United States arrranged according to subject matter.

Century of Dictionary
It is published by Century Company, New York in six volumes. It is the most complete of all pronouncing guides for biological names. This dictionary lists thousands of zoological names of common genera and also all the known names of more inclusive groups.

Directories
These are quite useful in knowing the names of the taxonomists alongwith their specialisations. The most recent and useful directories for consultation are:
a) Directories of the zoological taxonomists of the world by R.E. Blackwelder and R.M. Blackwelder, Carbonadale, Illinois University Press, 1961. b) Directory of the zoological taxonomists of India by V.C. Kapoor, Kalyane Publishers, Ludhiana, India, 1974.

6.3.9 International Trust of Zoological Nomenclature

This trust is housed in the British Museum, London and is responsible for some of the most important literature in Zoological Nomenclature viz.

i) International Code of Zoological Nomenclature : It is a booklet edited by N.R Stoll et.al. and published in 1964. It contains all the rules and regulations required and approved by the 14th International Congress of Zoology in 1961 for naming the animals in uniformity throughout the world.
ii) Bulletin of Zoological Nomenclature : This was started in 1943 for the sole purpose of debating the nomenclatural problems.

SAQ 2

a) Name the important indexes to vascular plants.

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b) How do you distinguish the terms in each of the following couplets.
   i) Manual — flora
   ii) Monograph — revision
   iii) Taxon — periodical

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c) Name some reference works in animal taxonomy.

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6.3.10 Guides to Journals

A few important Journals are mentioned below:

i) **Systematic Zoology**
It contains articles on animals systematics, and papers dealing with cytological attributes of species and higher taxa, distribution patterns, behaviour, taxonometrics, variability, endemism, extinction, serology, geographic distribution, speciation, rates of evolution, climate rules etc.

ii) **Publications of the Systematic Association, London**
This has been started in 1953 and comprises of useful publications and proceedings of occasional symposia.

iii) **Taxon**

It contains articles on the problems of plant taxonomy, nomenclature etc. and was first published by International Association of Plant Taxonomy in 1951.

6.4 KEYS FOR IDENTIFICATION

Identification is an integral part of all taxonomic work. It is the recognition of certain characters of flower, fruit, leaf or stem and the application of a name of a plant with those particular characters. Unknown specimens are identified by means of keys. A key is a device for easily identifying an unknown plant by a sequence of choice between two statements. It provides the correct identity of a specimen by a process of elimination. It is more efficient to identify a specimen by the use of keys than to shuffle through a stack of previously named herbarium specimen until a comparison is found.

6.4.1 What are Keys?

Keys are determined as devices to help in identifying plants and animals. These are merely an aid to identification based on successive choice between two contrasting characters. In plants keys are a part of floras or monographs given before the description of taxa and comprise of statements in a couplet which serve as lead. Lead are numbered and these begin from the same word in a couplet using prominent contrasting characters and are also referred to as diagnostic characters or key characters. The first contrasting characters in each couplet are referred to as primary key characters or lead characters followed by secondary key characters.

Now let us study an example of key prepared for the identification of major groups of plants and animals.

Key—I

1) Plants with net veined leaves, floral leaves in fours or fives, embryos with 2 or more cotyledons __________ 2. Dicots.
1) Plants with parallel veined leaves, floral parts in threes, embryos with one cotyledon __________ Monocots.
2) Perianth uniseriate and similar
2) Perianth biseriate sepaline and petaline __________ 3
3) Petals usually free __________ Polypetalae
3) Petals fused __________ Gamopetalae

In this case statement 11, 22 and 33 are the couplets, one of them being a lead and numerals 2 or 3 written after initial word of the lead of both contrasting characters of same organs are written in the same sequence in the two leads of the couplet. In 22 perianth is the leading word and contrasting characters are that of the number of series of perianth. Petal is the starting word in the couplet 33 and free or fused is their contrasting character.

Key—II

1) Plants with net veined leaves, floral leaves in fours or fives, Embryos with 2 or more cotyledons __________ Dicots
2) Perianth uniseriate and similar __________ Monochlamydeae
2) Perianth biseriate, sepaline and petaline
3) Petals free __________ Polypetalae
3) Petals fused __________ Gamopetalae
1) Plants with parallel veined leaves, floral leaves in threes, embryos with one cotyledon __________ Monocots

In this case the two couplet leads or clues are separated and subordinate other alternatives.

Key—III

A) Wings mostly hyaline
   B. Costal band dilated apically
   C. Scutellar bristles 1 pair __________ *Dacus cucurbitae*
   BB. Costal band not dilated apically

C. Thorax with median yellow stripe __________ *D. diversus*
CC. Thorax without middle stripe __________ *D. dorsatis*

AA. Wings mostly opaque
B. Wings with Stripes
C. Scutellum with 5 black spots __________ *Carpomyia vesuviana*
CC. Scutellum with 4 black spots __________ *C. zizyphae*
BB. Wings reteinlate
C. Posterior margin of Wings with 3 hyaline spots __________ *Tephracitura xanthotricha*
CC. Posterior margin of Wings with 5 hyaline spots __________ *Spathuliha aerolececa*

This type of key is advantageous in the sense that the relationship of various divisions is quite apparent to the eye and can be used in reverse also.

6.4.2 Types of Keys

Keys are of two types viz.

i) Artificial Key
ii) Natural Key

Artificial Keys
These are based on the resemblances and differences of some prominent characters in the taxa.

Natural Keys
These are based on the phylogenetic relationship between various taxa.

Artificial keys are of two types: Bracketed keys and indented keys.

Bracketed Keys
In bracketed keys two couplet leads of the same rank are bracketed together. The alternative clues or couplets are written or printed in adjascent lines and reference to their successive subordinate clues is given by number mentioned at their end.

The format of a bracketed key is as under:

1a ....

1b ....

2b ....

3a ....

4a ....

5a ....

5b ....

6a ....

6b ....

The leads in the format could be numbered in alphabets viz. A and AA for 1 and 1′ and 1′ or 1′ 1b or B and BB for 22′ or 2a 2b but the number of alphabets is restricted to 26. In case large groups where more than 26 couplets are needed the alphabets cannot serve the purpose and we have to use the numbers which can go upto any extent.

In indented keys the groups of one lead are disposed off first with the help of indented leads and the related taxa come together.

An indented key has the following format:

1a ....

  2a ....

  2b ....

  3a ....

  3b ....

1b ....

4b ....

4c ....

5b ....

5c ....

6.4.3 Construction of Keys

Keys are constructed using contrasting characters. The possible names in the key are divided into smaller and smaller groups. Each time a choice is made, one or more taxa are eliminated. Statements in the key are based on the characters of the plants. Such as herbaceous versus woody. If herbaceous eliminate woody plants
ii) zygomorphic flowers versus actinomorphic. If zygomorphic eliminate actinomorphic flowers.

Each time a choice is made, the number of taxa is reduced by the use of contrasting characters. Keys are constructed in a different manner while based on the same matter. A good key is strictly dichotomous, not having more than two alternatives at any point.

6.4.4 How to Use a Key?

The use of a key is analogous to travelling a high way, that forks repeatedly, each fork having roadside directions. If a traveller follows the proper directions, the destination will be reached.

The first step in identification of an unknown plant involves the use of keys to determine the family, next is the key to genera which will provide the generic name. After the genus is determined the keying process is repeated within the genus for a determination of the species.

If a number of plants ABCDEFG is given to you for identification, you have to place them in two group viz. **Dicots and Monocots** with the aid of keys already given to you. The characters that you have to study for their grouping are that of a) Leaves — their venation, b) flower — the number of floral parts, c) embryos — the number of colyledons.

Carry out the study of these characters in the plants provided to you and record these. Suppose in case of plant ACEF the answer given to three characters given in the key is identical to those mentioned in lead, these belong to dicots i.e. their leaves have a reticulate venation, their flowers are pentamerous or tetramerous and the number of cotyledons is 2 while in plant BD and G characters are identical to those mentioned in lead 1 i.e. leaves have a parallel venation, flowers are trimerous and the embryos have only one cotyledon, these belong to monocots.

Further classification of plants into three series of Dicots viz. Monochlamydeae, Polypetalae and Gamopetalae is possible by ascertaining the presence or absence of characters mentioned in leads 2 and 3 in the key 2 para 3.

While using a key

i) understand the terms clearly and use proper terms.

ii) Read both the leads (clues) of a couplet carefully. When the answer to one lead is positive and that of the alternative lead is negative. You are on correct lines. If the answer is positive or negative in both the cases there is some mistake.

iii) If the alternatives in the couplets are not clear and contrasting but these overlap, make the conclusion after checking the description matching with identified species.

iv) While checking the measurements of organs mentioned in the key, measure more than one such parts preferably in 3 replicates and take an average. You should understand that there is a variation in size in fresh and dried specimens.

6.3.5 How to Prepare a Key?

Let us prepare a key by making a choice of characters, listing significant and insignificant characters, tabulating these characters and forming dichotomies. List all the permanent morphological characters and write them in the same sequence on cards. Keep one card for each taxon. If we choose petiole as a character we have to write it at the same number in all the cards. If in some plants, petiole is absent we have to record its absence at the same place as shown in Table I.

Table I

Characters	Taxa I	Taxa II	Taxa III	Taxa IV
1. Embryo: No. of Cotyledons	2	2	2	1
2. Leaves Venation	reticulate	reticulate	reticulate	parallel
3. Flower No. of Floral leaves	tetramerous	Pentamerous	Pentamerous	Trimerous
4. Flowers with Perianth	Sepals and Petals	Sepals and Petals	Only one Type	Only one Type
5. Flowers with Petals	Free	Connate	Usually Absent	Perianth

From the table it is clear that taxa I, II and III fall into one group and IV in another. On the basis of characters noted at 1, 2 and 3. This is called Dichotomy. On the basis of perianth character written at No. 4 again two groups are made, one of taxa I and II and other of taxa III and IV. Taxa I and II are further separated on the basis of character of petals, free versus connate. Now sort out all the cards into two groups and separate cards of each group into two or more sub groups till all the taxa are dealt with and all the cards are sorted out. All the characters on the basis of which cards are sorted into groups form the couplets of leads. Now print the key and write flower trimerous and not trimerous flowers and leaves reticulate and not reticulate leaves. If size is a character then give range of measurements and do not use words like big, small large.

6.4.6 Punch Cards

Punch cards are used when the number of taxa to be keyed out is large. In this type of cards the holes at numbers corresponding to a character are made open by cutting the perforations upto the margin. Each number is allotted to the character. For example, following statement is prepared for the taxa I to IV already discussed in the table.

1. No. of Cotyledons — 1 (one)
2. No. of Cotyledons — 2 (two)
3. Leaves reticulate veined
4. Leaves parallel veined
5. Flowers trimerous
6. Flowers tetramerous
7. Flowers pentamerous
8. Flowers with sepals and petals
9. Flowers with one type of perianth
10. Flowers with one whorl of perianth
11. Petals free
12. Petals fused/connate

When the character is present, the corresponding holes are cut open upto the margin when a poker is inserted in a bunch of cards at that number. Such cards at which the number has been cut open on account of the presence of the character fall down and others don't. Thus two groups are made on the basis of this character. All cards belonging to taxa I will fall out, when characters at number 2, 3, 6, 8, 10, 11 are tried, while those belong to taxa IV will fall out when characters at No. 1, 4, 5 and 9 are attempted. Hence two groups shown at 1 and 1′ of the key 2 are obtained Fig. (6.13).

PUNCH CARDS

A. Punch Card.

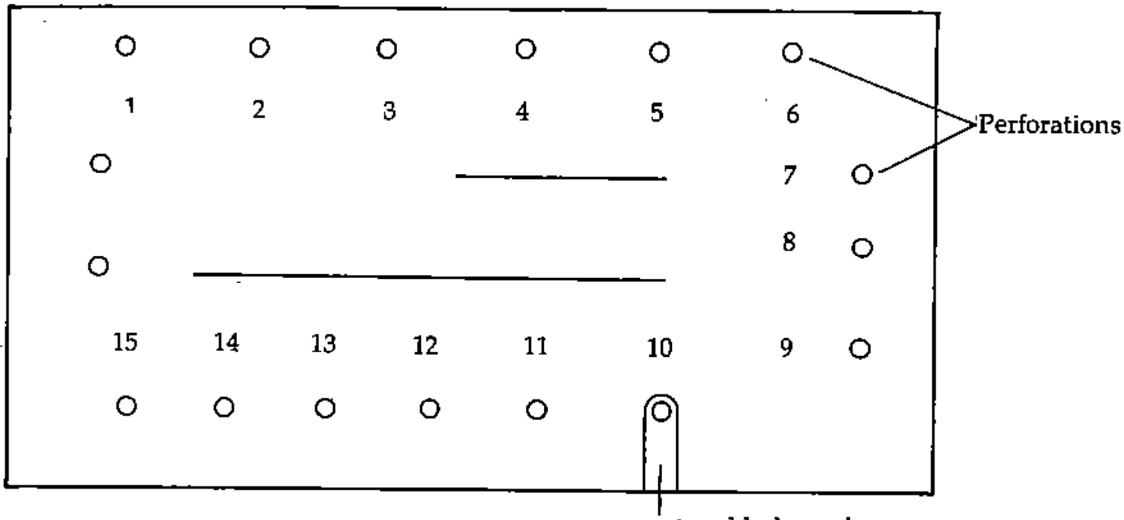


Fig. 6.13 : Punch Card.

6.5 HERBARIUM ETHICS

In Unit 5 you have read about herbarium methodology. You should also know that herbaria provide us with policy statements including such information as 1) filing arrangements, 2) reshelving, 3) loan procedures, 4) annotation lebels and 5) use of library collections. We should strictly adhere to the policy statements. If specimens are dry and fragile, mount them on paper that is flexible and keep these sheets flat. Lift these folders one at a time and avoid placing of heavy objects like elbows, books, coffee cups etc. on specimens. Use long armed microscope while studying specimens and avoid bending the sheet. If specimens are damaged keep them aside and inform curator. Do not dissect or remove flowers and fruits from the specimens, as they form the important organs of specimens and specimens are easily identified.

6.5.1 Collection of Specimens

Collection of plant specimens is essential for taxonomic research. These circumscribe species and document their variability. Plant material is carefully selected, pressed and preserved. While collecting specimens, both plants and animals, locations and habitat information is recorded, some features like flower colour and fragrance is noted because these are evident in living plants and are not easily observed in dried materials. For identification and research an intact and complete plant is collected. Representative leaves and reproductive structures are essential. The flowers, fruits and seeds of flowering plants are especially important. You have already read about the herbarium methodology in Unit 5. By now you must have understood that herbaria are the repository of "original documents" that is specimens upon which all our knowledge of the taxonomy, evolution, and distribution of the flora rests. The

Index Card Sketch

Flora .... No ....
Family ....
Botanical name ....
Local name ....
Habit ....
Flower colour ....
Habitat .... Locality .... Altitude ....
Ecological notes ....
....
....
Date of collection ....
Collector ....

Fig. 6.14 : Index Card Sketch.

collected specimens provide a standard reference collection for verifying the identification of newly collected plants. It documents the presence of a species at particular location and provides data on its geographic range and also points out the existence of classification problems. It also provides plant material and data in the form of vegetative and reproductive morphology, pollen samples, leaf samples for chemical analysis, anatomical samples and also ecological, economical and ethnobotanical data from the labels. Each label contains the information about local name, scientific name, locality, habitat, date of collection, name of collector and collection number. The labels are glued by one edge to the lower right corner of the herbarium sheet (Fig. 6.14).

6.5.2 Borrowed Material

For the study of as much relevant material as possible the material is obtained on loan. Borrowed specimens benefit the lending institutions because we have responsibility of annotating the specimens and revising identification. The loan specimens arriving from lending institutions are carefully checked for transit damage and the list is verified. The specimens are studied only on the institutional premises and housed in standard metal herbarium cases when not in use. For removing certain parts like pollen etc. prior permission is sought. The specimens are returned after proper annotation. The annotation label has the complete scientific name of the plant (genus, specific epithet and author), full name of the person making the annotation and the year of annotation. The original boxes and packing material is saved and used for return shipment giving details of packing.

6.5.3 Exchange of Material

The exchange of specimens among collectors is made on a one for one basis. It is an important means of augmenting a collection at minimal cost. The specimens for exchange are unmounted and loose in the pressing paper and properly labelled. We should always exchange good quality material, because poor quality materials are not normally acceptable by most curators as exchange materials.

6.5.4 Relationship with Co-workers

Herbaria provide visitors with policy statements and we have an obligation to adhere to the policy statements while visiting herbaria and in developing relation with co-workers. Visits to other herbaria are often profitable in terms of examining critical specimens and collections, searching the undetermined folders and exchanging ideas with other systematists. In order to make it possible for a co-worker to render some help we should send a note in advance. This will help the curator to prepare for our visit and to provide a place to work and a microscope. Since many herbaria are closed in the evenings and also on weekends the privilege of visiting after normal hours may be offered but should not be requested.

SAQ 3

1) Why is it efficient to identify a specimen by the use of keys.
2) Fill in the blank spaces with appropriate words from the text:
   i) Keys have long been used to identify .... and most manuals .... them.
   ii) The word key is derived from Latin ....
   iii) The use of modern keys is credited to ....
   vi) The diagnostic characters are also referred to as .... characters.
   v) Keys are of two types: 1) .... and 2) ....
   vi) Morphological characters are .... while cytological characters are ....
   vii) Punch cards are used when the number of taxa to be identified is ....
   viii) Characters following the lead are .... key characters.
   ix) Keys can be constructed in a different .... while based on the same ....

6.6 SUMMARY

Let us sum up whatever we have said so far:

- The more characters and types of evidence on which a taxon is based the better its taxonomy.
- No single type of evidence is intrinsically more valuable taxonomically than another.
- Identification is essential to the maintenance and refinement of any classification system.
- Suggestions for use of keys help one in the construction of keys.
- Taxonomic literature has been properly classified, identified, named and catalogued for effective storage, retrieval and use.
- Taxonomic literature is a form of documentation for the data, information, knowledge, research and scholarship of the past.

6.7 TERMINAL QUESTIONS

1) Write brief comments on the following:
   i) Artificial Keys
   ii) Natural Keys
   iii) Bracketed Keys
   iv) Indented Keys
2) How keys are constructed? Explain.
3) How many major groups of plants are identified. List the characters that you have to study for the grouping of plants.
4) Mention briefly as to what are the important points that you should understand while using a key.
5) Make a list of instructions that you should follow while framing the keys.
6) What is the difference between significant and insignificant characters?
7) What are punch cards? How are they used? Explain.

6.7 ANSWERS

Self-Assessment Questions

1) a) A truly natural classification is obtained from analysis and harmonisation of evidence from all organs and parts like root types, stem types, inflorescence etc.

   b) Morphological evidence is essential in systematic research because it provides the basic language for plant characterisation, identification, classification and relationship.

   c) i) tetramerous, pentamerous, trimerous

      ii) Silique, silicle, schizocarp

      iii) bundles, scattered, vascular, arranged, ring

      iv) monocolpate, dicots

      v) fossil, plants, animals

2) a) The important indexes to vascular plants are as follows:

      i) Index Kewensis Plantarum Phanerogamarum 2 vols. 18 suppl. Oxford, 1893-1985.

      ii) Gray Herbarium Card Index. Cambridge, Mass: USA.

      iii) Genera Siphonogamarum: Berlin 1900-1907.

   b) i) Manual: A manual is a book that contains information on the area of coverage and keys and descriptions to the families, genera and species.

Flora: A flora provides an inventory of the plants of an area and is often restricted to the vascular plants.

ii) Monograph: A monograph is defined as "the complete account as can be made at a given time of any one family tribe or genus, nothing being neglected of it".

Revision: Revision accounts for only a section of a genus or for the elements as restricted to a continent or smaller geographical area.

iii) Taxon: Taxon is a bulletin published periodically by the International Association of Plant Taxonomy, Netherlands.

Periodical: Periodical is a publication appearing at regular intervals. Each issue is called a number and collectively these numbers comprise a volume.

c) Reference works in Animal Taxonomy are:

i) Biological Abstracts

ii) Century of Dictionary

iii) Directories

3) a) It is far more efficient to identify a specimen by the use of keys than to shuffle through a stack of previously named herbarium specimen because the use of key provides the correct identity of a specimen by a process of elimination.

b) i) plants, contain

ii) clavis

iii) Lamark (1778)

iv) key characters

v) artificial, natural

vi) significant, insignificant

vii) vose

viii) secondary

ix) manner, matter

Terminal Questions

1) 1) **Artificial Keys :** These keys are based on the resemblances and differences of some prominent characters in the taxa.

2) **Natural Keys :** These keys are based on the phylogenetic relationship between various taxa.

3) **Bracketed Keys :** These are artificial keys in which the two couplet leads of the same rank are bracketed together.

4) **Indented Keys :** These are also the artificial keys in which the groups of one lead are disposed off first with the help of indented leads and the related taxa come together.

2) Keys are constructed using contrasting characters to divide the possible names in the key into smaller and smaller groups. Each time a choice is made one or more taxa are eliminated. Statements in the keys are based on the characters of the plants. For example, a key might separate taxa using the following choices:

1) herbaceous versus woody. If herbaceous the woody plants are eliminated.

2) Zygomorphic flowers versus actinomorphic, if zygomorphic the plants with actinomorphic flowers are eliminated.

Each time a choice is made, the number of taxa that remain is reduced by the use of contrasting characters.

Keys can be constructed in a different manner while based on the same matter.

3) Till date two major groups of plants are identified viz. monocots and dicots. The characters that you have to study for their grouping are that of 1) Leaves — their venation, 2) Flower — the number of floral parts, 3) Embryos — the number of cotyledons.

4) While using a key make sure that:
   i) You understand the terms clearly and use proper terms.
   ii) Read both the leads (clues) of a couplet carefully.

   When the answer to one lead is positive and to alternative lead is negative, you are on correct lines. If the answer is positive or negative in both the cases there is some mistake.

   iii) If the alternatives in the couplets are not clear and contrasting but these overlap, conclusion should be made only after checking the description matching with identified species.
   iv) While checking the measurements of organs mentioned in the key, more than one such parts should be measured, preferably in three replicates and average be taken. Also you should understand that there is a variation in size in fresh and dried specimens.

5) Following instructions should be followed while framing the key:
   i) Formation of dichotomies
   ii) Choice of characters
   iii) Significant and insignificant characters
   iv) Tabulation of characters
   v) Spreading of groups

6) **Significant characters :** The features of floral morphology are the significant characters in the classification of flowering plants. These are easily observed; natural selection, associated with successful reproduction maintains a basic similarity of the reproductive features of flowers, fruits and seeds within the various species, genera and families.

   Insignificant Characters : Insignificant characters are such characters as disjunctive geographic distributions and cytology because one may not always know the source of an unknown species, and cytological data of plants are of little help in identifying a plant. Chromosome numbers biologically may be significant but cannot be determined from a herbarium specimen and are of no help in a key.

UNIT 7 MODERN TRENDS IN PLANT TAXONOMY

Structure

7.1 INTRODUCTION

You have already read about 'Tools of a taxonomist'. In this unit, you will study about recent trends in plant taxonomy. The unit deals with how different branches of biology helps taxonomist in synthesising the classification. Each and every classification collected by taxonomists never becomes obslete and dispensable. It is retained progressively refined and continually added to by successive waves of new information which accumulate rapidly in the wake of important biological discoveries. In addition, new tools and techniques for studying various organisms provide interesting observations which are successively exploited by taxonomists. Thus, taxonomists are synthesisers of this information and the process of taxonomy and systematic botany is an unending synthesis.

Today, the modern taxonomist realises that the ultimate taxonomy of higher plants must be based on an understanding of the morphology, anatomy, embryology, cytology and breeding behaviour, besides chemistry and other features. This requires a multi-disciplinary approach and the taxonomist also uses computers to help him analyse data from different aspects of plant biology.

Thus, taxonomy includes both the latest developments and also the present state of the conventional approaches. The next unit deals about modern trends in animal taxonomy.

Objectives

After studying this unit you will be able to:

- describe various approaches in the study of plant taxonomy,
- differentiate between classical or alpha taxonomy and modern or omega taxonomy,
- explain the importance of morphology, anatomy and embryology in relation to taxonomy,
- appreciate the use of chromosomal information in cytotaxonomy and biosystematics,
- list the significance of plant chemistry in taxonomy,
- define numerical taxonomy with suitable examples.

Before we begin our study of modern trends in plant taxonomy, it is necessary to know about alpha and omega taxonomy.

7.2 ALPHA TAXONOMY AND OMEGA TAXONOMY

7.2.1 Alpha Taxonomy

This relates to the basic or preliminary classification based almost entirely on external morphology. This can be considered as the empirical approach in taxonomy where the classification is synthesised from the observed facts. Alpha taxonomy has also been called **Classical** or **Orthodox** or **Formal taxonomy**. This has been practised since ancient times and different aspects of this approach are in use even today. The name **'Alpha taxonomy'** was given by Turrill (1935), while two phases of development in taxonomy come under this approach according to other taxonomists such as Valentine and Love (1958), Davis and Heywood (1963). These phases are:

i) the **exploratory phase** involving collection and subsequent classification; and
ii) the **systematic** or **consolidation phase** involving extensive herbarium collections and field studies for preparing floras, monographs and detailed systems of classification.

7.2.2 Omega Taxonomy

After synthesising a basic classification, the taxonomist can attempt to improve upon it. Therefore, the observed facts are interpreted in **Omega taxonomy** to provide an interpretive classification. Evolutionary and phylogenetic approaches are applied to understand taxonomic and evolutionary relationships of plants at all levels. The name Omega taxonomy was also provided by Turrill (1935). However, this has also been called **Beta taxonomy** or **Neotaxonomy** or **Modern taxonomy**. According to Valentine and Love (1958), this represents the biosystematic or experimental phase in the development of taxonomy involving detailed cytological and genetical studies. Davis and Heywood (1963) suggest that Omega taxonomy represents the biosystematic phase as well as the encyclopedic or holotaxonomic phase in which the taxonomist analyses and synthesises all kinds of information.

7.3 MORPHOLOGY IN RELATION TO TAXONOMY

Morphology is the basic tool of taxonomy, because identification is primarily based on the characters of the plant. The morphological characters are easily observable in both living plants and in herbarium specimens. They have provided the basic information for a majority of the classification systems in plant taxonomy. In recent years, electron microscopy has provided a valuable tool to the modern taxonomist to study different morphological characters at high magnification and this information is used for purposes of identification, classification and for establishing relationships.

Heywood and Dakshini used the scanning electron microscope (SEM) to study the surface patterns of the fruit (called mericarp) in 40 species from 12 genera of the family Umbelliferae. They found that many microcharacters on the fruit wall observed with the help of the SEM are of great value in clarifying the relationships of the different genera. They also observed a great diversity in the structure of the fruit in these species and this provides new information of significant practical value for taxonomic purposes.

Most taxonomists have traditionally separated the genus *Glinus* Linn. from the genus *Mollugo* Linn. on the basis of seed characters; but sometimes there were difficulties in proper identification of the two genera. With the help of the SEM, the seed surface patterns have been examined in detail to establish the importance of seed surface microcharacters in the identification of the genera. Also, within the genus *Mollugo,* seed-coat micromorphology has helped in identifying different species.

These and other similar studies show that even in the present era of specialised and sophisticated botany, morphological characters continue to provide valuable taxonomic information.

7.4 ANATOMY IN RELATION TO TAXONOMY

The use of anatomical characters in taxonomy began with the development of the microscope which provided the biologist a new tool to observe the internal structure of organs and tissues. It was realised that anatomical characters are just as valuable as morphological ones. All parts of a plant provide numerous features which have been used for taxonomic purposes. Some anatomical features are very diagnostic and are commonly used in routine identification. We also know that this subject is of great importance to scientists who are called upon to identify small samples/scraps of plant material for particular purposes such as pharmacogonosist in the determination of the source of a drug, or by a forensic expert who may be able to provide clues to a crime investigation, besides others. These and other similar observations have firmly established the role of anatomy in plant identification and classification.

The leaf is perhaps the most varied organ of the angiosperms and provides many anatomical characters of potential taxonomic significance. In your Plant Physiology Course (Block 3, Unit 13) you have read about C_3 and C_4 pathways in photosynthesis. Investigation of the anatomy of leaves from plants following these pathways has brought out several significant features associated with the two types. The most distinct character observed in the leaves, is the presence of prominent chlorenchymatous sheath surrounding the vascular bundles in the leaves of plants showing the C_4 pathway and their absence in the leaves of plants showing the C_3 pathway. Thus, the leaf anatomy also provides information about the photosynthetic efficiency of a plant.

In angiosperms, leaves of dicotyledons show reticulate venation while leaves of monocotyledons show parallel venation

As a student of botany, from an early age, we learn that the basic pattern of venation differs in the two major divisions of the angiosperms. Within each division there are numerous leaf venation patterns and this feature has been used by taxonomist for understanding taxonomic and phylogenetic relationships in various plant groups.

Dr Lalitha Sehgal surveyed the leaf venation patterns in 150 species of the genus *Euphorbia*. She was able to recognise 12 major patterns and used this information along with other characters to identify and classify these species. She also correlated the leaf venation pattern with the habitat of the species and showed that xerophytic members of the genus had 'accumulated groups of tracheidal elements', while the herbaceous species having prostrate and ascending habit possessed a sheath around the veins. Several other features of the venation pattern were also found to be of taxonomic significance (table 7.1).

Table 7.1 : Classification of *Euphorbia* species on the basis of leaf venation patterns.*

Category 1.1	Uni-veined	6 species, e.g. *E. incisa*
Category 1.2	Bi-veined	4 species, e.g. *E. polygonifolia*
Category 1.3	Tri-veined	a majority of the species
	Group 1.3.1	Veins Ornamented
	Type 1.3.1.1 e.g. *E. indivisa*	
	Type 1.3.1.2 e.g. *E. hirta*	
	Type 1.3.1.3 e.g. *E. granulata*	
	Group 1.3.2	Veins Ornamented
	Subgroup 1.3.2.1	Three-stranded midrib
	Type 1.3.2.1.1 e.g. *E. milii*	
	Type 1.3.2.1.2 e.g. *E. pulvinata*	
	Type 1.3.2.1.3 e.g. *E. tirucalii*	
	Subgroup 1.3.2.2	Single-stranded midrib
	Type 1.3.2.2.1 e.g. *E. gorgonis*	
	Type 1.3.2.2.2 e.g. *E. glareosa*	
	Type 1.3.2.2.3 e.g. *E. peplus*	
Category 1.4	Special	18 species e.g. *E. neriifolia*

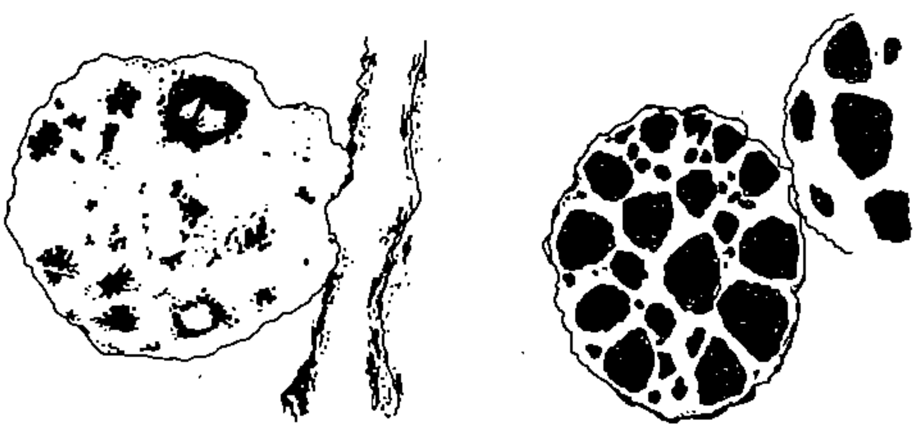
*Data courtesy Dr Lalita Sehgal

In another interesting study, Biesber and Mahlberg (1981) examined the laticifer cells and scanning electron micrographs of the starch grains for interpreting the evolution within the genus *Euphorbia*.

Several other features of the leaf anatomy have been used for taxonomic purposes. Some of these include the nature of the epidermis, stomatal types, the type of mesophyll, presence and type of sclereids and crystals etc. Foliar sclerids vary in their kind and distribution amongst various groups of angiosperms.

Another important anatomical feature used in taxonomy and phylogeny, is the structure of the secondary wood. Wood anatomy has been used at all taxonomic levels. This data along with other characters provides useful evidence for determining the taxonomic position of taxa whenever two or more possibilities are suggested. The classification of a genus or a family in its appropriate higher category can be determined in this manner. Similarly, petiole vascularisation pattern and nodal anatomy provide increasingly useful taxonomic evidences.

Behnke and his associates have investigated more than 1500 species from 380 families to understand the ultrastructure of the sieve tube plastids. There are broadly two types of sieve tube plastids: one is called S-type that accumulates starch; while the other type is called P-type that accumulates protein. This anatomical information obtained by using the transmission electron microscope (TEM) has been used for understanding relationships amongst different groups of both dicotyledons and monocotyledons.



A B

Figure 7.1 : TEM micrographs showing A. S-type plastids and B. P-type plastids in sieve tubes.

It is. however, important to remember that anatomical features have provided outstanding data for taxonomy. These characters when used alone may not provide vi ible system of classification, but when they are combined with knowledge from other disciplines, they have solved many taxonomic problem. Taxonomists should not separate anatomical data from morphological characters and they should incorporate this information in their formal taxonomic descriptions.

SAQ 1

a) In the following statements, put a tick (✓) mark on correct ones and a cross (×) on the wrong ones in the given boxes.

   i) Modern taxonomists can use knowledge from different fields of investigation. ☐

   ii) Alpha taxonomy follows an interpretive approach. ☐

   iii) Omega taxonomy is also called formal taxonomy. ☐

   iv) Morphological characters are not used in omega taxonomy. ☐

v) Plant anatomy provides characters for both alpha and omega taxonomy. ☐

vi) Morphology of foliar sclerids in different varieties of the tea plant can be correlated with the presence or absence of certain chemical substances in the leaf. ☐

b) Classical taxonomy and modern taxonomy follow distinct methods in solving taxonomic problems. Name the significant difference in the approach of these methods.

....

....

....

c) Plants showing the C_3 and C_4 photosynthetic pathways can be identified by their leaf anatomy. Which is the most significant anatomical feature?

....

....

....

In Thallophytes, the zygote directly develops into the new plant, or it divides into spores which then develop into new plants. But in Embryophytes (including Bryophytes, Pteridophytes, Gymnosperms, Angiosperms) the zygote first develops into an embryo, from which an adult plant is formed.

d) In what ways does information from sieve-tube plastids help taxonomists?

....

....

....

7.5 EMBRYOLOGY IN RELATION TO TAXONOMY

Embryological information has been used for taxonomic purposes at various levels of classification. You know of a very basic division of the plant kingdom into 2 units; the Thallophytes and the Embryophyta where plants are recognised on the basis of the behaviour of the zygote in addition to other characters (Table 7.2).

Table 7.2 : Embryological characters used in taxonomy.

1. Anther
2. Quadripartition of the microspore mother cell.
3. Pollen grain.
4. Development and structure of the ovule.
5. Origin and extent of the sporogenous tissue in the ovule.
6. Megasporogenesis and development of the embryo sac.
7. Form and organisation of the mature embryo sac.
8. Fertilisation.
9. Endosperm.
10. Embryo.
11. Seed-coat.
12. Special features.

In the same way you are also aware that the characters of the embryo along with several other features provide the basis for the division of the angiosperms into 2 major groups, the monocotyledons and the dicotyledons.

In the following paragraphs we shall elaborate on the value of embryological data as a modern trend in taxonomy of plants. By studying this section, you shall be able to know the various kinds of embryological characters used by taxonomists; understand the importance of embryological characters in taxonomy; and apply this knowledge from embryology for solving taxonomic problems.

Embryology strictly refers to the study of the development of the embryo and the structure of the mature embryo. However, Professor P. Maheshwari and many other famous botanists included, all events which led to the process of fertilisation besides the study of the embryo, under the term embryology. This enlarged concept has proved very useful for providing a large number of characters which can be used for taxonomic purposes, and during the last 50 years or so, a vast amount of knowledge has been accumulated which has been used for taxonomic purposes. These features from sporogenesis, gametogenesis, fertilisation and embryogenesis in flowering plants have been recognised as less prone to adaptive stress and therefore relatively stable. They are, therefore, of great significance in plant taxonomy, especially when external morphology has suggested two or more possibilities concerning taxonomic relationships.

There are several aspects which favour the use of embryological characters in taxonomy. The most significant and important feature is the high degree of correlation amongst embryological characters. There are, for example, as many as 10 embryological characters which always present themselves together in all plants classified under the order Ericales (Table 7.3). This highly significant correlation of characters is very important for identification of this order, and no other group of angiosperms shows all these characters together.

Table 7.3 : Embryological characters of the order Ericales

1.	Undifferentiated endothecium
2.	Glandular tapetum with multinucleate cells
3.	Pollen in permanent tetrads
4.	Unitegmic, tenuinucellate ovules
5.	Endothelium present
6.	Monosporic 8-nucleate megagametophyte
7.	Elongated zygote
8.	Cellular endosperm with the first 4 cells in a linear row
9.	Straight embryo
10.	Single layered seed-coat

Similarly, reproductive organs show less variability in different climatic conditions providing stable embryological characters for the purposes of identification. They also do not show ecotypic variation and remain unchanged at different ploidy levels in a polyploid series. These aspects and the fact that most biologists are of the opinion that embryological characters are conservative, increase the value of embryology as an important trend in modern taxonomy.

The value of embryology in solving taxonomic problems can be appreciated by studying some specific cases. Amongst the classical examples cited by embryologists is the taxonomic position of the genus *Paeonia.* In a majority of the classical systems of angiosperm classification, this genus is considered as a member of the family Ranunculaceae. However, several botanists have been recognising several characters of *Paeonia* which distinguish it from other members of the family Ranunculaceae. These include vascular and floral anatomy, basic chromosome number as well as the size and morphology of the chromosomes. The most significant difference between the genus *Paeonia* and other members of the family Ranunculaceae concerns several embryological characters and this study was carried out independently by Russian botanists Yakovlev and Yoffe as well as by the Indian botanist Prem Murgai. The most significant observation relates to the embryogeny in *Paeonia*. Unlike other angiosperms, this genus exhibits a unique type of embryogeny. According to the Russian botanists, the zygote nucleus undergoes repeated nuclear divisions forming a coenocytic structure. Later, the nuclei lodge themselves in a peripheral layer of the cytoplasm, and this is followed by wall formation so that the peripheral region becomes cellular. Some of the peripheral cells then function as embryo initials but only one of these develops into an adult embryo. Murgai on the other hand observed a division of the zygote into a 2-celled proembryo and the basal cell of this proembryo develops into the coenocytic structure leading to the development of the adult embryo as described by the Russian botanists. The other embryological characters which differentiate *Paeonia* from the rest of the Ranunculaceae are tabulated below. This justifies the separation of the genus *Paeonia* from family Ranunculaceae and its classification in the family Paeoniaceae (Table 7.4).

Table 7.4 : Comparison of embryological characters of *Paeonia* and Ranunculaceae

Feature	*Paeonia*	Ranunculaceae
Stamen	Spirally arranged, centrifugal	Spirally arranged, centripetal
Anther	Multilayered endothecium, mostly 2-layered tapetum	One-layered endothecium and one-layered tapetum
Pollen	Reticulately pitted exine, large and elongate generative cell	Granular, papillate or smooth exine, small lenticular generative cell
Female archesporium	Multicelled, many megaspore mother cells function	Uni- or multicelled, one cell functions
Antipodal cells	Persistent, not polyploid	Persistent (ephemeral in *Adonis*), nuclei one or more than one, polyploid
Embryogeny	Unique	Onagrad or, rarely, Solanad type
Seed	Arillate	Non-arillate
Fruit	Follicle	Achene

We are familiar with the 'water chestnut' commonly called 'Singhara' and botanically known as *Trapa bispinosa*. The classification of this plant has seen many changes. Bentham and Hooker classified the genus *Trapa* in the family Onagraceae, but other taxonomists including Engler and Hutchinson moved the genus *Trapa* to the family Trapaceae listing several morphological characters as evidence for this separation. Dr Manasi Ram undertook a detailed embryological study of *Trapa bispinosa* and listed several characters by which *Trapa* differs from Onagraceae thus supporting the classification of *Trapa* in a separate family Trapaceae (Table 7.5).

Table 7.5 : Comparison of embryological characters of *Trapa* and Onagraceae

Feature	*Trapa*	Onagraceae
Pollen grain	Pyramidal with 3 much folded meridional crests	Bluntly triangular, and basin-shaped
Ovary	Semi-inferior, biolocular with a single pendulous anatropous ovule in each chamber	Inferior, mostly trilocular with many ovules per chamber on an axile placenta
Embryo sac	Polygonum type	Oenothera type
Endosperm	Absent	Present and Nuclear
Embryo	Solanad type	Onagrad type
Suspensor	Well developed suspensor haustorium	Short and inconspicuous
Cotyledons	One cotyledon extremely reduced	Cotyledons equal
Fruit	Large, one-seeded drupe with prominent spines	Loculicidal capsule

Besides the examples discussed above, there are many other interesting observations on the genera *Exocarpus, Pentaphragma, Butomus, Daphniphyllum*, and the families Podostemaceae, Onagraceae, and Loranthaceae where embryological characters have been used for understand taxonomic relationships.

SAQ 2

a) Using embryological information, differentiate between:

i) Thallophytes and Embryophytes

....

....

....

ii) Monocotyledons and Dicotyledons

....

....

....

b) List six embryological characters used for taxonomic purposes:

i) ....

ii) ....

iii) ....

iv) ....

v) ....

vi) ....

....

c) Mention 3 features which render embryological characters significant in solving taxonomic problems.

i) ....

ii) ....

iii) ....

....

d) List 3 genera and 3 families of flowering plants in which embryological characters have helped in understanding taxonomic relationships.

Genera	Families
i)	....
ii)	....
iii)	....

7.6 CYTOTAXONOMY AND BIOSYSTEMATICS

Towards the end of the 19th century and in the early years of the 20th century, botanists were faced with a problem of analysing variations occurring naturally in plants. This led to a shift in the emphasis from descriptive classical methods in plant taxonomy to a new approach called experimental taxonomy whereby attempts were made to understand the cause of these variations. This new approach, also called biosystematics, depended largely on establishing the cytological basis of variation. This use of cytological data in taxonomy is now referred to as cytotaxonomy.

For the purposes of discussion, this trend in plant taxonomy may be considered under three broad headings:

i) chromosome number,

ii) chromosome morphology, and

iii) chromosome behaviour at meiosis.

7.6.1 Chromosome Number

We are generally aware that the number of chromosomes in each cell of all individuals of a single species is constant. It is also established that the more closely related species are likely to have similar chromosome numbers while the more distantly related ones shall have different numbers. Due to this relative conservativeness, chromosome number becomes an important and frequently used taxonomic character. In addition, there is a very wide range of chromosome numbers in the angiosperms from as low as $2n = 4$ (in *Haplopappus gracilis*) (Asteraceae) to as high as $2n = 530$ (in *Poa litterosa*) (Poaceae). A large number of angiosperms have been analysed for their chromosome numbers, providing useful taxonomic information.

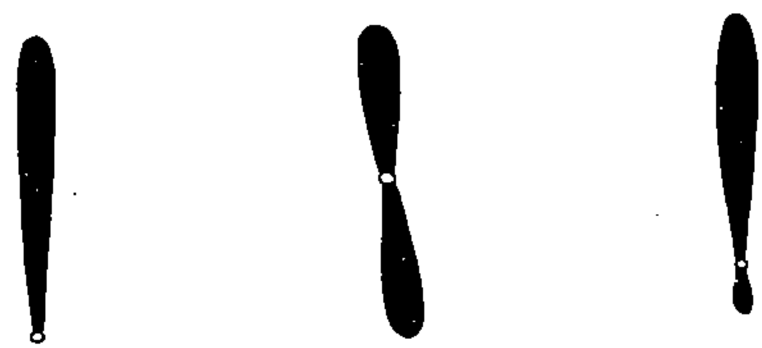
2n is equal to the diploid or somatic chromosome number; while n is the haploid or the gametic number.

x = n = diploid
2x = n = tetraploid
3x = n = hexaloid
4x = n = octaploid
5x = n = decaploid

Many interesting ideas have developed from knowledge of chromosome numbers. For example, in the genus *Festuca*, different species have different chromosome numbers forming a mathematical series. The chromosome numbers are 2n = 14, 28, 42, 56, 70, etc. From this information, a generalisation can be made, that different species may have some common basis. If we assume that these chromosome numbers are based on a common denominator called x (and x = 7), then we can consider the different species to have multiples of this number. This denominator or base number (x = 7) can be considered as the basic set of genetic information carried by a plant, and due to the multiplication of this basic genetic set, the evolution of different species has occurred. Such a series is said to be polyploid in which the basic number (x) is equivalent to the haploid number of chromosomes in a diploid species (i.e. x = n = 7). The other species would then be tetraploid, hexaploid, octaploid, decaploid, etc. respectively.

7.6.2 Chromosome Structure

Cytologists have studied chromosome morphology and have pointed out that the most interesting feature about the chromosome structure is the position of the centromere. The centromere or constriction in the length of the chromosome provides information about the relationship of the 2 arms of the chromosome. Thus, depending on the position of the centromere, chromosomes are described as metacentric, acrocentric, and telocentric (Fig. 7.2).



a b c

Fig. 7.2 : Chromosome structure—a) acrocentric, b) metacentric, c) telocentric.

The appearance of the basic chromosome set in a dividing cell is known as the karyotype of the cell. This can be analysed to provide information not only of the chromosome number, but also about chromosome size, chromosome volume, and type of chromosomes in the cell. This information is used by taxonomists for identifying plants and understanding relationships. The karyotype can be represented diagrammatically as an **ideogram** or **karyogram**, and these diagrams can be compared for taxonomic purposes. Another interesting observation is that the absolute size of the chromosomes of a karyotype is fairly constant since it is controlled by the genotype. Taxonomists have found that monocots generally have larger chromosomes than dicots, and that smaller chromosomes are found in hardwood plants in comparison to their herbaceous relatives.

7.6.3 Chromosome Behaviour

When we study meiosis, we not only observe the regularity of pairing which is important for the fertility of the plants, we are also able to make a chromosome to chromosome comparison. This provides valuable information about the role of chromosomes in heredity. Taxonomists use this information to understand relationships amongst different species of plants. We can also determine the nature of the genome to find out if it is homozygous or heterozygous. Genome analysis in plant taxonomy has been particularly useful in understanding polyploidy and for establishing the parentage of polyploids. A very significant study in this regard is the case of the common hexaploid bread-wheat, *Triticum aestivum*. The genome of this economically important plant has been designated as AABBDD with 2n = 42 chromosomes. Detailed genome analyses have established that 3 diploid species have contributed to the evolution of this hexaploid wheat. The A genome is from the diploid *Triticum monococcum* (2n = 14), the B genome is from a wild grass *Aegilops speltiodes* (2n = 14), and the D genome has been contributed by *Aegilops squarrosa* (2n = 14).

Finally, we must remember that as with any other character, the value of cytotaxonomic data depends upon the group or category under investigation. A combination of cytological information with data from other disciplines will provide a more useful tool to the taxonomist.

SAQ 3

a) Define

i) Basic chromosome number

....

....

....

....

ii) Haploid chromosome number

....

....

....

....

iii) Diploid chromosome number

....

....

....

....

b) By consulting books in your study centre, find out the diploid chromosome number in the following plants:

i) Rice (*Oryza sativa*)................................

ii) Potato (*Solanum tuberosum*)................................

iii) Tea (*Thea Sinensis*) ....

iv) Coffee (*Coffea arabica*) ....

v) Mango (*Mangifera indica*................................

vi) Onion (*Allium cepa*)................................

c) Where is the centromere located in a

i) acrocentric chromosome

....

ii) metacentric chromosome

....

iii) Telocentric chromosome

....

d) What is a karyotype? How does it provide information for cytotaxonomic purposes?

....

....

e) In what ways in genome analysis useful in cytotaxonomy?

....

....

7.7 CHEMOTAXONOMY

Chemotaxonomy is a science which uses chemical information as a character for taxonomic purposes. Before we analyse the basis of this modern trend in plant taxonomy, let us for a moment think about the different kinds of plants in our daily lives. When we drink tea or coffee, we appreciate the flavour or aroma and differentiate the two by this character. Similarly, when we eat fruits such as the mango, the banana or the apple, we find that they taste differently. This difference is due to the chemical constituents of these foods and this forms the basis of chemotaxonomy where the chemical features or chemical constituents serve as the evidence for taxonomy. The potential importance of chemical evidence in plant taxonomy has been suggested by both botanists and chemists and this has become an important recent trend especially because newer techniques for quick analysis of plant material have been developed. Chemotaxonomists suggest that chemical characters have a particularly high taxonomic value because they are i) stable, ii) unambiguous, and iii) not easily (if at all) changeable. Further, chemical characters will show chemical relationships amongst plants in the same way as morphological characters show morphological relationships.

Although chemotaxonomy is considered to be a relatively recent development in modern taxonomy, its origin can be traced to very early classical taxonomy. You will recall that the spice plants were identified on the basis of their aromatic properties, or the medicinal plants by their curative value. These aromatic properties or the curative value was largely based on the chemical constituents of the plants and taxonomists have classified them since ancient times using these chemical features along with morphological characters. However, it is only in recent years that chemotaxonomy as an important field of study has been established.

A review of the large amount of literature published in this field reveals that chemical data may be obtained from any part of the plant. Secondly, depending on the purpose of the investigation, the chemical information may be used for description or identification of plants, or for establishing relationships. This evidence assumes greater significance when it is used to sort out differences in taxonomic relationships when 2 or more possibilities are suggested on the basis of morphological characters.

Although theoretically, all chemical constituents of a plant are potentially valuable to a taxonomist, in practice some kinds of molecules are more useful than others. Thus we can use directly visible chemical constituents such as crystals, raphides, or starch grains occurring in different plants as chemical characters.

Alternatively, we can chemically analyse plant material for different chemical constituents and use this information for taxonomic purposes. Most chemotaxonomists recognise three broad categories of chemical compounds, primary metabolites, secondary metabolites, and semantides, as important taxonomically.

7.7.1 Directly Visible Chemical Characters

Very few chemical substances in plants can be observed directly, but the few substances such as starch grains which are present in most green plants as food reserves have been used for chemotaxonomic purposes. The type of starch grains present in different plants are very specific and this information can be used without any ambiguity. Reichert (1913) examined the starch grains in 350 species of plants and established their differentiation and specificity of occurrence in relation to genera and species, thus providing chemotaxonomic information. Tateoka (1962) reviewed the starch grain form in the grass family (Gramineae) and used this as additional information to classify the family into tribes. For example, in the Tribe Hordeae, the typical members such as *Hordeum* have compound starch grains, while other genera like *Lolium, Nardus,* and *Papapholis* have simple starch grains.

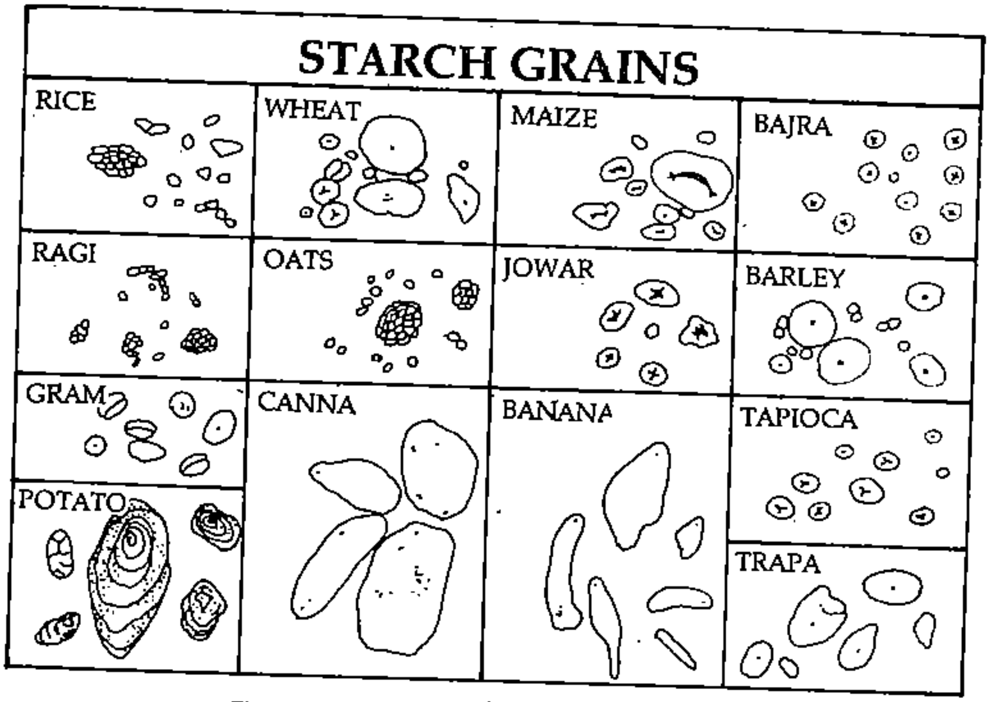


Fig. 7.3 : Types of starch grains (After Kochaer 1981).

Raphides are the crystals of calcium oxalate which are present in large cells in different plant tissues and can be observed directly. They are long needle shaped crystals, pointed at both ends and usually occur in bundles, thus being easily identified. They have been observed in as many as 35 families of angiosperms. Several families of the Order Centrospermae and the Family Cactaceae show the presence of raphides. This feature along with other chemical characters and the similarity in embryological characters strengthens the suggestion that the Family Cactaceae shows some relationship with the Order Centrospermae.

7.7.2 Primary Metabolites

As the name indicates, primary metabolites are molecules involved in vital metabolic pathways. They are of universal occurrence and not very significant in chemotaxonomy. However, these molecules become useful as chemotaxonomic features when the quantity of such molecules varies considerably between taxa. For example, the sugar containing carbohydrate 'sedoheptulose' is stored in large quantities as a reserve food in the genus *Sedum*. Thus members of this genus can be easily identified by the presence of this primary metabolite. Interestingly, sedoheptulose diphosphate is a part of the photosynthetic carbon cycle and in a majority of the plants sedoheptulose does not accumulate at all. In the same way, the 22 amino acids are of universal occurrence. They serve as the building blocks of proteins. They can provide useful macromolecular data for chemotaxonomy. The amino acid sequence of different proteins can be investigated and the degree of similarity is presumably proportional to the degree of genetic relationship. However, only a few out of about 3 lakh species of angiosperms have been analysed for amino acid sequences. For example, the amino acid data on wheat and barley confirms the relationship of these genera as suggested by classical taxonomists.

7.7.3 Secondary Metabolites

Secondary metabolites or secondary plant products are those macromolecules that lack nitrogen and are of restricted occurrence and therefore of greater taxonomic importance than primary metabolites. This group includes different kinds of compounds such as phenolics, alkaloids, terpenoids, etc. They are usually not involved in vital functions and are largely storage products or pigments.

Amongst the secondary metabolites, flavonoids, which are the commonest phenolic compounds of leaves, have been very useful for chemotaxonomic purposes. Both monocots and dicots have been extensively surveyed for these compounds which show structural variability and chemical stability besides widespread distribution. They can be rapidly and easily identified and provide important chemical characters for taxonomic purposes. For example, 80 species of plants from the family Ulmaceae were investigated for their flavonoid chemistry by Ciannasi (1978). A majority of the species contain flavonols, but a few species have glyco-flavonols and these two types of flavonoid compounds are never present together in any species. Interestingly, enough, in most classical systems of classification, the family Ulmaceae is divided, into two subfamilies called Ulmoideae and Celtoideae which are also distinguishable by the flavonoid chemistry. Therefore, morphological criteria combined with flavonoid dichotomy can be used to divide the family Ulmaceae (*sensu lato*) into two distinct families: family Ulmaceae (*sensu stricto*) characterised by the presence of flavonols, and family Celtaceae characterised by the presence of glucoflavonols.

Several other studies have used flavonoid chemistry for taxonomic purposes in families such as Arilidaceae, Cornaceae, Labiatae (Lamiaceae), Leguminosae (Fabaceae), Orchidaceae, Rutaceae, Lemnaceae and others.

A second group of secondary metabolites commonly examined by chemotaxonomists are the terpenes. Chemically speaking, these compounds can be classified on the basis of their molecular structure into monoterpenes, diterpenes, triterpenes, sesquiterpenes, etc., and each group can be used for taxonomic purposes. For example, in the genus *Salvia*, 19 species could be distinctly identified and classified on the basis of their monoterpenes. The terpene composition was as useful as the morphological characteristics in the analysis of introgression and hybridisation within the genus. Similarly, triterpenes and sesquiterpenes have been particularly important and useful in the classification of the families Cucurbitaceae and Compositae (Asteraceae) respectively.

Other secondary metabolites used in chemotaxonomy include the iridoid compounds, the alkaloids, and the ellagitannins.

7.7.4 Semantides

The information carrying molecules in plants are called semantides, and they have been recognised to be 3 kinds; deoxyribonucleic acid or DNA (primary semantide), ribonucleic acid or RNA (secondary semantide) and proteins (tertiary semantide) following the sequential transfer of the genetic code. Of these, the proteins are the most favoured molecules for chemotaxonomic purposes. Plant proteins can be studied by different methods; by electrophoresis or by serological methods, and both processes have been used for obtaining information about the protein chemistry of different plants.

In the common breadwheat, *Triticum aestivum*, the storage proteins were analysed by electrophoresis. For comparative purposes, the storage proteins of the tetraploid wheat, *Triticum dicoccum* and the diploid grass *Aegilops Squarrosa* were also analysed electrophoretically. This study confirmed the conclusion that the hexaploid wheat did contain a sum of the proteins possessed by the diploid species which have contributed to the evolution of the hexaploid wheat. This study supports the observations based on morphology and cytological evidence.

Serological analysis of proteins is based on the immunological reaction shown by mammals when a foreign protein is introduced into the system. In other words, this is based on the antibody-antigen reaction, the antibodies being specific to an antigen bringing about coagulation. This information can then be analysed to understand the relationships of the different plants on the basis of the serological evaluation of the plant proteins. Serology has proved a useful taxonomic tool at different levels of classification. J.G. Hawkes (1960) and his co-workers studied several tuber-producing species of *Solanum* to understand the evolution of the cultivated potato *Solanum tuberosum* and determine the species of *Solanum* which could be established as the ancestors of the common cultivated potato. Similarly, in the family Ranunculaceae, serological studies supported cytological data for the classification of the family into tribes and genera. Fairbrothers (1959) and his co-workers have studied several plant groups serologically particularly the members of grass family. A general conclusion from such studies is that the different amount of serological activity in members of different plant families may be interpreted as a reflection of the evolutionary differences in the primary structure of the proteins due to which serological differences can be recognised between members of different families.

SAQ 4

a) List 3 reasons for using chemical characters for taxonomic purposes:

i) ....

ii) ....

iii) ....

b) Name 3 kinds of chemical constituents which are useful to the taxonomists.

i) ....

ii) ....

iii) ....

c) Name 2 ways by which proteins can be analysed for taxonomic purposes and name one genus analysed by each method. Briefly indicate the principles on which these two methods are based.

....

....

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7.8 NUMERICAL TAXONOMY

Taxonomy today is, in many details, different from what it was a generation ago. The use of computers by taxonomists has established an interesting modern trend called **Numerical Taxonomy** or **Taximetrics**. Mathematical and statistical evaluation of taxonomic information and computation of this data has provided taxonomists with new approaches to understand classification. In this section, you shall learn about the fundamentals of numerical taxonomy; know the principles and important terms used in this science; and understand the procedures adopted by numerical taxonomists in arriving at a classification.

The book "Numerical Taxonomy" by P.H.A. Sneath and R.R. Sokal (1973, W.H. Frooman, San Francisco) provides valuable information relating to the aims, the principles, the methods and the results of numerical taxonomy

You had studied in Block I, units 1 and 2, that organisms are classified on the basis of evidence obtained from their characters. You have also studied that different kinds of classifications can be designed by using a few or many characters. M. Adanson (1763) proposed that a classification should use a vast range of characters covering all aspects of the plants, and in construction of a classification all characters must be given equal importance. This idea forms the basis of modern numerical taxonomy, also called Neo-Adansonian Taxonomy. So far as the character number is concerned there is no limitation but larger the number better is the approach for generalisation of the taxa. You should remember that numerical taxonomy is not a totally new approach, but it is an organised method of evaluating data with computers in an objective and repeatable manner enabling comparison of many characters from many populations of plants.

7.8.1 Principles of Numerical Taxonomy

Numerical taxonomy is based on the following 7 principles.

1) The greater the content of information in the taxa of a classification is and the more characters on which it is based, the better a given classification will be.
2) Every character is of equal weight in creating natural taxa.
3) The overall similarity between any two entities is a function of their individual similarities in each of the many characters for which they are being compared.
4) Distinct taxa can be recognised because correlations of characters differ in the groups of organisms under study.
5) Phylogenetic inferences can be made from the taxonomic structure of a group and from character correlations, given certain assumptions about evolutionary pathways and mechanisms.
6) Taxonomy is viewed and practised as an empirical science. Classifications are based on phenetic similarity.
7) Classifications are based on phenetic similarity.

7.8.2 Procedures Adopted by Numerical Taxonomists

Since numerical taxonomy is an operational science, the procedure is divided into a number of repeatable steps, allowing the results to be checked at every step.

i) **Choice of units to be studied:** The first step is to decide what kind of units to study. In numerical taxonomy, the basic unit of study is called the "operational taxonomic unit" (OTU). Thus the OTU can be an individual plant if the taxonomist is studying a single population of plants to find out the range of variations in its characters. Similarly, you may treat an entire population of plants as an OTU if you are studying a single species represented by different populations existing in nature; or the OTU may be different species when genus is being evaluated. Therefore, in numerical taxonomy, the OTU varies with the material being studied, and this helps the taxonomists in making an objective study.

ii) **Character selection :** After selecting the OTU's, it is necessary to select characters by which they are to be classified. By experience, you will learn that characters which vary greatly amongst the OTU's are clearly more useful in numerical taxonomy; and we know that as many characters as possible may be used. Preferably a minimum of 60 and generally 80 to 100 or more characters are needed to produce a fairly stable and reliable classification. The selected characters have then to be coded or given some symbol or mark. There are 2 methods of coding taxonomic information.

a) **Binary coding or two-state coding**—This is the simplest form of coding adopted in numerical taxonomy where the characters are divided into + and −, or as 1 and 0. The positive characters are recorded as + or 1 and the negative characters as − or 0. It is possible to use this method of coding for all characters studied. In case a particular character is not present in an OTU being examined, the symbol or code NC is used, indicating that there is no comparison for that characters. However, we find that by using this method of coding, we tend to increase our work because there are large variations in the plant, and very often a single character such as colour of flower can be represented in a wide range We can have white, pink, red, yellow and other colours in roses. If we are to use this data in a binary coding, then we will have to use each colour as a character and it would be coded as + or −, as the case may be.

b) **Multi-state coding**—An alternative method would be to use multi-state coding where a single character can be coded in a number of states, each being represented by a numerical symbol or code (e.g. 1, 2, 3, 4, 5, ...) depending on the range of variation. Thus, if we again look at the colour of the rose flower, we can give different codes to different colours such as white = 1, pink = 2, red = 3, yellow = 4, and so on. Besides qualitative characters such as colour of flower, type of placentation, etc., multistate coding is also useful of quantitative characters such as plant height, leaf length, leaf breadth, and other characters involving measurements. A code is prepared for the range of variation and appropriate symbols are allotted to each unit in the range.

The data obtained by scoring the characters in the OTU's are then presented in a table as a data matrix giving the OTU's on one side of the table and the codes for different characters against each OTU. Thus, if one has studied 25 OTU's and has scored 75 characters from each, the data matrix will contain 25 × 75 = 1875 units of information. This kind of large unit of information in the data matrix necessitates the use of computers to help the taxonomists to digest the knowledge quickly. It is also important to remember that computer programmes are based on mathematical equations and computer language and the data matrix is essential for this purpose. In addition, the next step in numerical taxonomy is entirely dependent on the data matrix.

The information is then presented in a t × n table or data matrix consisting of OTU's scored for n characters (table 7.6).

Table 7.6 : Coded data (t × n table)

Characters (n) (1–12)		Taxa OTU's (t)		
	A	B	C	D
1.	+	+	–	NC
2.	+	+	+	+
3.	+	+	+	–
4.	–	+	NC	NC
5.	+	+	+	+
6.	+	+	–	+
7.	+	+	–	NC
8.	NC	–	+	+
9.	+	+	+	+
10.	+	+	+	–
11.	+	NC	–	NC
12.	+	+	+	–

(After Sneath, 1962, in Microbial Classification, edited by Ainsworth and Sneath.)

iii) **Measurement of Similarity :** Overall similarity (s) is calculated by comparing each OTU with every other and is usually expressed as a percentage, 100 per cent S for identity and 0 per cent S for no resemblance. A similarity table or matrix is then constructed by tabulating the S coefficients for each one of the OTU (Fig. 7.4).

iv) **Cluster analysis :** After making a similarity table, it is then rearranged so that OTU's whose members have the highest mutual similarity are brought together. This can be done by several methods and related taxas or groups are recognised. These clusters are called phenons and can be arranged hierarchically in a tree diagram or dendrogram (Fig. 7.5).

The groups or clusters thus recognised may be treated as equivalent to the categories having ranks in classical taxonomy, such as the genus, family, order, etc. A problem faced by many taxonomists is whether there is any equivalence between the ranks in different taxonomic groups of organisms. Is a family of flowering plants, for example equivalent in any sense to one of algae, or other organisms? To overcome this problem, numerical taxonomists have advocated a new terminology. Here, the term "phenon" is introduced and the particular phenons are designated by numerical prefixes (e.g. 80 similarity) showing the level of resemblance by which they are defined. The delimitation of the phenons is done by drawing horizontal lines across the dendrogram at a chosen similarity value. Such a dendrogram will have reference to a given study only, and cannot be generalised. Thus, phenons will be arbitrary and relative to groups within the limits of only one analysis.

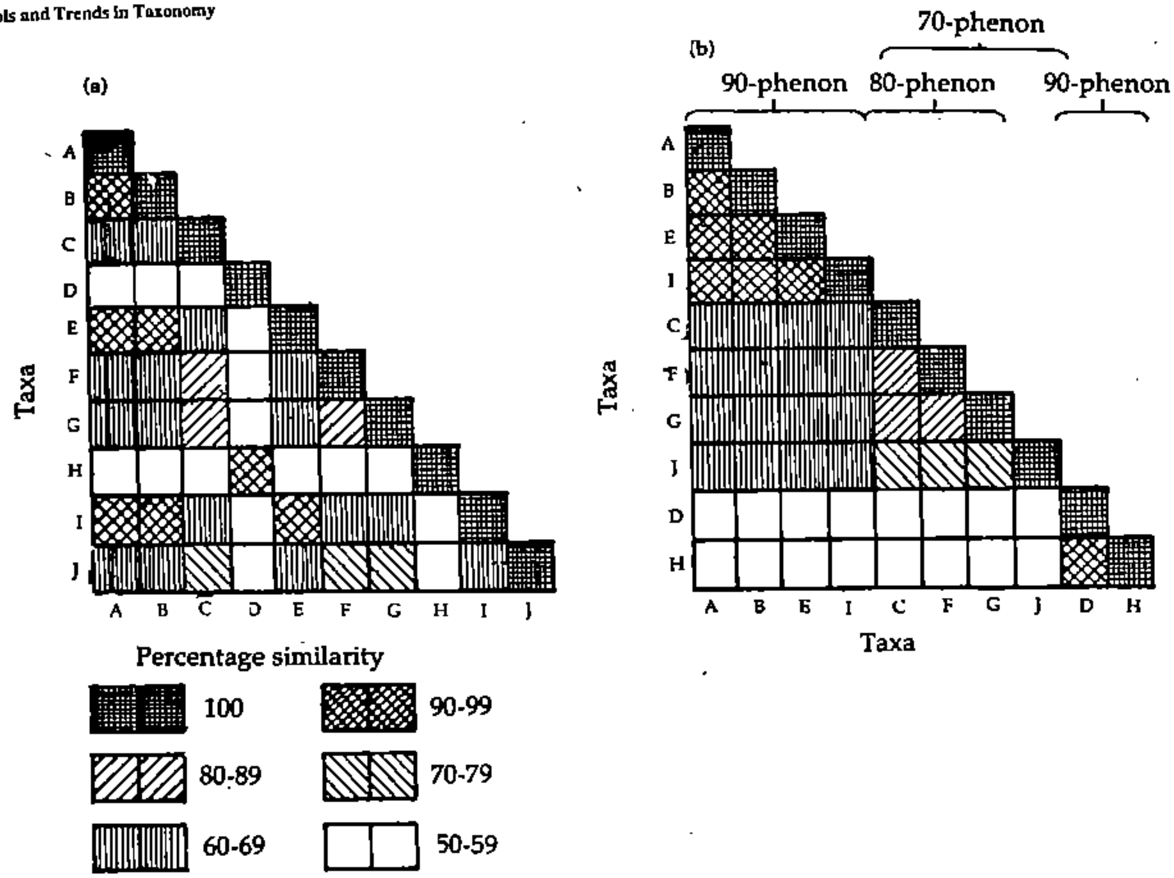

Fig. 7.4 : a) Schematic diagram showing a matrix of hypothetical similarity coefficent between pairs of group (taxa); the magnitude of the coefficient is shown by the depth of shading.

b) The same coefficient arranged by placing similar taxa next to each other; this gives triangle of high similarity values. Phenons are groups by desired rank (After Sneaths 1962, Microbial classification)

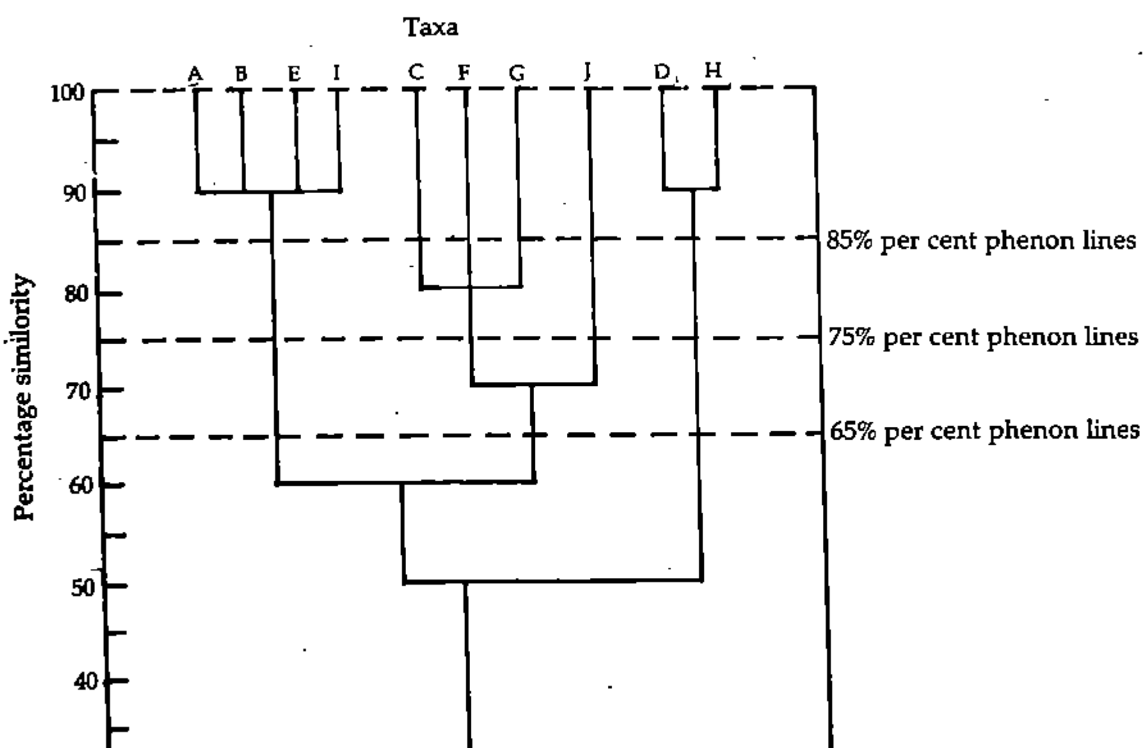

Fig. 7.5 : A dendrogram representing the hypothetical hierarchy of group (taxa) obtained from Fig 7.4. The ordinate indicates magnitude of similarity coefficient at which stems join to form higher ranking groups. Horizontal delimit groups of equal rank (per cent phenon lines). (After Sneath, 1962) Microbial Classification, edited by Ainsworth and Sneath. University of Cambridge).

Of the numerous numerical taxonomic studies, the reclassification of the dicotyledons by Young and Watson (1970) serves as a good example. They studied 83 characters from morphology and anatomy in 543 genera and computed this information to classify these angiosperms. The computer-based classification was in many ways similar to other traditional classification, as well as in some ways different. However, the different genera were clearly distinguishable into distinct categories on the basis of the nature of the ovule into crassinucellate (ovules with a massive nucellus) and tenuinucellate (ovules with a small amount of nucellus). In view of these, some taxonomists are of the opinion that numerical taxonomy may never replace traditional methods as standard procedure. It would, however, be successful where other methods have failed or are laborious or otherwise difficult to apply. The most important contribution of numerical taxonomy has been to help taxonomists analyse their methods, data, and conclusions more logically and objectively.

SAQ 5

a) Why is numerical taxonomy also called Neo-Adansonian taxonomy?

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b) Briefly describe the procedure adopted by Numerical taxonomists.

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c) What is meant by 'operational taxonomic unit' (OTU)?

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d) Differentiate between binary coding and multi-state coding.

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e) Mention 2 uses of a data matrix in numerical taxonomy.

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f) What is 'cluster analysis' and how is this arrived at in numerical taxonomy?

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7.9 SUMMARY

In this unit, we have briefly discussed various aspects of modern trends in plant taxonomy. This has helped you to study that:

- Taxonomy utilises data from all the other branches of biology.
- Taxonomic information never becomes obsolete, but it is progressively refined and successively exploited by taxonomists to synthesise systems of classification.
- Modern taxonomy follows a multi-disciplinary approach.
- Alpha taxonomy or classical taxonomy is based on an empirical approach involving the exploratory or pioneer phase and the systematic or consolidation phase of development of taxonomic knowledge.
- Modern or omega taxonomy follows an interpretive approach using evolutionary information to understand taxonomic and phylogenetic relationships. This involves usage of knowledge from the biosystematic or experimental phase and the encyclopedic or holotaxonomic phase of taxonomy.
- Morphological and anatomical characters can be studied with light as well as electron microscopes, and this information is useful for solving taxonomic problems.
- Plant embryology has proved extremely useful as a source of evidence in taxonomy
- Cytological and biosystematic data uses information from chromosome number, structure, and behaviour, and this helps taxonomists to understand relationships amongst plants.
- Chemotaxonomy provides useful data from chemical characters which show chemical relationships amongst plants in the same way as morphological characters show morphological relationships. Different kinds of chemical compounds can be evaluated in different ways to provide taxonomically useful information.
- Taxonomists can use computers to analyse large amounts of information in numerical taxonomy.

7.10 TERMINAL QUESTIONS

1) "Systematic botany is an unending synthesis". Elaborate.
2) a) Differentiate between "Ranunculaceae *sensu lato*" and "Ranunculaceae *sensu stricto*"
   b) Name the genus which led to this change in the circumscription of the family.
   c) List the important characters responsible for this change.
3) The common breadwheat, *Triticum aestivum*, is a hexaploid. List evidences from cytotaxonomy and chemotaxonomy to support the evolution of this hexaploid wheat from diploid ancestors.
4) Briefly outline the procedures adopted in numerical taxonomy.
5) Write explanatory notes on:
   a) Biosystematics
   b) Secondary metabolites as characters in chemotaxonomy
   c) Cluster analysis in numerical taxonomy

7.11 ANSWERS

Self-assessment Questions

1) a) i) √, ii) ×, iii) ×, iv) ×, v) √, vi) √

b) Classical taxonomy follows an empirical approach synthesising a basic classification from observed facts. Modern taxonomy follows an interpretive approach improving upon the basic classification.

c) The most significant anatomical feature differentiating leaves of C_3 plants from C_4 plants is the absence of a chlorenchymatous bundle sheath in the former and its presence in the latter.

d) Sieve tube plastids are basically of two types, called S-type (accumulating starch) and P-type (accumulating proteins). These are recognisable by electron micrographic studies and different plant families have been characterised on the basis of this information. It has also been possible to understand relationships amongst monocotyledons and dicotyledons using sieve tube plastid type as evidence.

2) a) i) In Thallophytes, the zygote directly develops into a new plant or it produces spores which develop into new plants. In Embryophytes, the zygote first develops into an embryo from which the new individual plant is then formed.

ii) In monocytyledons the mature embryo has one cotyledon, while in dicotyledons it has two.

b) List any six characters from Table 7.2.

c) i) There is a high degree of correlation amongst embryological characters.

ii) Due to less variability in floral characters, embryological characters, show stability.

iii) Embryological characters are not affected by ecotypic variation and they remain unchanged.

d)

Genera	Families
i) *Butomus*	i) Loranthaceae
ii) *Daphniphyllum*	ii) Podostemaceae
iii) *Exocarpus*	iii) Ranunculaceae

or any other genus or family in which embryological characters have been used for taxonomic purposes.

3) a) i) Basic chromosome number refers to the basic set of genetic information in the chromosomes of an individual of a species or a polyploid series.

ii) Haploid chromosome number is the gametic chromosome number present in the sex cells or the gametes.

iii) Diploid chromosome number is the somatic chromosome number usually seen in the vegetative cells of an individual.

b) Diploid chromosome number in:

i) Rice – $2n = 24$, ii) Potato – $2n = 48$, iii) Tea – $2n = 30$,
iv) Coffee – $2n = 44$, v) Mango – $2n = 40$, vi) Onion – $2n = 16$

c) i) The centromere is located in between the short arm and the long arm of the chromosome.

ii) It is located in the middle of the two equal arms of the chromosome.

iii) It is located at the tip of the arm of the chromosome.

d) The karyotype refers to the appearance of the basic chromosome set (genome) under the light microscope. It tells us about the number of chromosomes, the different types of chromosomes and their relationship with each other. This information can be compared for cytotaxonomic purposes.

e) Genome analysis is the study of chromosome pairing in diploid hybrids. It helps in the investigation of polyploids for determining the ancestral genomes and this information is used for ascertaining taxonomic relationships.

4) a) i) Chemical characters are stable

ii) They are unambiguous

iii) Chemical characters are not easily changeable.

b) i) Directly visible chemical constituents such as starch grains.

ii) Secondary metabolites such as phenolic compounds, alkaloids, etc.

iii) Semantides or information carrying molecules such as DNA, RNA, or proteins.

c) Proteins can be analysed by gel-electrophoresis or by serological methods. The genus *Triticum* has been analysed by gel-electrophoresis, while the genus *Solanum* has been analysed by serological methods.

Proteins are separated electrophoretically on the basis of their amphoteric properties in a column of acrylamide gel which is positively or negatively charged to various extents. In serology, proteins are analysed on the basis of the immunological reactions. This requires a test animal to evaluate the antibody-antigen reaction.

5) a) Numerical taxonomy is also called Neo-Adansonian taxonomy because it is based on the same basic taxonomic principles formulated by M. Adanson in the 18th century.

b) Carefully read the Section 7.8.2 and rewrite the procedure in your own words.

c) 'Operational Taxonomic Unit' or OTU is the basic unit of study in numerical taxonomy. It can vary with the nature of the material being investigated as well as the purpose of the investigation.

d) Binary coding is two-state coding according to which every character studied can be analysed in 2 states viz. present (+) or absent (−); whereas multi-state coding analyses more than two states in which a particular character exists and each state is given a definite symbol or code.

e) The data matrix basically presents taxonomic information in a tabular form for all the OTU's examined and all the characters studies. It also provides information for clustering of the OTU's.

f) Cluster analysis is a process by which the OTU's are sorted out to form groups or clusters on the basis of their overall similarity. Similarity or dissimilarity coefficients are calculated by comparing each OTU with every other OTU and this is represented as a percentage. This information is used for cluster analysis in numerical taxonomy.

Terminal Questions

1) Taxonomists utilise information from many disciplines for synthesising classifications. This process is a continuous one. The material provided in this unit has briefly described the developments in modern taxonomy to elaborate the unending nature of systematic botany. You must carefully study the entire unit and write out an essay of about 1500 words to answer this question.

2) a) Ranunculaceae '*Sensu lato*' refers to the broad concept in the taxonomy of the family Ranunculaceae. While Ranunculaceae '*sensu stricto*' refers to a restricted concept after one or more genera have been removed from the family and classified in a separate family, thus changing the circumscription of the family.

b) The genus *Paeonia* was first classified in the family Ranunculaceae (broad circumscription) but later it was separated from this family Ranunculaceae giving it a restricted circumscription.

c) See answer 2 d.

3) The origin of the hexaploid breadwheat *Triticum aestivum* from diploid ancestors has been established cytotaxonomically. *Triticam monococcum* and *Aegilops speltoides* both diploid species can hybridise and the hybrid can, by chromosome doubling give rise to a tetraploid wheat, *Triticum dicoccum*. This in turn can hybridise with another diploid species, *Aegilops squarrosa* and by doubling the chromosomes of the hybrid, the hexaploid wheat, *Triticum aestivum* is produced. In chemotaxonomy, protein gel-electrophoresis of the seed proteins from *Triticum dicoccum*, *Aegilops squarrosa*, and *Triticum aestivum* provide evidence to show that the hexaploid wheat arose by hybridisation.

4) Carefully read Section 7.6 for (a), 7.7.3 for (b) 7.8 for (c).

5) a) See Section 7.4

   b) See Section 7.5.3

   c) See Section 7.8.2, particularly the paragraphs on cluster analysis as in answer 5 f.

UNIT 8 MODERN TRENDS IN ANIMAL TAXONOMY

Structure

8.1 INTRODUCTION

In Unit 6, you learnt how taxonomy is interrelated to other biological fields. You also learnt how information is used from other fields of biology along with morphological data in the identification of a large number of plant species.

Similarly, in this unit you will see how often morphological observations are not sufficient for accurately identifying or classifying animals and taxonomists have to supplement their information from other scientific fields such as electron microscopy, embryology, ethology, cytology, biochemistry and computer analysis.

Furthermore, you will learn that the use of such data has given taxonomy a much wider dimension. It is now no longer limited to just classifying animals but is also involved in working out the phylogenetic relationship between species. As a result taxonomy is now a part of systematics or biosystematics on which it relies heavily for its theories and concepts. Biosystematics has a broad base as it not only includes the function of identification but also the comparative study of all and every aspect of the organism and also the interpretation of the evolutionary history.

After you have gone through this unit, you will be able to:

- differentiate between taxonomy, systematics and biosystematics,
- explain the alpha, beta, gamma phases of taxonomy,

- define neotaxonomy and enumerate the various approaches used in this field,
- describe and explain the techniques, and importance of various approaches used in neotaxonomy—electron microscopy, embryology, ecology, ethology, cytology biochemistry and numerical taxonomy.

8.2 TAXONOMISTS AS SYNTHESISERS

Your study of the earlier units of taxonomy, in particular its history must have made you aware that the field of taxonomy has changed considerably. Nowadays, it is a very dynamic and broad field and no longer deserves the reputation that persists even today among some biologists of being a dry and static field. It is no longer limited to just preserving and cataloguing organisms. After going through this unit you will realise that taxonomists today do not depend on morphological data alone, but use along with it, relevant information and techniques from the scientific field of physics, chemistry, biochemistry, cell biology, ethology, mathematics etc. The present day taxonomists thus try to use whenever possible or wherever available a synthesis of relevant data and techniques from other scientific fields for identifying organisms and so can aptly be called 'synthesisers' of biological knowledge and techniques.

8.3 TAXONOMY, SYSTEMATICS AND BIOSYSTEMATICS

The three terms taxonomy, systematics and biosystematics are often used interchangeably and may confuse you, especially since they are not synonymous. Each has a specific meaning as you will see below.

Taxonomy

The term taxonomy which is derived from the Greek word 'taxis', meaning order or arrangement and 'nomos' meaning law, deals with the study of 'principles of classification'.

It is concerned with the grouping and classification of organisms. This involves recognition, description, naming (nomenclature) and classification of the organisms. Taxonomy is a part of systematics and biosystematics on both of which it relies heavily for its theory and concepts.

Systematics

Systematics is defined as the study of relationship among organisms which means reconstruction of phylogenies. It is that branch of biology which employs the techniques of other branches of biological knowledge like biochemistry, genetics, biophysics etc, for the comparative study of the interrelationships of groups of organisms.

In other words, there are two parts of systematics. The first part is taxonomy which is concerned with identifying, describing and naming the various kinds of organisms. The second part is evolution which is concerned with understanding the origin of organisms in nature and the processes which tend to change or maintain them.

In systematics four types of relationships are studied and they are:

1) Relationships of phylogeny (evolutionary descent) or the degree to which two organisms are thought to be related to a common ancestor.
2) Relationships of similarity in morphology (appearance and structure) physiology, cytology etc.
3) Spatial or geographical relationships
4) Trophic or nutritimal relationships, which study the extent to which two or more organisms depend upon each other or compete with each other for food.

Biosystematics

Biosystematics is basically synonymous with systematics, though it places more emphasis upon genetic (concerning inheritance) and cytological data (concerning cell function and structure) rather than upon morphological, anatomical physiological or spatial information, alone. It tries to infer evolutionary relationships with the study of reproductive compatibility and gene flow. Biosystematists assess the genetic variation in population and among species. Using information from their genetic studies, biosystematists make inference about the ancestral history of a species and thus study speciation (the evolution of one species into two). They collect data on variation in a population of organisms and then analyse the data in order to construct a model of genetics of the population. For example, in Winconsin, a single population of fly maggots has begun to feed, mature and then reproduce near either apple or cherry trees. Since these two types of trees bear fruits at different time of the year, the apple eating maggots and the cheery eating maggot may at one point of time become reproductively isolated from one another. A biosystematist might infer that in this case speciation is occurring.

SAQ 1

Fill in the blanks choosing appropriate words from the list given below:

a) A scientist who studies the comparative characters of the species of frog (genus *Rana*) with respect to their morphology, ecology, distribution and genotype and works out their interrelationship on basis of speciation is more appropriately called a..............................

b) A scientist who studies the comparative characteristics of the species of the cat family with respect to their morphology, ecology and ethology and works out their interrelationships is more appropriately a ....

c) A scientist who identifies the various species of *Rana* on the basis of their morphological characteristics is more appropriately called a

....

(biosystematist, taxonomist, systematists)

8.4 STAGES IN TAXONOMIC PROCEDURES

The taxonomic procedures used in the study of a given group of organisms can be divided into three levels or phases:

1) Alpha (α) phase, 2) Beta (β) phase, 3 Gamma (γ) phase.

8.4.1 Alpha Taxonomy

The alpha phase of taxonomy is analytical. At the level of alpha taxonomy, the organisms are identified, named and characterised.

8.4.2 Beta Taxonomy

This stage is also known as macro taxonomy or synthesis taxonomy. At this level the species are arranged or classified into a natural system of higher and lower categories. At first this arrangement is constructed from the maximum number of available characters i.e. it is a purely phenetic classification.

8.4.3 Gamma Taxonomy

This phase of taxonomy is also called biological taxonomy and is concerned with the study of speciation. It is involved primarily with the analysis of intra specific variations which leads to the study of origin, evolution and determination of biological species and its subspecies.

These three phases of taxonomy have been explained to you separately though in practice they are not that clearly demarcated as they tend to overlap and intergrade.

Systematic studies in most of the groups of animals have not yet progressed beyond the alpha and beta taxonomy. It is only among a few insect orders such as

Lepidoptera (months and butterflies) and vertebrates especially birds that any real progress have been made at the gamma level of taxonomy.

SAQ 2

Fill in the blanks with appropriate words from the list given below:

a) A biologist who examines, identifies, describes and names a species of birds is working at the level of .... taxonomy.

b) A biologist who identifies a species of bird and places it in its scheme of classification, modifying the classification if necessary, is working at the level of .... taxonomy.

c) A biologist who studies a group of birds for the purpose of working out their phylogenetic relationship is working at the level of .... taxonomy.

[beta (β), alpha (α), gamma (γ)]

8.5 NEOTAXONOMY

In earlier units, you have learnt that most taxonomists use comparative morphology in identifying organisms. However, morphological features themselves are often not sufficient for identification and so taxonomists nowadays use data from various other fields to help them, supplement the information.

The aim of neotaxonomy or systematics or biosystematics is not only to describe, identify and arrange organisms in convenient categories but also to understand their evolutionary histories and mechanisms. Earlier approaches were primarily based exclusively on observed or morphological data without considering intraspecific differences. Many of the species are thus known by single or few specimens. Recently, however, great attention is paid to sub-groupings of the species like populations and subspecies. The old morphological species are now called biological ones, which also includes ecological, ethological genetical and other characters. All these new approaches have contributed greatly in explaining the true structure of the species and their evolutionary position and in modification of the basic system of taxonomy. However most of the new approaches need specific methods. A brief account of some of the more important current approaches are discussed in this unit. Some of these approaches are still developing and provide much excitement by generating new data and information. You should, however, bear in mind that even today it is the morphological features which are used the most, as they are most easily observed. In addition while going through the new approaches you will realise that data from just one approach may not be sufficient to identify organisms. Taxonomists try as far as possible to use data from as many approaches as possible for accurate identification. Thus today taxonomy is usually called biosytematics or systematics or evolutionary taxonomy or neotaxonomy as it tends to place organisms which share a common ancestor (monophyletic ancestory) within the same group. Inference of ancestory is based upon similarity and difference among organisms. These differences and similarities are not limited to morphological traits alone. They include a wide variety of similarities and differences in behaviour, embryological structures, fine morphological details with the help of electron microscopes, biochemistry, ecology, cytogenetical data and statistical data.

8.6 ELECTRON MICROSCOPY IN TAXONOMY

Morphological features that are easily observable with the naked eyes or with the stereomicroscopes permit quick identification and still dominate taxonomic studies. The invention of the electron microscope has made it further possible for the taxonomists to obtain useful data from the study of the ultrastructure of various morphological characters. This is because electron microscope studies have revealed differences in the finer structures of the morphological characters which looked the same when studied with the naked eyes or under the light microscopes. Thus, this new method of study has led to the discovery of new and more reliable characters.

The scanning electron microscope (SEM) is now being used extensively in systematic study (Fig 8.1 a and 8.1 b). It is being used very often in the study of invertebrates, particularly the arthropods. This is because there are many fine features in insects, mites, ticks and other small arthropods which can only be observed when highly magnified by the SEM.

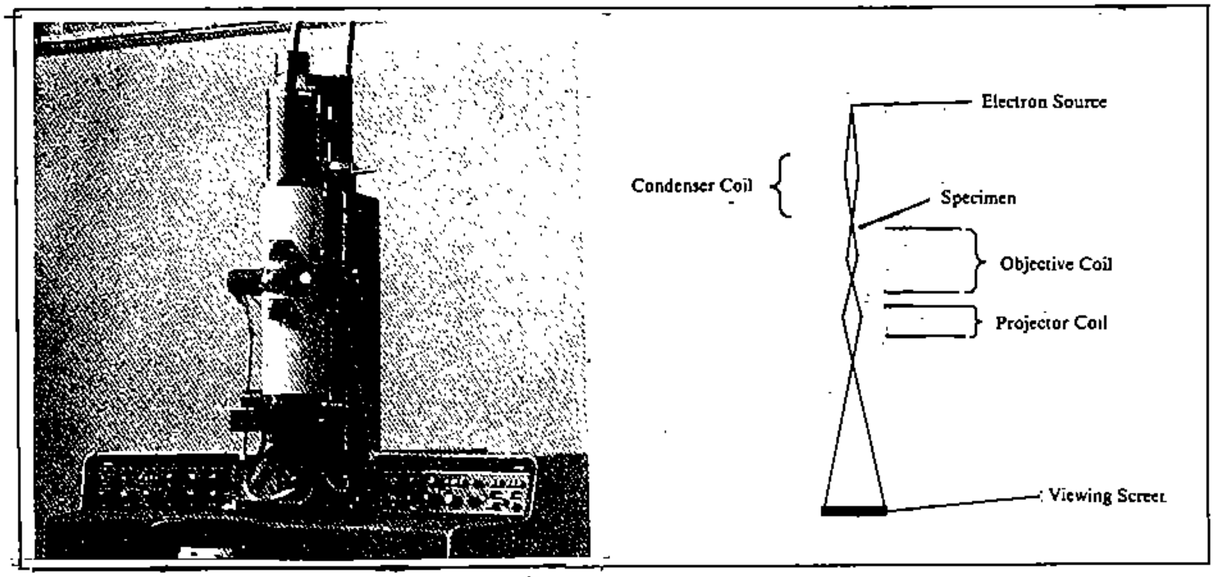


Fig. 8.1 : Showing scanning electron microscope. a) an external external view (b) an internal view

As you are aware the SEM in comparison to the light microscope has a much greater magnification and resolution. Furthermore it gives a depth of focus which is about 300 times more than the light microscope. Thus, the SEM provides excellent, quasi three dimensional images of the body surface with a magnification of 50 to 10,000 x.

The scanning electron microscope has aided, for example, in the biosystematic study of tick Argas (Figure 8.2 a and b). In *Argas* the SEM studies have also helped in finding out new characters in addition to revealing unsuspected details of other characters which has led to the discovery of new species and also preparation of dichotomous keys.

This type of work is still being carried out in other groups of invertebrates and it is hoped that it will lead to the resolution of a number of species complex, so that classification would be simplified to a great extent.

Another type of microscope used for studying the finer details of morphological characters is the transmission electron microscope (TEM) Fig. 8.3 a and b. TEM has greater magnification than the SEM and has been used to study very thin sections of the organs of the organisms, eggs and embryos of the organisms or of the whole organism itself. It has proved extremely useful in those organisms which have very few external surface features, such as the protozoans. For example, it has helped in the identification of two very closely related genera of protozoan—*Ameoba* and *Thecameoba* and the biosystematics of the planarians *Turbellaria*. However, TEM so far has been used less in comparison to SEM in systematic studies.

TEM studies have also helped in the identification of two economically important fruit files *Dacus olae* and *Ceratitis capitata* (Diptera: Tephritidae) whose eggs show superficial similarity in shape and size and are separated only on the basis of character of anterior pole studied under the SEM (Fig. 8.4a). However, TEM studies of the eggs show additional, distinct differences in their eggs shells (Fig. 8.4b).

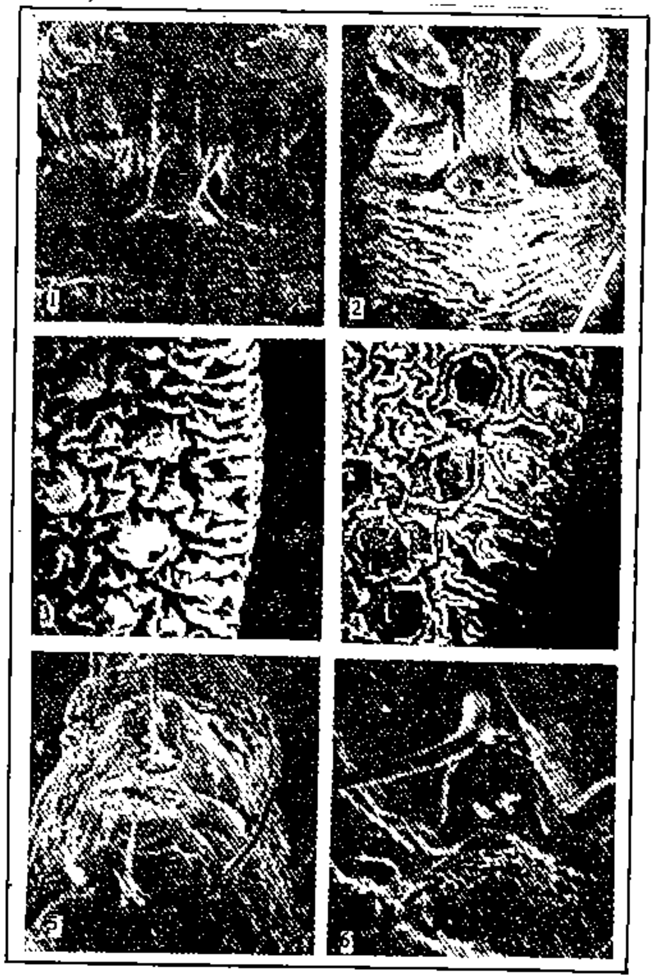


Figure. 8.2a: Scanning electron micrographs of 4 species of Argas (all females) Dorsal view—1. *polonicus*; 2 vulgaris. Postero dorsal integument—3. *moreli*; & *monachus*;

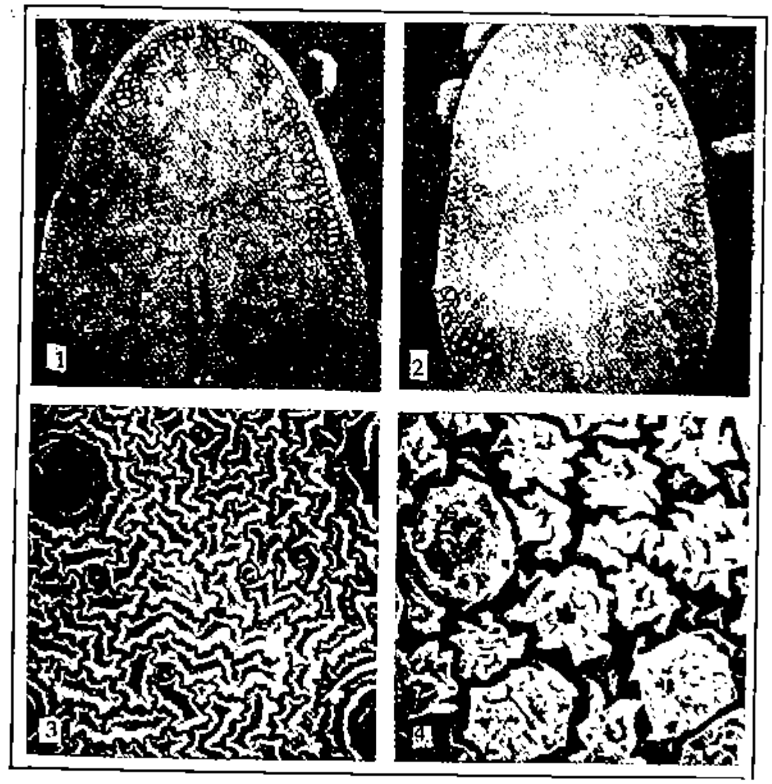


Figure 8.2b: Capitulum ventral view—1. *polonic* 2. vulgaris. peripheral strinted area 4. moreli. Haller's organ area—5. *polonicus* 6. vulgaris

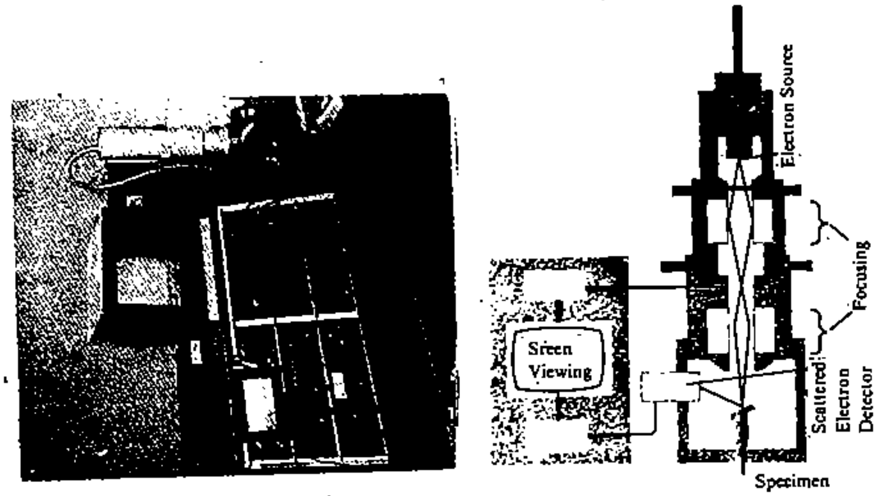
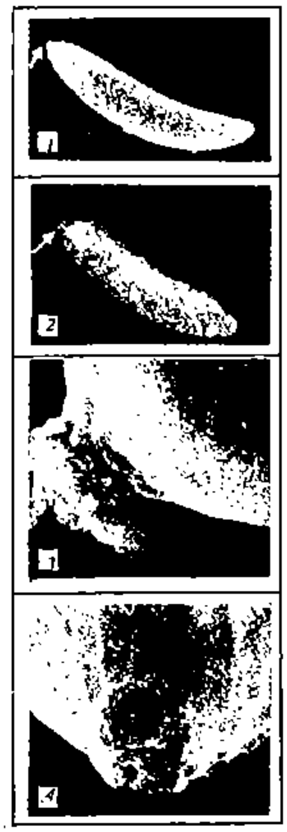


Figure 8.3: Shows a Transmission election microscope (a) An external view (b) an internal view



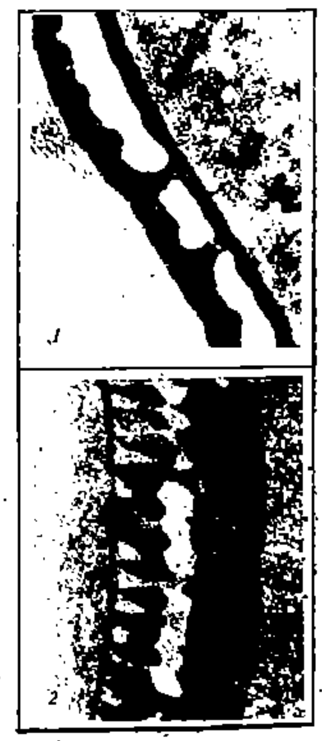


Figure 8.4a: Scanning electron micrographs of whole eggs of 1) *Ceratitis capitata* 2) *Dacus oleae* Anterior pole of eggs shown with arrows (SEM). 3) *Dacus oleae* 4) *Ceratitis capitata.*

Figure 8.4b: Transmission electron micrographs of thin sections though main body of the eggs of 1) *Ceratitis capitata* 2) *Dacus oleae*

8.7 EMBRYOLOGICAL APPROACH IN TAXONOMY

In animal systematics the study of just the adults is not enough. Their embryonic and juvenile stages often help greatly in their identification, especially in those organism which include several distinct larval stages, each separated by a moult. Furthermore, the study of both the adult and their larvae helps in avoiding confusion in those organisms where adult and larvae are totally distinct morphologically.

Taxonomic studies, in such case, would be based on the morphological as well as other characteristics of the adult as well as the sum total of all characters of the various juvenile stages. There are many animal groups where classification is greatly helped by the use of immature stages. The study of egg structure has been used to resolve the *Anopheles maculipennis* complex into a number of sibling species.

In the nematode of genus *Cactodera*, the characters of second stage juveniles are also studied while identifying the species (Fig. 8.5).

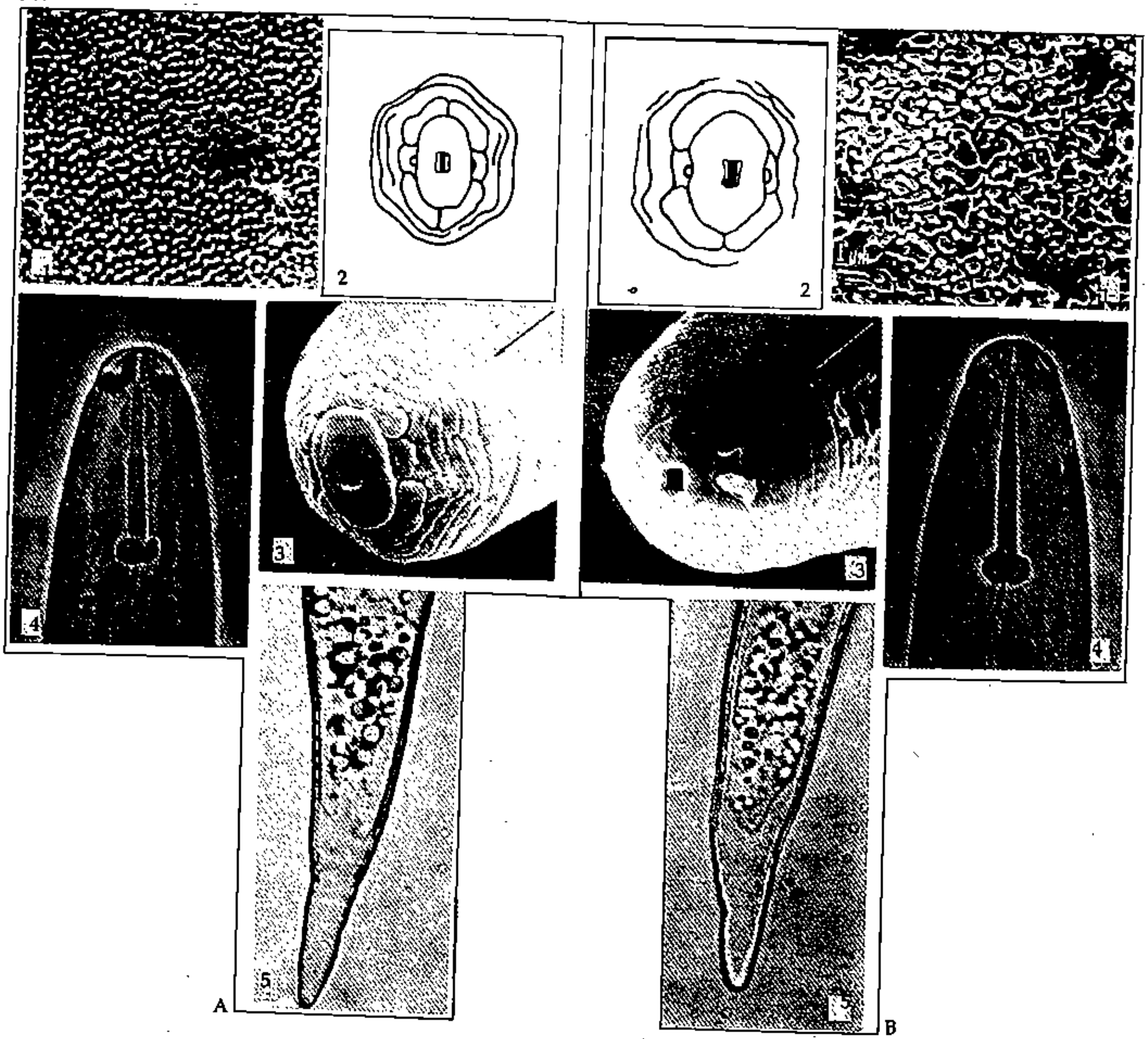


Fig 8.5 : The larval characters used in the identification of two species of nematode *Cactodera*. A1-6 *C milleri*, B 1 - 6 *C cacti*. A & B - (1) SEMS OF egg shell puachatims, (2) enface view (line drawing), (3) enface view (SEMS), (4) LM photo of head region (lateral), (5) tail region.

Embryological studies have also helped in the classification and separation of species of those animal groups whose morphological traits are less reliable, as for example sponges.

8.8 ECOLOGICAL APPROACH IN TAXONOMY

You already known that the use of ecological data in classification has been used since the time of Plato, who considered aquatic, terrestrial and aerial habitats as characteristics in the identification of organisms. However, it was Aristotle who laid a great stress on such characteristics in animal identification and used them liberally in his classification system.

Today ecological data in systematics is used quite often, particularly in case of identification of closely related or sibling species. The ecological approach in taxonomy is based on the fact that every species occupies its own niche in nature which differs from its closest relative in terms of food preference, breeding tolerances to various physical factors etc. Thus, when two closely related species coexist in the same general habitat they avoid fatal inter specific competition by differing in their ecological species characteristics like food preference etc. i.e. their niche.

Closely related species living in different habitats usually have quite similar ecological characters though they may differ in other traits.

Ecological data in systematics has helped in the identification of several animal species. It has been used to identify, for example, two species of *Drosophila, D. mulleri* and *D. aldrichi* both of which live in the same habitat, which is the decaying pulps of the fruits of the cactus *Opuntia lindheimeri*. The are separated on the basis of their specific preferences for certain yeasts and bacteria. Similarly, the *Anophelese maculipennis* complex has been broken into six independent species on the basis of ecological differences as you can see in Table 8.1.

Table 8.1 : Shows the breaks up of six sibbing species of *Anopheles maculipennis* complex on basis of ecological data

Species	Water Type	Habitat	Hibernation
1) *atroparrus*	Brackish	Cool water	–
2) *labranchiae*	Brackish	Mostly warm water	–
3) *maculipennis*	Fresh Water	Cool running water	+
4) *melanoon*	Fresh Water	Rice fields	–
5) *messeae*	Fresh Water	Cool standing water	+
6) *saccharovi*	Often brackish	Shallow standing water	–

8.9 ETHOLOGICAL APPROACH IN TAXONOMY

The use of behavioural or ethological characteristics in animals is relatively new, though extremely useful, particularly in the identification of closely related species. Like most of the other characters ethological characteristics too are genetically determined and so are transmitted from generation to generation. Furthermore, they also play an important role in isolating mechanism and in initiating new adaptations. It is because of these factors, that ethological features are considerably important taxonomically and are often used along with other approaches.

Some important ethological characters used in animal systematics are: a) sound production, b) bioluminiscence, c) various other ethological activities.

Sound production

Different mating calls result in different mating habits in terms of season, time etc thus leading to reproductive isolation.

The sonograms of bird of the same species ofter do exihibit variation and so the use of the sonograms taxonomy is employed with great care, taking into consideration the possibility of the local and individual variation.

The most used, ethological feature in identification is the sound produced by various species of animals. This is because it has been observed that the sound patterns of the various animal voices and their mating calls, recorded on the spectrograms or sonograms are unique for each species. The uniqueness of the mating calls plays an important role in speciation or isolation mechanism. This is due to the fact that females of a particular animal species are only attracted to and respond to the mating

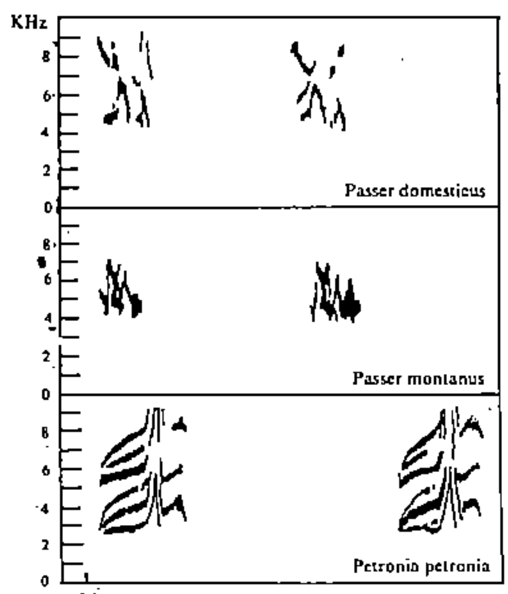


Figure 8.6: Sound spectrograms of three species of birds (After Thielcke, 1964).

or breeding call of their own male species, thus avoiding breeding with other species. Due to this the spectrograms of mating calls in birds has helped greately in identifying closely related species (Fig. 8.6).

For recording insect sounds a similar device called recording oscilloscope is usually employed. Such recordings have helped greatly in identifying sibling species of the *Gryllus* (field cricket) complex (Fig. 8.7). Sound patterns have also been used in other animals like other insects, amphibians, mammals etc.

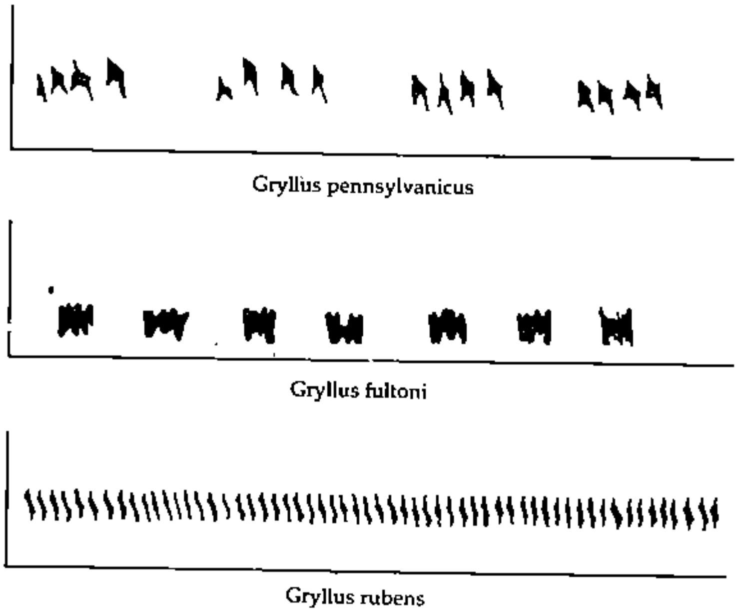


Figure 8.7 : Sound spectrograms or sonograms of three species of *Gryllus* (field cricket)

Bioluminescence

In those animals which exhibit bioluminescence. The pattern produced by the bioluminescence is used in taxonomy. It has been used, for example, in the identification of sibling species of the fire fly *(Photuris)* (Fig. 8.8).

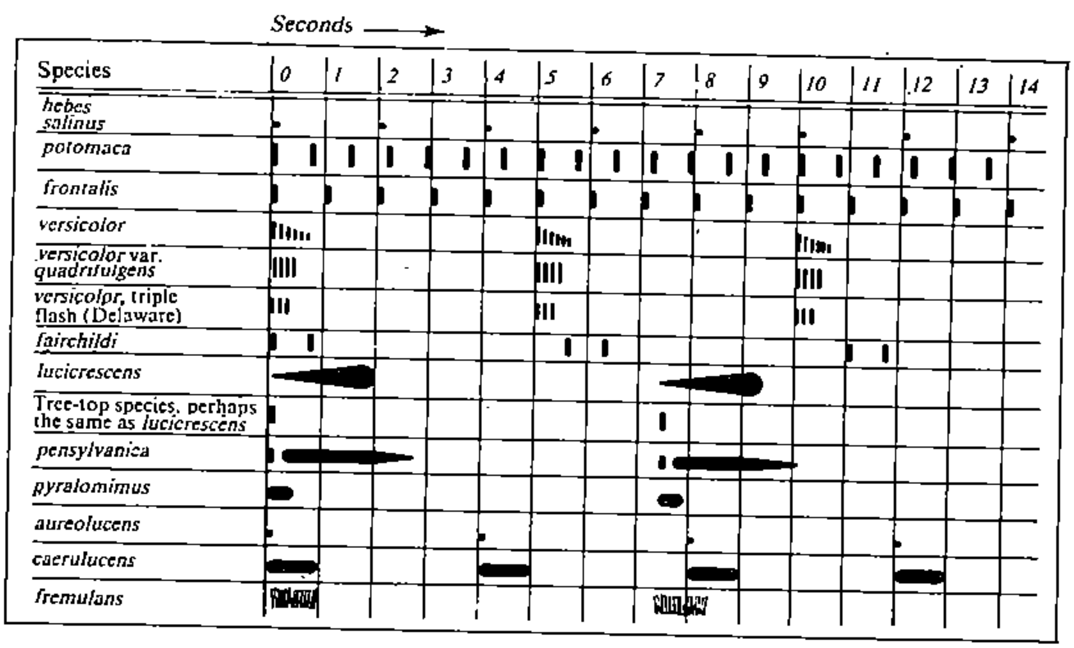


Figure 8.8 : Flash pattern in some species of fireflies of the genus *Photuris* (fruit flies) (modified from Babar, 1951).

The study of the frequency, intensity, colour and shape of individual flashes, flash sequences which may be of short or long duration, of constant intensity or may increase or decrease in intensity has made it possible to identify 18 sibling species of *Photuris* instead of just the 3 known before. Since the separation of the species on basis of bioluminiscence, other differences have also come to light, in terms of differences in preferred habitat, in the breeding seasons and in body colour.

Other ethological activities

Comparative studies of behaviour or activities are also used in systematics for identification of organisms. The comparative study of the behaviour of the fidler crab (*Uca*) show that the males display their large right chelipads in a characteristic manner. That is the males, of each species have a specific 'fiddling display pattern'. This characteristic display makes it possible to recognise even closely related species from a distance.

The ethological activity of nest building and its resulting structure is also used in systematics and has proved very useful in identification of not only birds but in insects as well as in other animals.

It has been used, for instance, in separating two morphologically similar bees of genera *Anthidium* and *Dianthidium*. The identification is based on the type of material used in nest (hive) construction by the two species. The former uses cotton plants fibres while the latter uses resinous plant exudations and sand or pebbles.

Another ethological characteristic used in systematics is the type and nature of web construction which has proved extremely useful in identification of mites, caterpillars and spiders. Thus ethological data is frequently used in systematics along with taxonomic information from other approaches.

SAQ 3

Match the items given in column I with those given in column II. Write your answers in the box provided and compare them with those given at the end of this unit.

Column I		Column II
1) Ecological approach	[ ]	a) The mating seasons of 2 species of frogs were observed and it was found that both differed in their breeding season
2) Embryological approach	[ ]	b) The ultrastructure studies of the head region of two very similar nematodes helped their separation into different species.
3) Ethological approach	[ ]	c) Two very similar species of fireflies were separated on the basis of their well defined food preference.
4) Electron microscopy	[ ]	d) Two very similar species of nematodes were separated on basis of the structure of their juvenils into different species

8.10 CYTOLOGICAL APPROACH IN TAXONOMY

Cytotaxonomy deals with all the aspects of taxonomy at a cellular level. This includes, the structural, genetical and biochemical aspects and is used to compare genetic affinity between organisms. This helps in the identification of organisms.

The type of cytological data commonly used in systematics are basically from

1) DNA hybridisation studies
2) Karyological studies.

8.10.1 DNA Hybridisation

This technique is used to study or compare the genetic affinity between two organism. In such studies the deoxyribonucleic acid (DNA) of both organisms is extracted. Then the DNA strand of both of them are separated. After this the single strand of each organism is made to come in contact with each other in vitro, in order to unite or hybridise them.

The extent to which this union occurs i.e. the degree of hydribisation is an indicator of the closeness or distantness of the two organisms. Table 8.2 shows the use of this technique in estimating the genetic similarities among some vertebrates.

Table 8.2 : Genetic similarities among some vertebrates as estimated by DNA Hybridisation technique

Compared Taxa	Percentage Difference in DNA Sequences
House mouse-Norway rat	20.0
Cow-pig	20.0
Cow-sheep	7.5
Human-chimpanzee	1.6
Human-gibbon	3.5
Human-rhesus monkey	5.5
Human-galago	28.0

DNA matching or hybridisation technique holds great promise in solving taxonomic problems. However, incomplete fossil records in many animals may make it difficult to solve all evolutionary or phylogenetic relationships by this method.

8.10.2 Karyological Studies

The karyological data mainly used in biosystematics is 1) karyotype—the configuration or number and structure of the chromosome at metaphase.

Karyotype

In animals systematics, it is the karyotype, that is the chromosome number and structure which are used quite extensively either separately or both together.

Chromosome number as you know is quite constant within a species, though it may vary from one species to another even within the same genera. Among animals the chromosome number ranges from a diploid of 2 in *Parascaris equorum var univalins* to 446 in the lycaenid butterfly *(Lysandra atlantica)*. However, in most animals it is between 12-60 chromosomes.

Generally, the chromosome number is not enough for identifying organisms, though in some it has proved to be quite useful, as for example in the marsupial family Didelphidae (opossums) where species of genus *(Monodelphis* have a diploid number of 18 chromosomes and those of genus *Didelphis* have a diploid number of 22 chromosomes.

Similarly in the order of Trichoptera, the chromosome number alone has been used to plot the phylogenetic relationships among the various families as you can see in Fig. 8.9.

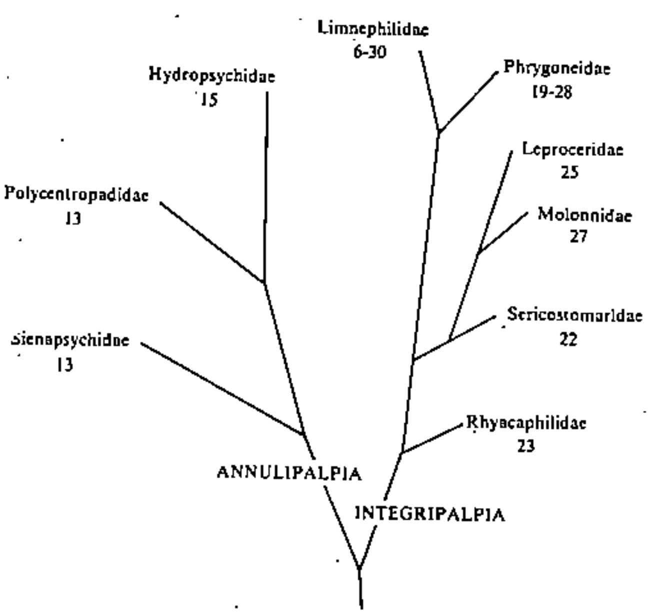


Figure 8.9 : The phylogeny of Trichopteran families plotted on basis of chromosome numbers (From Klauta, 1967).

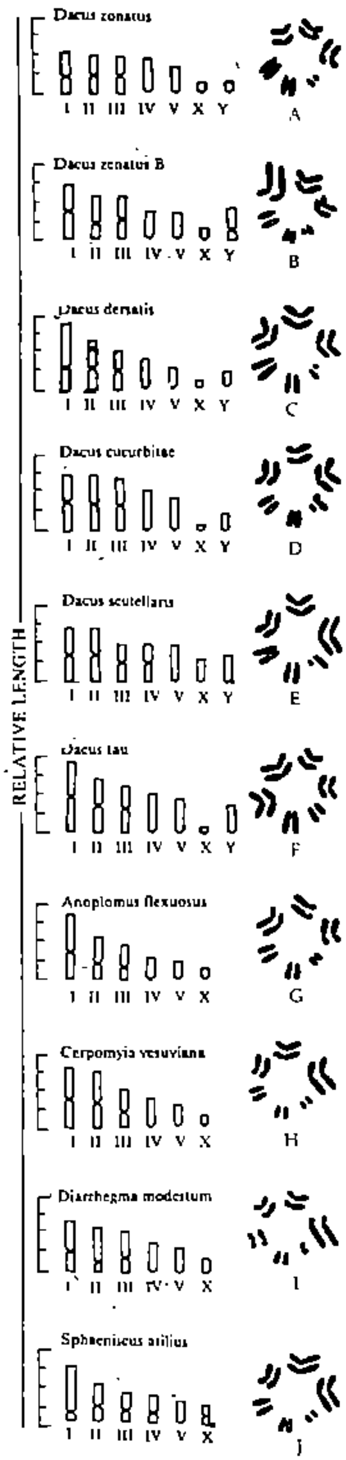


Figure 8.12 : A Diagrammatic presentation of the idiograms of some fruit flies species and their karyotypes alongisde them.

In most cases though as we mentioned earlier, the chromosome number alone is not enough in the identification of the organisms. This is because different species in a genus or in different genera may have the same number of chromosomes. In such cases the structure of the chromosomes becomes important as well. The reason for this is that though the different organisms may have the same number of chromosomes, the structure of the chromosomes may vary. Thus usually the karyotypes of organisms is used a great deal in identification of a large number of animals. Features studied in the karyotypes are, as you know, the dimensions of the individual chromosome, the position of the centromere and the presence or absence of secondary constriction.

These features are important as each chromosome has a relatively constant length and a specific centrometric position. Furthermore, the presence or absence of the secondary constriction is also fairly constant.

The differences in the centromeric position in the X chromosome of the species of the genus *Marmosa* has helped in its classification. In *M. robinsoni* it is metacentric, in *M. murine* it is submetacentric, while in *M. alstoni* it is acrocentric (Fig. 8.10).

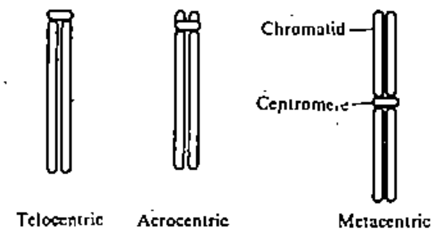


Figure 8.10 : Chromosomes showing different centromeric position.

Recently, improved techniques in cytology have also made it possible to work with difficult animal groups like birds, mammals and insects (Lepidoptera). This has resulted in more reliable karyotypes for about one thousand species of mammals, several hundred species of fishes, amphibians, reptiles and birds. Furthermore, a number of species complexes have also been broken up particularly in the case of mammals, urodeles and insects, Fig. 8.11 shows, two synonymised species of earwig (genus *Labidura)* differentiated on the basis of karyotype.

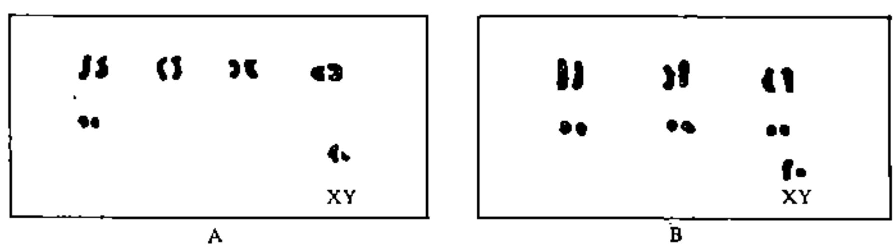


Figure 8.11: Male karyotypes—A. *Labidura riparia;* B. *Labidura bengalensis.*

Similarly, karyotype studies have also helped in the identification of fruit fly species (Diptera: Tephritidae) (Fig. 8.12).

So, you can see how the use of karyotypes in animal systematics has helped greatly in identification. However, you should be aware that in the species of a number of genera there appear to be few or no easily demonstrable differences in the karyotypes. For instance among grasshoppers, there is great uniformity in the Acrididae (2n = 23 acrocentrics) Pamphagidae (2n = 19 acrocentrics) and Pygomorphidae (2n = 19 acrocentrics).

Furthermore, it has been observed that in some animal groups, the karyotype has remained substantially constant throughout the long evolutionary stages, while in others it has undergone distinct changes, even in closely related species. For example, among insects belonging to Odonta, Diptera and Coleoptera, the chromosome number has remained fairly constant, while in insects of Lepidoptera, Trichoptera and in scorpions and fishes it has exhibited marked variations.

In addition to this many closely related species may also exhibit a lot of karyotype variations, while well defined and reproductively isolated species may have very similar karyotypes, differing only in their gene content.

These exceptions should make you realise, that karyotype data alone cannot be used in identification. It has to be used in combination with other taxonomic characters.

SAQ 4

A biologist studied the karyotypes of two animals. He found that both had the same karyotypes and concluded that the two animals belong to the some species. Comment.

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8.11 BIOCHEMICAL APPROACH IN TAXONOMY

Comparative biochemistry is being used increasingly in the systematics of animals, both for identification of organisms as well as for working out interrelationships between them. This is because sometimes it becomes impossible to distinguish between similar organisms using the above described methods. In such cases identification may be possible by comparing the chemical substances of the organisms.

The earliest biochemical studies were done in taxa higher than families.

In this approach the taxonomist studies the demonstrable differences and similarities in the biochemical compositions of the organisms to be identified. The taxonomist uses biochemical data in identification, by comparing the same class of compounds which perform the same function in different animal species. This comparison is done in terms both of the biochemical properties of the compounds as well as their distribution in different organs of the body.

Non protein compund have, however, been ocassionally used in chemo taxonomy. For example, there have been studies on the distribution of different phosphagens, the indoles and the imidozoles in primate blood, urine and bile salts. Basically though, proteins are the main focus of biochemical taxonomy.

The compounds studied in most of the cases are proteins, amino acids and peptides. As a result biochemical studies in the taxonomy are often referred to as 'protein taxonomy'.

Two main types of difference can be found in studies of protein taxonomy.

1) Relative quantitative difference

This analysis involves the study between the amounts of different proteins and more significantly, of different constituent amino acids of the protein in different animals.

An example of how quantitative analysis helps in solving taxonomic problem can be seen in birds (Fig 8.13). Here the phylogenetic relationships among the various orders

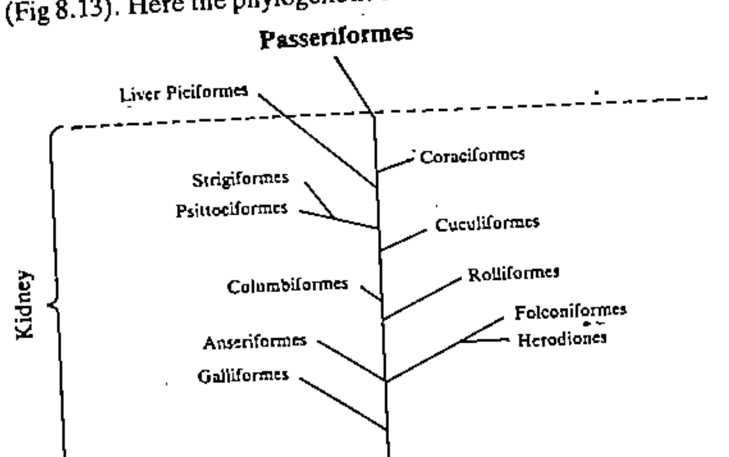

Figure 8.13: Probable phylogenetic presentation in birds on the basis of the sites of synthesis of L-ascorbic acid; In few both in liver and kidney. In some only liver, and most incapable of.

are worked out on the basis of quantitative analysis of ascorbic acid which in some birds is produced in the kidney, in some in the liver, in some in both liver and kidney, and in others in neither. The analysis of this by taxonomists indicated that the ancestral enzyme systems involved occurred first in kidney, were later transferred to the liver and finally lost completely in some of the more evolved passerine birds.

2) Qualitative Differences

The animals are identified by means of two important types of analysis

i) The analysis of amino acid sequence on a particular peptide in various animals being studied

ii) The comparison of a particular protein by comparing the number of similar amino acids or peptides present in the different animals under study.

The analysis of the relative order or the sequence in which the amino acids are arranged along the length of the polypeptides is of greater significance. Studies on the structure of fibrinogen from different species have given valuable information on mammalian classification.

The amino acid sequences in the fibrinopeptide of 34 different species, mainly mammalian has been worked out and has proved especially suitable for taxonomic studies. This involves in splitting off the fibrinopeptide from the parent fibrinogen molecules by the action of thrombin.

Fibrino peptide are useful for taxonomic studies as they constitute genetically equivalent parts of the fibrinogen from different species.

The fibrinogen molecule consists of the three polypeptide chain (α, β and γ) linked by disulphide bridges (Fig. 8.14). The proteolytic enzyme thrombin splits off two fibrinopeptides, one from the α and one from the β chain. It is in these two which are known as fibrinopeptide A and B, that the sequences have been worked out.

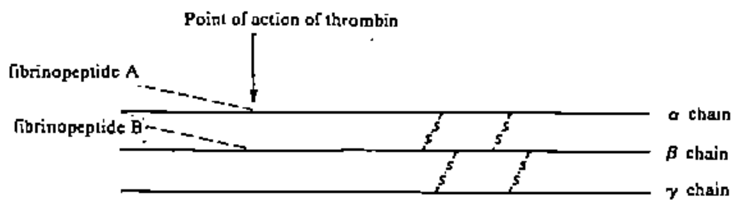

Figure 8.14: Diagrammatic representation of a fibrinogen molecule showing formation of A and B fibrinopeptides.

The classification of species worked out on basis of amino sequences in the peptides have been found to be in agreement with the general accepted schemes of classification based on morphology. So, it is possible to construct phylogenetic relationships within organisms on basis of the amino acid sequences in the peptides, as you can see in Fig. 8.15.

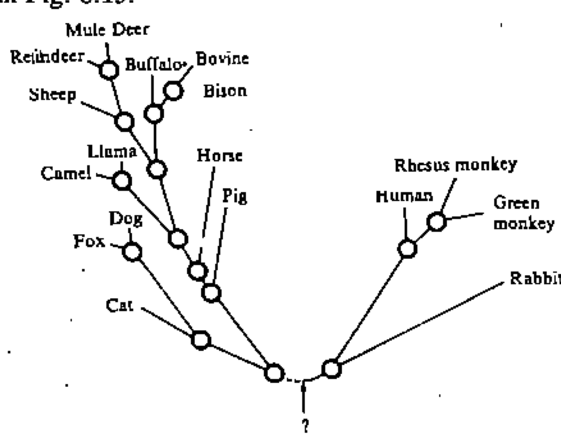

Figure 8.15: Phylogenetic relationship of some mammals based on fibrinopeptide structure, (Modified from Eck. R. V. and Dayhoff, M. O. (1966). Atlas of Protein Sequence and Structure, National Biomedical Research Foundation, Maryland.

Another peptide in which the amino acid sequences have been worked out and which has proved very useful in identification is the cytochrome C. This is present in the cells of all living organisms and contains about 110 amino acids, the sequence of which have been worked out for many animal species (Fig. 8.16a & b). It has been observed that the classification of species according to their amino acid sequences in the cytochrome C also fits fairly well with the current classification.

	Human	Monkey	Pig, Bovine, sheep	Horse	Dog	Rabbit	Kangaroo	Chicken, turkey	Duck	Rattlesnake	Turtle	Tuna fish	Moth	Neurospora	Candida	Yeast
Human	0															
Monkey	1	0														
Pig, bovine, sheep	10	9	0													
Horse	12	11	3	0												
Dog	11	10	3	6	0											
Rabbit	9	8	4	6	5	0										
Kangaroo	10	11	6	7	7	6	0									
Chicken, turkey	13	12	9	11	10	8	12	0								
Duck	11	10	8	10	8	6	10	3	0							
Rattlesnake	14	15	20	22	21	18	21	19	17	0						
Turtle	15	14	9	11	9	9	11	8	7	22	0					
Tuna fish	21	21	17	19	18	17	18	17	17	26	18	0				
Moth	31	30	27	29	25	26	28	28	27	31	28	32	0			
Neurospora	48	47	46	46	46	46	49	47	46	47	49	48	47	0		
Candida	51	51	50	51	49	50	51	51	51	51	53	48	47	42	0	
Yeast	45	45	45	46	45	45	46	46	46	47	49	47	47	41	27	0

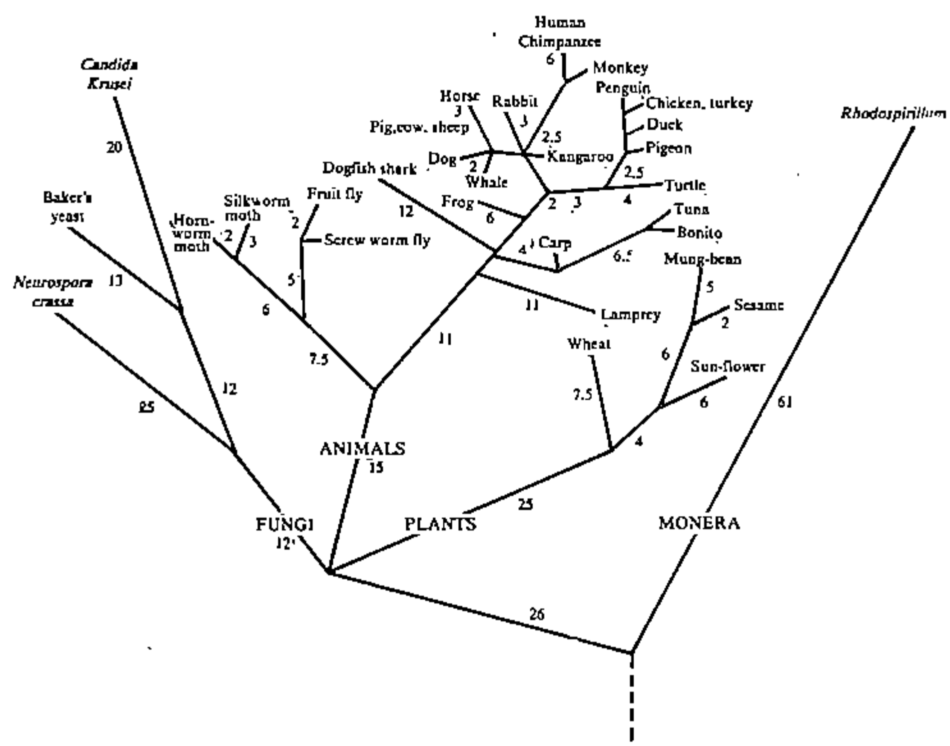

Figure 8.16 a): A diagram showing the differences in amino acid sequences in cytochrome c obtained from different species of microorganisms, plants and animals. The numbers refer to the number of different amino acids in the cytochrome c from the species compared. (From Dayoff M. O., and Eck, R. V.: Atlas of Protein Sequence and Structure. Silver Spring, MD, National Biomedical Research Foundation, 1968.)

b) An evolutionary tree constructed by giving a computer the amino acid sequence of the cytochrome c molecule of each organism. Numbers beside the branches indicate the number of amino acids changed per 100 between forks. Below each branch point is the ancestral cytochrome c common to all organisms shown above it. Redrawn from the Atlas of Protein Sequence and Structure. Vol. 5, 1972).

ii) Comparison of particular protein in different animals

It is not always necessary, however, to do a full sequence analysis of protein in order to discover evolutionary affinities. Sometime all that is required is to separate the chemical substances present in different species and compare the result. This may reveal similarities or the differences which will indicate how closely or distantly related the species are. Some of the important techniques employed for such studies are:

1) Chromatography
2) Electrophoresis
3) Immunology studies

Included in such studies are conjugated molecules, protein and enzymes.

8.11.1 Chromatography

This involves the separation and subsequent identification of a mixture of solutes (compounds) in a solvent. The separation is brought about by the differential movement of the individual solutes (in a solvent) moving through a porous medium like a piece of paper (paper chromatography) or a column of powdered chalk (column chromatography).

Chromatography is used to identify the different amino acids in the proteins of the organism. To do this the protein is hydrolysed by appropriate enzymes into its constituent amino acids then separated by chromatography. In most cases two way separation of the solutes is employed. This involves a second run at right angles to the first run (Fig. 8.17).

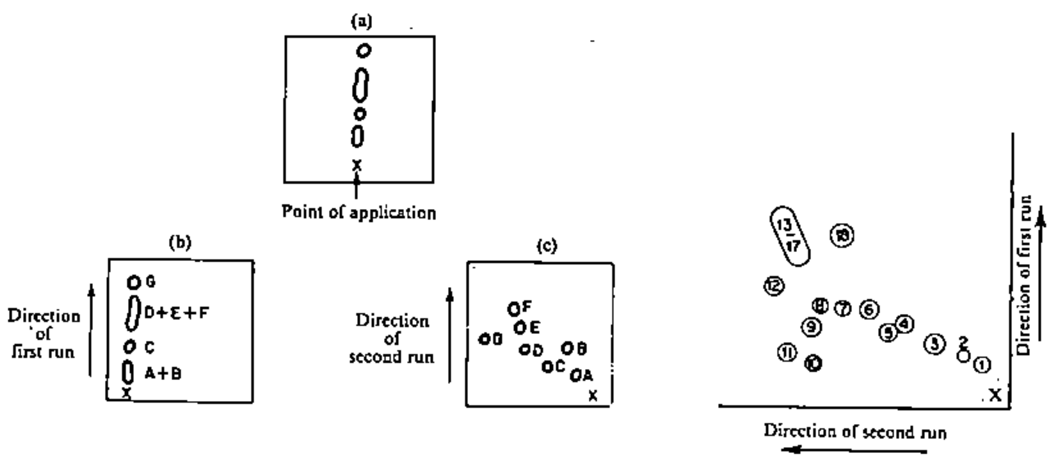

Figure: 8.17: Diagrammatic representation of single and two way chromatography (a) one way chromatogram (b) two way chromatogram after first run (c) two way chromatogram after second run (d) two way *chromatogram of a protein* hyrolysate-amino acids revealed by ninhydrin and identified by their positions resulting from distances of movement in both directions from point of application 1. cystine 2. aspartic 3. glutamic acid 4. serine 5. glyine 6. threonine 7. alanine 8. hydroxyproline 9. histidine 10. lysine 11. arginine 12. proline 13. methionine 14. valine 15. phenylalanine 16. isoleueine 17. leueine 18. tyrosine.

The technique most commonly used in animal taxonomy is partition chromatography either on paper or on a thin layer of alumina silica gel or on a glass plate, the 'chromoplate'.

In animal taxonomy paper chromatography is widely used, mostly to compare the chemical composition of closely related species. The compounds studied are peptides and amino acids, through nonhydrin treatment to reveal the presence of amino acids by the blue lilac colour that develops on heating. The spots obtained are identified by the comparative distance they have moved in both directions as you can see in Fig 8.17. The spots of the amino acids or peptides of each species form a unique pattern called 'chromatogram.'

Chromotographic techniques have helped in identification of a number of animals. They have been used, for example in detecting about 21 amino acids in adult mosquitoes which has helped greatly in their systematics. Similarly species of Lymnae (gastropods) and fishes have been separated on the basis of amino acids occurring in their muscle protein.

Chromatography techniques have helped greatly in systematics. Identification of animal species is on the basis of the comparative study of their chromatograms which are unique for each species.

SAQ 5

How do you use chromatography in identification of animals?

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8.11.2 Electrophoresis

This is a technique similar to chromatography as it involves the similar movement of dissolved organic molecules through a fixed medium. However, in this case the movement and subsequent separation and identification of the organic molecules is due to the potential difference created by an electric field. Put in another way, we can say electrophoresis is simply the movement of ions in solution under the influence of an electric field (Fig. 8.18).

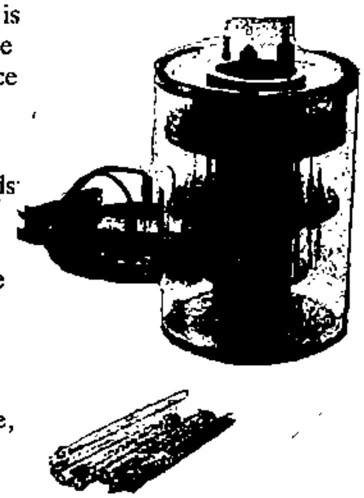

Figure 8.18: Appa ratus for proteins gel electrophoresis. In this apparatus, a strong electric potential is applied to a tube of gel containing a protein. The protein migrates in the gel in response to the electric potential, but speed of response deponds up in its its chemical makeup.

In the electric field the negatively and positively charged molecules will move in the opposite direction, the former moving towards the positive end and the latter towards the negative end.

The rate at which ions or the charged compounds move, depends on their size, shape and other characteristics. Thus a whole range of molecules can be separated in a solution by this technique. Nowadays various methods of electrophoresis have replaced to a considerable extent, most of the techniques of chromatography.

Electrophoresis is used to compare protein profiles of a particular substance example, in order to determine the relationship between species (Fig. 8.19). The proteins migrate in response to the electric field, their speed depending upon the chemical make up. When exposed to an appropriate agent the proteins can be observed and their patterns compared. Similar proteins are assumed to indicated a close relationship between organisms being compared.

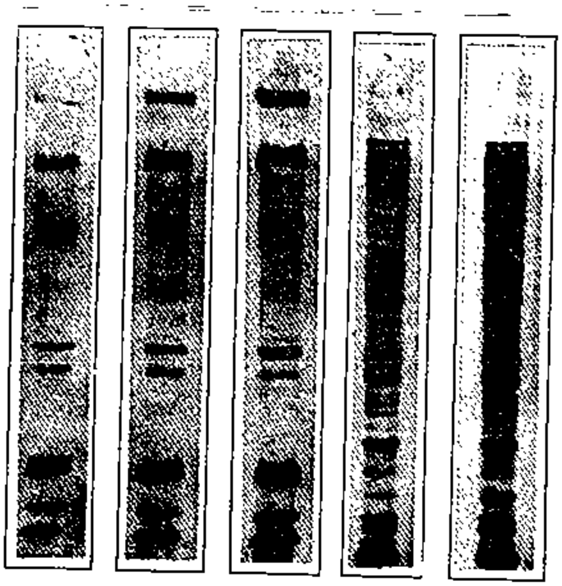

Figure 8.19: The proteins obtained by gel electrophoresis when treated with an appropriate reagent, can be seen and their patterns compared. Similar proteins are assumed to indicate a close evolutionary relationship between the organisms being compared. (NASCO.)

Electrophoresis in simple solution (boundary or moving boundary electrophoresis) is now rarely used, having been replaced by 'zone-electrophoresis'. In zone electrophoresis the solution containings the ions is supported in a more or less inert material such as paper, agar, starch, acetate cellulose or polyacryalamide.

Disc electrophoresis is one of the most commonly used form of zone electrophoresis. However, all these electrophoresis procedures are usually unable to separate proteins of similar mobility. Recently, separation of proteins of similar mobility but dissimilar molecular size has been made possible by the latest electrophoresis technique called 'polyacrylamide gradient gel electrophoresis'.

In this method the proteins migrate through progressively smaller pores, the sizes of which are regulated by adjusting the gel concentration. The proteins are retarded and eventually stopped when the pore size becomes too small to allow any further movement. The progressive reduction in pore size hinders the movement of the leading edge of the migrating zones, thus giving rise to compact concentrated zones.

This method, as you know, however, cannot separate proteins of similar sizes. These can be separated by the two directional electrophoretic techniques, which involves first the separation of molecules of similar size along one axis and then their further separation according to their mobility by running the zone electrophoresis at right angles to the first.

The use of electrophoresis in systematic study of different animal groups has been quite successful. It has helped both in comparative identification and in the working out of phylogenetic relationships. Electrophoresis for example, has shown the biochemical difference in the amino acids of various animals like oxen, horses, sheep and pigs. For instance, the insulin of the oxen, horses and sheep was found to be different; the ACTH of pig was found to differ from that of oxen.

These finding have helped considerably in solving phylogenetic problems which cannot be solved by traditional taxonomy.

Similarly, eletrophoresis of the egg white of birds have aided in working out their phylogenetic relationship and subsequent construction of hypothetical dendodograms of their relationship. For example, you can see in Fig. 8.20 the comparison of electrophoresis of egg whites in lesser flamingo (*Phoeniconaians minor*), typical duck (*Anas georgica*) and typical heron (*Arden herodias*). Here you will observe that as electrophoresis proceeds the similarity between the profiles for heron and flamingo remain but gradually diverge from that of duck, indicating that heron and flamingo are more closely related than the duck.

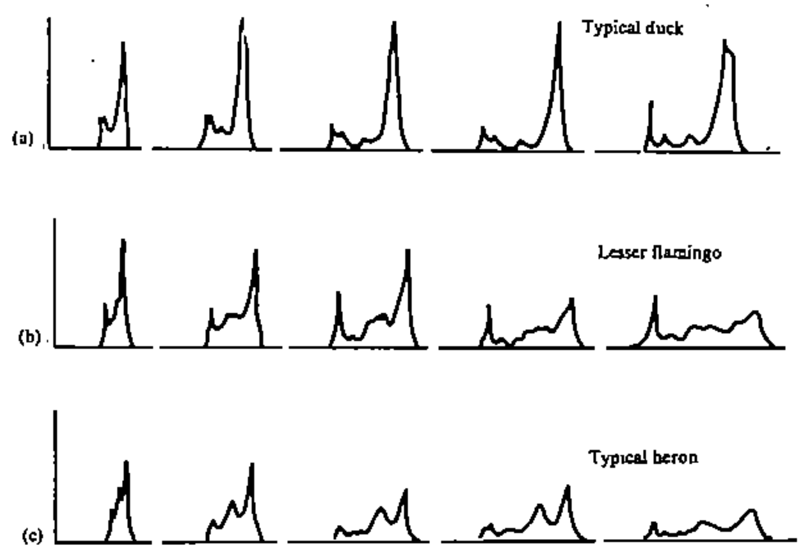

Fig. 8.20 : Progressive density profiles for comparison of typical duck (a) with the lesser flamingo (b) and a typical heron (c). Sčblev. G.C., 1960

Similarly, the flamingos which have posed quite a problem in recent, classification of birds, have been classified with the help of comparative electrophoretic profiles of Phoenicopteridae (flamingos), Anseriformes (ducks and geese), Ciconiiformes (storks and herons) and Charadriiformes (sand pipers) and a hypothetical dendogram of their relationships has been constructed (Fig. 8.21).

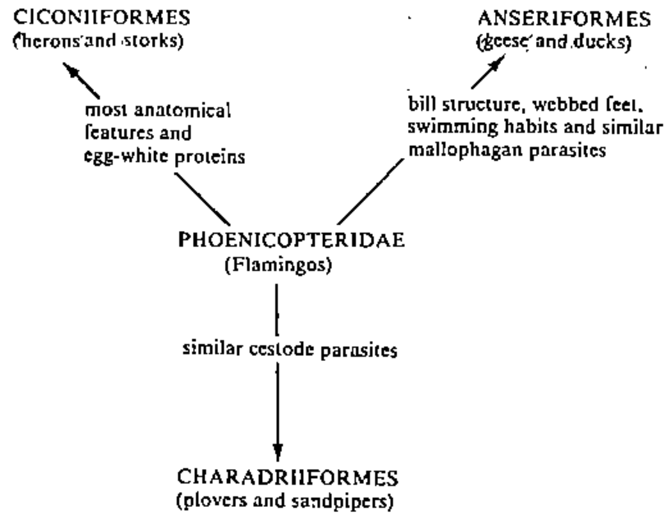

Fig. 8.21 : Similarities which suggest affinities of the Phoenicopteridae.

Electrophoretic analysis has also proved useful in molluscan taxonomy. It has been used to separate some species of the genus *Bulinus* through their egg protein studies (Fig. 8.22).

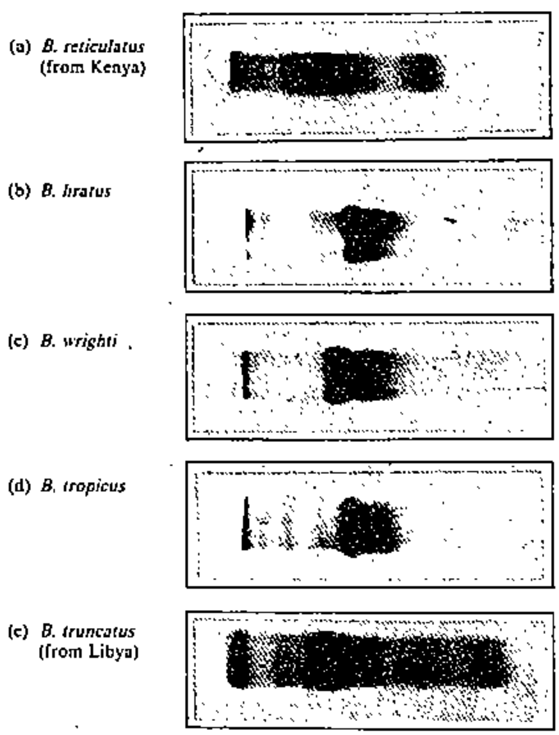

Fig. 8.22 : Electrophoretic analysis egg proteins of *Bulinus* (from WRIGHT. 1974).

Electrophoretic studies for identification have now been also carried out on a number of other animals by using various substances for analysis. Recently, in addition to the use of enzymes, substances like milk, tears, haemolymph, snake venom, liver and muscles are also being analysed for identification.

SAQ 6

A biologist who studied the electrophoretic patterns of the eggs of 2 morphologically similar populations of snail of genus *Bulinus* found that they had identical electrophoretic patterns. What can be inferred?

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8.11.3 Immunological Technique or Immunotaxonomy

Immunological techniques in animal systematics provide methods for comparing immunological differences between various species of animals which yield measures of overall similarity and supposedly of taxonomic affinity.

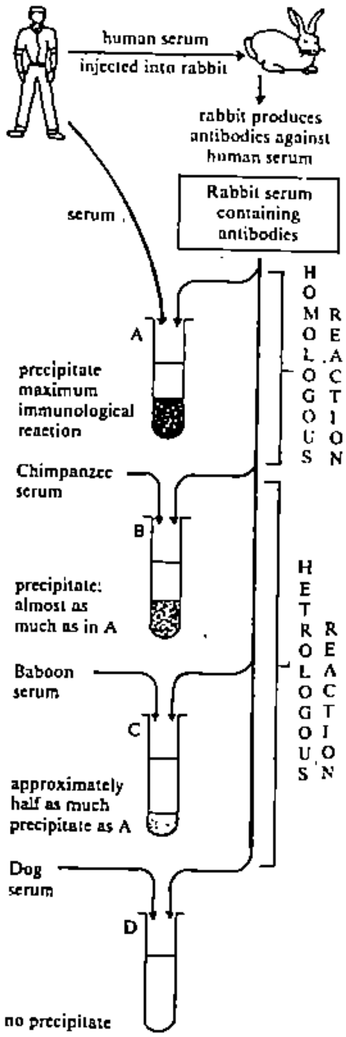


Fig. 8.23 : The basis of serological tests as a means of establishing evolutionary relationship. (*After Moody*, Introduction to Evolution, *Harper*).

These techniques help in working out phylogenetic relationship among various animal species by the indirect comparison of their proteins. The basis of immunological studies, is that organisms which are closely related have similar, though not identical genotypes. As a result these organisms would have similar proteins. The demonstration of the closeness of animals on this basis involves the use of immunological or serological technique. The theory behind which is as follows (Fig. 8.23). Suppose we want to find out the affinity between human and certain other mammals. If we inject some human serum protein into say a rabbit, the latter responds by producing antibodies (also protein) against the antigens in the serum. If some of these antibodies are mixed with human serum, an immunological reaction takes place resulting in the formation of precipitate. Now, if the antibodies obtained in such a manner are made to mix with the serum of a number of animals separately then a precipitation still results (Fig. 8.23). The degree of precipitation of antigen-antibody reaction indicates the degree of relationship.

The precipitation is total when it is between the antibodies and specific antigen that orginally stimulated their formation. This total antigen-antibody reaction is called 'homologous' or 'reference reaction'. When the precipitation occurs but to a lesser extent i.e. the antigen is chemically different from but related to the original one which stimulated the antibody production then such a reaction is said to be a 'heterologous' or 'cross a reaction' (Fig. 8.23). Complete absence of precipitate indicates wide difference in the relationship of the organisms.

In general, the more closely related animals are to one another, the greater will be the similarity in their chemical makeup and consequently also in any antigen derived from them. In heterologous reactions the closer (taxonomically) the animals are which produced the antibodies, the greater will be the degree of precipitation. This is the 'Law of Proportionality' on which immunotaxonomy or serotaxonomy is based. The antigen used for stimulating antibody production may be egg proteins, serum proteins, eyelens proteins, tissue homogenates and in the case of small animal even total animals.

The comparative preciptative reaction in immunotaxonomy of animals are usually studied by the following techniques:

1) Ouchterlony and other gel diffusion methods
2) immunoelectrophoresis

Ouchterlony and other gel diffusion methods — Techniques which require small quantities of antigen and antibody are used more in animal taxonomy nowadays. So, the economical method of gel diffusion is often used. In these techniques the antigens and the antibody are allowed to diffuse through the gel, usually agar. At the place where they meet, a line of precipitation occurs.

The most popular technique is the 'double diffusion method of Ouchterlony'. In this, gel is placed in a petridish and circular wells are cut in the agar. The well in the centre contains the antibody. This is surrounded by about four to six other wells for antigen from various animals (Fig. 8.24).

The antibody diffuses outwards towards the antigen containing wells and then meet the antigens diffusing inwards, arcs or opaque lines of immuno-precipitation are formed and become visible (Fig 8.24). Where adjacent wells contain identical antigens (i.e. from same animal species) the arcs become continuous (1) where there is partial identity an arcs may occur but with a peripherally projecting spur (II). In the case of non identity the arcs do not join but cross one another (III).

Immunoelectrophoresis

Immunoelectrophoresis is used in such multiple systems where there are a mixture of antigen in a single well and a corresponding mixtures of antibodies, as a result of which it often becomes difficult to interpret the arcs correctly.

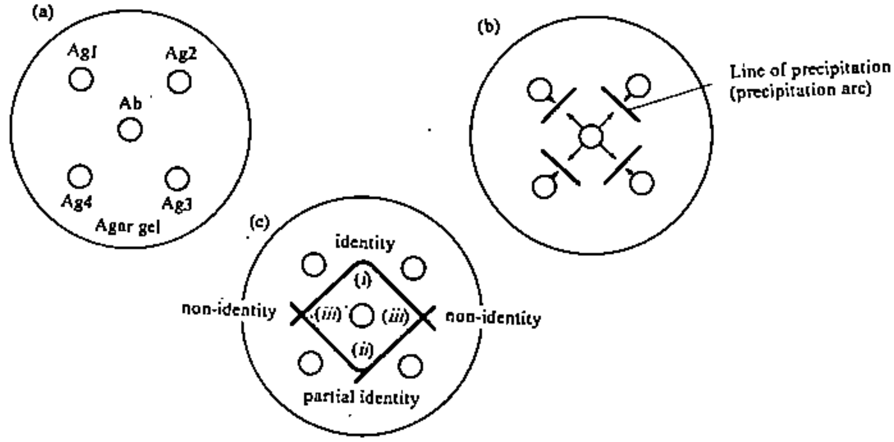


Figure 8.24 : Diagrammatic representations of the double diffusion technique (a) Ouchterlony plate with antibody (Ab) and antigens (Ag1-4) in wells, (b) precipitation ars forme where the diffusing antibody and antigens meet at optimal concentrations, (c) Ouchterlony spectrum showing the three main types of information that can be obtained.

In such instances the antigens are separated first on basis of their electrophoretic mobility and then allowed to diffuse through the gels towards an advancing line of diffusing antibody. Separated precipitation arcs form at the place where they meet.

Immunoelectrophoresis is now often carried out on a microscale, usually in a gel, coating one surface of a microscope slide as can be observed in Fig. 8.25. The gel may be polyacrylamide, starch, agar or some other suitable material.

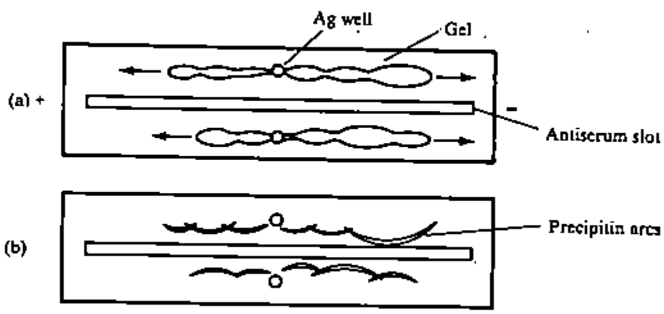


Fig. 8.25 : Comparison of precipitin arcs from two different taxa by immunoelectrophoresis (a) separation of antigen components by electrophoresis (b) precipitin arcs form where diffusing antigens and antibody meet.

The use of immunological techniques in animal systematics is now fairly widespread. They have helped in the determination of relationships of a large number of anima. groups. Such studies have shown, for example, that Cetacea (whales, porpoise and dolphins) are more closely related to Artiodactyla (even-toed ungulates) than to any other mammals. These techniques have also helped in demonstrating the 'taxonomic position of individual genera or species. For instance immuntaxonomic studies have provided evidence that the giant Panda *(Ailuropoda)* has a closer affinity with the bear (Ursidae) than with the small red Panda which is probably related to kinkajous (Procyonidae) and racoons. The North American musk ox (*Ovibos*) is related more closely to sheep and goats (Caprinae) than to the cattle (Bovinae).

Immunological studies have also helped in the determination of interrelationship of species within a group, as you can see by the crab interrelationship. depicted in Fig. 8.26.

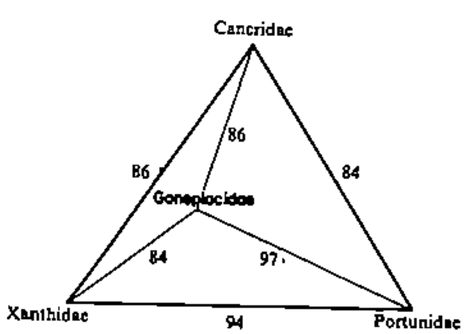


Fig. 8.26 : Pyramidal representation of immunological distances between four crabs families (after Boyden).

Other interrelation studies have been made on turtles, pigeons, cockroaches and various other animals. Immunotaxonomy has also helped in the confirmation of affinities and phylogenetic speculations. It has helped in working out the phylogenetic tree of primates, based on immunoelectrophoretic studies of vertebrate eye-lens proteins Fig 8.27.

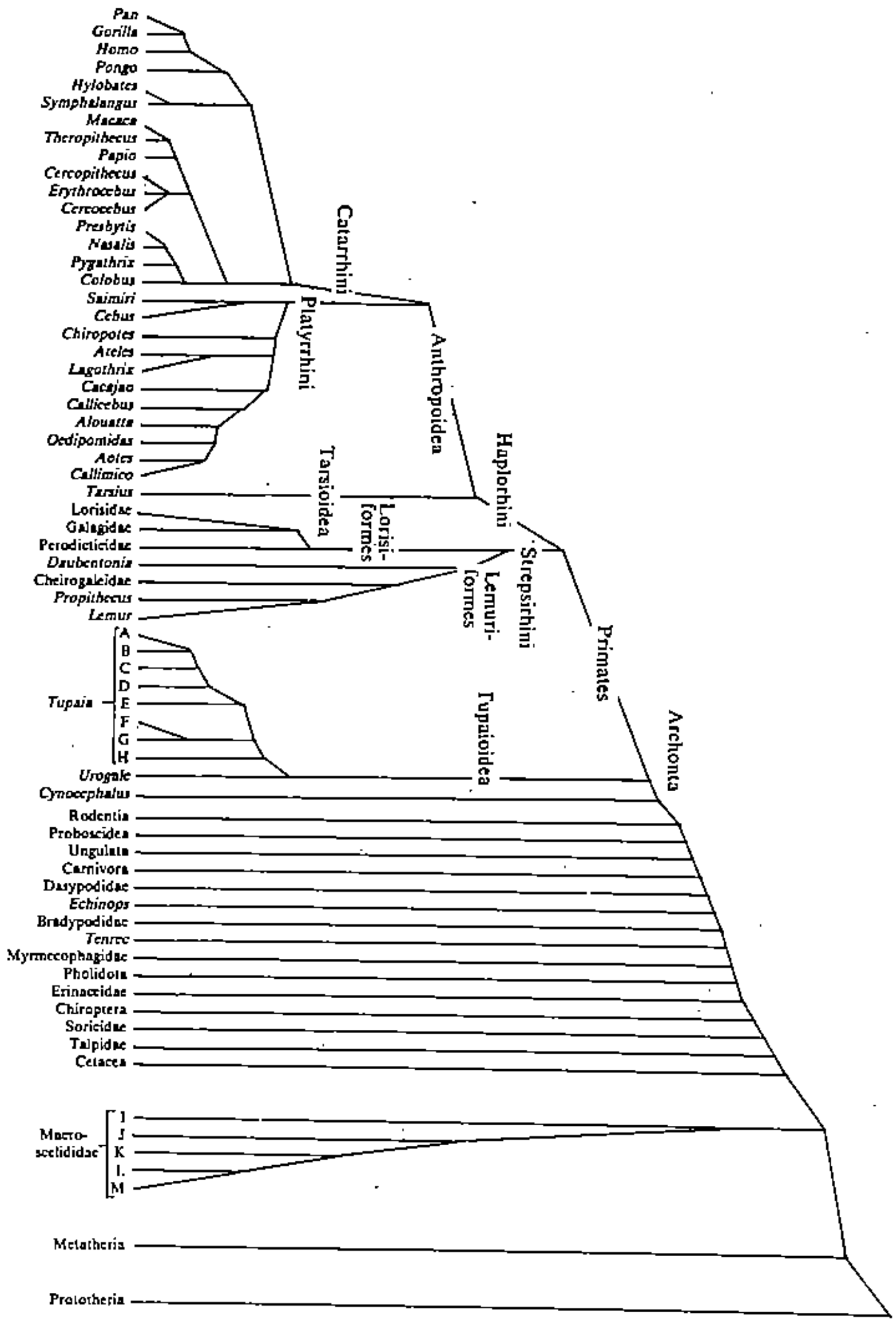


Fig. 8.27 : A dendrogram tree based on Immunodiffusion plate comparisons. Heavy lines descend to taxa as homologous species: fine lines to those used only as heterologous species. (From Goodman, M., 1976, in *Molecular Evolution* edited by F.J. Ayala, pp. 141-59).

In addition to this, immunotaxonomic studies have also helped in the discovery of a large number geographical races and sibling species.

SAQ 7

Complete the equation.

$\underset{1}{\underline{\qquad\qquad}} + \underset{2}{\underline{\qquad\qquad}} =$

(Precipitate, antigen, antibodies)

8.12 NUMERICAL TAXONOMY

Numerical methods in taxonomy are not new. Simple statistical methods like standard deviations, t-tests and chi-squared have been used for several years. Recently with development of electronic digital computers, numerical analysis of a large quantity of taxonomic data in a relatively short period of time has become possible. This has led in the last twenty years to the development of a new branch of taxonomy called numerical taxonomy or taxometrics.

The computation of data by evaluating numerically the affinity or similarity between organisms and then ordering them into taxa takes very little time, probably a few seconds. However, the preparation of the data in a suitable form for input into the computer is a very tedious task requiring painstaking examination and recording of information.

The use of computers in numerical taxonomy has made it possible to compare a large number of characters from many organisms with relative ease. After comparisons of the organisms they are grouped according to overall similarity or dissimilarity and wherever necessary presented graphically.

The number of characters studied in numerical taxonomy are usually about 50-100 from approximately the same or greater number of organisms.

The term organism in this field refers to individuals, populations, specific genera or any other taxonomic category and so far this reason they are generally called as 'operational taxonomc units' or 'OTUs'.

The different conditions in which the identification characters occur are known as 'character state'. A particular organ may be absent or present, functional or non-functional. In such simple cases they are said to be 'two state characters'.

Many traits, however, exhibit a number of possible states and so are termed as multistate characters. Both two state characters and multistate characters may be qualitative or quantitative. Now let us see the stepwise manner in which numerical data is prepared and analysed.

The very first step in numerical taxonomy is to decide the OTUs to be studied.

1) Then the characters to be used for studying the OTUs are selected. Usually a large number of characters are taken as it is presumed that the greater the number of characteristics the more valid the classification.

2) The characters chosen include any observable attribute or trait of the OTUs: morphological, behavioural, ecological embryological etc. All such traits have to be observable phenotypic characters and so it is for this reason that the resultant grouping, classification or key obtained from taximetric is said to be phenetic. In other words, it is not based on evolutionary or phylogenetic or phyletic relationships. All the selected characters are given equal weightage. Thus each character is of the same value as the other.

Certain taxonomic characters are inadmissible like absence of eyes and so inability to see.

3) Once the characters are selected they have to be recorded in a suitable form. This process is called coding. Quantitative attributes like the number of lips in the nematodes or measurements of parts of the body can be recorded directly. Two state or multistate characters need to be coded. In the case of two state characters the presence is usually coded as 1 or + and absence as 0 or –.

4) When a character exists in more than one qualitative state, these may be broken down into a series of two state characters. For example, the cuticle of an insect may be white, yellow, brown or black, the character can be coded + or 1 when present or – or 0 when absent for each state in turn. Or each of the possible states can be indicated by a number and the disagreement or agreements (usually termed mismatch or match) can be recorded as + or – for each comparison between OTUs.

5) An alternative method would be to use multistate coding where a single trait can be coded in a number of states, each being represented by a numerical symbol or code e.g. 1, 2, 3 etc. depending on the range of variation. Thus if we again look at the colour of the cuticle of an insect, we can assign different code to different colours such as white = 1, brown = 2, black = 3, and so on. Besides qualitative characters such as colour of hair, cuticle etc. multistate coding is also

useful in quantitative characters such as number of lips, setae, length of body, width of body, number of markings and other characters involving measurements. A code is prepared for the range of variation as for example, body length may be coded as 5–10 mm = 1, 11–15 mm = 2, 16-20 mm = 3, 21-25 mm = 4 etc.

Occasionally due to some reason or another no comparison is possible or data may be missing for one of the traits of the OTUs. Such situations are coded as NC (no comparison).

6) Now the next step after the OTUs have been selected and the character states and their subsequent coding has been determined is the presentation of data in the form of a primary data matrix or txn matrix where 't' represents the OTU's and 'n' the characters Fig. 8.28a and 8.28b.

Characters (n)	1	2	3	4	5 Taxa (t)
A	+	+	+	+	-
B	+	-	-	NC	+
C	-	-	+	-	+
D	-	-	+	+	-
E	-	+	-	+	-

a

	1	2	3	4	5
A	2	2	2	2	1
B	2	1	1	NC	2
C	1	1	2	1	2
D	2	1	2	2	1
E	1	2	1	2	1

b

	A	B	C	D	E
A	5/5	1/4	1/3	4/5	3/5
B	1/4	4/4	2/4	2/4	1/4
C	1/5	2/4	5/5	2/5	1/5
D	4/5	2/4	2/5	5/5	2/5
E	3/5	1/4	1/5	2/5	5/5

c

	A	B	C	D	E
A	100	25	20	80	60
B	25	100	50	50	25
C	20	50	100	40	20
D	80	50	40	100	40
E	60	25	20	40	100

d

Figure 8.28-a and b: primary data matrix (txn). c and d matrix of coefficiant of similarity calculated in fractions(c) and in percentage (d).

If we have studied 50 OTUs and scored 100 characters from each, then we will obtain 50 × 100 = 50,000 Units of information. Thus the large amount of information obtained make the use of computers usually absolutely necessary in numerical taxonomy.

7) Now, in the next stage, each OTU is compared in turn with all the others with respect to their character states (Fig. 8.28). In order to accomplish this there must be some means of comparing the degree of similarity. This is achieved by calculating the coefficient of similarity (S) S = m/n. Here, m is the number of matches of character states between pairs of OTUs, and n is the total number of characters (NC entries are excluded). The coefficient of similarity is presented as you can see in Fig. 8.28 c & d in a tabular form in a similarity matrix in which each OTU is compared with every other one.

The coefficients of similarity for OTUs are indicated as fractions (Fig 8.28c) or more usually, however, in decimal fractions or percentages (Fig. 8.28d & 8.29). In Fig. 8.29 we have chosen a hypothetical similarity matrix of 10 OTUs (A-J) (n) and their corresponding observable characters 1-10 (t).

TAXON (OTUS) (n)

TRAITS (t)	A	B	C	D	E	F	G	H	I	J
A	100	53	80	63	62	82	50	83	50	60
B	53	100	55	57	57	55	86	56	87	56
C	80	55	100	62	64	85	51	86	50	62
D	63	57	62	100	74	63	54	65	56	96
E	62	57	64	74	100	64	56	67	56	72
F	82	55	85	63	64	100	54	87	52	65
G	50	86	51	56	56	54	100	54	85	65
H	83	56	86	63	67	87	54	100	54	67
I	50	87	50	56	56	52	85	54	100	55
J	60	56	62	96	72	65	65	67	55	100

Figure 8.29 : A hypothetical similarity matrix in percentage of 10 OTUs (A-J) and their corresponding observable traits(t)

8) Let us see how the coefficient of similarity is calculated in percentage. Consider, the OTUs A and B in Fig. 8.28c. You will observe that one out of a total of 4 of its characters match so the similarity between them will be 1/4 × 100 = 25 per cent. Obviously 100 per cent would mean that the two groups are identical with respect to the characteristic chosen and 0 per cent means they are totally different. The type of numerical taxonomic analysis described here is the simplest of a large number of possible techniques and is known as 'single linkage cluster analysis' in which the measure of similarity is based on match/mismatch. In Fig. 8.29 as we mentioned before we have chosen a hypothetical similarity matrix worked not in percentage of 10 OTUs (A-J) and their corresponding observable characters 1-10 (t) in order to explain to you how the measure of similarity is further worked out by the single linkage cluster analysis.

9) You will observe that the figures on the upper and lower sides of the diagonal line in Fig. 8.28d and 8.29 are mirror images. So it is customery to illustrate only one part as we have done in Fig. 8.30.

	A	B	C	D	E	F	G	H	I	J
A	100									
B	53	100								
C	80	55	100							
D	63	57	62	100						
E	62	57	64	74	100					
F	82	55	85	63	64	100				
G	50	86	51	56	56	54	100			
H	83	56	86	65	67	87	54	100		
I	50	87	50	56	56	52	85	54	100	
J	60	56	62	96	72	65	55	67	55	100

Figure 8.30: Only one side of the similarity matrix of Fig. 8.29 is shown here as both the sides on either side of 100 are mirror images.

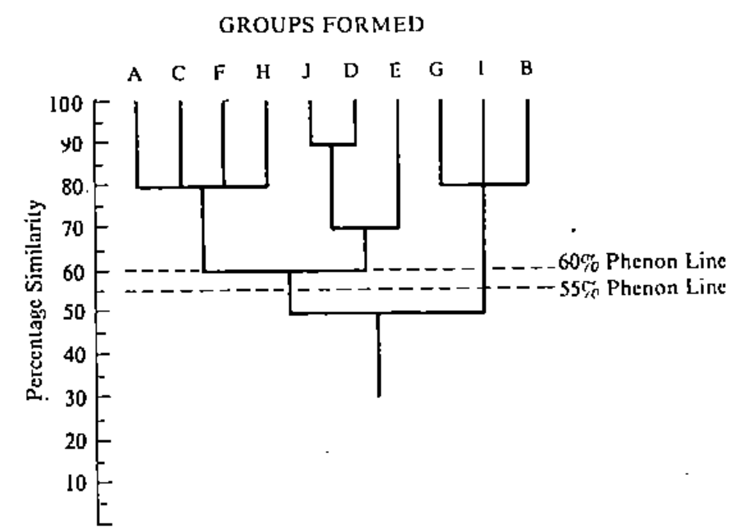
10) Now, the next step involve the rearrangement of the similarity matrix so that the groups of OTUs which show closest similarity are clustered together. Again several techniques are available for doing this. However, with the small numbers of OTUs and their correspondingly small number of characters, chosen by us, it is possible by just looking at Fig. 8.29 to observe immediately a high degree of similarity between ACF and H, between D E and J and again between B, G, and I. So, the matrix can be organised to form blocks of high similarity as indicated in Fig. 8.31. Usually however the date of the similarity matrix to very large and so blocks of ligh similarity can only be calculated with the help of computers.

	A	C	F	H	J	D	E	G	I	B
A	100									
C	80	100								
F	82	85	100							
H	83	86	87	100						
J	60	62	65	67	100					
D	63	63	63	65	96	100				
E	62	64	64	67	72	74	100			
G	50	51	54	54	55	56	56	100		
I	50	50	52	54	55	56	52	85	100	
B	53	55	55	56	56	57	57	57	87	100

Figure 8.31: The similarity matrix is rearenged to show clusters of OTUs on basis of their similarity.

11) The blocks of similarity in Fig. 8.31 are based on the percentage of shared character states and can be represented graphically in the form of a tree or dendogram known as 'phenogram' (Fig. 8.32). In this type of data presentation, the phenetically similar OTUs can be linked together by horizontal lines drawn at appropriate distances in relation to a vertical scale, which represents degrees of similarity and which, as you can see, is expressed in percentage. The clearly evident clusters of similar OTUs are termed as 'phenon' and the levels which indicate the degree of similarity on the vertical scale are known as phenon lines.

In the hypothetical dendogram (Fig. 8.32), the OTUs A, C, F and H form a phenon which have a similarity of 80-87% D and J have 96% similarity and both are joined to E at about 70% level. G, I and B are joined at 85-87% level. The group formed by J, D and E is linked to A, C, F and H at 60% phenon line. More distant from all of these seven are G I and B to which they are linked with only 50-57% similarity.



% Phenon Line
% Phenon Line

Figure 8.32: A phenogram constructed on the basis of information shown in Fig. 8.31

It is quite tempting though not justifiable to regard such dendograms as phylogenetic trees or at least approximations to them. It is mainly because of this and because of the subjective nature of categories, such as genus, subfamily, family etc. that levels of phenon lines have been used to delimit taxa above the species level. For instance, phenon with about 70% similarity may be regarded as of generic rank and those of say 50% of family rank. This provides an obvious though arbitrary method of standardizing the level of various categories in the taxonomic hierarchy. Whether or not genera and family should be delimited in this manner by more or less constant levels of phenon lines is a debatable points.

Many other techniques of numerical taxonomy are available now, some with special objectives.

Classification based on the methods of numerical taxonomy almost certainly have some phyletic component as they result to some extent from similarities due to common ancestry.

As mentioned before, usually no 'a priori' weighting or extra weightage is given to characters employed in numerical taxonomy. However, once the procedure outlined above have been completed and a classification constructed, it is then possible to reconsider the characters used and to determine which are good characters. That is, which are constant and highly correlated with other characters. These characters are then given special weighting in the diagnosis of taxa and identification with the help of keys. Such weighting is said to be 'a posteriori' or 'correltion' weighting.

The development of computer techniques in numerical taxonomy, have been proved useful for various other applications such as in key construction automatic identification programs, in storage and retrievel of taxonomic data and in studies on evolutionary pathways.

SAQ 8

Prepare a coefficient of similarity matrix in percentage from the present data.

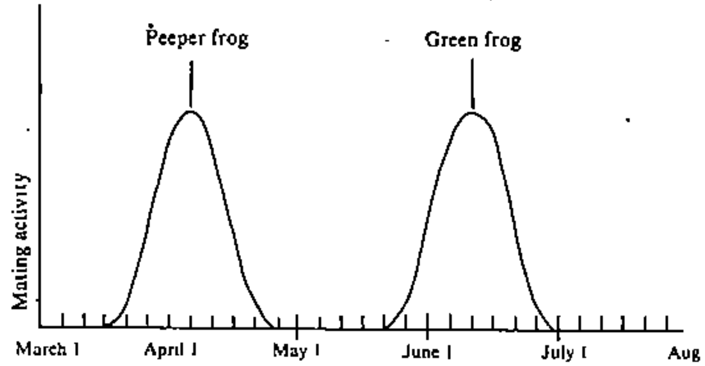
	A	B	C	D
A	+	−	+	−
B	+	+	+	−
C	+	+	−	+
D	−	+	+	+

8.15 SUMMARY

- Systematics is the scientific study of taxonomy and evolution of organisms
- Biosystematics is synonymous with systematics, though it focuses mainly on the study of speciation of organisms.
- Taxonomy relies heavily on systematics and biosystematics for its concepts and theories and it deals with the study of classification and nomenclature of organisms
- The identification of a particular animal group passes through three main stages (a) Alpha (α) taxonomy (b) Beta (β) taxonomy and (c) Gamma (γ) taxonomy
- Alpha taxonomy is the level at which species are characterised and named.
- Beta taxonomy is the level at which the species are arranged into a natural system of lower and higher categories.
- Gamma taxonomy is the level at which the analysis of interspecific variation and evolutionary studies of organisms are done.
- Neotaxonomy or modern taxonomy uses along with just morphological information, data from other biological fields like electron microscopy, embryology, ecology, ethology, cytology, biochemistry numerical taxonomy etc in identifying organisms.
- Electron microscopy—This involves the study of the ultra structure of morphological feature with the help of scanning electron microscope and transmission electron microscope. Such studies have proved useful in identification of closely related and sibling species.
- Embryological approach—This approach involves the study of the eggs, embryo and larvae or juveniles of animals. This study is very important in the identification of those animals whose immature stage are very different from the adults.
- Ethological approach—In this approach animals species are identified on the basis of differences in their behaviour, like different mating calls, differences in bioluminiscence pattern and other ethological activities such as type of nest building, web construction etc.
- Cytological approach—In this approach, animals are identified on the basis of differences in degree of DNA hybridisation and difference in chromosome number or shapes or both (karyotype).
- Biochemical approach—This approach identifies animals on the basis of demonstrable biochemical differences between them. 'Various techniques used in such identifications are: 1) chromatography, 2) electrophoresis, 3) immunological techniques
- Numerical taxonomy—This approach is based heavily on electronic digital computers, which compare and analyse statistically a large number of numerical data of various characters of a number of animals (OTUs).

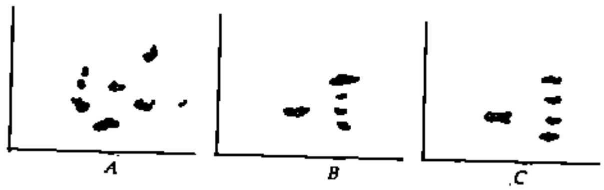
8.16 TERMINAL QUESTIONS

1) Study the graph below. What kind of approach is it depicting? Can a biosystematist infer something from this graph?



Graph showing breeding period of of frogs.

2) On the basis of chromatograms given below, which 2 birds appear more closely related.



3) Study the Figure given below. It shows corresponding the parts of the cytochrome C. amino acid sequence of nine vertebrates. The numbers along the side of the figure refer to the position of these sequences in the chain. The letters identify the specific amino acids in the chain. On the basis of this figure answer the question numbers. i, ii, iii, iv.

	Horse	Shark	Turtle	Monkey	Human	Rabbit	Chicken	Tuna	Frog
42	Q	Q	Q	Q	Q	Q	Q	Q	Q
43	A	A	A	A	A	A	A	A	A
44	P	Q	E	P	P	Y	E	E	A
46	F	F	F	Y	Y	P	F	Y	F
47	T	S	S	S	S	S	S	S	S
49	T	T	T	T	T	T	T	T	T
50	D	D	E	A	A	D	D	D	D
53	K	K	K	K	K	K	K	K	K
54	N	S	N	N	N	N	N	S	N
55	K	K	K	K	K	K	K	K	K
56	G	G	G	G	G	G	G	G	G
57	I	I	I	I	I	I	I	I	I
58	T	T	T	I	I	T	T	U	T
60	K	Q	E	E	G	G	G	N	G
61	E	Q	E	E	E	E	E	N	E
62	E	E	E	D	D	D	D	D	D
63	T	T	T	T	T	T	T	T	T
64	L	L	L	L	L	L	L	L	L
65	M	R	M	M	M	M	M	M	M
66	E	I	E	E	E	E	E	E	E
100	K	K	D	K	K	K	D	S	S
101	A	T	A	A	A	A	A	A	A
102	T	A	T	A	T	T	T	T	T
103	N	A	S	N	N	N	S	S	S
104	E	S	K	E	E	E	K	—	K

A chart showing the corresponding parts of the cytochrome C amino acid sequence of nine vertebrates. The numbers along the side of the figure depict the position of these sequences in the chain. The letters refer to the specific amino acids in the chain.

i) Under what approach would you obtain such a data?

ii) Make a table to record your data. Head columns 'Species' and Number of differences. For each vertebrate count the amino acid sequences that differ from the human sequence and list them in your table.

iii) List the eight organisms in descending order, according to their degree of evolutionary closeness to humans based on the similarity of amino acid sequences.

iv) a) which organism of all vertebrates listed is most closely related to human.
b) which is most distantly related to humans.

4) In the following statements, put a tick [√] mark on the correct ones in the given boxes.

a) Biosystematist study the process of
   i) taxonomy [ ]
   ii) speciation [ ]
   iii) genetics [ ]
   iv) development [ ]

b) A systematist can use data from DNA hybridisation to
   i) predict future changes in species [ ]
   ii) to determine when a species diverged from a common ancestor [ ]

iii) To identify phylogenetic similarity among species [ ]
iv) explain the origin of life [ ]

5) How many units of information have to be fed into the computer when the number of OTUs taken are 150 and the traits considered are 100?

8.17 ANSWERS

Self-assessment Questions

1) a) biosystematist b) systematist c) taxonomist
2) a) α, b) β, c) γ
3) 1) c, 2) d, 3) a, 4) b
4) The biologist cannot identify animals, just on the basis of karyotypes as many different animals have similar karyotypes. He should have also considered other taxonomic characteristics like morphology, embryology, biochemistry etc.
5) Chromatography is used to help in detecting the amino acid composition of various animals. After which the amino acid compositions are compared. Those with similar composition are believed to be more closely related.
6) Since the protein samples for both the *Bulinus* populations were identical, the biologist can assume that they belong to the same species.
7) Antigen + antibody = precipitate
8)

	A	B	C	D
A	100	75	25	25
B	75	100	50	50
C	25	50	100	50
D	25	50	50	100

	A	B	C	D
A	4/4	3/4	1/4	1/4
B	3/4	4/4	2/4	2/4
C	1/4	2/4	4/4	2/4
D	1/4	2/4	2/4	4/4

Terminal Question

1) The biosystematists on observing the graph, will see that the two frog populations breed at different periods, indicating that they are ethologically reproductively, isolated. They can thus infer that the two frogs are most likely, members of different species.
2) B and C are thought to be more closely related, since their chromatographic patterns are quite similar. However, data from other approaches, has to be used as well, in order make a definite identification.
3) i) Such a data would be obtained in biochemical approach.

Humans	Horse	Shark	Turtle	Monkey	Rabbit	Chicken	Tuna	Frog
0	6	14	8	1	4	7	9	8

difference in the amino acid sequence with respect to humans

Shark	Tuna	Turtle	Frog	Chicken	Horse	Rabbit	Monkey	Humans
14	9	8	8	7	6	4	1	0

Vertabrates arranged in descending order according to their degree of closeness to humans

iv) a The monkey appears to be most closely related to humans on basis of data provided in the chart

iv) b the shark seems to be very distantly related to the humans.

4) a (ii) b (iii)

5) 150,00 units of information.

GLOSSARY

achene : a dry indehiscent, one-seeded fruit, formed from a single carpel and with the seed distinct from the fruit wall.

antibody : a blood protein, produced by β cells of the lymphocytes as a result of the entry of the antigen into the body. The antibody tries to destroy the antigen by binding to it specifically.

antigen : a substance that stimulates production of antibodies.

antropous : an ovule with the micropyle close to the underside of the funicle and with the chalaza at the opposite end.

arachnids : members belonging to a particular class of phylum of arthropods which include mites, spiders, ticks and scorpions.

arthropods : a phylum which contains animals characterised by jointed appendages and stiff external skeleton. Examples include carbs, barnacles, insects, spiders etc.

aves : the class which contain birds.

behavioural variations : differences in behaviour among closely related organisms.

bioluminescence : light produced by living organisms (like fire-flies) as a result of chemical reaction.

biosystematics : the study of reproductive capability and gene flow.

cetaceans : members of the mammalian order—whales, dolphins etc.

chelipad : in arthropods, a claw used to capture food and provide defense.

chromatography : the procedure of the separation of a mixture of a chemical substance into its components. The separation is based on differences in their sizes and electrical charges, which result in their separation, due to the differences in the rates of the their movement.

coagulation : the solidifying, or setting of protein. This change is irreversible.

coenocytic : a multinucleate vegetative cell.

concentration gradient : the charge in concentration of a substance over a distance.

crustacea : a class of arthropod which includes crabs, shrimps, lobsters, barnacles etc.

cuticle : a layer of waxy waterproof substance secrered on the outer surface of an organism.

cytochrome : an electron carrier molecule consisting of a protein, a porphrin ring and a metal ion.

diploid : having two full set of chromosomes per cell

drupe : a fleshy fruit, with a thin epicarp, a fleshy mesocarp, and a hard endocarp. containing a single seed. The seed and endocarp fom the stone e.g. a plum.

electrophoresis : the migration of charged particles in an electrical field. This method is used widely in the separation of the components of a large variety of mixture.

endothecium : the fibrous layer in the wall of an anther.

fibrin : the long sticky threads that help in blood clotting.

fibrinogen : a blood protein essential for formation of blood clot.

follicle : a many-seeded dry fruit. derived from a single carpel, and splitting longitudinally down one side at dehiscence.

fossils : petrified remains or traces of a once living organism, preserved in the rocks of the earth's crust.

gastropods : members of a class of molluscs, that include slugs nudibranches etc.

gene flow : the movement of genes from one gene pool into a second gene pool.

gene pool : all the genes for all the traits in a population.

habitat : the physical area in which an organism lives.

haploid : having a single set of chromosome per cell.

hominid : a sub-group of primates that includes human beings and their immediate ancestors.

hybridization : the production of a hybrid by crossing two individuals of unlike genetic constitution.

hymenoptera : order of insects that includes bees, wasps, ants etc.

larva : immature stage of an animal with very different appearance and way of life from the adult.

lepidoptera : order of insects that includes moths and butterflies.

loculicidal : a fruit which splits open along the midribs of the carpels.

marsupials : mammals whose young are born early in development and complete their development in their mother's pouch or marsupium where they remain attached to the nipple during the entire development process, for eg kangaroo.

molluscs : the phylum consisting of soft bodied animals with a mascular, head-foot and a mantle which often secrete a shell, e.g. clams, snails, squids etc.

morphology : external appearance of an organism.

phylogenetic tree : a visual model of inferred evolutionary relationship among organisms.

phylogeny : evolutionary history.

primates : order of mammals that includes monkey, apes, humans etc.

proembryo : the group of cells, few in number, formed as the zygote begins to divide, and from one or some of which the embryo proper is organised.

reproductive isolation : the inability of formely interbreeding organisms to produce offsprings.

resolution : the power of microscopes to show details.

serological methods : a method of identifying various, organisms and their chemical components, and their relations to one another. One acts as an antigen in blood serum, against which activities of another can be examined.

setae : (single seta) external bristles.

speciation : the formation of new species.

tapetum : a food rich layer of cells around a group of spore-mother-cells in vascular plants. They disintegrate to liberate the contents which are absorbed by the developing spores.

taxon : (pl. taxa) one of the hierarchial categories into which organism are classified, e.g. species, order, class etc.

taxonomy : the science of grouping organisms according to their presumed relationship by the process of classification and identification.

terpenes : these are unsaturated hydrocarbons ($C_{10}H_{16}$), essential oils with straight chain or ring structure derived from isoprene.

ungulates : hoofed mammals e.g. camel.

urodela : order of amphibian including newts, mud puppies, salamanders etc.

yolk sac : in amniotic eggs (the four membrane eggs of a terrestrial vertebrate), the membrane that encloses the yolk to supplies food to the embryo.

Dear Student,

While studying the units of this block, you may have found certain portions of the text difficult to comprehend. We wish to know your difficulties and suggestions, in order to improve the course. Therefore, we request you to fill and send us the following questionnaire, which pertains to this block. If you find the space provided insufficient, kindly use a separate sheet.

QUESTIONNAIRE

LSE-07
Block 2

Enrolment No. | | | | | | | | | |

1) How many hours did you need for studying the units?

Unit Number	5	6	7	8
No. of hours				

2) How may hours (approximately) did you take to do the assignments pertaining to this block?

Assignment Number		
No. of hours		

3) In the following table we have listed 4 kinds of difficulties that we thought you might have come across. Kindly tick (√) the type of difficulty and give the relevant page number in the appropriate columns.

Page Number and line Number	Types of difficulties			
	Presentation is not clear	Language is difficult	Diagram is not clear	Word/Terms are not explained

4) It is possible that you could not attempt some SAQs and TQs. In the following table are listed the possible difficulties. Kindly tick (√) the type of difficulty and the relevant unit and question numbers in the appropriate columns.

Unit No.	SAQ No	TQ No.	Type of difficulty			
			Not clearly posed	Cannot answer on basis of information given	Answer given (at end of Unit) not clear	Answer given is not sufficient

5) Were all the difficult terms included in the glossary. If not please list the words in the space given below.

6) Any other suggestion(s)

To,

The Course Coordinator (LSE-07, TAXONOMY AND EVOLUTION)
School of Sciences
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UGZY/BY-10

Taxonomy and Evolution

Block

3

EVOLUTION — I

BLOCK 3 EVOLUTION—I

The last two blocks of this course dealt with the history, principles and tools of taxonomy as well as its trends. Beginning with this block, we shall be dealing with the second aspect of this course, namely evolution.

Evolution as defined by Darwin is descent with modification. But the definition of evolution has undergone changes after the principles and mechanisms of inheritance became better understood. Today, the Darwinian concept of natural selection is fully explained in terms of gene frequencies and the changes they undergo from one generation to the next. Although Darwin had no knowledge of genetics, he could predict that variability in populations is responsible for the origin of adaptations. Today we know that variability is generated continuously in populations by mutations and further enhanced by genetic recombinations. These processes, together with the action of natural selection, bring about changes in gene frequencies in populations.

This block consists of three units. In Unit 9, you will be introduced to the concept of evolution, the origin and development of evolutionary thought and the various theories that are associated with the notion of organic evolution. A brief account of the origin of life from the viewpoint of creationists is also provided. In Unit 10, you will be studying various lines of evidence which taken together, support the idea of evolution. They are drawn from various branches of biology such as palaeontology, biogeography, anatomy, embryology, physiology and biochemistry. What comes through clearly is the organic continuity in structure and adaptation among the several organisms belonging to different taxa. In Unit 11 of this block there is a deeper excursion into the Darwinian concept of evolution revealing some of its finer ramifications. In this unit we also discuss the principles of action of natural selection under varying environmental conditions.

In the next block we shall proceed to a discussion of specific examples illustrating natural selection in action. We shall also discuss current concepts on the mechanism of speciation and of human evolution.

Objectives

After reading this block you should be able to:

- present a brief history of the origin and development of evolutionary thought from the time of early Greek philosophers to the present,
- document the fact of occurrence of evolution by lining up evidence available from the various disciplines of biology,
- interpret the evolution of adaptations through natural selection based on the Darwinian tenets,
- describe the sources of heritable variations and the manifestation of variability and
- discuss the characteristics of different kinds of selective forces.

UNIT 9 CONCEPT OF ORGANIC EVOLUTION

Structure

9.1 INTRODUCTION

From the time he took the first hesitant steps towards civilized living, primitive man — much like his modern counterpart — must have wondered about his own origin as well as the origins of the many different kinds of living forms around him Two features of the living world have impressed him. On the one hand, he would have noted their diversity and, on the other, the unmistakable relatedness between seemingly different organisms. After all, while there are a whole lot of different kinds of birds, they are all birds and, as such, are clearly distinct from, say, the fish or the quadrupeds. Clearly, therefore, plants and animals can be bunched into or classified into recognizable groups.

The simplest — perhaps we should say, the most obvious — explanation that occurred to man at the dawn of civilization was that all this was an act of God. Indeed, early Indian thought, credits the Supreme Being with creating, by the simple method of becoming, all of the various living species. Curiously enough, Indian thinkers apparently did not, in the succeeding centuries, feel the need to go beyond this metaphorical view of the origin of living forms.

Today, however, following that great 19th century naturalist — Charles Darwin, we talk of modern plant and animal species as having evolved from more primitive ancestors. Note the term organic in the title of this unit. The point is, evolution can be talked of at different levels — we can discuss the evolution of the universe, of the system of stars, of the living from the non-living. To indicate that our concern here is only with the evolution of living forms, the word 'organic' has been included.

In this Unit, we shall be tracing, in broad outline, the history of thinking on organic evolution. One thing that is bound to strike you is how speculative early notions on this subject were. It was only later — indeed, much later — that the methods of science were put to use in the study of organic evolution. By the methods of science, we mean the process of gathering data, building a hypothesis from the data and testing the hypothesis on the basis of deductions made from it. If, as a result of several independently designed tests, the hypothesis is found to hold, it is then promoted to the status of a theory. You are aware, I am sure, that to test a hypothesis you need to set up one or more appropriate experiments. Quite clearly, it is not so easy to set up experiments aimed at testing a theory on the evolution of species. Nevertheless, such experiments — rather limited in scope — have been performed. On the other hand, if you are alert, you can watch the experiments that Nature herself conducts and use the results to evaluate your hypothesis. It is here that Darwin excelled! More of this later.

Objectives

After studying this unit, you should be able to:

- give an account of early Greek views on evolution,
- discuss the implications of the biblical doctrine of 'Genesis' for a theory of evolution,
- trace the evolution or unfolding of notions on the origin and diversification of species in the century preceding the celebrated formulation of Darwin's views,
- discuss how Darwin's problem of the mode of origin and transmission of heritable traits was resolved following Mendel's epoch-making discoveries and the subsequent 'Modern Synthesis', and
- assess for yourself the relevance of 'creationism' in today's world.

9.2 PRE-DARWINIAN EVOLUTIONARY THINKING

Mention was made of how early notions on the origin of species were, in reality, mere speculations — that is, products of imaginative thinking. Surprisingly, however, some of the early Greek philosophers were fairly down to earth.

9.2.1 Greek Contribution

You may perhaps be aware that in the middle ages (in Europe), alchemists were attempting to *transmute* baser metals into gold.

In the pre-Christian Western world, some atleast, of the early Greek philosophers were apparently good observers too. Based on their observations on the relatedness of many of the animal species, they brought up the question of evolution, that is, of an unfolding or an unrolling, of a gradual working out of the 'higher' forms of life from the 'lower'. Anaximander (611-547 B.C.) considered that life arose by spontaneous generation and that the first animals were fish, produced in moisture and provided with a spiny skin. In course of time, according to him, their descendants left the water and reached dry land. The various other animals came into being through a series of **transmutations** — that is, transformations. Man, in turn, arose by transmutation from some lower, probably aquatic, species.

A related idea, of considerable significance to later students of evolution, was brought forward by Xenophanes (576-490 B.C.). He came across fossil animals on dry mountain heights, and recognised them as forms or replicas of organisms that had lived in earlier periods of earth's history. He further concluded that in earlier times these mountains must have been submerged in water.

Aristotle (384-322 B.C.) is a name you are familiar with. In addition to being a distinguished philosopher, he was an industrious man of science. In particular, he was an outstanding marine biologist. On the basis of his extensive knowledge of animal forms, he could set up a system of classification. He noted that living organisms may be arranged in a ladder — like linear hierarchy, based on the complexity of their organisation. This notion of the "scale of being" or "scala naturae" (Latin) was to profoundly influence evolutionary thinking in the 18th and 19th centuries. You will agree, however, that merely postulating a scale of being is not the same thing as putting forth a well-founded theory of evolution.

Other thinkers, Greek and Roman, followed. However, their ideas on organic evolution were entirely speculative and so we pass them by.

9.2.2 The Origin of Species according to Genesis

In contrast to the pioneering Greek thinkers, men of the Judaeo-Christian world were inclined to take the biblical story of Genesis as literal truth. According to this doctrine, God created the earth, separated land from water and then proceeded to create in separate acts, Man, as well as all the plant and animal species. All this happened a few thousand years ago — according to one Anglican bishop this was all done in the year 4004 B.C. Ever since their first creation, all living forms have reproduced their own kind and remained unchanged.

Three important ideas are implicit in the story of genesis: (i) the earth cannot be more than a few thousand years old; (ii) as created by God, species are immutable and immortal.

9.2.3 The Post-Renaissance Period

Renaissance was an intellectual movement that began in Italy in the 14th century (A.D.) and slowly spread through Europe over the next two centuries. It influenced just about all aspects of human activity and marked the watershed between medievalism and modernism. Among other developments, it led to a revival of interest in the question of the origin of species. Many adventurous explorers sailed the oceans and brought back exciting news of life in the New World. They talked about the presence there of unusual forms of plants and animals. Even more intriguingly, they noticed the absence of species familiar to Europeans — the horse, for example. It was also disturbing to hear of natives in parts of the New World who appeared to be only slightly 'superior' to apes and who were, in consequence, barely recognizable as human.

Later on, seemingly unrelated developments in the rapidly growing fields of biology and geology eventually converged to give rise to the beginnings of a cogent theory of evolution of living forms.

Take the contributions of that remarkable Swedish naturalist, Carl Linnaeus (1707-1778). He provided the scientific foundation for the idea, that species are not immutable. The outcome of this idea was his system of binomial nomenclature of plants and animals that has won universal acceptance. Ironically enough, late in his career, he began to entertain doubts as to the mutability of species.

A contemporary of Linnaeus, the Comte de Buffon (1707-1788), was equally celebrated and can now be seen as a true forerunner of Darwin. In the first place, he recognised the existence of varieties within a given species and had an explanation for their origin "...... among the numerous families brought into existence by the Almighty, there are lesser families conceived by Nature and produced by Time" True, he adheres to the notion of God-generated species. Nevertheless, he talks about another agency, namely Nature, taking a hand. Nature, acting over a period of time, produces minor variations on the theme of species. Well may we ask: Given the production in nature of varieties, can we not visualise the occurrence, by further differentiation over longer stretches of time, of species from varieties?

Note that "lesser families" is another way of referring to varieties.

The second significant observation that Buffon made was that, underlying the differences in form between families could be noticed a basic similarity of structure. Some years later, his fellow-countryman and younger contemporary, Baron Cuvier, would call this 'the unity of body plan' and make it the basis of his pioneering study of comparative anatomy

Finally, Buffon drew attention to the tendency of animals to increase their kind faster than can be supported by available food supply. He further noted that this results in the death of many and the survival of but a few in each generation. It is of interest to note here that ten years after Buffon's death, Thomas Malthus (1766-1834) published his famous essay on this very theme. His work was raised to the status of a law — the so-called Malthusian Law.

The next figure we want to consider Jean Baptiste de Lamarck is so important that he merits a section all to himself! But before that do the following SAQ.

SAQ 1

Match the items given in Column I with those of Column II.

	Column I			Column II
i)	Aristotle	( )	a)	He gave the system of binomial nomenclature of plants and animals.
ii)	Carl Linnaeus	( )	b)	He was the first one to recognise the varieties that exist within a given species.
iii)	Buffon	( )	c)	God created the earth and various life forms which are immutable and immortal.
iv)	Genesis	( )	d)	He classified the organisms in a linear hierarchy based on the complexity of their organisation.
v)	Anaximander	( )	e)	The sponteneous generation and the first animals, the fish were produced in moisture and provided with spiny skin.

9.2.4 Lamarckism

Fig. 9.1 : Jean Baptiste de Lamarck

Jean Baptiste Lamarck (1744-1829, Fig. 9.1) began as a botanist and wound up as a zoologist. Though his contributions dealt with a range of subjects, he is chiefly remembered for being the first to cogently argue against the immutability of species and for his famous theory that came to be known as Lamarckism.

To Lamarck, evolution was a continuing search for perfection on the part of God's creations. He believed in the Aristotles notion of the scale of being and indeed made it the foundation for his theory of evolution. According to him, life originates all the time as a simple form. It then proceeds to unfold over many generations and, thanks to its own inner drive, achieves complexity. Thus, through a series of intermediate gradations, it ascends [the scala naturae!] to higher levels of organisation.

Lamarck recognised that the physical environment changes with time and so, he argued, the organism is obliged to alter its way of life in order to survive. How does this come about? In the first place, said Lamarck, organisms as a whole as well as their constituent parts, such as organs, show a tendency to increase continually in size. Secondly, with changing environment, needs arise and, in consequence, new organs are brought into being. Thirdly, organs that are in constant use become highly developed; on the other hand, disuse leads to degeneration. Organisms thus respond to changes in the environment by undergoing changes — brought about by slow degrees — in their bodily structure. Every such change, no matter how small, is passed on to the offspring. Cumulatively, the consequence of such **inheritance of acquired characters** over extended periods of time is evolution. This view is referred to as Lamarckism.

Lamarck's classical example of the operation of his principle was the giraffe. According to him, the ancestors of the modern giraffe showed the same proportion of neck and shoulders as any other typical mammal given to browsing on tree leaves. However, with increasing competition for the leaves available in the lower branches, some individuals stretched their necks and shoulders in order to reach leaves higher up in the trees. Given the inheritance of acquired characters, the small gains in each generation eventually built up to the classical long neck and high shoulders of the giraffe. We may, at this point, note that Erasmus Darwin (1731-1802) — the physician grandfather of Charles Darwin, had, independently of Lamarck, arrived at a similar view which he set forth in his "Zoonomia" (1794).

A number of biologists, including Darwin himself, were attracted to Lamarck's theory. However, it is now a discredited theory. This is because it failed to stand the test of rigorous experimental evaluation. The latest attempt to prove the validity of Lamarckism was made by Steele and Gorczynski in the early 1980s and involved the phenomenon of immunological tolerance. Immunological tolerance means that the immune system of an individual is said to be tolerant or unresponsive to their own cells and macromolecules and does not normally attack them or produce antibodies against them. If you were to inject mice with cells from an unrelated donor, a strong immunological response will be evoked in consequence of which the foreign cells will be eliminated from the host's body. Immunological tolerance to these foreign cells can, however, be experimentally induced in the host animals such that these cells are not eliminated. The important point is that such immunological tolerance has to be induced in every individual, every time. Steele and Gorczynski claimed that, following induction of immunological tolerance with one set of mice, they could propagate it through generations, using immunologically tolerant males for breeding. In other words, they claimed to have demonstrated the inheritance of an acquired characteristic — namely, immunological tolerance. Unfortunately, however, this claim could not be independently substantiated by other, equally competent, investigators.

We conclude that, as of today, there is no scientific support for Lamarckism.

9.2.5 The Pioneers of Geology and Pre-Darwinian Evolution

The age of Buffon and Lamarck was also the age that saw the rising science of geology contribute both to the undermining of the tenets of Genesis and to paving the way for a truly scientific understanding of the origin of species. There are two major figures in this story — James Hutton (1726-1797), 'father' of historical geology and William Smith (1769-1839), founder of **stratigraphy.** These two pioneers successfully deciphered the story contained in the earth's crust. Several layers of compacted sediments went to make up the earth's crust. Most of them carried some fossil specimen or the other. Sometimes, the fossils were unique to a particular layer. Often however, the same set of fossils were found repeated in several adjoining layers. Here again, some of these were not absolute repeats. That is to say, while they obviously formed a related series, they did show modifications. The forces that were responsible for what we see by way of the geological sediments are also the ones that change the contours of the earth. Not only they have operated in geological times, they continue to do so today. They have uniformly exerted their effects on earth's crust. What are these forces? They are, amongst many other, i) the sudden unswelling of submerged land to create mountains [remember Buffon!], ii) the subsidence of land below the sea, iii) erosion of land mass due to the action of wind on exposed soil, iv) silting of river beds, and v) transport and deposition of silt into the sea.

The branch of geology which deals with the study of the nature and origin of layered or stratified rocks, their sequence in the earth's crust and their relationships with rocks of similar age but from different locations, is called stratigraphy.

An important corollary of the above uniformitarian interpretation of the geological layers is the notion of a geological time-scale, running into millions of years, in order to account for the phenomena of Nature. This is what interests us, for, as you can readily anticipate, vast amounts of time are a pre-requisite for any theory of evolution of species based on gradual, heritable changes in living organisms.

9.2.6 Baron Cuvier and Comparative Anatomy

Mention has just been made of fossil finds. These consists not only of the shells of marine invertebrates but of land and aquatic vertebrates as well. Identification and interpretation of the vertebrate fossils had to await the birth of the discipline of comparative anatomy. Recall that Buffon had already drawn attention to the underlying similarity of structure among animals that were clearly dissimilar in appearance and habits. Baron Cuvier (1769-1832) brought scientific precision to the study of comparative anatomy. Based on extensive examination of the anatomy of living species, he came to the significant conclusion that, in the animal kingdom, there were but a limited number of body plans. Accordingly, he conceived of four major groups : the Vertebrata, the Mollusca, the Articulata and the Radiata. He also recognized the close correlation between structure, i.e. anatomy, and function. He held that anatomy has to be viewed 'holistically', i.e., in terms of the animal as a whole in relation to its adaptation to the particular environment in which it lives. For example, adaptation to flight in birds calls not only for the modification of the vertebrate forelimbs into wings, but also the spongification of the major bones so as to make them light — and filled with air-sacs — thus enabling the bird as a whole to be flight-worthy. Clearly, no one part can be fitted to perform a particular function unless other related parts also undergo appropriate modification.

It was this conviction, together with this extensive knowledge of the comparative anatomy of contemporary species, that enabled Cuvier to decipher the riddle of incomplete fossil remains. For, very rarely does one encounter the fossilized remains of a complete animal. Many times a picture of the whole animal has to be conjured up from a few isolated bones — even just a single bone! Reminds of you of the method of Sherlock Holmes!

On examining anatomical details in relation to the age of the fossil-bearing rocks, he discovered that there is a "very remarkable succession in the appearance of the different species". It became clear to him that the geologically younger alluvial deposits contained animal forms more similar to contemporary species than those strata representing more remote (geological) epochs. It followed as a corollary that the rocks revealed a gradual advance in the complexity of living forms. You will study more about the fossil records in the next unit.

So, what perspective have we gained by this brief review of pre-Darwinian ideas on the origin of living forms and their possible relationships?

The makings for a cogent scientific explanation gradually fell into place. As yet, however, no one individual had the insight to pull all the seemingly disjointed observations — and speculations — into a cohesive theory. We may summarize them as follows:

1) The age of the earth is to be thought of in terms of a few hundred million years.
2) Species are not immutably fixed, nor are they immortal. Application of the principles of comparative anatomy clearly suggests that within the major categories of the animal kingdom, there is unity of body plan, be it of contemporary or of fossil species. At the same time, variations on the basic theme are also evident. The stratigraphic layers of the earth's crust exhibit fossil remains suggestive of increased complexity of form with the passage of time.
3) The concept of diversification of species through transmutation is considered a distinct possibility — atleast by some.
4) The Lamarckian theory of inheritance of acquired characters appears to be the closest anyone came to providing a mechanism for such transformations.

Before we proceed further to discuss Darwinism, try the following SAQ to check upon your progress.

SAQ 2

a) Can acquired characters be inherited? Support your answer with an example.

....

....

....

....

....

....

b) Fill in the blanks with appropriate words from the text.

i) The forces responsible for the formation of sediments acted .... on earth's crust.

ii) Baron Cuvier held the view that there existed a .... between structure and function of living organisms.

iii) Fossil remains in the stratigraphic layers of earth's crust show .... of forms with the passage of time.

iv) Unity of body plan within the major categories of animal kingdom is suggested by the studies of ....

9.3 DARWINISM

Towards the end of the last section (9.2), we concluded that the essential ingredients for an acceptable theory of the origin of species were all available and only needed an individual with the requisite insight to pull all the seemingly unrelated observations and speculations into a well knit story. We have all heard the saying, 'the hour produces the man'. Such a man was Charles Darwin (1809-1882, see Fig. 9.2)

Charles Darwin was born into a well-to-do upper middle class family — which meant that he did not have to work for a living! It was expected that he would follow the family tradition and become a physician. Accordingly, he was sent to Edinburgh to qualify in medicine. While there, however, Charles evinced little interest in his career, but fell, instead, into the company of naturalists. When, later, his father was willing to let him train for priesthood, he moved to Cambridge. Here, again the formal courses of study interested him the least. He once again cultivated the company of naturalists, in particular. Adam Sedgwick, the geologist and Dr. J.S. Henslow, the botanist. It was, in fact, the latter who secured for him the post of naturalist on board the H.M.S. Beagle on its voyage around the world. The saga of Darwin's tour of duty on this vessel is an oft-told and well-known story!

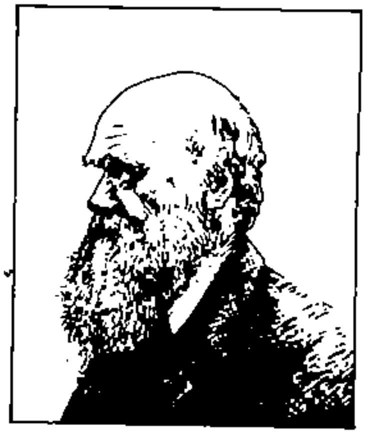

Fig. 9.2 : Charles Robert Darwin

9.3.1 Darwinism : The Basic Tenets

Darwin based his theory of evolution on five observable facts of Nature and three deductions from them.

Fact No. 1:

The observation that offspring, in the early stages of their existence, are always more numerous than their parents suggests that all organisms tend to increase their numbers in an exponential manner.

Fact No. 2:

In spite of this tendency to progressive increase, the number of individuals in a population of a given species remains more or less constant.

Fact No. 3:

Natural resources are limited and tend to remain constant in a stable environment.

Inference No. 1:

Since more individuals are born than can be supported by the available resources and since the size of the population remains stable, there must, quite evidently, be a "struggle for existence". In less colourful terms, this means competition for available resources. Such a competition among the individuals of a population results in the survival of only a part — often, a very small part—of the progeny of each generation.

Fact No. 4:

No two individuals in a given population are identical; that is to say, every population displays considerable variability in the characteristics of its individuals.

Inference No. 2:

From the perspective of the struggle for existence, some of these variations will be advantageous, others unfavourable. Consequently, a higher proportion of individuals with favourable variations will, on average, survive — whereas a higher proportion of those with unfavourable variations will die, or fail to leave progeny. This unequal survival is the process of natural selection.

Fact No. 5:

Much of the variation mentioned above is heritable.

Inference No. 3:

Thus, natural selection, in the short run, will act constantly to improve — or, at the very least, maintain — the adjustment or adaptation of animals and plants to their surroundings and their ways of life. In the long run, i.e. over several generations, given the heritable nature of most variations, the process of **differential** (i.e. unequal) survival through natural selection will result in a **continuous** and **gradual** change in the characteristics — morphological, physiological — resulting in the production, i.e. in the evolution, of new species. The following summary statement puts it succinctly : "Evolution is descent with modification through variation and natural selection"

9.3.2 The Significance of Darwin's Contribution

"In considering the Origin of Species, it is quite conceivable that a naturalist, reflecting on the mutual affinities of organic beings, on their embryological relations, their geographical distribution, geological succession, and other such facts, might conclude that species had not been independently created, but had descended, like varieties, from other species", sums up best what it is of significance that he himself contributed to evolutionary thinking. It is true, as Darwin points out, that any naturalist could have deduced, on reflection, the phenomenon of organic evolution. But then, nobody did! Others before him had eyes only for one facet or aspect of the problem. A Cuvier could interpret data from comparative anatomy. A Lyell could read the story written in fossils. But it took a Darwin for the crucial synthesis of information from several independent lines of study. As Richard Leakey remarks: "Darwin brought many different kinds of information to bear on the question of evolution; among them: heredity and variation, fossils, geological formations, geographical distribution, embryology, taxonomy and homology .... it was Darwin who first showed us where to seek evidence for evolution".

How could he accomplish all this? The first hints, surely must have come from what he read in his grandfather's "Zoonomia". Then there was the influence of his Edinburgh friends and Cambridge mentors that set him on the path of field studies in natural history and geology. There was Lyell's "Principles of Geology" that he enjoyed studying at leisure on board the Beagle. Clearly, his was a "prepared" mind which could then assimilate all that he saw and experienced during that protracted sea voyage. His observations were not limited to any single field. He was geologist, palaeontologist, zoogeographer, ecologist — all rolled into one! Consider also his own experiments — on his return to England — on breeding pigeons and his extensive conversations with farmers and animal breeders. And think of the years (about twenty!) he took to putting down all he knew and "mulling" over them.

Of course, he did not stop with showing us where to look for evidence of organic evolution. He went further. His insight provided the answer to the all important question of "how?". And the answer was : through natural selection acting on heritable variations.


Fig. 9.3 : Alfred Russel Wallace

In fact, Darwin took so long over setting forth his ideas that he was almost 'second'. There was this younger contemporary of his, Alfred Russel Wallace (1823-1913, Fig. 9.3). He was known to Darwin with whom he had extensive correspondence. In later years, when he had returned to England for good, he became a friend, admirer and ally. Thanks to his correspondence, he was aware that Darwin was engaged in unravelling the mystery of the origin of species. However, he had no idea exactly how far the latter had proceeded. While on an extended tour (spanning eight years!) of the Dutch East Indies as a naturalist collecting specimens, he also was pondering over the same riddle. Amazingly enough, he came to the same conclusion: natural selection is the 'force' behind the evolution of species.

It was his paper, written while in the East Indies, describing his ideas, that galvanized Darwin into action. Wallace had forwarded the paper to him with the request that it be communicated to the Linnaean Society of London. Faced with this situation, Darwin — on the advice of his friends — wrote up a summary of his own work. By prior arrangement, both papers were read in the same meeting of the Society. Thus both Darwin and Wallace received equal credit. If, nevertheless, Darwin's name alone is associated with the thesis that evolution is descent with modification through variation and natural selection and is the means whereby species originate, it is in recognition of his systematic and thorough treatment of the subject. He meticulously considered every aspect, weighed all of the available evidence — even if some of it went against his thesis—and, most important, was honest enough to admit weaknesses in his arguments or evidence.

One such was the question of how heredity worked. Not knowing the answer to it meant not being able to account for heritable **variations**, so important to Darwin's scheme. Darwin held conflicting views on this vital question, unable to make up his mind between Lamarckism and his own highly speculative "*pangenesis*"

To repeat what was stated earlier, Darwin's crucial insight was that he could look into the role of natural selection as the agent of evolution. The gradual, cumulative effect of natural selection acting on small, heritable variations is speciation. When spread over the geological time-scale, the same mechanism would account for variability and involve the higher taxonomic categories.

SAQ 3

State whether the following statements are true or false. Write your answers in the space provided.

i) It is a fact that all organisms tend to increase their numbers in an exponential manner. ( )

ii) Competition among the individuals of a population results in the survival of the entire progeny in each generation. ( )

iii) Every population displays considerable uniformity in the characteristics of its individuals. ( )

iv) Much of the variations exhibited in living systems is heritable. ( )

v) Lamarck was the author of the 'Theory of Pangenesis' ( )

9.4 NEO-DARWINISM AND THE MODERN SYNTHESIS

In his life time, Darwin's thesis that species evolved gradually over vast spans of time, found fairly ready acceptance. That was not the case, however, with his concept of the key role of natural selection in the evolution of species. There was a good reason for this. Since natural selection is crucially dependent upon the availability of heritable variations, there was a clear need for a credible mechanism of heredity. For, if we do not know how heritable traits are passed on from one generation to the next, we cannot explain how such traits can vary. In modern terminology, if we have no clue as to the nature of genes we cannot understand how they mutate. As pointed out earlier, Darwin was totally in the dark in this matter. Consequently, his notion of natural selection came in for criticism.

It is one of those ironies in the history of science that while the answer to Darwin's dilemma was actually available in his own life-time, neither he nor any of his peers was aware of this. John Gregor Mendel (1822-1884) had the misfortune of publishing his work on the garden pea in an obscure journal and was, in consequence, lost to view, till unearthed in 1900.

9.4.1 Mendelism and Darwinism

Since Darwin had no knowledge about the mechanism of inheritance nor had he access to Mendel's findings, he was forced to rely upon the Lamarckian view of inheritance of acquired characters. In 1880, August Weissman made clear distinctions between somatoplasm and germplasm and showed by his experiments that heredity always moves from germplasm to somatoplasm and never backwards. G.G. Simpson in 1949 designated Weissman's idea as Neo-Darwinism. The rediscovery of *Mendelism,* as the laws of inheritance discovered by Mendel came to be known, did not immediately provide the Darwinists with the solution to their dilemma. Hugo de Vries (1848-1935), one of the three scientists instrumental in rediscovering Mendel, argued that the Mendelian mode of particulate inheritance of individual characters cannot provide the basis for the gradualistic evolution of species. This is because mutations in the genetic factors is saltatory, i.e. they are abrupt. How can abrupt changes in the genetic determinants ensure smooth and gradual changes in the characteristics of a population so as to lead to speciation?

It is characteristic of Darwinism that the basis for progressive speciation — in other words, evolution — is change occurring at the level of populations, not individuals.

Fig. 9.4 : Theodosius Dobzhansky

True, heritable variations, i.e. mutations in Mendelian genes, occur only in *individuals* and influence their fate in the "struggle for existence". The consequences of natural selection, on the other hand, are seen at the level of the population. Clearly, therefore, application of Mendelian genetics to populations is the only logical way of combining the insights of Mendelism with those of Darwinism. The focus has to shift from the consequences to the individual of mutations to the frequency of distribution in a population of the mutation-derived allelomorphs of a given gene — as well as changes in such frequencies following natural selection. This, precisely, is the concern of *Population Genetics*, a discipline initiated and promoted by mathematically inclined evolutionists. What happens with such an approach is that even though mutations are admittedly saltatory, their consequences at the level of populations are not abrupt and jerky, but smooth and gradual. To the population geneticist, evolution is simply a question of shifts in gene frequencies within populations.

Between 1930s and 1940s more specifically in 1937 with the publication of "Genetics and Origin of Species" by Dobzhansky the era of the modern synthesis was born. Dobzhansky (see Fig. 9.4) showed that experiments could be conceived and executed to explain natural selection.

Allopatric species refers to a population or species living in a geographic area as distinct from another populations or species. This term is antonym to the sympatric species which refers to two species or populations occupying the same geographic locality.

Simultaneously, Ernst Mayr (see Fig. 9.5) through his book — Systematics and Origin of Species' in 1942 defined the term species precisely and showed that the allopatric speciation was the common means of species formation. Mayr's definition of species is that they are the members of an aggregate group of populations that interbreed or potentially interbreed and are reproductively isolated. This is the most widely accepted definition and to date there has not been any alternate definition for the term nor any alternate explanation for the speciation phenomenon.

The third significant contribution to the modern synthesis was from palaeontologist G.G. Simpson (see Fig. 9.6) and his books — 'Tempo and Mode in Evolution' — published in 1944 and the 'Major Features of Evolution' published in 1953.

Dobzhansky, Mayr and Simpson were, thus, the chief architects of this modern synthetic theory of evolution and are come to be known as the trinity of evolutionary biology. Besides, the trinity there were others who contributed to the modern synthetic theory. Ronald. A. Fischer and J.B.S. Haldane in England and Sewall Wright from USA largely contributed to the mathematical theory of gene frequency changes under natural selection and pointed out that slight selective differences could bring about evolutionary change. Julian Huxley in his book 'Evolution: The Modern Synthesis' provided a comprehensive account of synthesis between genetics and systematics. G.L. Stebbins in his book 'Variation and Evolution in Plants' argued that the neo-Darwinian principles of genetic change accounted not only for the origin of species but the higher taxa as well. One major accomplishment of neo-Darwinism and the Modern Synthesis, therefore, is the integration of Mendelian analysis of heredity into evolution through its application to populations.

Fig. 9.5 : Ernst Mayr

The question that has often being asked is whether the synthetic theory is different from the Darwinian concept of natural selection. E. Mayr denies this emphatically and says, "synthesis was not a revolution on its own, but simply the final implementation of Darwinian revolution". In the following sub-section we briefly discuss the events that occurred between the discovery of Mendel's laws and the emergence of the molecular biology.

9.4.2 The Chromosome Theory of Heredity and Darwinism

Even as students of population genetics were busy applying Mendelian genetics to Darwinism, important developments were taking place in another area that would provide the physical basis for the phenomenon of heredity. Cytologists discovered the chromosomes and described their characteristic behaviour during mitosis and meiosis. It thus became logical to place the determinants of Mendelian particulate inheritance — the genes — on chromosomes. You are familiar with the "beads-on-a-string" model of the organisation of genes on chromosomes. The crucial evidence linking genes with chromosomes was provided, in a series of remarkable studies, by Thomas Hunt Morgan and his students.

Two important consequences for Darwinian evolution that flow from the chromosomal theory of heredity concern us here. In the first place, while mutations of genes are the only source of heritable variations, the large 'pool' of variability generally found associated with populations is the result of the 'shuffling' of genes by recombination that takes place during meiosis, when segments of chromosomes are exchanged between partners. You realise, of course, that the greater the pool of variability in a population, the greater is the scope for the action of Darwinian natural selection.

An equally significant advance that we owe to the chromosomal theory of heredity is the realisation that the term mutation must be extended to cover more than the random heritable changes associated with the genes, including gene duplication. We now know that chromosomal translocations, deletions, inversions and duplications, all have significant phenotypic consequences that provide a basis for the action of natural selection. In fact, duplication of the entire set of chromosomes (polyploidy) as well as of one or more individual chromosomes (aneuploidy) have played important roles in the evolution of plants.

Fig. 9.6 : G.G. Simpson

9.5 FROM THE MODERN SYNTHESIS TO MOLECULAR GENETICS

Increased understanding of the role of genes as determinants of heritable traits inevitably followed the complete working out of the chromosomal theory of heredity. Such an advance was considerably aided by relating genetics with another young discipline : biochemistry. Thus was born *biochemical genetics*, in which the activities of the gene are sought to be understood in biochemical terms.

9.5.1 Biochemical Genetics and Evolution

The most significant contribution of the new discipline is undoubtedly the one-gene-one enzyme theory put forward by Beadle and Tatum on the basis of their pioneering work using the bread mould, *Neurospora crassa.* This theory has now been more broadly generalised as the 'one-gene-one-polypeptide' theory, since not all proteins are enzymes. There are nuances to this concept that we cannot go into here. However, a corollary that concerns us is that the immediate phenotypic consequence of gene expression is a protein.

What should appeal to you, right away, as flowing from this concept, is that just as anatomical and embryological relationships and differences have been exploited to document organic evolution and also erect phylogenetic trees, it should be possible to compare the structure of proteins — i.e. look at the ordering of their constituent amino acids — serving the same function in different organisms to seek evidence for their 'evolution'. Indeed, this has been an active area of research as you shall find in the next Unit.

9.5.2 'Molecular Evolution'

Molecular evolution came into existence as you can readily see, with the advent of the study of the aminoacid sequences — what is called the primary of structure — of proteins, mentioned above. With the establishment of the structure of the gene and followed by methods for sequencing DNA molecules, it became possible to examine the architecture of genes themselves and their evolution, rather than at the products of their expression, namely the proteins. In more ways than one, this is an important and significant advance. For one thing, looking at the evolution of genes is not quite the same thing as examining the evolution of proteins. The reason is simple. Proteins are products of expression of structural genes. And structural genes, especially in higher organisms, account for a small percentage of the total DNA content. Thus the study of the evolution of DNA sequences is a pursuit that can be justified in its own right and important advances, of consequence to our concept of organic evolution have resulted from such studies.

SAQ 4

Tick mark (√) the correct alternative in the following sentences:

i) Population genetics is concerned with changes in the gene frequencies in population/smooth and gradual changes in the characteristics of populations.

ii) Systematics and Origin of Species was authored by Theodosius Dobzhansky/Ernst Mayr. ( )

iii) Immediate phenotypic/genotypic consequence of gene expression is a protein. ( )

iv) The science of the understanding of the activities of gene in biochemical terms is known as molecular evolution/biochemical genetics. ( )

v) The crucial evidence of linking genes with chromosome was provided by Morgan/Beadle. ( )

9.6 CHALLENGES TO DARWINISM

In sixties even as the molecular genetics was making a big breakthrough in the very fine degree of the resolution of gene using such techniques as nucleotide sequencing and aminoacid sequencing there were challenges to the synthetic theory of evolution from molecular geneticists. They were discovering in the genomes of humans and other organisms very many sequences of nucleotides duplicated several thousand times but without any function. Such functionless and meaningless duplications of genes went on to suggest that such actions were not under the influence of natural selection. The molecular geneticists further said that several of the mutations were neutral and had no impact on the survival of organisms. This theory known as neutralists theory proposed that the large measure of evolutionary process did not require the action of natural selection. It was later explained by the protaganists of natural selection theory that the claim of molecular geneticists was not true since the neutralists mistake the average rate of evolution to be a constant rate.

In seventies the synthetic theory was challenged by palaeontologists led by S.J. Gould. They suggested that the fossil record revealed that evolution had occurred in spurts punctuated by long periods of equilibrium or stasis. The concept known as punctuated equilibrium suggested that evolution occurred in jerks contrary to the phyletic gradualism proposed in modern synthesis. G.G. Simpson explained with his model of adaptive grid that organisms pass through during course of evolution narrow and broad adaptive zones, with non-adaptive zones intervening. Organisms entering into narrow adaptive zone are subject to intense natural selection — the period of apparent stasis. Therefore the periods of stasis were also the periods when natural selection acted. Thus, the modern synthetic theory of evolution has withstood the challenges posed by different disciplines and it could not be falsified.

Although, Darwin spoke very little about human evolution, it does not mean that Darwin treated the evolution of man very different from those of other animals. Darwin prophetically said 'light will be thrown on the origin of man and his history'. In fact, during Darwin's time no human fossils worth their names were yet discovered. But since 1920s there has been a rich collection of fossils mostly from Africa. These fossils have traced the human history to the ape like ancestors. Thus, the modern synthetic theory of evolution offers most plausible solutions to the various problems posed by evolutionary biology. Evolution is a continuous process. The question often asked: after human evolution what is next? The answer may not be simple but definitely greater attempts will be made to have a more deeper and richer understanding of the contemporary evolutionary process. Then our understanding of evolution may improve further.

9.7 CREATIONISM

Today, science is a universal endeavour and scientists take pride in the fact that science knows no national barriers. The fact remains, however, that it is very much a product of western civilisation and has its roots in the intellectual movement that has come to be known as Renaissance (see 9.2.3). It is not surprising, therefore, that at every stage in its development, it came into conflict with established Christian theology. Galileo (1564-1642), the celebrated astronomer who, on the basis of his own observation, supported the Copernican heliocentric view of the solar system, had to recant when he was declared a heretic and thus ran the risk of being burnt at the stake. At the same time, there were outstanding scientists who were also genuinely pious and found no conflict between science and religion. Sir Isaac Newton (1842-1727) — an all-time great, as a scientist—saw God as presiding over and setting in motion the mechanics of cause and effect governing the Universe.

Given this setting, you can readily understand the twists and turns that evolutionary thinking underwent over the centuries. Pious naturalists were shocked by the mechanistic conclusions to which their observations led. Others, not so committed to religious orthodoxy, had yet to be cautious in their statements for fear of reprisals — from the church or the believing lay public. Such was the hold of the Church, and echoes of that are still to be heard today in what is being propagated, in parts of the Western world, as creationism.

The doctrine of creationism has itself undergone 'mutations' in efforts to meet the challenges of well-documented scientific evidence supporting Darwinian evolution. Indeed, there are now, in some of the Western nations, educational institutions wholly dedicated to propagating the creationist view and doing research in support of it. One measure of the extent of their influence is their success in having legislation passed in some of the southern states of the United States of America that compels high school teachers to devote equal time to expounding creationism as well as Darwinism. Without detailing the creationist controversy in all its pros and cons, we shall here summarise the essence of the situation. We may classify Christian thinkers for and against the mechanistic view of evolution into four categories.

I. The Confirmed Evolutionists

Who uphold Darwinism and therefore consider that organic evolution has indeed occurred, that its course has been decided purely by chance — *remember,* mutations are unpredictable! — and that the process has to be measured in terms of millions of years. In other words, these are scientists who do not believe in "mixing" science and religion.

II. The Theistic Evolutionists

Who subscribe heartily to the above mechanistic view but add the significant rider that it was so designed and set in motion by God.

III. The Avowed or Openly Confessed Creationists

Who affirm that everything was created by Divine 'fiat' and came into being no earlier than a few thousand years ago. According to them, fossil-containing stratified rocks are merely evidence of a global catastrophe that occurred in Noah's time.

IV. A fourth and final view is that we have no way of knowing precisely how God ordered the world in the geological past, prior to the advent of Man — whether by 'fiat creationism" or by something resembling Darwinian evolution. Furthermore, somehow, somewhere along the line, 'something went wrong' that excited the wrath of God and this brought that older world to a catastrophic end. This was followed by re-creation at a fantastically speeded-up pace that literally took only six days. As a consequence, the world was restructured so as to provide the proper setting for that star of Creation — Man.

Given the basic philosophical foundations of science as we know and practice it today and taking into account the tools of science, we shall here admit that, as students of science and the scientific method, we have no means of assessing the relative merits and shortcomings of alternatives II to IV above, for they call for metaphysical considerations. Therefore, we shall pass no judgement, but conclude with the following quotation that characterizes the attitude of a distinguished Indian physicist whom, perhaps, we may do well to emulate:

> "Creative thinkers like Krishnan .... carry out their inner *dharma* unperturbed by changing fashions, ... (and) explore the explorable and quietly venerate the inexplorable."

Prof. (Sir) K.S. Krishnan, was the first Director of the National Physical Laboratory, New Delhi.

SAQ 5

a) Comment briefly on the following:

   i) Neutralists' theory of evolution.

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ii) Punctuated equilibrium.

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b) Having gone through this unit, do you think that the life could have been created on this planet earth?

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9.8 SUMMARY

In this unit you have studied that:

- The evolutionary thought existed in the pre-Christian era and most of the pre-Darwinian evolutionary thoughts linked the idea of evolution to the supernatural powers.
- The contributions of pre-Darwinian intellectuals such as Linnaeus and Buffon provided the scientific foundation for the idea that species are not immutable.
- Lamarck, another pre-Darwinian zoologist was the first one to bring the theory of evolution under a conceptual scheme of science, although his laws of use and disuse and inheritance of acquired characters could not be verified and therefore, discredited.
- The study of evolution was revolutionised by the publication of the 'Origin of Species' by Charles Darwin in 1859 and his idea of descent with modification caught the attention of the contemporary scientific community.
- The rediscovery, of Mendel's work in 1900. the germplasm theory of August Weismann in 1880s and the birth of Modern synthesis between 1930 and 1940 have all made the theory of natural selection a reality.
- The creationists presented their view of the origin of species and advocated that the earth and the life were created by a Divine 'fiat'.

9.9 TERMINAL QUESTIONS

1) Critically evaluate the Lamarckian concept of evolution.

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2) What do you understand by the term struggle for existence?

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3) How do biochemical genetics helped in the understanding of the evolutionary process?

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4) What do you understand by the term Modern synthesis?

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9.10 ANSWERS

Self-assessment Questions

1) i) d, ii) a, iii) b,
iv) c, v) e

2) a) The theory put forth by Lamarck that acquired characters can be inherited is now a discredited theory and has no scientific support. One example can be of holes made in the ears of Hindu women from generation to generation but never a girl child is born with holes in her ears. If Lamarckism were to be true then the children of the soldiers who lost their limbs in wars should also be born without limbs.

b) i) uniformly
ii) close relationship
iii) increased complexity
iv) comparative anatomy

3) i) T, ii) F, iii) F, iv) T, v) F

4) i) Change in gene frequencies in populations,
ii) Ernst Mayr
iii) Phenotypic
iv) Biochemical genetics
v) Morgan

5) a) i) The neutralists' theory stated that since many sequences of nucleotides are found duplicated several thousand times in our genomes without any specific function, it could be that such functionless and meaningless duplication of genes were not under the influence of natural selection.

ii) The concept of punctuated equilibrium theorised that the fossil records reveal that evolution has occurred in spurts punctuated by long periods of equilibrium or stasis.

b) The student can write his own opinions by way of answer to the question.

Terminal Questions

1) The Lamarckian laws of use and disuse and the inheritance of acquired characters are untenable propositions. The repeated use of any structure cannot result in adaptation. For example the green colour of the insect that escapes predation is a clear case of adaptation, but how can an insect practise becoming green by sitting on a green tree. Likewise if acquired characters were to be inherited, then effects of malnutrition and mutilations would accumulate in population.

2) The struggle for existence as perceived by Darwin refers to the competition among the individuals of a species for the limited resources of the environment. The competition is a test to the variations in the traits of the organisms. Such of those traits which are useful to the organisms in a given environment are deemed to be adaptations.

3) The biochemical genetics came into prominance with the proposal of one gene one enzyme hypothesis of Beadle and Tatum which was subsequently modified as one gene one polypeptide theory. Through biochemical genetics it should be possible to compare the structure of proteins and the sequence of amino acids serving the same functions in different organisms to seek evidence for their evolution.

4) The modern synthetic theory of evolution developed between 1930 and 1940 brought out the importance of natural selection based on the contributions of genetics, systematics and palaeontology. The geneticists clearly showed that the acquired characters are not inherited and genes regulate the phenotypic effects of the organisms. The systematists provided evidence that variations within and among the geographic races had a genetic basis and the palaeontologists provided evidence that the fossil data were fully consistent with Darwinian theory.

UNIT 10 THE EVIDENCE FOR EVOLUTION

Structure

10.1 INTRODUCTION

The history of the development of the idea of organic evolution was traced in Unit 9. You learnt therein of Darwin's theory that evolution is a process of descent with modification brought about by natural selection acting on heritable variations. As of today, Darwinism provides the most convincing explanation for Nature's immense living diversity. However, direct demonstration that organic evolution has indeed occurred during the lifetime of an individual is not possible. The reason is simple. Speciation through evolution takes place on a time scale that is so much vaster than the life-span of an individual. Consequently, no one individual can observe an evolutionary phenomenon from start to finish. Therefore, scientists have brought in indirect evidence from a variety of disciplines that, taken together, support the thesis that evolution has in fact occurred. Palaeontology, biogeography, comparative anatomy, developmental biology, physiology and biochemistry have all contributed to support the concept of organic evolution and it is these aspects that we shall be examining in this unit. In the next unit you will be introduced to the theory of natural selection, as proposed by Charles Darwin, which explains the process of evolutionary change.

Objectives

At the end of your study of this unit, you should be able to:

- relate the presence of fossils on the earth's crust to the occurrence of organic evolution ; in particular to piece together the major events that took place during the evolution of plants and animals,
- link the geographical distribution of various species of contemporary plants and animals to the course of evolution,
- discuss the concepts of homology and analogy and their significance for correlating structure and function as influenced by evolution,
- describe the contributions of developmental biology to the evolutionary argument, leading to generalisations such as Haeckel's and von Baer's laws, and
- explain evolution from the stand point of physiology and biochemistry.

10.2 THE GEOLOGICAL RECORD

Our interest in the geological record is owing to the preservation in the earth's crust of living organisms from ages past in the form of fossils. To correctly interpret the significance of fossils we need to know some basic facts about how this record was built up. We will, therefore, briefly review a few elementary concepts of geology.

One of the outstanding accomplishments of the founders of modern geology, was to establish the great age of the earth. Rock formation has been going on since the birth of this planet and fossilisation has been taking place since the advent of life. Rocks are formed as a result of various geological processes such as erosion, wind action, submergence, elevation, volcanic activity, transportation, physical weathering and climatic changes. In the course of such processes mud, sand or stones are transported to the floor of depressions, lakes or oceans and accumulate there. Sometimes various organisms also die and get buried at the bottom of such water bodies. Material so deposited later becomes compressed and solidified, forming layers or strata of the rocks entrapping the remains of life in the form of fossils. Examination of the nature and distribution of stratified rocks enables the construction of the geological history of the area from which the rocks were obtained. By analysing the rocks it is also possible to discover the environmental conditions under which they were formed and also estimate their age.

How do we determine the age of rocks? Geologists use two methods to date rocks : **relative dating** and **absolute dating**. You are going to read about these methods in the following sub-sections:

10.2.1 Relative Dating

The position of rocks in the strata or successive layers is the principle underlying the process of relative dating. Sediments carrying with them the remains of plants and animals slowly settle in the oceans and other large bodies of water. At the bottom, they are gradually compacted into layer upon layer of rock. Of the sedimentary rocks which remain undisturbed, the deepest strata should be the oldest and the most superficial the most recent. However, there are complications. Although all strata are originally deposited sequentially in horizontal layers, deformation may take place later, tilting or even overturning the strata. Therefore, other criteria such as grading of rock beds need to be applied. By grading we mean that thick or fine-grained strata are formed as a result of a long and continued deposits and thin or coarse-grained strata are formed due to short periods of depositions. Thus, the strata of rock give some insight into the ages of rock deposits, but because rates of sedimentation are variable, only relative estimates are possible. William Smith, who was mentioned in Unit 9, was a civil engineer who worked out the principles of relative dating.

An astute observer of the rocks through which he dug, Smith noticed that different strata were characterised by different sets of fossils. Older strata lying below and younger strata lying above a given horizon had different fossils. With this discovery it became possible to recognise the age of rocks which were miles away from familiar localities and even when the rock type was changed — because the fossils were the same. Particular fossils are never repeated in the earth's history — once an organism is extinct, it never returns. Thus you can understand the role of fossils and the superposition of layers in estimation of the age of the rocks. Let us now discuss how the absolute age of rocks is determined.

10.2.2 Absolute Dating

The absolute age of rocks and fossil deposits can be estimated by radioactive dating. This method is based on the fact that, radioactive isotopes present in earth's crust decay into stable, nonradioactive elements at a well defined and constant rate. Thus, they form the radioactive clock, which can tell time.

Radioactive dating, also called radiometric dating, is based on the fact that each radioactive isotope has a characteristic 'half-life' Half-life is the time taken for one half of a given quantity of a radioactive isotope to decay. For example, the half-life of uranium 238 is about 4.5 billion years. So in the course of this time only half the molecules of a given amount of uranium will break down forming lead and helium.

The final decay product of uranium 238 is lead with an atomic weight of 206. Thus, by measuring the proportion of the parent radioactive material to the decay product in a rock sample, scientists can calculate the absolute age of the specimen.

The other isotopes used for radiometric dating include potassium-40 and carbon-14 Radioactive potassium and its final decay product argon are more abundant than uranium and are, therefore, more widely used. Dating with radioactive carbon can also be used for any carbon containing (organic) material. Living organisms utilise a small, but constant proposition of their organic carbon in the radioactive form. The half-life of radioactive carbon is 5,760 ± 30 years. Hence, remnants of bone, wood, or other carbon-containing remains of dead organisms can be assayed for their radiocarbon content. The difference between the average amount in fresh tissue and in the fossil may then be attributed to radioactive disintegration and the age of the fossil calculated from the known half-life.

Some rocks underwent melting during their formation. Such rocks are called igneous rocks. Many igneous rocks do not contain any fossils but do contain potassium or other elements that can be dated radiometrically.

With the availability of various techniques for dating rocks it has thus become possible to determine their age, and of fossils contained therein in the range of a hundred thousand to a few million years. In the next sub-section we will discuss the geological time scale but before that try the following SAQ.

SAQ 1

Fill in the blanks with appropriate words from the text.

i) .... of rocks in the strata is crucial to the process of relative dating.

ii) .... are the tools to recognise the age of rocks located distantly.

iii) With the advent of technology using .... absolute dating of rocks has become possible.

iv) Age of the fossils with an organic content in them can be determined by the use of ....

10.2.3 The Geological Time Scale

Based on stratigraphical data, palaeontologists have established a geological chronology and divided the age of the earth into different **eras, period** and **epochs.** They have been able to estimate the relative lengths of the various geological periods in terms of millions of years. The fossil record obtained from different strata tells us the time when the major groups of organisms appeared. It also gives us an idea of the possible ancestors and close relatives of some of the modern species.

The eras, periods and epochs are arranged on the time scale in order of their age and this arrangement is called the **geological time scale**. This is summarised in Table 10.1. A perusal of the table reveals many facts of evolution. It shows that the inhabitants of a given period are descended from only a part and not all of the inhabitants of an earlier period. It also indicates that many species and genera disappeared from the scene without leaving any descendents, i.e. they became extinct.

Table 10.1 : Life through the Geological Time Scale

Era	Period	Epoch	Time from beginning to present (Millions of years)	Geological Conditions	Biological Features
Cenozoic (Era of Modern Life) (Age of Mammals)	Quarter-nary	Recent	0.025	End of 4th ice age, climate warmer	Modern man, mammals, birds, fishes, insects.
		Pleistocene	1	Four ice ages, climate cold and mild	Extinction of great mammals; Primitive man common.
	Tertiary	Pliocene	10	Volcanic activity, climate dry and cool	Emergence of man from man-like apes; Formation of modern mammals.
		Miocene	25	Development of plains and grasslands, climate moderate	Mammals at peak, First man-like apes formed.

Table 10.1 (Contd.)

Era	Period	Epoch	Time from beginning to present (Millions of years)	Geological Conditions	Biological Features
		Oligocene	40	Mountain building, climate mild	Extinction of archaic, mammals. Rise of first monkeys and apes, and ancestors of modern mammals.
		Eocene	60	Mountain erosion, heavy rainfall, climate warmer.	Diversification of placental mammals.
		Palaeocene	70	Mountain building, climate cool to moderate	Dominance of archaic mammals; rise of first primates, placental mammals and modern birds.
Mesozoic (Era of Medieval Life)	Cretaceous		135	Spread of inland seas and swamps, Mountains (Andes, Himalayas, Alps, Rocky, etc.) formed.	Extinction of giant reptiles and toothed birds; Rise of first modern birds; Archaic mammals common.
	Jurassic		180	Continents fairly high, shallow seas over part of Europe and USA	Rise of first toothed birds; Reptiles dominant; Dinosaurs became large.
(Age of reptiles)	Triassic		230	Continents elevated, widespread deserts	Rise of first dinosaurs and egg laying mammals; Extinction of primitive amphibians.
Palaeozoic (Era of Ancient life)	Permian		270	Rise of continents, increasing glaciation, cool dry climate	Extinction of many marine invertebrates; Rise of modern insects, spread of reptiles.
(Age of Amphibians)	Carboniferous		350	Increase in inland seas and mountains, climate first warm later cool.	Origin of reptiles and winged insects; spread of sharks and amphibians; crinoids at peak.
(Age of Fishes)	Devonian		400	Formation of inland seas and mountains, lands higher	Origin of amphibians and forests; fishes abundant.
	Silurian		440	Rise of lands, relatively flat continents, climate mild	Origin of jawed fishes and wingless insects; invasion of land by arthropods and plants.
(Age of invertebrates)	Ordovician		500	Submergence of lands, expansion of oceans, climate warm even in arctic	Origin of vertebrates (jawless armoured fishes); invertebrates abundant.
	Cambrian		600	Lands low, climate mild	All invertebrate phyla established; trilobites and brachiopods dominant.
Proterozoic (Era of Early Life)			2,000	Great sedimentation, volcanic activity, extensive erosion, repeated glaciation, climate warm-moist to cool-dry	Origin of simple marine invertebrates without shell; scanty fossils.
Archeozoic (Era of Primitive life)	Precambrian		3,600	Great volcanic activity, some sedimentation, extensive erosion	Origin of life; no recognizable fossils.

10.2.4 Fossils

The most convincing and direct evidence for evolution comes from the study of fossils. Fossils are records of organisms of the past, preserved by burial in rocky layers. A fossil may be the product of preservation of an entire organism or of a part. The organism itself may be dissolved away, leaving **a natural mould;** or the mould may be filled with desposited material, forming a **natural cast**. Sometimes a fossil may be a mere animal **footprint** or the **imprint** of a leaf on the rock. Fossils which only represent an activity characteristic of an organism are called **trace fossils.** Some examples of trace fossils are tracks or trails, burrows and also 'fossil dung' In Fig. 10.1 a, b & c you can see some examples of fossil records.

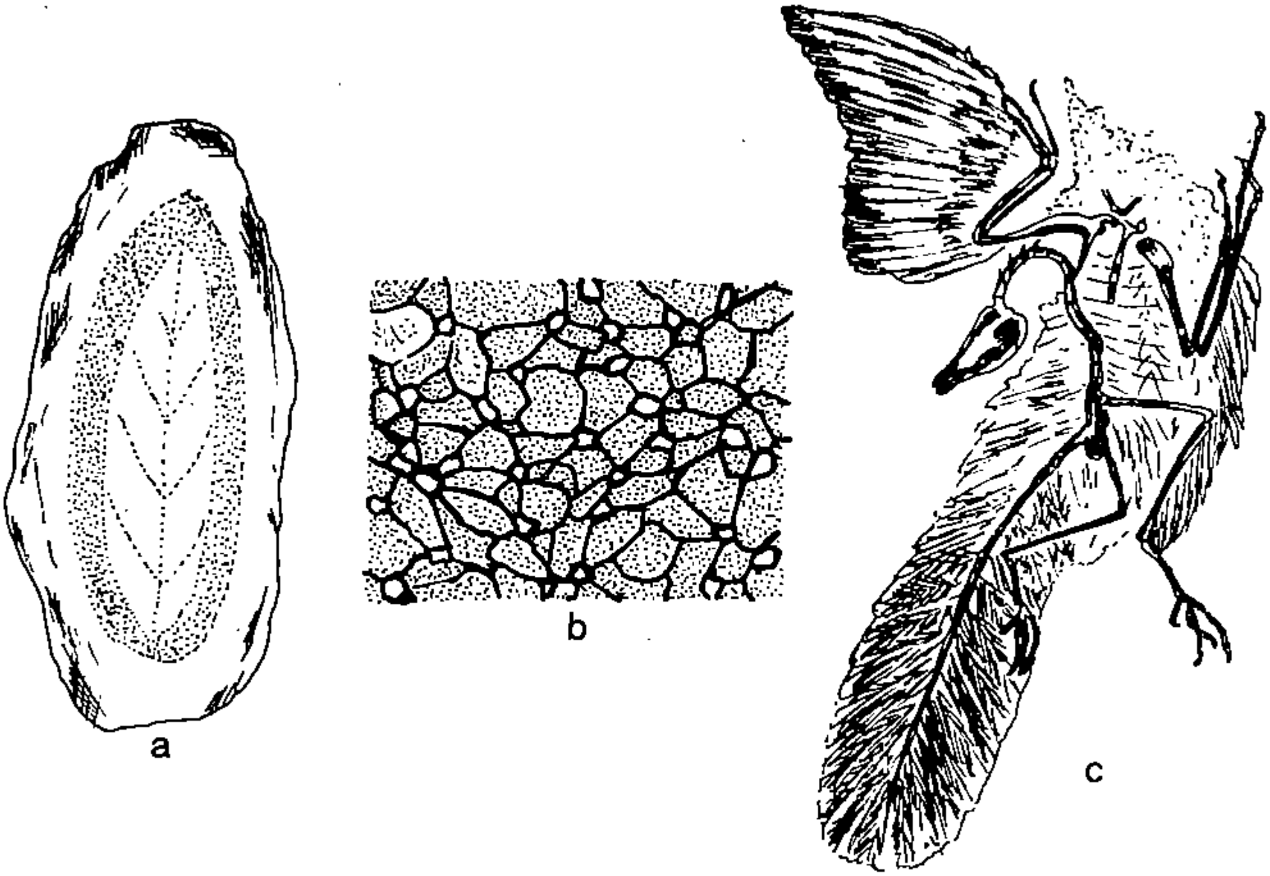

Fig. 10.1 : Examples of fossil records: a) an impression of a leaf; b) cuticle of the lower epidermis of a leaf; c) *Archaeopteryx* — a fossil bird.

As a general rule, hard parts are necessary for fossilisation — for example, teeth and bones of vertebrates, shells and spicules of invertebrates, woody parts of plants. It is rare to find soft parts preserved in fine-grained sediments. You can take the example of **Archeopteryx**, the first bird whose feather impressions have survived the ages. Sometimes even fossil faeces called **coprolites** may give us important clues about the food habits of extinct animals.

However, the fossil record is not a perfect geological record. Let us briefly examine the reasons for this incompleteness. Only a small fraction of the millions of organisms that existed through the ages has survived as fossils. The remains of the organisms may decay and be destroyed or may be wholly or partially eaten away by predators or scavengers. Most species are not fossilisable. Among the species which can be fossilised, most individuals are not buried as is necessary for preservation. Organisms which are not living in areas of sedimentation are unlikely to be preserved, and this fact rules out most areas on land except those in or near water bodies or flood plains. Not all the periods in the earth's history have been equally favourable for the formation and preservation of sedimentary rocks. The remains from periods of submergence of land are richer in fossils than those from periods of elevation. Also, the rocks with their fossils may be disturbed and altered in many ways by various geological processes. Now, you can understand why the incompleteness of the fossil record should be kept in mind while using it to trace evolutionary history.

Perfectly preserved fossils of whole families, together with their belongings and pets have been found in Pompeii, which was buried in 79 A.D. under the lava from Mount Vesuvius.

However, the fossil record for certain animals such as the horse, the camel and the elephant is so complete that, arranged chronologically, a complete series is formed from which the entire course of their evolution can be pictured. As an example, we will now discuss the evolution of the horse.

10.2.5 Evolution of the Horse

The phylogeny of the horses was the first to be deduced from the fossil record. The record shows us that during the course of evolution nearly every part of the skeleton of the horse was affected. Let us briefly go through its evolutionary history.

- A general increase in size.
- Enlargement of the brain (especially the cerebral hemispheres) and a corresponding increase in the size of the head.
- Increased length and mobility of the neck.
- An increase in the height and complexity of the molar teeth.
- An enlargement of the last two, and finally, of the last three premolars until they became comparable to the molars.
- Elongation of the limbs for speedy running, but with a loss of rotational movement.
- Fusion of bones in the limbs to provide better hinge joints. This also makes for more efficient support of the body weight.
- Reduction of the toes from five to one long toe (third) on each foot, which is covered by a hoof (claw). The lateral toes are gradually reduced and finally only small bones of the second and fourth toes persist as splints.

By these changes during its long evolutionary history, the horse became a long-legged, swift-running mammal adapted to live and feed on open grasslands. The prominent teeth having many enamel ridges help grind tough grassy vegetation.

You can see in Fig. 10.2, a brief sketch of the fossil record of the horse which covers 60 million years and includes five continents. It documents evolutionary trends and patterns of diversity through time, patterns of origin and extinction and even migration between the continents.

In the next sub-section, we shall discuss the evidence for evolution obtained from the pattern of geographical distribution of various life forms. Before that try the following SAQ to check upon your progress:

SAQ 2

a) Match the items given in column I with those of column II. Write your answers in the space provided.

	Column I			Column II
i)	Geological chronology	[ ]	a)	Product of the activity characteristic of an organism
ii)	Cast fossil	[ ]	b)	Era, periods and epoch
iii)	Trace fossils	[ ]	c)	Moulds filled up with various substances
iv)	Incomplete record	[ ]	d)	Fossil deposition only under water bodies

b) List any two major changes that took place in the history of the evolution of modern horse.

....

....

....

....

10.3 BIOGEOGRAPHY

An important line of evidence that Darwin carefully built up in support of his thesis of evolution through variation and natural selection comes from a knowledge of the distribution of contemporary as well as fossil species of plants and animals — the realm of biogeography. As a matter of fact it was his extensive field observations during the voyage on the Beagle that alerted him to such a possibility. The distribution of organisms is by no means uniform. Firstly, organisms separated by physical barriers are often quite different even if the environment is the same. Secondly, identical or closely similar species often exist in places which are widely separated. These species have no representatives in the intermediate territory.

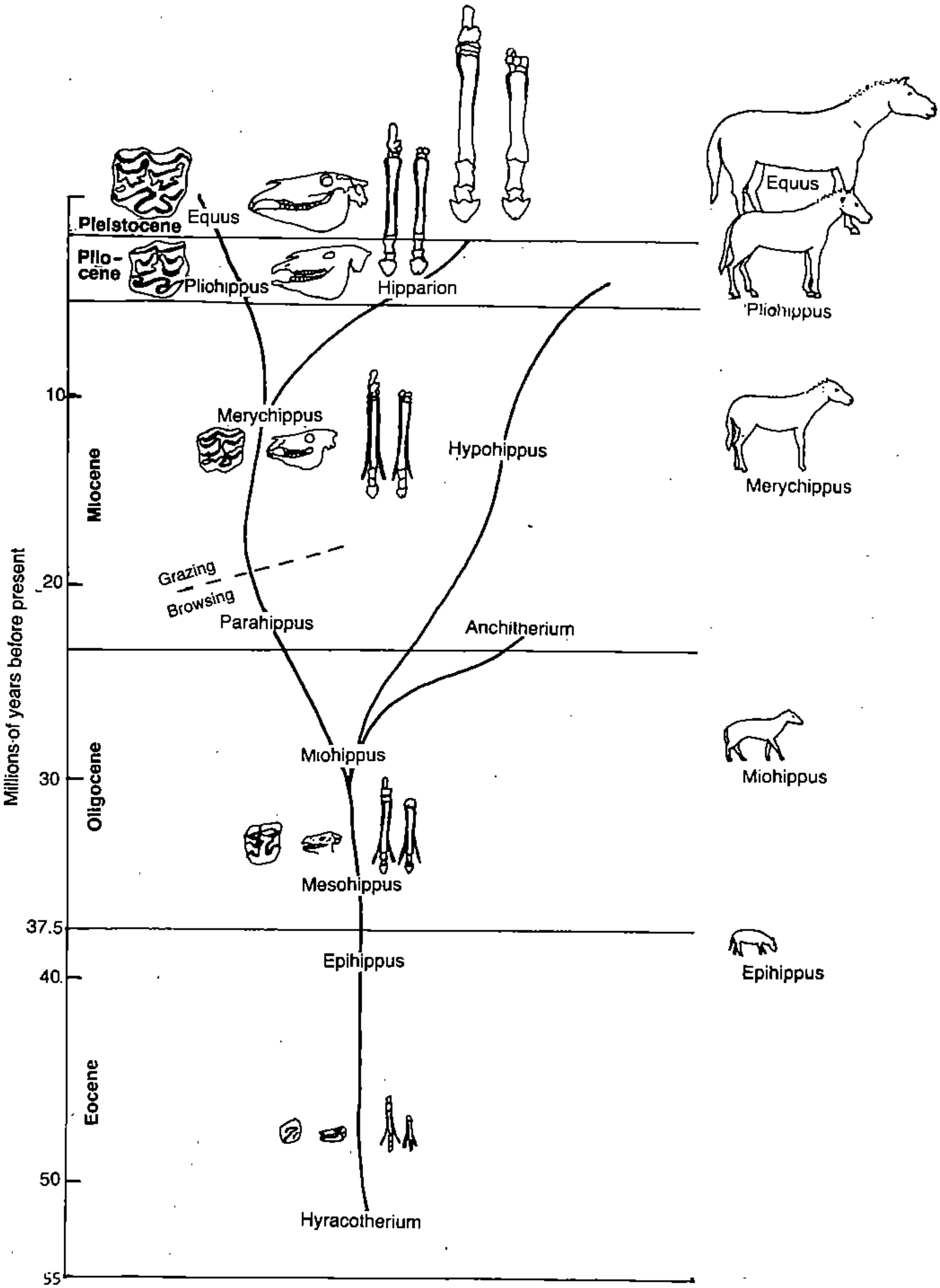

Fig. 10.2 : Schematic diagram showing the evolutionary trends in horses within a span of 60 million years. Note the diversity of horses during miocene and pliocene period and extinctión of all other horses except for single toed species by the end of pliocene.

Finally, on oceanic islands there are fewer number of species and most of these are peculiar to each island. Let us now briefly go through various aspects of biogeographical distribution.

10.3.1 Biogeographical Regions

The world has been divided into six biogeographical regions on the basis of the similarities and differences in the distribution of fauna and flora.

i) **Palaearctic region** (old world),

ii) **Nearctic region** (North America).

These two regions are collectively referred to as the **Holarctic region** which includes all of Europe, Asia north of the great mountain ranges — the Himalayas and the Nan Ling, Africa north of the Sahara desert, and North America north of the Mexican Plateau. Bears and foxes of the genus *Vulpes* are some of the typical mammals of this great region.

iii) The **Ethiopian region** includes Africa south of the Sahara Desert. Mammals such as gorilla, giraffe, lion and hippopotamus are found in this region.

iv) The **Oriental region** is comprised of those portions of Asia south of the Himalayas and the Nan Lings and is marked by the gibbon, the organgutan, the Indian elephant and the flying fox.

v) The **Neotropical region** includes South and Central America and has mammals like tapirs, sloths, prehensile tailed monkeys and vampire bats.

vi) The **Australian region** includes Australia and is marked mainly by the presence of marsupial mammals, bats and some rodents. All the above regions also include their associated islands.

These biogeographical regions are separated from one another by barriers of long standing such as deserts, mountains and the oceans.

Look for all these different regions of the world in Fig. 10.3.

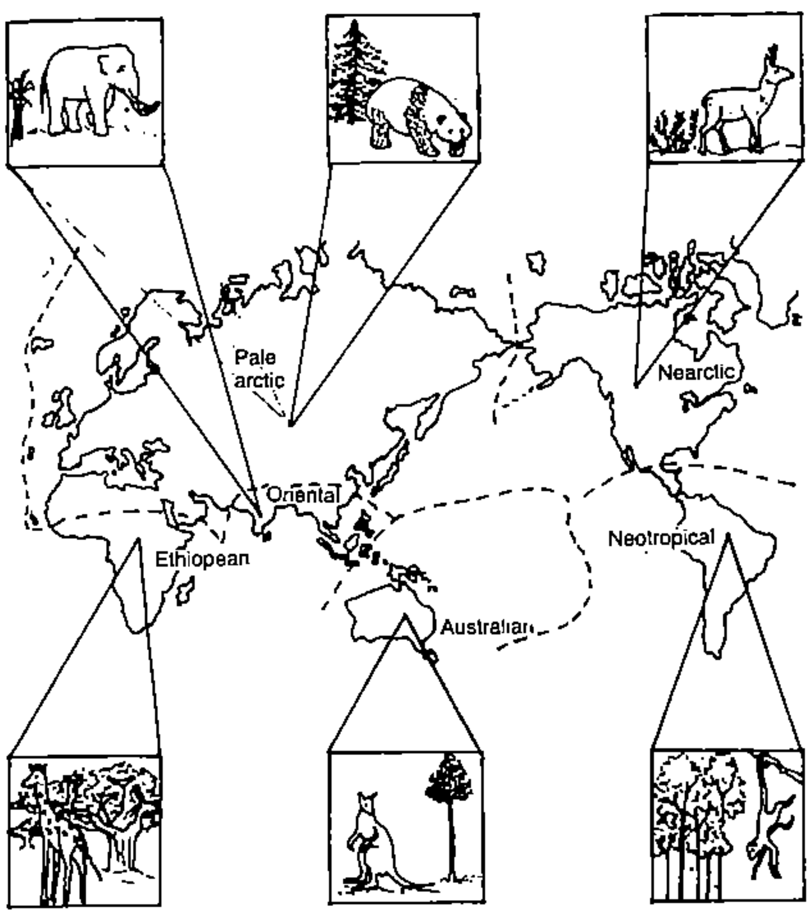

Fig. 10.3 : Biogeographical regions of the world. Each region is marked by its typical flora and fauna.

There is one other aspect that we need to consider here. The physical conditions of one region may be closely similar to that of the other. So one would expect that plants and animals of one region should have no difficulty in inhabiting the other region. Yet they have only a few common organisms which may be isolated survivors from groups which were once present world wide. This difference in the flora and fauna of similar regions can only be explained by evolutionary theory, on the basis that, in different regions, evolution has taken a different course.

10.3.2 Discontinuous Distribution

As mentioned earlier, closely related organisms may be found in widely separated areas. Let us take the example of *Nyssa*, the black gum tree. Presently, *Nyssa* and some closely related species occur naturally only in South East Asia and in eastern North America. These areas have a similar physical and biotic environment. You will not find naturally occurring *Nyssa* in the vast area that separates these two regions. Fossil evidence indicates that during a warmer age *Nyssa* and the associated species were distributed over a continuous range that comprised much of the northern hemisphere. During the glacial age the climate became too severe for these plants in most of the area in this range. As a result *Nyssa* became extinct in most parts and survived only in those areas where the climate was milder (see Fig. 10.4).

If these had arisen independently in widely separated areas, one would expect them to be present also in other areas having similar conditions. Such a distribution whereby populations of the same species are widely separated is called **vicariant.**

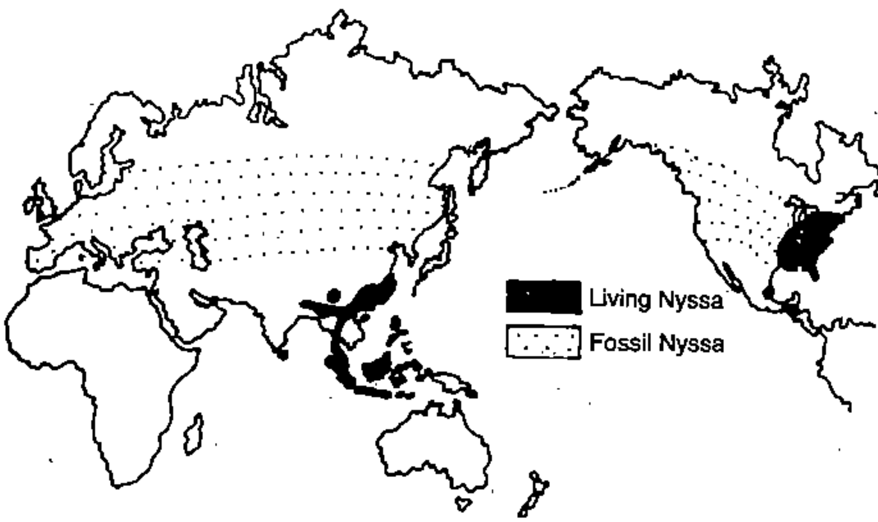

Fig. 10.4 : Distribution of *Nyssa*. The shaded area indicates the distribution of fossils and the dark area indicates the distribution of the living forms.

10.3.3 Life on Islands

During his voyage on the Beagle, Darwin observed that oceanic islands lying beyond the continents account for much less number of naturally occurring species of organisms. Many of the species on these islands are **endemic,** that is they are found nowhere else.

Darwin found 26 species of land birds in the islands of the Galapagos archipelago. Of these 21 to 23 were found to be endemic. But of the 11 species of marine birds found there, only 2 were endemic. In Fig. 10.5, you can see the heads of the birds of the subfamily Geospizinae, showing the different beak structures. This difference is correlated with different feeding habits, which enabled them to occupy different ecological niches within a restricted area.

In another example, Galapagos islands include 436 species of flowering plants. Of these 223 species are endemic. Many of these are restricted to one or a few islands in the archipelago. Struck by the endemic nature of the flora and fauna of Galapagos islands, Darwin proposed that islands were colonised by occasional migrants from the mainland. In due course of time their descendants would have been modified, eventually evolving into new and distinct species. As they spread to the various islands of the archipelago, each isolated population would have been modified independently, thereby forming groups of closely related endemic species. Also the wide water barrier would greatly reduce the probability of these new species

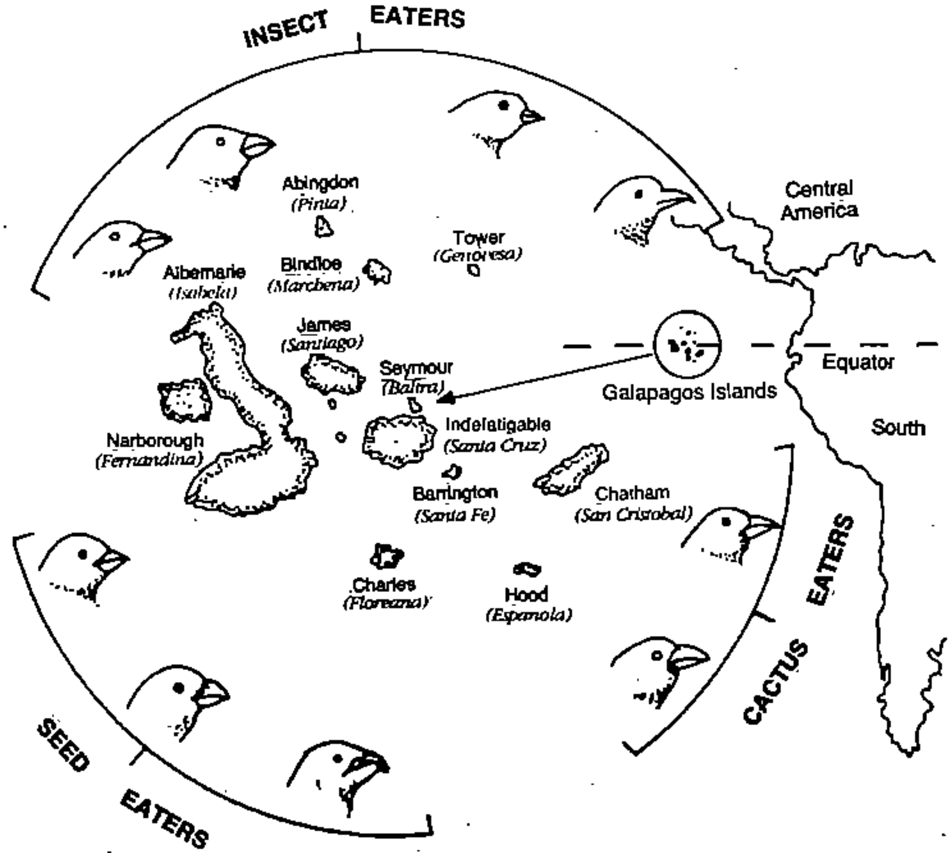

Fig. 10.5 : Galapagos Islands and different beak structures of birds of subfamily Geospizinae, owing to different feeding habits. Galapagos islands are situated between 500 and 600 miles west of South America.

spreading to other localities. For marine birds, such a barrier is less formidable. It is because of this that you find a smaller proportion of endemics amongst the marine birds.

At first glance the contemporary species on the archipelago and their continental counterparts may appear wholly unrelated. However, on the basis of what we have said above it should be clear to you that sometime in the geological past they must have shared a common ancestor.

On the other hand, many plants and animals introduced by humans on these islands survived and multiplied successfully. This proves that these islands are well suited to support a much greater variety of organisms.

The amphibians and terrestrial mammals, though not bats, are usually entirely absent from oceanic islands. When introduced, however, they often multiply rapidly so as to become a nuisance. The toad *Bufo marinus* was introduced into Hawaii to help in the control of insects, but these toads themselves have now become a nuisance on the islands. You can now understand that had all species been created in the places in which they now exist, then amphibians and terrestrial mammals would be as frequent on oceanic islands as on comparatively similar continental areas.

10.3.4 Life in the Oceans

Oceans, like lands have distinct biotic regions which offer different kinds of habitats. As shown in Fig. 10.6 oceans have the following regions:

i) **Littoral or intertidal zone** is the zone on every shore and is always exposed to the tides.

ii) **Continental shelf** is beyond the littoral zone, the higher portions of which form the continental islands.

iii) **Neritic zone** is over the shallow continental shelf and is not more than 600 feet or 183 meters deep. At the edge of the continental shelf the ocean floor drops off rapidly to great depths and correspondingly there are additional zones.

iv) **Pelagic zone** consists of water going down to a depth of 600 feet. The water is well oxygenated and lighted. Further, at this level the water is also subject to wave action.

v) **Bathyal zone** consists of water down to a depth of 6000 feet. Here, the water is quiet and poorly lighted.

vi) **Abyssal zone** lies below the bathyal zone and receives no sunlight. The water here is always cold and quiet.

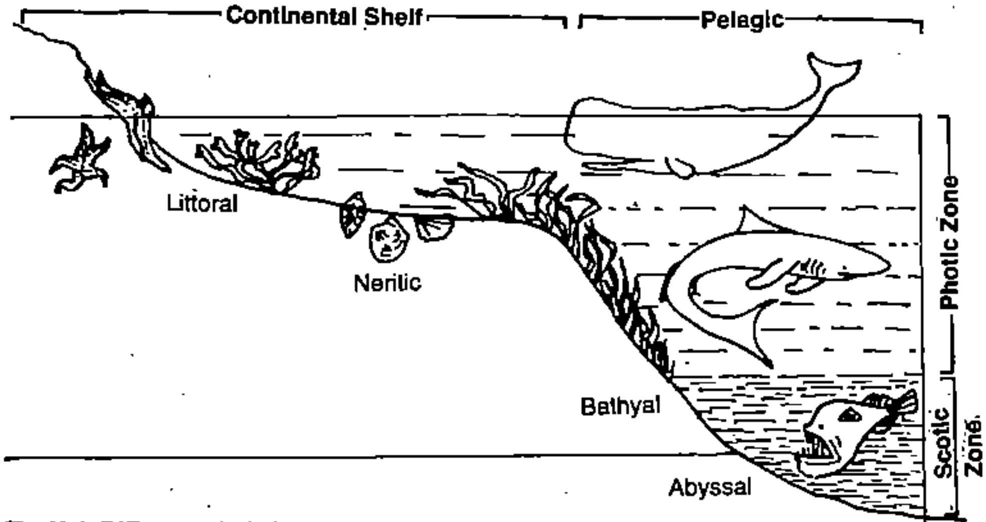

Fig. 10.6 : Different ecological zones of an ocean. Each zone is the barrier for the organisms of another zone.

You can now understand that these zones have different ecological habitat and thus are barriers to each other. As you can see in the figure, different zones have different types of flora and faunna. The first three zones are most richly inhabited.

It is time now you do another SAQ. After that we will study the evidence from comparative anatomy in support of the theory of evolution.

SAQ 3

Tick mark (√) the correct statements and (×) the incorrect statements in the space provided.

i) Similar species exist only in places which are widely separated. ( )

ii) Various geographical regions have their own typical flora and fauna. ( )

iii) Most of the species on oceanic islands are not endemic. ( )

iv) All the species presently found on earth have arisen at one place and later migrated to all regions. ( )

v) Oceans like lands have distinct regions which are ecologically different. ( )

10.4 COMPARATIVE ANATOMY

It becomes evident from a comparative study of the anatomy of different species of organisms that they exhibit many structural similarities, clearly suggesting their evolution by divergence from one or more common ancestors. Based on similarities in the structure and/or function of organs and organ systems in different organisms, biologists have identified three types of structures: homologous, analogous and vestigial. In the following sub-sections you will study these structures and interpret their significance in relation to evolution.

10.4.1 Homologous Organs

Homology is the similarity of structures in various related organisms arising from common ancestory and is usually reflected in common embryological origin. Such structures, called **homologous organs,** are the consequence of divergent evolution and enable the organisms to carry out different functions.

Superficially, they look different. The study of homologies is a major aspect of comparative anatomy. You may find examples of homologies in organs and organ systems of all groups of living organisms. These homologies provide important evidence for evolution. The forelimbs of vertebrates provide an excellent example of organs with similar structure but different function. The forelimbs of several vertebrates such as those of amphibians, lizards, birds, bats, and men are all constructed on the same basic plan and include similar bones in the same position.

But they have become morphologically different in the course of evolution as a result of modifications to suit different requirements. In Fig. 10.7, you can see some examples of vertebrate forelimbs, modified to suit various functions.

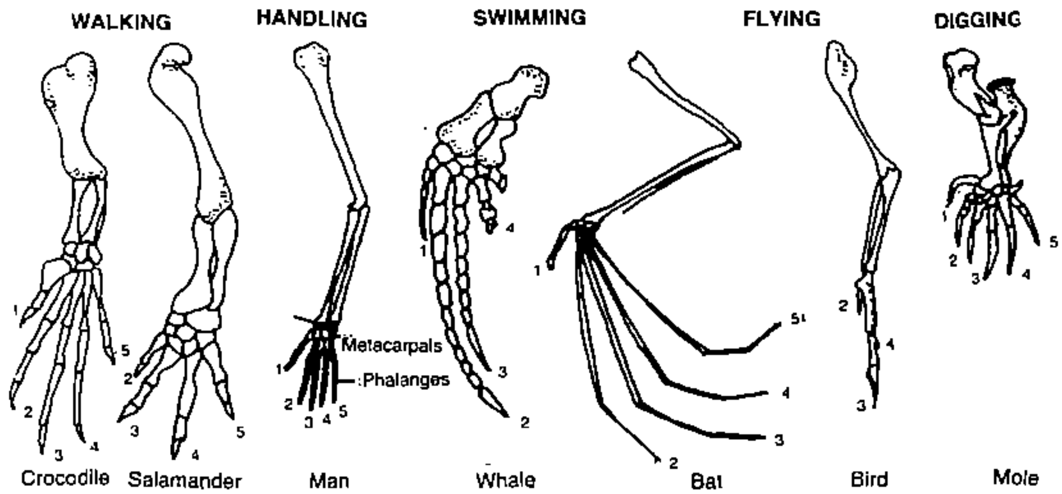

Fig. 10.7 : Homology in the bones of the left forelimb in the vertebrates. Similar bones in each animal are adapted for special use by differences in length, shape and bulk of various bones.

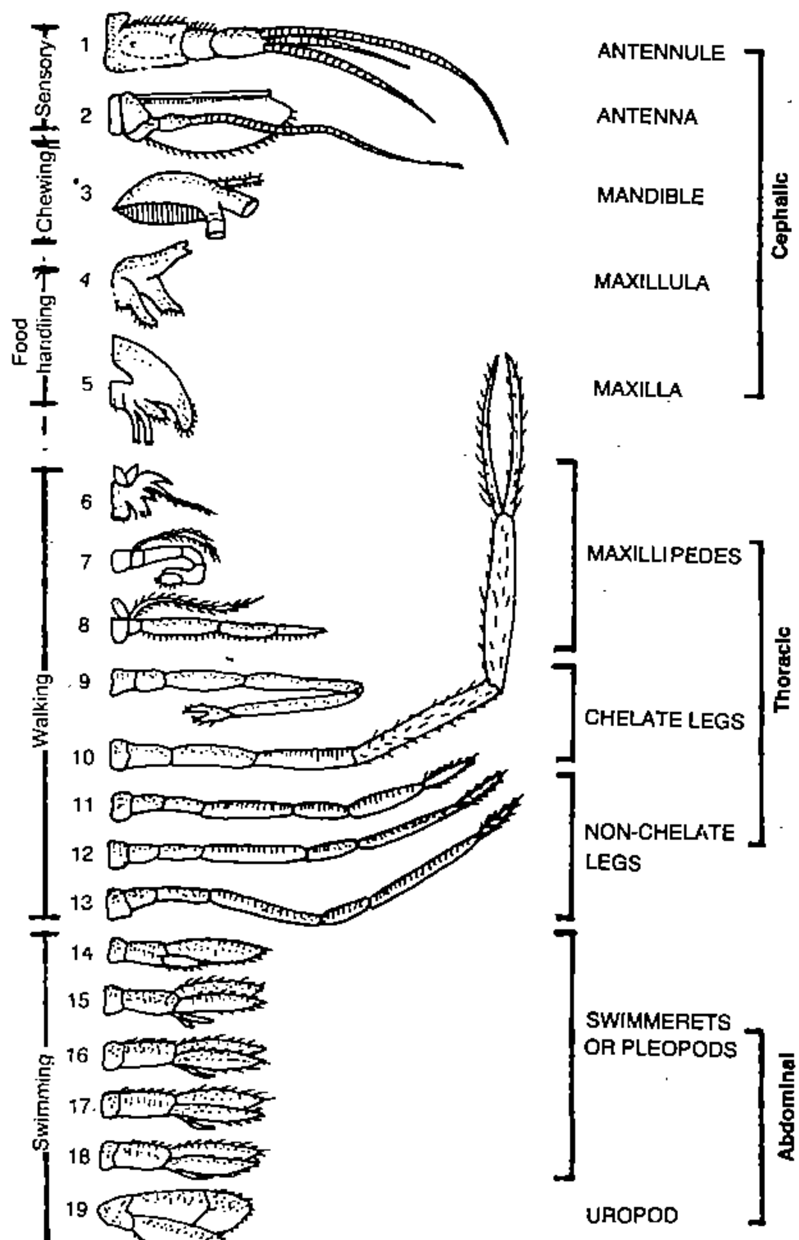

Fig. 10.8 : Serially homologous appendages of prawn. Note the structural modifications to suit the various functions performed.

A special type of homology is shown by metameric animals. A striking example is that of the appendages of arthropods — especially those of crustaceans. In the typical crustacean, one pair of appendages is borne by each segment of the body. These appendages have evolved from a single structure plan and modified in a serial order so as to perform various functions. This is known as serial homology. You can see in Fig. 10.8, an example of serial homology in the prawn.

Homology represents the consequences of **adaptive radiation** from a common ancestor enabling organisms to adapt successfully to different ecological niches. A classical example of adaptive radiation is the structure of the forelimb of mammals There is always a single long bone, the humerus in the upper arm. In the forearm there are two parallel bones, the ulna and the radius. In the wrist there are typically eight carpal bones arranged as two rows of four. Five parallel metacarpals form the skeleton of the palm of the hand, and rows of three phalanges each from the skeleton of the digits, excepting the first digit which has only two phalanges. Now, look at Fig. 10.9 for examples. The tenrecs (scaly ant eater) of the order Insectivora show the primitive **pentadactyl** arm structure. The moles, which are their relatives, are highly modified for digging in order to adapt to a subterranean habitat. All the bones of the limbs are short and broad and give the limb a shovel-like appearance. In the bats of the order Chiroptera, the humerus, radius and ulna, as well as four of the digits are greatly elongated so as to support the wing membrane. The forelimb is thus modified for flight. In ungulates like the horse, which are adapted for running or a cursorial habit, the humerus is short and heavy. The remaining bones of the forelimb are generally elongated and the digits are reduced in number. Fusion of bones is quite common in adults. The details of the structure differ considerably among the various families of ungulates. In aquatic mammals, like the whale, the forelimbs are modified into flippers to aid in swimming.

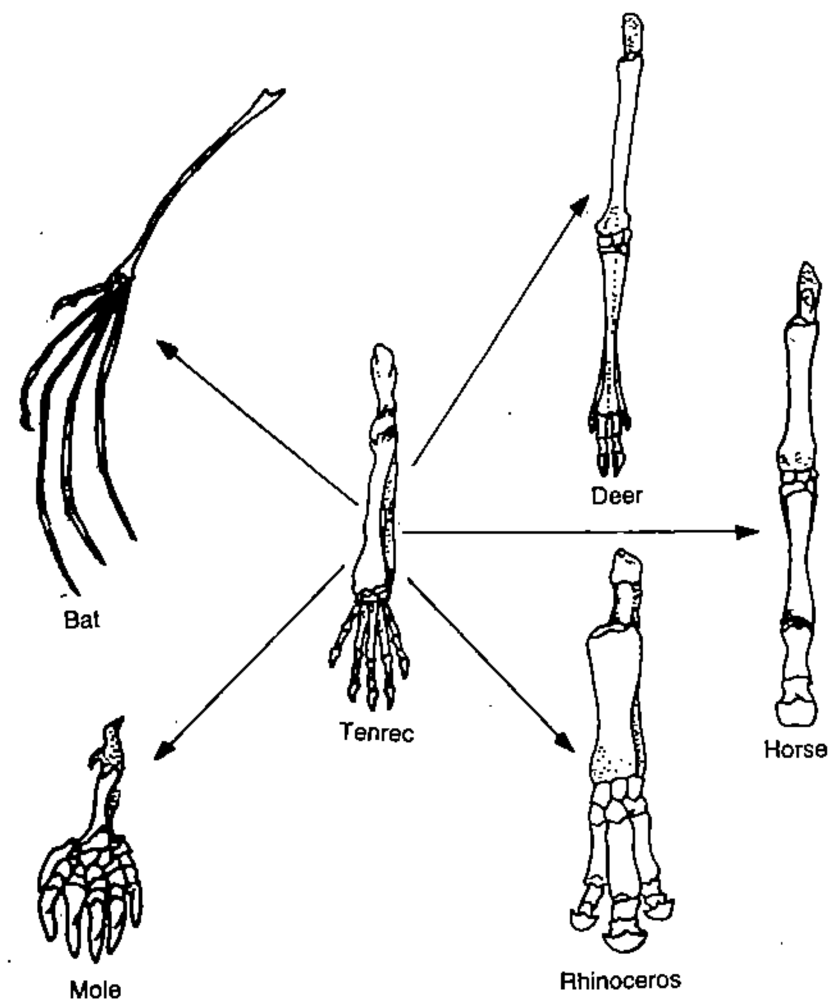

Fig. 10.9 : Adaptive radiation in the forelimbs of mammals.

You can find homologous structures in plants also. For example, a thorn in a bougainvilla or a rose and a tendril in the cururbits, are homologous, arising as they do in the axillary position.

development of an organism comes under the purview of embryology. Let us now discuss the evidence furnished by comparative embryology in support of evolution.

10.5.1 Haeckel's Law

Embryological evidence for organic evolution came into prominence with the postulation of the **recapitulation theory** or **biogenetic law** by the German anatomist, Ernst Haeckel. The law states that **ontogeny recapitulates phylogeny**. This means that in the developmental history of an organism there is a remembering or a recalling of its racial history. This in turn implies that embryos in their development repeat the evolutionary history of their ancestors in an abbreviated form. Haeckel believed that the different stages in the early development of an individual (ontogeny) represent the different forms and types through which the race or species passed (phylogeny) during the course of evolution and thus provide direct evidence of its line of descent.

As shown in Fig. 10.12 crustaceans provide a good example. The larvae pass through six distinct stages in successive moults. Each larval stage strongly resembles the adults in a sequence from the primitive to the advanced form in this group. The larvae of primitive crustaceans stop growth and differentiation at an early stage in this series, whereas the advanced crustaceans show all or most of the stages.

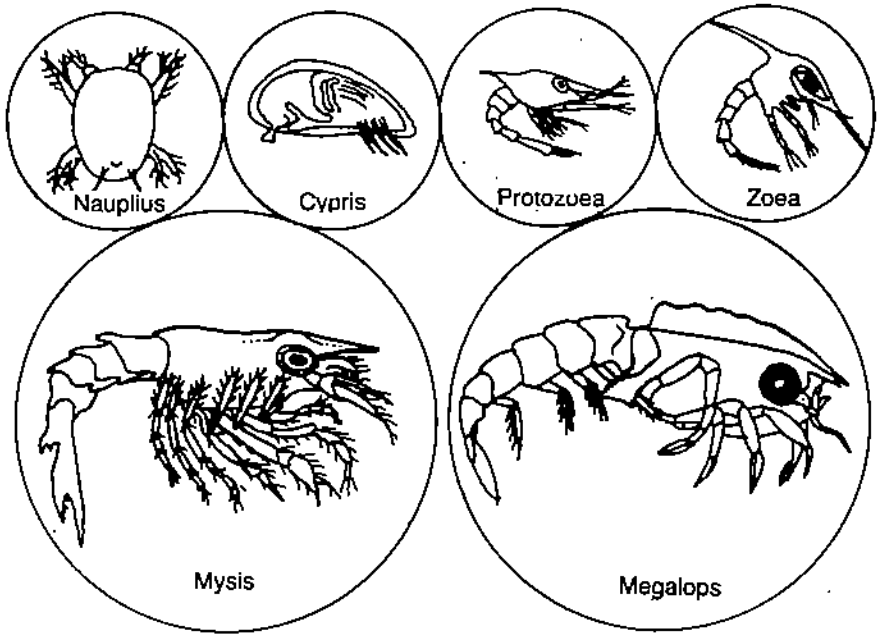

Fig. 10.12 : Six larval stages during development of crustaceans. Larval stages often resemble adults of the groups with corresponding names.

In another example, the kidneys of all vertebrates develop from the **nephrotome** a segmented mass of the mesoderm. Yet there are three distinct types of kidneys among the vertebrates: *pronephros, mesonephros* and *metanephros* which are formed one after the other during growth and development. The first type is replaced by the second which in its own turn gives way to the third. All vertebrate embryos first develop a pronephric kidney which utilises just the anterior-most part of the nephrotome. Only hag-fishes and a few bony fishes retain this pronephric kidney as the functional adult kidney. In most other adult fishes and in amphibians as well as in the embryos of reptiles, birds and mammals, the kidney development goes up to the next stage, i.e. the mesonephric stage. The mesonephric kidney is functional in adult fishes and amphibians. Finally in reptiles, birds and mammals development of the kidney proceeds to the stage of the metanephros, the functional organ in the adult organism. These facts suggest that higher vertebrates have evolved from the lower ones as a result of elaboration of various structures.

Let us now look at the embryos of different vertebrates, in Fig. 10.13. The embryos of a variety of vertebrates show a high degree of similarity at various stages of development. They become morphologically different only during the later stages of growth and differentiation.

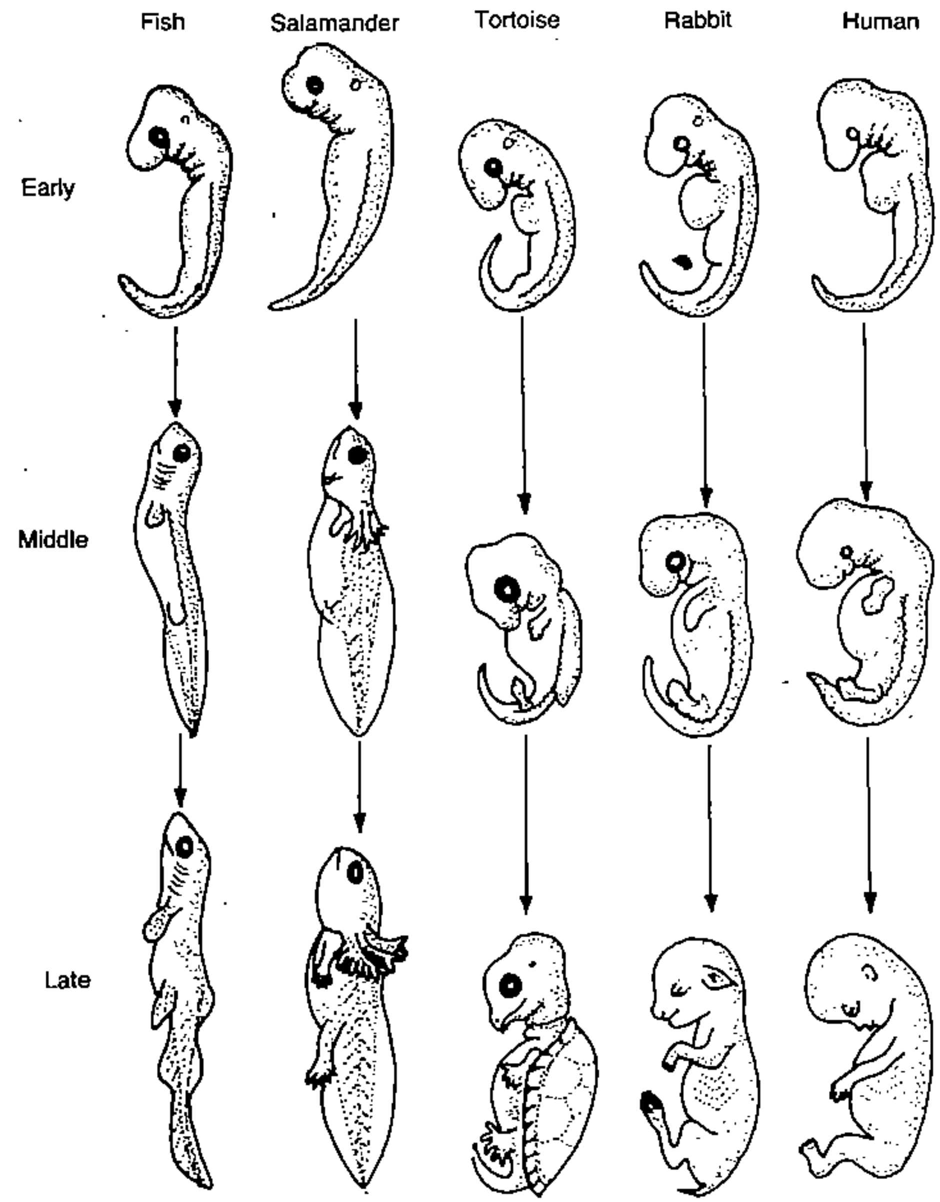

Fig. 10.13 : Embryos of a series of vertebrates compared at three stages in development. The series has been used as evidence for recapitulation.

In plants, recapitulation is not so evident as their embryology is much simpler, yet good examples are available. The *Acacia* tree has highly compound leaves, but its seedlings have simple leaves like its ancestors. Another good example with which you must be familiar is the *Eucalyptus*. As shown in Fig. 10.14, the leaves of adult trees are narrow blades turned to present the thin edge to sun. But the leaves of the seedlings are broad and oriented like those of more familiar trees.

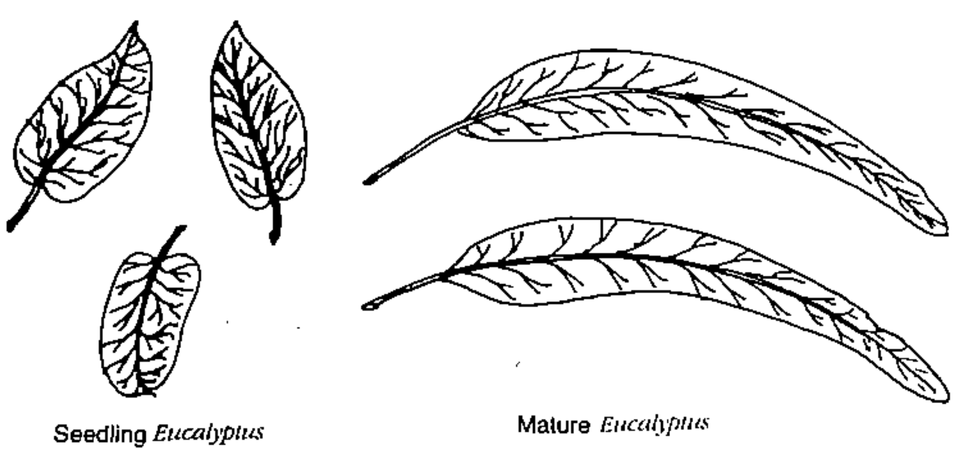

Fig. 10.14 : The mature *Eucalyptus* plant exhibits long narrow leaves. The seedlings have leaves similar to those of less specialised trees.

One very interesting and probably comparable phenomenon has been found in the conifers. If conifers are injured and the wound allowed to heal, the new growth may differ histologically from normal tissue. The new tissue shows a type of structure which is well known from fossil conifers of the Mesozoic era.

Haeckel's biogenetic law met with a lot of criticism as it was pointed out there is **no true phylogenetic recapitulation** during ontogeny. This is because the resemblances seen in ontogeny are primarily between **embryos** of related animals and not among **embryos and adult ancestors.** Only incidentally do they sometimes suggest adults. Thus ontogeny recapitulates phylogeny only in the sense that ancestral embryonic stages are repeated and even these may be drastically modified by adaptations that are favoured by natural selection. You will read about natural selection later in this course.

The recapitulation theory assumes that embryos need only repeat the past, condensing some stages and eliminating others, without adapting to the embryonic mode of life. The fact is quite otherwise; embryos must adapt themselves to cope up with a hostile environment, just like adults. For example, differences in cleavage pattern in various embryos are correlated with the amount of yolk in the eggs. This is an adaptive trait of fundamental biological importance. Also, consider the adaptations of eggs in order to develop in fresh water, salt water or terrestrial habitats. There are significant differences among various groups of echinoderms which are referable to embryonic adaptations. Many biologists feel that these differences are a result of extensive modifications of larvae through natural selection, since separation from their ancestors.

10.5.2 von Baer's Principles

Haeckel had based his observations on von Baer's principles of embryonic differentiation, which are as follows:

- During embryological development the appearance of those characters that are typical of the particular phylogenetic line ('general' characters) precedes those that are characteristic of the species itself ('special' characters).
- There is thus a progression from the more general to the less general, and finally to the special characters during development.
- An animal, during its development, departs progressively from the forms of other related species.
- The juvenile stages of an animal resemble the embryonic stages of lower animals but not those of adults.

These principles of embryonic differentiation put forward by von Baer are a better guide to the interpretation of evidence from embryology, supportive of organic evolution.

How about doing another SAQ? After that we will discuss the evidence from physiology and biochemistry.

SAQ 5

Fill in the blanks with appropriate words.

i) Haeckel's law states ....

ii) All vertebrate embryos first develop a .... type of kidney.

iii) The leaves of .... are thinner and their edges face the ....

iv) Embryos tend to .... to the forces of natural selection.

v) von Baer's principles are a .... to the embryological evidence

10.6 COMPARATIVE PHYSIOLOGY AND BIOCHEMISTRY

So far, we have been discussing evidence in support of Darwinism from 'classical' disciplines such as palaeontology, anatomy and embryology. The biology of Darwin's time was almost exclusively morphological. Physiology and biochemistry had not yet become recognisable sciences. Today, biologists agree that all morphological traits are the ultimate consequences of the immediate expression of genes in the form of proteins. In between are the biochemical pathways governing physiological processes. Therefore, evidence provided by these fields in support of evolution is significant. Let us now discuss a few aspects of such evidence.

10.6.1 Physiology

Looked at from the point of view of the chemical basis of living organisms it is evident that there is complete uniformity. The elements that are characteristically associated with life are identical over the entire phylogenetic scale. Similarly, the 'building blocks' of living matter such as amino acids, vitamins and fatty acids are also identical. For that matter, there is also uniformity with respect to the major pathways by which organisms are able to derive energy for bodily functions. All of this clearly implies that speciation must have occurred according to the mechanism proposed by Darwin. You will read about speciation later in this course.

Let us now take two examples related to physiological function. You are aware that the process of digestion is very much dependent upon the action of various enzymes. Take any one particular enzyme, say for instance trypsin which breaks down large-sized proteins into smaller peptide molecules. All animals possess this enzyme. What is interesting is that the chemical structure of this enzyme in all these organisms is essentially similar. On the basis of such similarities as well as points of difference we can erect a phylogenetic tree exactly as though you are considering a morphological character. To cite an example from the plant kingdom, a number of enzymes used in the process of photosynthesis are found in all green plants — right from algae to angiosperms.

Another class of substances of great importance in the physiology of higher plants and anima' re the hormones. They function by coordinating the activities of different organs. We can take the example of the thyroid hormone in the animals. The thyroid hormone is found in all vertebrates and has been proved to be interchangeable among themselves. For the treatment of thyroid deficiency beef thyroid has been successfully used. In the case of the frog, if the thyroid gland is removed from the tadpole, it will not undergo metamorphosis into the adult frog. But if it is fed with thyroid tissue from mammals, the process of metamorphosis starts again.

The study of various physiological processes such as respiration, digestion, excretion and reproduction from unicellular to multicellular organisms shows us that they have progressively diversified and in many instances increased in complexity in parallel with species divergence and evolution. However, the underlying principles of all the processes remain the same which supports the theory of evolution. Let us now discuss the evidence obtained from biochemistry.

10.6.2 Biochemistry

Comparative biochemistry has given us the insight that many synthetic and degradative pathways are common to most of the organisms, whether closely or distantly related. All organisms depend primarily on carbohydrates and fats and to a lesser extent on proteins for energy. If one were to trace the pathways leading to energy production, one can find invariably the glycolytic cycle, the TCA cycle and the electron transport chain as the common pathways in most of the organisms.

Comparative serology is another field which provides us with evidence for evolution. These studies are based on the fact that an animal will form **antibodies** against complex compounds like proteins that are foreign to that animal's body. A substance which will induce the formation of antibodies is called an **antigen**. If a small amount of the serum of any animal is injected into another test animal, the foreign serum acts as an antigen and causes the production of circulating antibodies in the test animal.

Serum is the fluid portion of blood that remains after clotting has been allowed to take place and consists of a mixture of proteins.

If we prepare such an **antiserum**, and add to it a few drops of the original antigenic serum, a precipitate will be formed. Such a type of antibody forming mechanism is called the immune mechanism. In other words, we have immunised the test animal against the kind of serum that was injected. Such antibodies that react with the antigen to form a precipitate are called **precipitating antibodies** and the test is known as a precipitin test.

Let us take an example where a rabbit is injected with human serum. The rabbit will be immunised against human serum and form antibodies against it. The antiserum obtained from rabbit's blood containing antibodies against human serum now serves as a test fluid and is divided into four test tubes. As shown in Fig. 10.15, in test tube 1 antiserum is mixed with human serum. Antigen-antibody reaction will occur and a soft white precipitate will be formed and settle down at the bottom of the test tube. In test tube 2 antiserum is mixed with chimpanzee serum. Here, the antigen-antibody reaction will depend upon whether or not proteins of chimpanzee serum are similar in chemical structure to those of human serum. If they are similar, antibodies formed against one will also react with the other. As shown in the figure, the same amount of precipitate is formed in test tubes 1 and 2 indicating that chimpanzee serum is homologous to human serum.

Similarly if you mix this antiserum with serum obtained from baboon, a smaller. amount of precipitate will be formed as seen in test tube 3 in the figure. This is because the representative proteins in baboon serum are not sufficiently similar to human serum proteins and therefore, we do not get a marked precipitin reaction.

In test tube 4, antiserum is mixed with dog serum. Here, you can see no precipitate. This indicates that proteins of dog serum are so different from their counterparts in human serum that they do not react at all with antihuman serum antibodies. So, you can see that the amount of precipitate formed reflects the degree of relationship amongst the various organisms. The results of serological tests obtained from various animal groups support relationships that were originally based on comparative morphology.

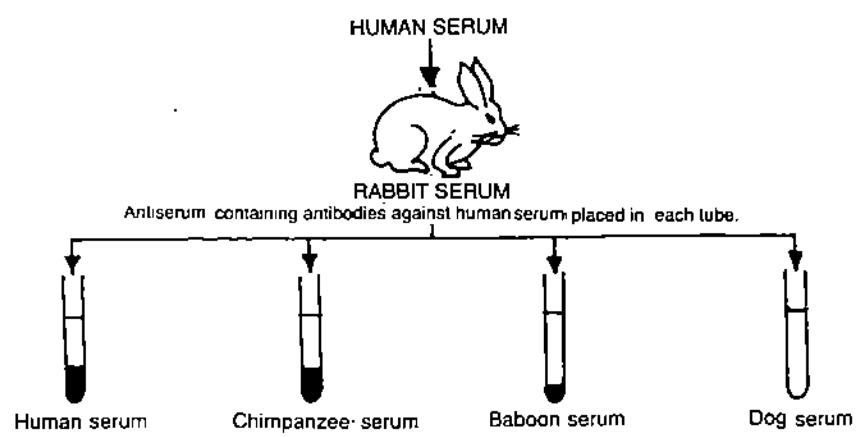

Fig. 10.15 : Principles of antigen-antibody reaction test (precipitin test) used to establish the animal relationships.

Amino acid sequences of widespread proteins are determined for various species in order to assess their relatedness. Let us take the example of cytochrome C, a respiratory pigment which is an essential component of the mitochondrial electron transport system.

Cyctochrome C is a single polypeptide-chain composed of 104 amino acids in mammals. The sequence of amino acids of cytochrome C has been determined for over 67 plants and animal species — from yeast and fungi to humans. Studies have shown that certain of the amino acids occupying specific positions in the polypeptide chain are invariant. This means that these amino acids in their specific position are essential for the function of the protein. On the other hand, there are very many positions on the polypeptide chain where a given amino acid can be replaced by another without affecting the biological activity of the protein. When one examines the phylogeny of cytochrome C one finds that sequence differences between cytochrome C from different species occur only amongst amino acids whose replacement does not affect its activity. Closely related species differ from one other by fewer amino acid residues than distantly related species. Similarity of cytochrome C in all these life forms indicates the common ancestry. You can see in Fig. 10.16 the evolutionary classification of species based on the similarities and differences in the structure of cytochrome C. This evolutionary tree is similar to the phylogenetic classification based on morphological criteria.

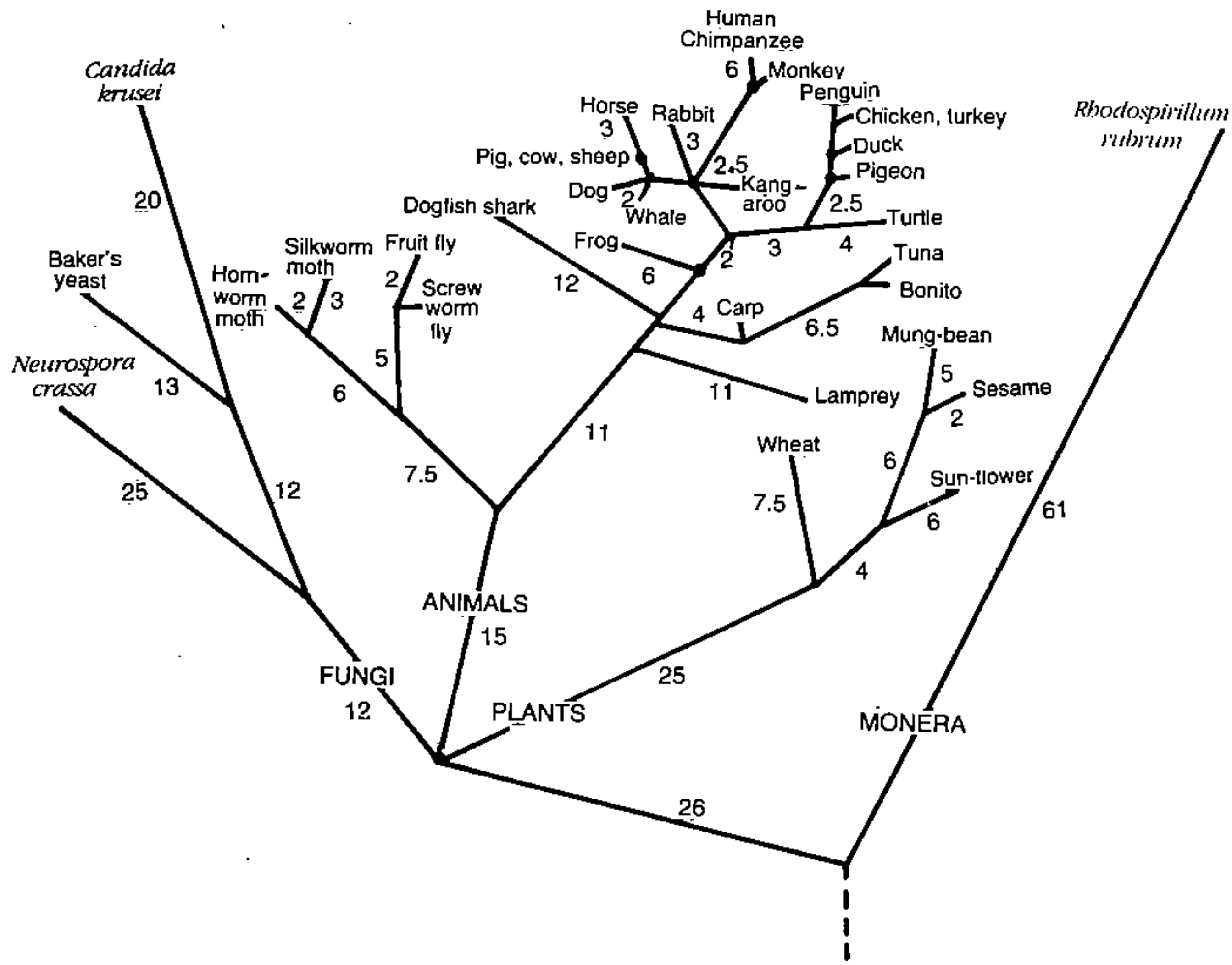

Fig. 10.16 : Evolutionary tree of the species based on the structure of cytochrome C in various organisms. Numbers indicate the changes in the percentage of amino acid composition.

The other method in biochemical studies is **nucleic acid hybridisation** to trace molecular phylogeny. In this method DNA is extracted from a test species, say a human volunteer. The double stranded molecule is then separated into single strands by heating. These single strands are then trapped into blocks of gel so that complementary chains do not join after cooling. Similarly, DNA from another species B, labelled with radioactive phosphorus, are obtained, converted into single-stranded DNA and passed through the gel blocks containing the strands from species A. The portions of the strands of species A and B which are complementary to each other will unite to form double strands. Once the double strands have been formed on the gel, it is then possible to separately recover the uncombined fraction as well as the double stranded DNA. These can then be quantitatively estimated. You will readily see that the closer the relationship bewteen the organisms from which the DNA sample were obtained, the greater will be the proportion of double stranded DNA recovered from the gel. This again will enable us to set up a phylogenic tree.

With this we end our discussion of evidence obtained from various fields to support the theory of evolution. You can learn more by reading the books listed in further reading.

SAQ 6

i) While talking about evidence from physiology, trypsin was cited an enzyme as being present in all animals. Can you think of any other enzyme or protein that is common to many animal groups suggesting a common ancestry?

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ii) Thyroxine from a mammalian source is known to induce metamorphosis in frogs. Do you agree that insulin from a bovine source would regulate blood glucose concentrations in man? Are you convinced that this again is suggestive of common ancestry?

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iii) The diagram given below illustrates the results of a serological test performed by reacting an antiserum for a gorilla protein with serum of other animals. Intrepret the following data.

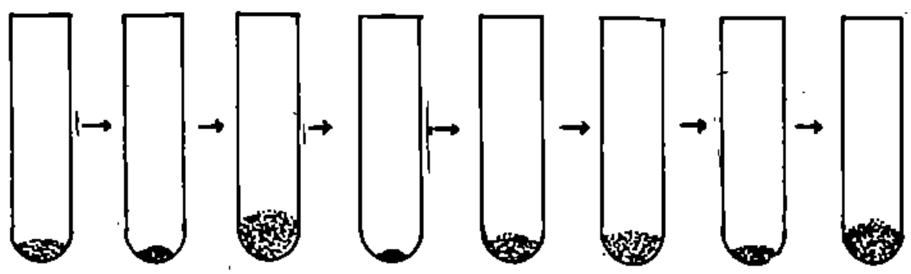

Fig. 10.17 :

10.7 SUMMARY

In this unit, we have discussed the several lines of evidence supporting the concept of organic evolution based on various fields related to the study of biology. You have learnt that:

- Fossil record documents the succession of life over an immense period of time. The age of rocks and of fossils they contain is determined either by relative dating or absolute dating. The ages through which life progressed is divided into eras, periods and epochs in the geological time scale. The fossil record is incomplete in many cases. However, records of vai ous organisms like horses are complete in the sense that they provide us the evidence of its origin, diversification, extinction and trends.
- The geographical distribution of various organisms throughout the world suggests that each group originated in one of the major regions of the world, then spread to occupy as many different areas as it could — despite the physical and chemical barriers and competition from various other species of organisms.
- Embryology tells us that living beings have a history. The embryonic development of invertebrates and vertebrates shows us that developmental stages of various related organisms resemble each other. Also, the general characters of a class appear first which are followed by more specific characters of that group during

the embryonic stages of the members of that group. Such observations tell us that the higher organisms have descended with various modifications from pre-existing ones.

- The evidence from comparative physiology and biochemistry is important in phylogenetic analysis. The same physiological processes occur throughout the living world. At the biochemical level, the degree of molecular differentiation is a reflection of the taxonomic distance between the degree of taxonomic separation of the species in which these molecules occur.

10.8 TERMINAL QUESTIONS

1) Do you think that fossil record is incomplete? If so justify your answer with examples.

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2) Explain with the help of an example, why there is a marked discontinuity in the geographic distribution of some species.

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3) The presence of vestigial vermiform appendix in humans provides evidence for evolution. Explain briefly how?

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4) What is the major criticism of Haeckel's law?

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5) Outline the major steps involved in a precipitin test.

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10.9 ANSWERS

Self Assessment Questions

1) i) Superposition ii) Fossils
   iii) radioactive isotopes iv) radioactive carbon

2) a) i) b, ii) c, iii) a, iv) d
   b) i) general increase in size
      ii) Fusion of bones of forelegs and reduction of toes from five to one in each foot.

3) i) ×, ii) √, iii) ×, iv) ×, v) √

4) a) Homologous organs have similarity in structures because of common origin without regard to function.

   Analogous organs are the organs which perform the same function but have different origin.

   b) The appendix is rudimentary in man as a consequence of adaptation to changed dietary habits.

5) i) ontogeny recapitulates phylogeny
   ii) pronephiric
   iii) adult Eucalyptus, sun
   iv) adapt
   v) better guide

6) i) Haemoglobin, the respiratory pigment is present in all vertebrate red blood cells. It is also present in the serum of earthworms. Similarly cytochrome C is a respiratory protein that is present in the cells of animals ranging from protozoa to man.

   ii) Yes, insulin from cattle can regulate the blood glucose concentrations of man. In fact, the insulin sold in market for the treatment of diabetes is from an animal source. Such examples do suggest a common ancestry for various animal groups.

   iii) The serology test indicates the possible relationship among the various animals listed. The line of descent could be:

   tree shrew → lemur → tarsier → macaque → gibbon → chimpanzee → gorilla → man

Terminal Questions

1) Fossil record is incomplete. Only organisms with hard parts and living in areas where sedimentation was taking place were likely to be preserved. (Students can give any example.)

2) It can be explained with the help of the example of living and fossil *Nyssa*. *(Refer to Section 10.3.2)*

3) Appendix is vestigial in man because he has evolved from other groups of mammals which take coarse fibrous diet and need developed appendix to digest cellulose. In man the dietary habits have changed, so appendix is rudimentary.

4) Haeckel's law states that ontogeny repeats phylogeny, i.e. embryos of organisms resemble the adults of the group. This is not so. In fact, the embryonic stages of organisms resemble the embryos of the members of the group and not the adults.

5) i) Induction of antibodies in the blood of an animal by injecting serum from another animal.

   ii) Testing the precipitate formation by adding blood of different animals to parts of the antiserum.

   iii) Establishing the relationship among various organisms by measuring the amount of precipitin.

UNIT 11 THE PROCESS OF EVOLUTIONARY CHANGE

Structure

11.1 INTRODUCTION

Units 9 and 10 of this Block introduced you to the concept of Evolutionary Biology. The Unit 9 dealt with the origin of the concept of evolution and the major contributors to the development of evolutionary thought. In that Unit you also learnt about Darwin, who based on his extensive observations and interpretations showed that evolution is a simple fact of nature. It was Theodosius Dobzhansky, a population geneticist and one of the trinity to structure the modern synthetic theory of Evolution, who emphatically stated, "Nothing in Biology makes sense, except in the light of evolution". Today the Darwinian concept of evolution through natural selection has stood the test of time. As Julian Huxley rightly pointed out "Darwin rendered evolution inescapable as a fact, comprehensible as a process and all embracing as a concept". In Unit 10 of this Block you were cited several examples from studies on palaeontology, biogeography, anatomy, embryology, physiology and biochemistry as evidence in support of the evolutionary process. In this Unit we will more specifically discuss the mechanism of evolutionary change. We will elaborate on the Darwinian concept and look into its basic tenets. There will be a detailed discussion on the sources of variability, since variability is the raw material on which natural selection acts to produce adaptations. We will also explain the concept of Darwinian fitness and relate it to the reproductive success of organisms. Finally you will also become familiar with the different ways in which selection can act. In other words, this Unit will highlight that natural selection promotes structural, functional and ecological adaptations of individuals, populations and species to their existing environments.

Objectives

After studying this unit you should be able to:

- justify the concept that natural selection is fundamentally a process of differential reproduction,
- identify the sources of variability which furnish material on which selection acts,
- define the term fitness or adaptive value and explain how it is a measure of selective process, and
- examine the working of natural selection in homogenous, heterogenous and changing environments.

11.2 THE BASIS FOR NATURAL SELECTION

In the first Unit of this Block, you have learnt the basis on which Darwin propounded his thesis of evolution as descent with modification through variation and natural selection.

Darwin put forth the notion of the survival of the fittest. How do we define 'fittest'? The answer usually given is those who survive. So you can readily see that this is a circular agrument and doesn't really help us understand what really happens following natural selection quite clearly. The idea of fitness as a matter of survival will not do. Therefore in the course of the development of what we have earlier referred to as the modern synthesis the notion of fitness was related to the ability of the individual to maximise the number of progeny left in the next generation. In other words the notion of fitness was translated into reproductive success. Given the idea of fitness as being measurable in terms of reproductive success we can now go back to basic tenets of Darwinism detailed in Unit 9. The first of the five observations mentioned therein was the tendency on the part of living organisms to reproduce in an exponential manner. We noted that the consequence of this is competition for available resources which results in "the survival of the fittest" Clearly, therefore. in terms of reproductive ability nature is truly prodigal.

11.2.1 The Prodigality of Nature

By prodigality of nature it is meant that organisms have an enormous potential to reproduce. A carp or salmon is known to lay over a million eggs. A frog may lay as many as 12,000 eggs. If all the eggs survive and reproduce, then within a short time the entire earth would be strewn with frogs. Darwin himself worked out the reproductive rates of elephants which are known as slowest breeders of all known animals. Assuming an elephant during its 100 years of existence gives birth to six calves in sixty years of its active reproductive life, in around 750 years there should be at least 19 million elephants living in the world. Several such examples could be quoted to highlight the fact that organisms have an immense potential for reproduction.

How is it that in spite of an enormous potential to reproduce, the numbers of most of the species are always maintained at optimal levels? How is it that lakes are not choked with fishes, or fields not strewn with frogs or the earth not crowded with elephants? This is because that various limiting factors in the environment, both biotic and abiotic, keep a check on the increase in numbers.

11.2.2 Factors that Limit the Reproductive Potential

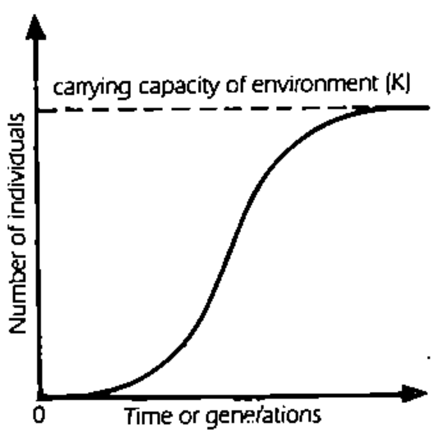

Fig. 11.1 : The graph showing the sigmoid growth curve of population.

Organisms are made to compete for their needs from the environment. The competition as we pointed earlier could be for the food and territory, to overcome the adverse climatic conditions, to escape from predators or to combat an infectious disease. This is indeed the "struggle" It is this "struggle" that keeps the population numbers under manageable levels and from increasing on a logrithmic scale. We earlier referred to the reproductive potential of frogs. If the potential is fully realised, then in a short time, they would be placing a severe strain on the resources on which they depend and soon all of them would starve. However, this is not the case. Most of the population sizes do not increase enormously but they only fluctuate to a small extent from time to time. Some other populations however, do increase dramatically in certain seasons and decrease even more dramatically in certain other seasons. In laboratory one can grow cell cultures in which any one of the resources such as food, space etc. is limited. Under these circumstances the population growth rate of the cells which is exponential to begin with decreases and levels off. The resulting sigmoid curve is characteristic of biological growth in general. (Fig. 11.1) The factors that we mentioned earlier are the ones which delimit the numbers or size to the **carrying capacity** of the environment in natural populations. For instance, the carrying capacity of the environment for plants is controlled by the amount of space required by the individuals of their own and other species. No new seeds or shoots can develop in that particular area until the older plants fall. Population sizes in animals, as mentioned earlier can be limited by food supply. Here the number of individuals increases until the food shortage occurs. Such a shortage of resources would decrease the reproduction. Now a situation would arise where the population size is decreased and the carrying capacity of the environment becomes high enough to support more number of individuals. The cycle thus repeats itself.

If a small number of individuals is introduced into a suitable environment with abundant resources, birth rates are high and death rates are low. As more individuals are added to population, resources become scarce and death rate increases. Also the birth rate decreases. The growth of the population stops as the density reaches the maximum number of individuals that environment can support. This density is known as carrying capacity.

By word of caution we may mention here that the term "struggle" should not be interpreted too literally. In fact after Darwin published his, 'Origin of Species', there was criticism that Darwin's theory suggested war, aggression, fighting between races and classes, and ethnic competitions. But as rightly pointed out by G.G. Simpson such a "nature red in tooth and claw" approach to natural selection is unfortunate The struggle as mentioned by Darwin is a very subtle one. For instance, plants which 'struggle' in dry environments develop devices which would prevent loss of water from them and not by sucking water from each other.

So from among a population of individuals, if only a certain proportion is able to overcome the 'struggle' and survive to produce the next generation's offspring, the questions that come to one's mind are: Is it that chance alone determines which of the individuals should survive and which ones should die? If not, what is it that determines the survival of individuals? These questions lead us to the next element in the process of natural selection, namely, the element of variability in populations.

11.2.3 Variability in Populations

Variability refers to the differences in heritable traits exhibited by the individuals of a species. One of the major contributions of Darwin to the study of evolution was his book of 1868, 'The Variation of Animals and Plants under Domestication'. Darwin pointed out that populations of living organisms are not composed of identical individuals.

It is indeed true that even **monozygotic twins** may express differences between them. One can cite a number of examples to indicate the differences in different traits in a population. Certain traits are continuously varying such as the height or colour, and certain other traits exhibit two or a few distinct, different categories of individuals with no intermediates. For example in human population, there are PTC tasters and non-tasters; individuals with blood groups A or B or AB or O, individuals with black or brown or blue eyes, individuals suffering from sickle cell anaemia and individuals who are normal. so on and so forth. Sweet peas may have either red flowers or white ones; Drosoph may have normal or vestigial wings, red or white eyes etc. Essentially the major source of variability in organisms is the genetic variability caused by mutations of all kinds (Refer to Unit 16 of LSE-04 genetics) and genetic recombination. Also the subtle effects of environment add another dimension to the variability of traits in natural populations. An oft cited example is the differences exhibited in a number of traits of monozygotic quadruplets of a nine-banded armadillo. The monozygotic offspring could exhibit such differences, because of the differences in the uterine environment in which they undergo development. It should be obvious to you that four genetically different zygotes developing in the same uterus should be even more different. We will have a more detailed discussion on the role of natural selection in a changing environment later in this unit.

11.2.4 Natural Selection

Assuming that variability of populations were non-genetic, that is, not controlled by genetic material, once again chance events alone would determine which of the organisms would survive. But phenotypic traits of all organisms have a genetic component and heritable to some degree. If an individual has some form of a trait that gives him a better chance of survival in a given environment, evidently his offspring inherit the trait. This is known as differential survival. Differential survival would refer to the survival of individuals in an environment to which they are well adapted. Individuals who do not possess such adaptations for the given environment may not survive to reproduce. The adaptations are genetically controlled and heritable. Differential survival leads to differential reproduction of alleles responsible for the survival of the next generation. In fact it is customary to say that natural selection is synonymous with differential reproduction. The consequence of differential reproduction is not so much that individuals survive, but that such individuals are able to perpetuate their genes in subsequent generations. Thus what really survives is the set of genes.

Natural selection can therefore mean differential reproduction among members of the same **gene pool**. We earlier said that selection would promote those alleles that give rise to phenotypes that are better adapted to a given environment. In other words, the frequencies of such alleles would tend to increase and those of ill-adapted ones would tend to decrease. What we are saying is that natural selection is a matter of changes in gene frequencies (see box for a brief discussion on changes in gene frequencies). Differential reproduction has a dual role to perform. One it leads to or maintains adaptations and therefore determines whether individuals of a population or species will survive; and two, it is a process which determines what changes will occur in the frequencies of alleles in a gene pool of sexually reproducing individuals.

GENE FREQUENCIES AND THE CHANGES THEY UNDERGO IN POPULATIONS

G.H. Hardy, an English mathematician and W. Weinberg, a German physician independently formulated the central theorem of population genetics. According to them, the frequencies of a pair of alleles in a population would remain constant generation after generation, provided that the population is infinitely large and randomly mating one, and that there is no mutation, no selection, no recombination and no gene migration in the population. But in natural populations, these conditions can not be met and therefore, the equilibrium conditions can not be obtained. In other words, in natural populations gene frequencies cannot be expected to remain constant in every generation, since phenomena such as mutation, recombination, migration etc., occur randomly. Let us try to explain how gene frequencies change in population with a simple example.

Assume that two alleles A and a, have frequency p and q respectively in a large population. Let us assume that frequency of A and that of a put together is equal to 1. Then, $(p + q) = 1$ or $(1 - p) = q$. Let us say that the two alleles A and a form three genotypes, AA, Aa and aa. The frequency of the genotypes would be the binomial expansion of $(p + q)$; that is $(p + q)^2$

$$(p + q)^2 = p^2 + 2pq + q^2$$

Therefore, the frequency of AA $= p^2$, the frequency of Aa $= 2pq$ and the frequency of aa $= q^2$.

Since we said $(p + q) = 1$, $(p + q)^2$ is also equal to 1. The law states that at equilibrium conditions, the frequencies will not change. Therefore, in next generation, frequency of A would be determined by the number of gametes carrying A and this would depend on the number of carriers of A in the population. Then frequency of A $= p^2 + pq$ (one half of 2pq) $= p^2 + p(1 - p) = p^2 + p - p^2 = p$ and frequency of a $= (1 - p) = q$. Then in the absence of any force tending to change gene frequency — mutation, selection, gene flow etc., the frequency remains constant from generation to generation.

But evolution manifests as change in gene trequencies. Let us briefly look into the effect of mutation on gene frequencies. Let us say that allele A mutates to a at a rate of u. Assuming the frequency of A is p and that of a is q initially, then in the next generation frequency of A would be:

$$p_1 = p_0 - p_0u$$

p_0 is the initial frequency, p_1 is the frequency in the next generation and p_0u is the frequency of mutated alleles.

$$p_1 = p_0 - p_0u = p_0(1 - u)$$

In other words, the frequency of A has changed from p to $p_0(1 - u)$ and that of a will be $[1 - (p_0(1 - u)]$ or $(1 - p_1)$. A more detailed discussion on the subject can be obtained from the unit on 'Behaviour of Genes in Population' in LSE-03 Genetics course.

On this note we end this discussion on the basic Darwinian principles. You may attempt the following SAQs before we look into the possible sources of chromosomal and genetic variability and cite certain examples to illustrate the expression of variability.

SAQ 1

Say whether the following statements are true or false:

i) Darwin and Wallace were the coauthors of the book 'Oiigin of of Species' ( )

ii) It was Dobzhansky who said that 'nothing in biology makes sense except in the light of evolution'. ( )

iii) Variations are rare in nature. ( )

iv) By 'struggle for existence', Darwin meant fighting among the individuals of a species with weapons. ( )

v) One way to describe natural selection is that it refers to changes in gene frequencies in a population. ( )

v) Adaptations evolve because of the interaction between the genotype and environment. ( )

11.3 THE SOURCES AND EXPRESSION OF VARIABILITY

In the preceding section we emphasised the fact that evolution or the continuous adaptations to the environment can take place only when phenotypes exhibit variability. In the absense of variability, the chances are that existing living organisms would become extinct since with the change in the environment these organisms would die without leaving progeny. Fortunately in living systems mutations and recombinations generate the required variability. However, organisms often strive to arrive at populations which are more or less uniform. This is possible because selection process acts in such a way that a certain degree of uniformity of phenotype is imposed among individuals of a population. If an individual were to be very different in some way from the rest of the population, he would be less well adapted to the environment as compared to other members of the population and therefore unable to compete successfully with them. However, in a continuously changing environment, a slight phenotypic variability should be maintained in a population. In a changing environment no phenotype remains optimally adapted for long. This is the precise reason why variability needs to be generated continuously in a population and used to develop adaptations in the way Darwin suggested. We shall look into the mechanisms that generate variability.

11.3.1 Sources of Variability

Mutations and genetic recombination (in sexually reproducing organisms) are major sources of variations in natural populations. In this section we will briefly mention the various types of mutations, their rates and how they are caused. For a more detailed account of mutations and mutagenesis you may refer to Unit 16 of Block 3 of the LSE-03 Genetics course.

Mutations

The term mutation is used to designate the process by which changes arise in the genetic material and, the end products of such processes. Mutations form a separate category of sources of variability, distinct from variability arising from genetic recombination or independent assortment of chromosomes, characteristic of sexually reproducing individuals. There are two categories of mutations. (1) Chromosomal mutations which affect the number of chromosomes and the number or the arrangement of genes in a chromosome; (2) gene mutations which affect only one or a few nucleotides in a gene. We shall now discuss these two aspects of mutations.

1. Chromosomal mutations:

Following are the ways in which chromosomal mutations occur: For a detailed discussion on chromosomal mutations refer to Units 9 and 10 of LSE-03 Genetics Course.

a) Changes in number of genes in a chromosome.

i) *Deficiency or deletion* : Refers to the loss of a segment of a chromosome containing one or several genes.

ii) *Duplication* : Refers to the occurrence of more than once of one or more genes in a chromosome. Duplications often occur in random, that is, two or more duplicated segments may lie adjacent to each other on the same chromosome.

b) Changes in the arrangement of genes in a chromosome

i) *Inversion* : The given sequence within a segment of a chromosome is reverted

ii) *Translocation* : The location of a block of genes is changed in the chromosome. Usually translocation is reciprocal which means that it is an exchange of a block of genes between two non-homologous chromosomes.

c) Changes in chromosome number

i) *Aneuploidy* : One or more chromosomes of a normal set may be lacking or present in excess. The term nullisomy refers to absence of both the chromosomes of a pair. Monosomy, trisomy, tetrasomy etc., refer to the occurrence of a given chromosome once, thrice, four times etc., respectively in a diploid organism.

ii) *Polyploidy* : Refers to the occurrence of more than two sets of chromosomes in an individual. Most organisms are diploid, that is they have two sets of chromosomes in their somatic cells, but only one in their gametic cells. Polyploid organisms would be triploid when they have three sets of chromosomes, tetraploid if they have four sets and so on. Polyploidy occurs frequently in plants but is a rare phenomenon in animals. Polyploidy has been a common means of speciation in plants. Many of the cultivated plants, such as wheat, oats, tobacco, potato, banana, coffee, sugarcane and many flowering plants are polyploids. Plant breeders always attempt to induce polyploidy by artificial means to create new varieties. Polyploidy can be regarded as the only means in bisexual organisms by which a new species could arise in one step.

2. Gene mutations

Gene or point mutations occur when the DNA sequence of a gene is altered and the new nucleotide sequence is passed on to the offspring. This occurs either due to addition or deletion or substitution of one or a few nucleotides. Nucleotide substitutions can be either transitions or transversions. Transitions are replacements of a purine by another purine (A by G or vice versa) or a pyrimidine by another pyrimidine (C by T or vice versa). Transversions are replacements of a purine by the pyrimidine or vice versa (G or A by C or T or vice versa). We will briefly explain the different types of gene mutations.

a) Substitutions : Substitution of one base by another would result in an altered amino acid in a polypeptide chain. For instance triplet AAT in DNA (UUA in mRNA) would specify leucine. But if the first A is replaced by C, it will code for valine. Some of the codons are degenerate and substitutions may not alter the amino acid specified. For instance, in the triplet AAT if the first A is replaced by G the amino acid coded would still be leucine. Gene mutations which do not normally affect the active site of a protein will not alter its biological functions. But nucleotide substitutions that change a triplet coding for an amino acid into a termination codon would produce adverse effects. Once again in AAT, if the second A is replaced by T (ATT), the resulting mRNA codon UAA is a termination codon. When a termination codon is present in the middle of an mRNA molecule the subsequent codons are not translated and an incomplete polypeptide will be released from ribosomes.

b) Additions and deletions : Addition or deletion of a nucleotide pair in the DNA sequence of a structural gene often results in an altered sequence of amino acids in the coded polypeptide. Essentially such additions or deletions shift the reading frame of nucleotide sequence from the point of addition or deletion to the end of the molecule. Look at the following DNA sequence.

CAT — CAT — CAT — CAT — CAT —
↑

If a nucleotide T were to be inserted immediately after the first C, the sequence would read as

—CTA — TCA — TCA — TCA — TCA — T

The original DNA sequence when transcribed and translated would yield five successive valine residues. But the altered sequence would correspondingly read one aspartate and four serine residues. Mutations resulting from the addition or deletion of base pairs are called frameshift mutations.

So far we have discussed the several ways in which the genetic material could be altered. Mutations could be either spontaneous or induced. In recent years there has been a more clear understanding of the causes of mutational process. **Tautomeric shifts,** ultraviolet radiations, chemicals such as hydroxylamine, nitrous acid and a variety of alkylating agents can cause permanent alterations of nitrogenous bases. Aromatic compounds such as **acridines** can cause addition or deletion of one to more than twenty bases in DNA.

We have briefly discussed mutations, a way or source of variability in natural populations. Together with recombinations occurring at the time of meiosis they form the raw materials for selection to act on. Before we discuss briefly about recombination, let us have a quick look at mutation rates in organisms. For a detailed discussion on mutation rates you may refer to the Unit 16 of Block 3 of LSE-03 Genetics course.

3. Mutation rates

Each gene has a characteristic mutation rate. Mutation rates are often described as an average per gene basis. For instance, Drosophila has one detectable mutation per 10,000 loci, that is, 0.01% per locus. In humans spontaneous mutation rates have been calculated for some of the dominant lethal genes such as **retinoblastoma, chondrodystrophy and Huntington's chorea.** These genes have rates varying from 0.01% to 0.001% per locus which means that one out of 10,000 or 100,000 loci mutates. This is true of most of eukaryotic mutation rates which range from 10^{-4} to 10^{-6} per locus. In prokaryotes the rates may be much lower, ranging from 10^{-7} to 10^{-10} per locus. Mutations can also occur in reverse direction by which it is meant that a mutant gene can mutate back to its wild type form. However, **reverse** or **back mutation** rates are much lower than the forward mutation rates.

4. Genetic recombination

Mutations are the only kind of variability generating mechanism in prokaryotes and asexually reproducing organisms. But in eukaryotes where sexual recombination occurs, even in one generation there is a marked reshuffling of genes in the chromosomes which amplifies the genetic variability in a population. The kind of variability generated by recombination is tested by natural selection in as many genetic backgrounds as possible and in as short time as possible (say in one generation). Thus one of the **greatest and fundamental advantages of sexual reproduction is the generation of variability.** Provided the populations are large, even if mutations do not exist, the mechanism of sexual recombination alone would be generating new genotypes for very long time.

11.3.2 Expression of Variability

In the previous sub-section we discussed the possible ways by which variability can be generated. We shall now examine one instance that illustrates the consequence of variability on phenotype.

Any genotype is essentially an encoded hereditary information for a specific phenotype over a small range of environmental conditions. In other words a phenotype which arises as an interaction between genotype and the environment is represented by a structure or function of an organism that would possibly come under the influence of natural selection. Let us now look into an instructive example of sickle cell anaemia — a genetic disease, the allele for which manifests differently in different environments under the influence of natural selection.

Sickle cell anaemia in man is caused by a defective chain of haemoglobin. The abnormal haemoglobin known as HbS differs from natural haemoglobin (HbA) in one amino acid. A substitutional mutation causes the replacement of glutamic acid by valine in the sixth position from the amino terminal end of the β chain polypeptide. This is because instead of the triplet GAA or GAG which codes for glutamic acid in normal chains, the abnormal mRNA has GUA or GUG which codes for valine. HbS in deoxygenated state precipitates out of solution forming elongate crystals. The formation of crystals in turn produces a characteristic deformation of RBCs and the cells acquire a crescent or sickle shape, hence the name sickle cell anaemia. The deformation of red cell weakens the red cell membrane and lyses the cells. The loss of red cells and haemoglobin leads to anaemia and this causes oxygen deficiency to the tissues per unit time. A single substitution, more specifically, replacing the thymine by adenine in the second position of the sixth triplet of the β chain gene triggers a variety of responses that affects several aspects of the physiology of the organism as shown in Fig. 11.2. Individuals who are homozygous (HbS/HbS) for the gene usually die early in life. In heterozygotes (HbA/HbS) some proportion of red cells lyse periodically but this does not cause any serious harm to the individual and in any case the survival is not affected.

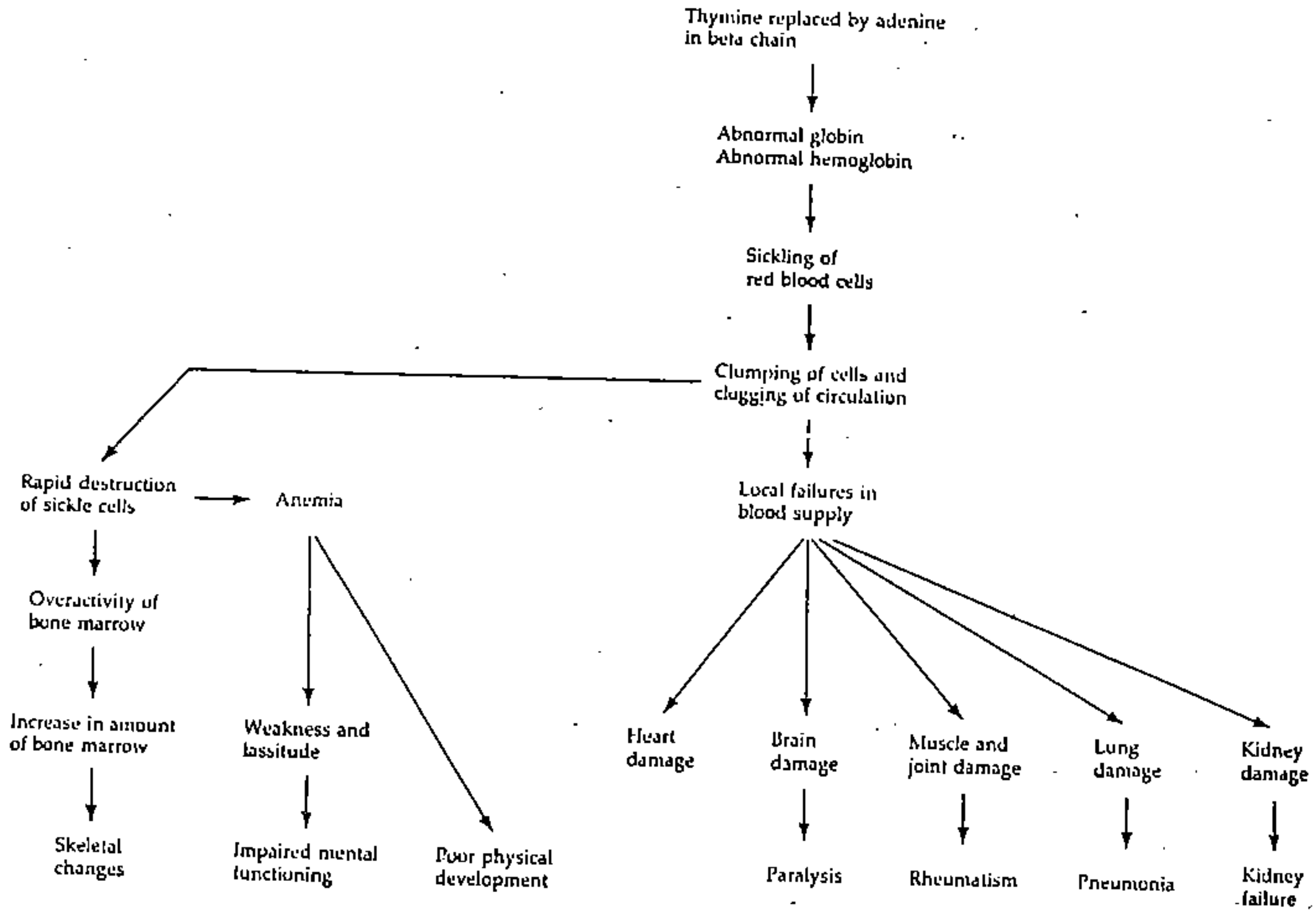

Fig. 11.2 : Effects of sickle cell anaemia. The figure shows that a substitution of a nitrogenous base by another, triggers a variety of responses that nearly affect several aspects of organism's physiology.

In other mammals sickle cells do appear in population, but do not lead to the lysis of erythrocytes. For instance, deer populations have been shown to possess sickle cells extensively in their blood. It is suggested that the thickness of the red cell membranes of deer populations would prevent the lysis of the cells. What is more interesting is that the abnormal allele of the β chain gene is present in high frequency in some human populations. How can a gene that is imposing deleterious and lethal effects on its homozygotes be present in such large numbers in certain human populations? This essentially means that natural selection in some places favours or at least is not eliminating the allele. We earlier said that in heterozygotes there is only a small loss of haemoglobin. But all other factors being equal, even such a small loss cannot be considered as a favourable condition and natural selection would eliminate the allele from the population. Under these circumstances there should be some compelling reasons for the maintenance of the allele in large numbers in African and certain Asian populations. The allele for sickle cell haemoglobin (HbS) almost coexists with normal allele (HbA).

Evidence is available that heterozygotes carrying HbS are resistant to falciparum malaria. In the malarial belt of Africa and Asia, the frequency of HbS allele is quite high. Medical examination of children in hospitals has indicated that those with sickle cell trait (not the disease) do not exhibit falciparum malaria symptoms. Studies have shown that even when bitten by carrier mosquitoes, individuals do not contract the malaria provided they are heterozygous to the haemoglobin β chain gene, whereas normal homozygotes (HbA/HbA) did contract the disease. The HbA/HbS heterozygote has a greater advantage than the normal haemoglobin homozygote (HbA/HbA) in that the former gets a complete protection against the malarial attack. Sickle cell anaemia is an example, where having a defective allele or part of the genotype proves to be an adaptation.

When genes are represented by only a single wild type allele obviously their variability will be low in the population. Certain genes may exhibit greater variability. Physiological traits appear to have a wide range of variability as against anatomical traits. The coefficient of variation (a measure of variability — see marginal remarks) for a randomly chosen set of physiological traits in animals ranges from 7.1 to 304. Anatomical traits in mammals have a range from 4 to 10. It is also true that variability of certain of the traits is indirectly related to some final important physiological function. For instance blood pressure is a physiological trait closely monitored by natural selection showing a low variability among the individuals of a population under identical conditions. Contrarily the heart rate, capillary diameter, or the force of ventricular contraction could be highly variable in a population. Each of these contributes to the final important product namely the heart beat. The blood pressure may be arrived almost to a fixed value by different contributory values of various components. For example, it could be said that the value 6 can be arrived at by 12/2, 18/3, 24/4 etc.

Apparently there is not much of a variation in anatomical traits such as the length of head or relative length of forelimbs or in certain physiological traits such as stamina, swimming speed or blood pressure etc. Once developed these traits appear more or less fixed. Such constancy is seen in the structure of protein molecules as well. For instance, analysis of amino acid composition of the cytochrome C of 33 species of diversely related organisms ranging from humans to sesame seeds has shown several similarities. For instance amino acid positions 14, 17, 18 and 80 are invariant since they all interact with heme molecule. Any change in these amino acids would adversely affect the functioning of vital heme group which undergoes oxidation-reduction reaction. Amino acids 80 to 85 are always hydrophobic, 99 to 104 is never hydrophobic, 86 to 93 is charged and 94 to 98 is never charged. These charge consistencies suggest that all these cytochrome C molecules are folded in the same way. In order to preserve the three dimensional structure of the molecule, natural selection has preserved the charge pattern of this vital protein.

We end our discussion on sources and expression of variability here and before we move on to the next section, attend to the following SAQs.

SAQ 2

Fill in the blanks:

i) Continuous adaptations to the environment can take place only when phenotypes exhibit ....

ii) The major sources of variability in natural populations are .... and ....

iii) Changes which result in the arrangement of genes in a chromosome are .... and ....

iv) .... has been responsible in a major way for the evolution of cultivated plants.

v) Mutations resulting from the addition or deletion of base pairs are called ....

vi) In sickle cell anaemia in β chain of haemoglobin .... is substituted for ....

vii) In African populations resistance to malaria is provided by ....

11.4 CONCEPT OF FITNESS

While discussing the Darwinian premise of natural selection we observed that the term selection is synonymous with non-random reproduction, and that the success of the survivors is related to the number of offsprings they leave behind. Is it possible to quantify such success? In other words can natural selection be quantified? The answer to these questions is yes and is related to the notion of 'fitness'. The term fitness variously known as **Darwinian fitness** or **selective value** or **adaptive value** is a measure of the reproductive efficiency of one genotype relative to another genotype within a given population of species Let us now look into the details of the concept of fitness.

Let us take an example to explain this concept.

Let alleles A and a form three genotype AA, Aa and aa. Let genotypes AA and Aa produce four progeny each and genotype aa produce only two progeny. The fitness or the adaptive value of genotypes AA and Aa would then be 4/4 = 1 and that of aa would be 2/4 = 0.5. The two genotypes AA and Aa have similar fitness values and aa has 50% of the fitness value of the other two. The genotype with highest reproductive efficiency is given the fitness value of 1 and the fitness of the other genotypes are calculated relative to the one with maximum fitness value. Fitness is denoted by the letter w. Table 11.1 explains to you the method of calculating the fitness value for the various genotypes.

Table 11.1 : Table illustrating method of calculation of adaptive value and selection coefficient of genotypes

		Genotypes			
		BB	Bb	bb	Total
1.	No. of genotypes in one generation	30	60	15	105
2.	No. of zygotes produced in 2nd generation	90	80	10	180
3.	Average number of progeny	90/30 = 3	80/60 = 1.33	10/15 = 0.66	
4.	Darwinian fitness (w) (relative reproductive efficiency)	3/3 = 1	1.33/3 = 0.44	0.66/3 = 0.22	
5.	Selection coefficient s = (1−w)	0	0.56	0.78	

The measure of selection pressure on any genotype is referred to as **selection coefficient**. Darwinian fitness and selection coefficient are related to each other by the equation $w = (1 - s)$ or $s = (1 - w)$ where w is the Darwinian fitness and s is the selection coefficient. s actually measures the amount of reduction in the fitness of any genotype. Table 11.1 shows that the fitness of genotype BB to be one. This means that the selection coefficient for this genotype is zero which means that no individual with this genotype is eliminated by the action of natural selection. For genotype Bb and bb the selection coefficient would be 1−0.44 = 0.56 and 1−0.22 = 0.78 respectively. In these cases 56% and 78% of the progeny are eliminated by natural selection. Fitness values are useful in predicting the changes in the frequency of genotypes from generation to generation. (For a detailed discussion on the allelic and genotypic frequencies and their changes in population refer to the Unit 20 Block 4 of LSE-03 — Genetics course.)

From the above discussion it should be clear to you that the fitness of genotypes is measured relative to each other and as such do not give us absolute values. It is the relative reproductive efficiency of the different genotypes within a population that is related to changes in gene frequencies and this is essentially natural selection in quantitative terms. Fitness values are affected by a number of factors all of which are collectively referred to as **fitness components**. These could be viability, role of development, successful mating, fertility etc. The difference in fitness values which different genotypes exhibit are due to the differences in one or several components. For example **thalassemia major**, an inherited disease is caused by a defective α chain locus. The affected individuals would die young. Therefore fitness values of such individuals is zero. On the other hand **achondroplastic dwarfs** reproduce only 20% as efficiently as normal individuals. In thalassemia individuals zero adaptive value is due to the non-viability of individuals. In achondroplastic dwarfs it is due to reduced fertility.

11.5 NATURAL SELECTION UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

In this section we will be learning the action of natural selection on the populations under different environmental conditions namely (1) environments which are more or less uniform (2) environments which are constantly changing (3) environments which are heterogeneous.

11.5.1 Action of Natural Selection in Uniform Environments

In the absence of any large scale environmental change, that is, in more or less uniform environments, populations often maintain a stable genetic constitution with respect to many traits. Natural selection in the absence of environmental change maintains a genetic homeostasis. This phenomenon is known as **normalising selection.**

Several of the phenotypic traits of individuals can be arranged on a linear scale. The distribution curve of the traits usually takes a bell shape, so that the number of individuals is greater at intermediate values and gradually decrease towards the extremes as shown in Fig. 11.3a. As stated earlier, normalising selection occurs when individuals with intermediate phenotypes are favoured and those with extremes are under selection pressure (11.3b). This tendency continues generation after generation. If there is a strong selection pressure against the phenotypes occupying the extremes of normal curve, then the population may show less variability although the mean remains the same (Fig. 11.3c). Natural selection has more often a normalising or stabilising effect on populations with mid-values for the traits and individuals with intermediate values for their traits have better chances of survival. For instance, new born infants which weigh very less or very more than the average weight have high rate of mortality. Contrarily infants of intermediate weight have less problems of survival. We discuss two examples below, one from nature and the other from the experiments of Dobzhansky and Spassky to explain the concept of normalising selection.

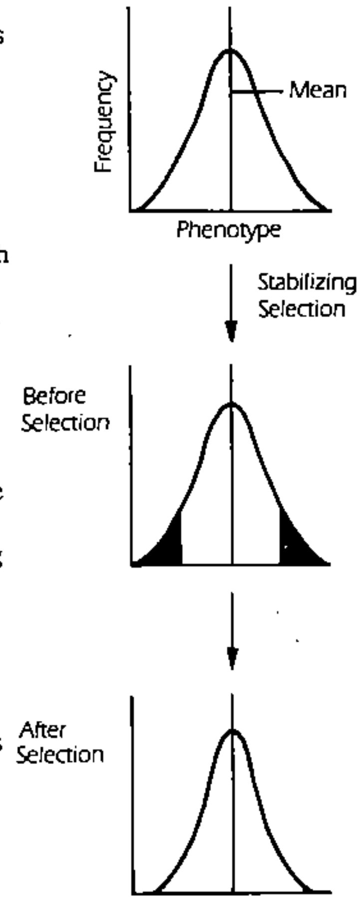

Fig. 11.3 : Normalising selection
a) Before selection the population has a normal distribution of individuals for a specific trait. You may observe that more individuals in the population has a mean measurement (dotted line) for the trait.
b) Selection acts on individuals with extremes of measurements (shaded areas).
c) As a result, the variability of the population has narrowed but the mean has remained the same.

i) The Observation of Bumpus

An interesting observation made by an American biologist H.C. Bumpus (1899) provides a good explanation for normalising selection. Bumpus collected some 136 injured house sparrows after a severe snow and sleet storm with high winds at Woods hole. Of these birds 64 died, resulting in two groups of sparrows, those that were killed by the storm and the ones that survived. Bumpus, made measurements of a number of randomly chosen traits such as wing length, wing span, tarsus length etc., and found that those that were killed by the storm had measurements which fell at the ends of the bell shaped curve. In other words, birds which had either mean or close to the mean measurements were the ones to survive. Normalising selection generally eliminates during a catastrophe or a stressful situation individuals whose traits vary markedly from the mean values. By way of interpreting Bumpus's observations, it could be said that the birds which were blown down easily by the winds had either their wings too long for their body weight and therefore presented a larger surface area or they had too short wings for their body size and therefore could not fly against strong winds. Prior to the catastrophe the range of individual measurements was larger as compared to the range of measurements that survived the catastrophe. Every catastrophe may narrow down the variability of the population thereby weeding out suboptimal genotypes.

ii) The Experiments of Dobzhansky and Spassky

Theodosius Dobzhansky and Boris Spassky demonstrated the working of normalising selection on a behavioural trait in two populations of *Drosophila pseudobscura*. The two populations were subject to artificial selection. One population was selected for **positive phototactic** behaviour and the other **negative phototactic** behaviour Flies were placed in a container from where they could choose to go towards light or darkness. The photopositive flies or those that moved towards light were collected and bred, as also the ones which exhibited photonegative (movement away from light) behaviour. The breeding experiments were repeated for several generations and for each generation the artifical selection was maintained. At the end of several generations of artificial selection, it was observed that two distinct populations resulted, one increasingly photopositive and the other increasingly photonegative. More importantly, once the artificial selection was terminated natural selection favoured individuals with neutral behaviour towards light, and both populations reverted back to an intermediate phototactic score as shown in Fig. 11.4

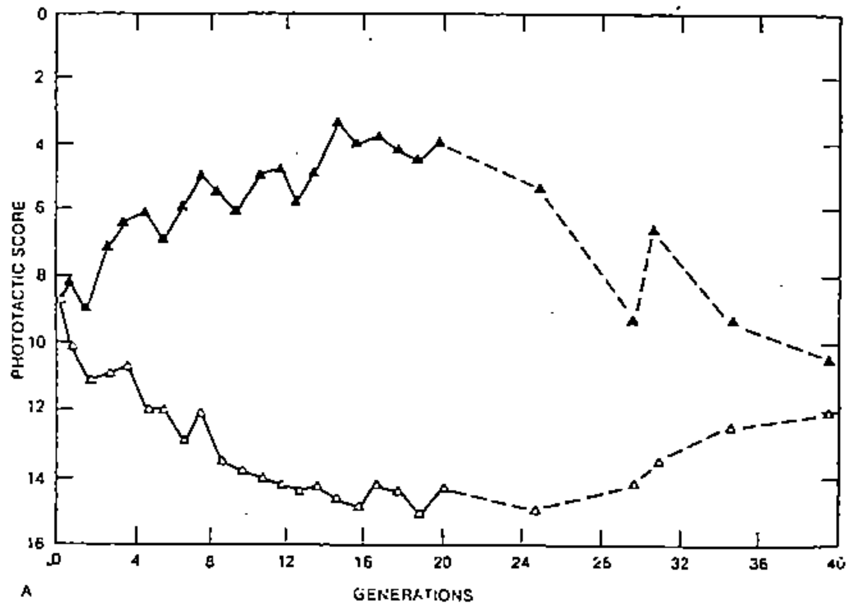

Fig. 11.4 : Artificial selection for positive and negative phototaxis followed by normalizing natural selection in laboratory populations of *Drosophila pseudoobscura*. Artificial selection for 20 generations is successful for both negative (light triangle) and positive (dark triangles) phototaxis. When the artificial selection is stopped after generation 20, natural selection favours a mean value once again.

The above two example are illustrative of the fact that selection normally favoured phenotypes which fall in the middle of the distribution, reduces variability around the mean but does not change the mean value.

11.5.2 Action of Natural Selection in Changing Environments

Directional or **progressive selection** is the mode of selection associated with environmental change. We said earlier that in an unchanging environment stabilising selection removes "unusual" forms of traits or extreme measurements every generation. But in an altered environment, the previous mean may no longer be the optimal measurement of the trait. Under these circumstances, selection would weed out the individuals from the two ends of the normal curve unequally (Fig. 11.5b). This in turn shifts the mean of the trait to a new favoured extreme (11.5c). You may understand that directional selection is a modified form of stabilising selection in that it does not work evenly at both ends of the distribution curve.

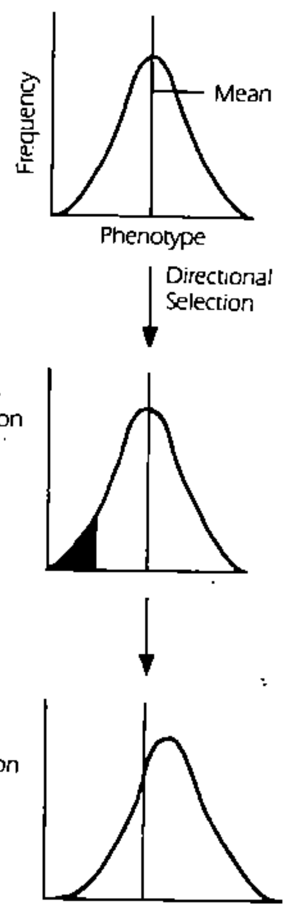

Fig. 11.5 : Directional selection
a) Distribution of the population prior to selection.
b) Due to change in the environment, selection weeds out individuals from the two ends of the curve unequally (shaded area indicates the individuals on whom selection acts).
c) The mean value of the trait is shifted to a new favoured extreme.

A revealing example of directional selection in operation is the ability of pest populations to develop resistance to pesticides. Man has been largely responsible for changes in the environment of many organisms. In order to adapt themselves to changes in environment, organisms respond rapidly through directional selection. Ever since the first report on the resistance of houseflies to DDT was made in 1947, more and more reports of insects becoming resistant to a variety of pesticides have been coming in over the past four decades. In all cases the story is same. Initially a small concentration of a new pesticide is sufficient to control the pests. Slowly the concentration is increased even as the insects develop resistance to higher concentrations. Finally the pesticide becomes totally ineffective or the use of it is economically impractical.

In every generation the directoral selection eliminates from the population those insects which are less and less resistant to the insecticide. Stated differently, in every generation more and more insects that exhibit a higher resistance to the pesticide are selected. Pesticide resistance by insects reflects the efficacy of directional selection since the pesticides are normally synthetic substances and the insects were never exposed to them previously in natural environments.

Another interesting example of directional selection in a changing environment is industrial melanism — a species of melanic moths escaping predation because of altered environment. We have a detailed discussion on this subject in Unit 12 of Block 4.

11.5.3 Action of Natural Selection of Heterogeneous Environments

While describing normalising selection it was said that in uniform environments selection limits the variability of populations and evolves a genetic homeostasis. The type of selection process that is in progress in heterogeneous environments is known as **diversifying selection.**

Diversifying selection is the converse of normalising selection. Let us assume that a population occupying a certain environment, has two or more groups of genotypes (AA, Aa and aa) and meets two or more sub-environments or habitats. Among the two or more genotypes, let us say that a rare genotype (aa) that is well adapted to its habitat will be promoted by selection and the frequency of that genotype will increase as long as the habitat is not fully occupied. But when the habitat is saturated, no further increase in the frequency of that genotype can be observed. It is quite likely that the excess population could spill over to another sub-environment. The genotype may not be completely adapted to the new habitat and it is here that diversifying selection plays a role so as to establish a population consisting different genotypes. The phenomenon where two or more genotypes for a given trait exist in a population is called genetic polymorphism. As you can see from 11.6, the different sub-environments come to be occupied by different genotypes and such an occupation would be as complete and efficient as possible.

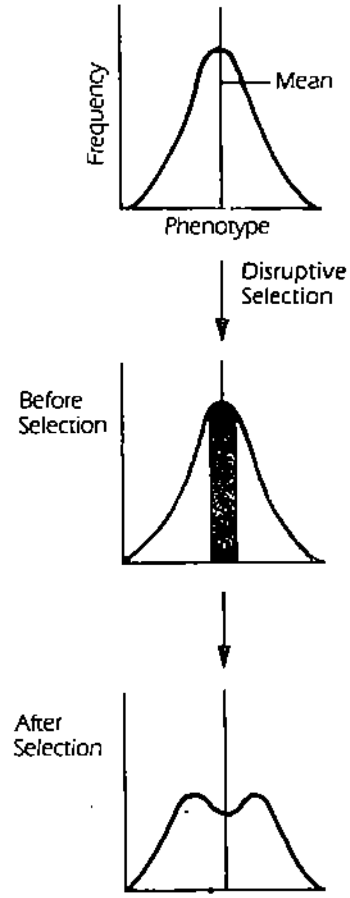

Fig. 11.6 : Disruptive selection
a) Distribution of the population prior to selection.
b) Selection acts against intermediate phenotypes and favours both extremes, (shaded area indicates the action of selection on individuals with intermediate traits).
c) Two distinct neighbouring populations each with its own mean is produced.

A.D Bradshaw and D. Jonell provided evidence that populations could become genetically differentiated while being physically close to each other, through their studies on bentgrass growing on heavy metal contaminated soils. Heavy metal contaminants such as lead and copper are found in heaps of mine spoils and to most plants including the bentgrasses growing in the surrounding uncontaminated soils, the contamination is toxic. Yet, dense growth of bentgrasses could be seen on spoil heaps. Essentially such plants have genes that have conferred resistance to high concentrations of lead and copper. One could observe the resistant bentgrass plants being surrounded by non-resistant varieties a few meters away in the uncontaminated soils. The efficiency of diversifying selection is obvious. Although cross fertilisation could occur between resistant and non-resistant varieties, genetic differentiation is maintained because of the inability of non-resistant seedlings to grow in contaiminated soil, whereas they outgrow the resistant varieties in uncontaminated soils. Considering the fact that some of the mines are less than 400 years old it should be observed that diversifying selection has produced resistant forms in a short period of time.

SAQ 3

Match the following:

a) Selection coefficient	i) measurement of reproductive efficiency of one genotype relative to another genotype.
b) Diversifying selection	ii) Maintains genetic homeostasis.
c) Progressive selection	iii) measure of selection pressure.
d) Adaptive value	iv) selection acting in a heterogeneous environment.
e) Normalising selection	v) selection that weeds away individuals from both ends of normal curve unequally.

11.6 SUMMARY

- The principle of natural selection as put forward by Darwin is based on certain facts and deductions. The observation that the organisms have an enormous potential to reproduce and that in reality only a small proportion survives leads to the deduction that there is competition among the individuals of a species for their various needs as provided by the environment. This deduction when combined with the fact that variations in heritable traits are universal in nature suggests that in such a competition those genetic variations which are useful to the organism in a given environment become adaptations and such adaptations improve their reproductive efficiency. In essence the Darwinian concept of natural selection is related to differential reproduction of the species.

- Mutations and genetic recombinations account for the most of the variability presented by the organisms. Both chromosomal and gene mutations occur in living systems. Chromosomal mutations include changes in the number as well as the structure of the chromosomes. Gene mutations, otherwise called point mutations, bring about changes in the structure and in turn, in the function of the gene, by the substitution or addition or deletion of a nitrogenous base. Mutation rates for eukaryotic genes are of the order of 10^{-4} to 10^{-6} per locus and prokaryotes are of 10^{-7} to 10^{-10}. Sexual recombination ensures that there is a reshuffling of chromosomes so that the genome of the zygote is to a certain extent different from those of the parents.

- In quantitative terms the reproductive efficiency of genotypes is measured as fitness value. Variously termed as Darwinian fitness and adaptive value, the fitness is an index of the reproductive efficiency of one genotype relative to alternative genotypes within that population. The converse of fitness is selection coefficient which is a measure of selection pressure acting on a genotype. Fitness value (w) and selection coefficient (s) are related to each other by the expression $w = (1 - s)$.

- Selection works on genotypes depending on the type of environments which they occupy. If the environment is uniform and homogeneous, the type of selection that operates is the normalising or stabilising kind which weeds out phenotypes with extremes of measurements, assuming the selection pressure is very severe on such traits. Under these circumstances the variability of population is reduced, but the mean value of the trait remains the same. However, under conditions of an environmental change, the mean value of the trait would change as the selection acts on the two extremes of normal distribution unequally. The mean value is shifted to a new position. The development of resistance by insects to pesticides is an example of this type of selection known as directional selection or progressive selection. Finally selection acting on a population distributed over a heterogeneous environment is known as diversifying or disruptive selection. In heterogeneous environment each genotype comes to occupy a sub-environment as a result of which the normal distribution curve becomes a bimodal one with each genotype having a separate mean value for the traits concerned.

11.7 TERMINAL QUESTIONS

1) How do you justify the statement that natural selection is synonymous with differential reproduction?

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2) If the heritable variability does not exist in populations, could there have been an evolutionary process?

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3) What is meant by the term fitness value? Assuming that the selection coefficient of a genotype is 0.35, what is the fitness value of the genotype?

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4) What is the type of selection operating in African population in maintaining the heterozygous genotypes HbA/HbS at a higher frequency? (HbA — allele for normal haemoglobin and HbS — allele for sickle cell haemoglobin.)

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5) A population of isopod crustaceans *Asellus aqualicus* was found to contain two variants of a gene locus coding for the enzyme amylase which breaks down starch. The A_1 variant has optimal activity on the starch of beech tree leaves and the A_2 variant is found to have optimal activity on the starch from willow tree leaves. The pond occupied by isopods has most of the beech trees confined to one side, and the willow trees to the other side. The frequency of genotypes with beech digesting amylase was found to be higher in isopods collected only at "beech side" and the frequency of genotypes with willow digesting enzyme was higher in collections made at the "willow side". How do you interpret the above situation?

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11.8 ANSWERS

SAQ 1

i) False, (only Charles Darwin was the author)
ii) True
iii) False (They are universal in nature)
iv) False (See sub-section 3.2.2 for details)
v) True
vi) True

SAQ 2

i) Variability
ii) Mutations and genetic recombinations
iii) Inversions and translocations
iv) Polyploidy
v) Frameshift mutations
vi) Valine, glutamic acid
vii) Sickle cell trait

SAQ 3

a) iii); b) iv; c) v; d) i; e) ii.

Terminal Questions

1) Natural selection as proposed by Darwin states that the genetic variations produced as adaptations to changing environment are pre-requisites for the survival of the organisms. Essentially those that survive reproduce. Among those that reproduce, the ones that leave behind the largest number of offsprings are regarded as the 'fittest'. Therefore the terms natural selection and differential reproduction have similar meanings.

2) If the heritable variability does not exist in populations, then chance alone would determine which of the organisms would survive and which would not. In the absence of variability, essentially all organisms of a population would be uniform. It is quite likely that any change in environment, that is adverse to the organisms, would wipe out the entire population. Therefore, in the absence of variability, there may not be any evolutionary change.

3) Fitness value quantifies the relative reproductive efficiency of a genotype with reference to another genotype. If s, the selection coefficient of a genotype is 0.35, then w, the fitness value of the genotype is $1-0.35 = 0.65$.

4) In African populations, selection maintains the hetrozygotes HbA/HbS at high frequencies. The two homozygotes are not favoured for the following reasons. The HbS/HbS genotype causes the sickle all disease and the persons homozygous for HbS die early because of the lysis of erythrocytes. (Refer section 11.3.2). HbA/HbA homozygotes are susceptible to falciparum malaria. In hetrozygotes where an HbS allele is present, there is the sickling of cells to a certain extent, but the genotypes exhibit resistance to malaria. Since both the homozygotes are selected against and only heterozygotes favoured, it is the normalising selection that is operating in African population.

5) The example illustrates the action of diversifying selection. In the pond there are two isopod populations differing from one another in the type of amylase they possess. The isopods come to occupy heterogeneous environments, one population confined to 'beach side' and the other the 'willow side'. Natural selection has separated the two genotypes (they are two genotypes because of the differences in the amylase activity of the two populations) but retained them in the same neighbouring environments.

GLOSSARY

Acridines : a group of aromatic dyes whose dimensions are same as a nitrogenous base pair. They wedge between purines and pyrimidines of intact DNA inducing distortions in the helix causing additions or deletions. Acridine orange is a well known mutagenic agent.

Adaptive radiation : the tendency of successful species to diversify into all types of ecological niches.

Biogeography : the study of the distribution of organisms over the earth and of the principles that govern their distribution.

Carrying capacity : the population density that can be sustained by limiting sources.

Chondrodystrophy : a hereditary disease causing the deformation of skeletal system.

Endemic : refers to organisms which are narrowly restricted in their distribution.

Epoch : a unit of geological time; it is the principal subdivision of periods.

Fossil : petrified remains of the organisms of the past.

Gene pool : the total of all genes possessed by reproductive members of a population.

Geology : study of the science of earth.

Huntington's chorea : a rare hereditary disease affecting brain resulting in choreiform (dance like) movement, intellectual deterioration and psychosis.

Isotopes : elements having the same atomic number but different atomic weight.

Monozygotic twins : twins produced from a single fertilised egg. The first division of the zygote produces two cells, each of which develops into an embryo; also known as identical twins.

Mutation : an inheritable change in gene.

Palaeontology : the study of the life of the past through fossil records.

Pangenesis : a theory of inheritance proposed by Darwin according to which all organs in the body produce pangenes, that is minute particles that are carried away by the blood stream and segregated out into gametes.

Pentadactyly : refers to the presence of five digits in limbs, very characteristic of higher vertebrates.

Positive phototactism : ability to respond to light or move in the direction of light. This is in contrast to negative phototropism in which organisms tend to avoid light and move towards darkness.

PTC taster : phenotypes who can taste a solution of phenyl thiocarbamide bitter. The ability to taste the solution is controlled by a single dominant gene. PTC non-tasters do not have any taste to the chemical.

Radioactive dating : determining the age of geological deposits and fossils based on the rate of decay of radioactive elements.

Recombination : a phenomenon occurring at the time of meiosis leading to the shuffling of chromosomes and as a result the genes as well.

Stratigraphy : the study of layers of rock with reference to relative age of forms contained in them.

Tautomeric shifts : a reversible change in a molecule brought about by a shift in the location of a hydrogen atom. In nucleic acids tautomeric shifts in the bases of nucleotides can cause changes in other bases during replication and are a source of mutation.

Ungulates : hoofed mammals.

Vicariance : A pattern of distribution in which related populations replace each other in widely separated areas.

FURTHER READINGS

1) Dodson, E.O. (1985) *Evolution: Process and Product.* Wadsworth Publishing Company, California, USA.
2) Lull, R.S. (1984) *Organic Evolution*(Revised edition). Seema Publications, Delhi.
3) Moody, P.A. (1978) *Introduction to Evolution* (Third edition). Kalyani Publishers, Delhi.
4) Stebbins G.L. Jr. (1968) *Variation and Evolution in Plants.* Oxford and IBH Publishing Co. Calcutta.

Dear Student,

While studying these units you may have found certain portions of the text difficult to comprehend. We wish to know your difficulties and suggestions in order to improve the course. Therefore, we request you to fill and send us the following questionnaire which pertains to this block.

QUESTIONNAIRE

LSE-07
Block-3

1) How may hours did you need for studying the units?

Unit Number					
No. of hours					

2) How many hours (approximately) did you take to do the assignments pertaining to this block?

Assignment Number		
No. of hours		

3) In the following table we have listed 4 kinds of difficulties that we thought you might have come across. Kindly tick (√) the type of difficulty and give the relevant page number in the appropriate columns.

Page Number	Types of difficulties			
	Presentation is not clear	Language is difficult	Diagram is not clear	Terms are not explained

4) It is possible that you could not attempt some SAQs and TQs.
In the following table are listed the possible difficulties. Kindly tick (√) the type of difficulty and the relevant unit and question numbers in the appropriate columns.

Unit No.	SAQ No.	TQ No.	Type of difficulty			
			Not clearly posed	Cannot answer on basis of information given	Answer given (at end of Unit) not clear	Answer given is not sufficient

5) Were all the difficult terms included in the glossary. If not, please list in the space given below.

6) Any other suggestion(s)

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To

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Taxonomy and Evolution

Block

4

EVOLUTION-II

BLOCK 4 EVOLUTION-II

In Block 3 of the Course on Taxonomy & Evolution, you have learnt the basic principles underlying the organic evolutionary phenomenon. We outlined the history of the evolutionary thought, listed the evidence in favour of the occurrence of evolution and discussed the significance of the natural selection as a process in bringing about the evolutionary change.

In this Block you will study the role of natural selection in evolving adaptations among the members of a species as well as in organisms belonging to unrelated species. You will find that adaptations evolved by individuals belonging to different species occupying similar ecological niches result in coadapted communities. Natural selection acting on species occupying different ecological niches has evolved very specific associations such as symbiosis, parasitism or predation. You will also learn the classical definition of the species as provided by Ernst Mayr and get an insight into the various mechanisms of isolation that contribute to the distinctness of the species.

The last two units of this Block discuss elaborately the origin of the human species widely regarded as the pinnacle of the evolutionary process. The first of these units describes the sequential events in the evolution of man based on the fossil data, beginning with very early primates culminating in the origin of *Homo sapiens*. The second unit is concerned with certain philosophical issues such as the evolution of language facility, culture and societies. The evolution of such aspects has to be based on circumstantial evidence as the fossilisation of such phenomena is an impossibility. There is a brief discussion on the direction in which the present human evolution is progressing and the role played by natural selection in it.

Broad Objectives

After studying this block you should be able to :

- describe with specific examples the role of natural selection in evolving adaptations among the members of species, coadapted communities among the members of closely related species and animal associations between species occupying different ecological niches,
- comprehend the definition of the species as provided by Ernst Mayr and describe the role played by different types of isolating mechanisms in the evolution of species,
- trace the fossil history of the *Homo sapiens* from his primate ancestors and describe the diagnostic characters of the different fossils at various stages in human evolution, and
- discuss the evolution of language and culture in humans and make a meaningful guess as to the direction in which the human evolution is progressing.

UNIT 12 NATURAL SELECTION IN ACTION

Structure

12.1 INTRODUCTION

In Unit 11 of Block 3 you studied that natural selection is the fundamental operating mechanism for the evolution of adaptations in organisms. It is the mechanism that also directs all the long term evolutionary phenomena. You have also learnt that successful individuals are those who contribute gametes to produce the largest population of next generation's fertile survivors. Once individuals in a population attain ecological success, they aim at increasing their share of the next generation by increasing the number of gametes they produce. Natural section therefore aims at maximising the reproductive potential of all organisms. Further, you have learnt that conspecific individuals in the same population compete with one another for their requirements from the environment. You might be aware by now that such intraspecific competition puts the variations of the individuals (we here refer to genetically controlled traits) to test in a given environment. The variations that are useful to an individual in a given environment can be deemed as adaptations. Such adaptations make survival possible in a given environment, and contribute to the reproductive success of the individual. With a change in environment (no environment is static), the adaptations may lose their significance and a fresh set of adaptations may have to emerge. Therefore natural selection is essentially a continuous process.

You have already learnt that selection aims at evolving adaptations that, in turn help to maximise the reproductive potential of individuals in a species. In this unit we shall discuss the role of natural selection in evolving adaptations in individuals belonging to related as well as entirely unrelated species. Such adaptations are the effects of interspecific competition. In the present unit we shall also discuss extensively the competition between individuals belonging to different species. We shall discuss with concrete examples the positive role played by natural selection in perfecting adaptations of competing species occupying a similar environment.

Also this unit will also illustrate the role of natural selection in evolving various types of relationship between species occupying different levels in a food chain. Some of these relationships have been an antogonistic one, such as prey-predator and host-parasitic relationships. Selection aims at converting even such adverse relationships into an advantageous one to both the adversary and the affected individuals. In this unit you will also be introduced to the concepts such as sexual selection, kin selection and group selection and their evolutionary implications.

Objectives

After studying this unit you should be able to :

- distinguish between intraspecific and interspecific competition,
- discuss that natural selection promotes the formation of coadapted communities,
- describe the role of natural selection in facilitating niche specialisation, and explain phenomena such as ecological exclusion and character displacement,
- describe the concept of coevolution in relation to prey-predator, herbivore-plant and host-parasite relationships,
- explain that pronounced sexual dimorphism is a device promoted by natural selection for enhancing the attractiveness of each sex towards the other, and
- recognise that altruistic behaviour of individuals as well as groups has far reaching evolutionary significance.

12.2 INDUSTRIAL MELANISM

"In India, in the vicinity of the cement producing factories, the pale dust of the smoke settles down over a large area of trees. Here one may expect a reverse of industrial melanism, the pale coloured insects enjoying the cryptic advantage. This may be called *industrial albinism*, and is recommended as worthy of investigation as an evolutionary phenomenon."

J.C.B. Abraham (1990) *Biology Education* (Macmillan India) 7 (4), 248-250.

In this section, we shall discuss a classic example of natural selection in action. In the preceding unit, it was stated that natural selection always aims at eliminating alleles, which are less adapted to the environment. Conversely selection indirectly aims to promote those alleles or individuals that are well adapted to a given environment. The promotion and establishment of an allele and the resultant phenotype may take several hundreds of years in natural populations. But there are indeed instances where the selective forces have brought changes in the character of individuals within historical times.

The peppered moths *Biston betularia* occur in two forms, the melanic and non-melanic. As shown in Fig. 12.1 the melanic forms are black in colour and non-melanic ones are mottled grey. Until the early part of the 19th century, the melanic forms were regarded as rare and prize collections by insect collectors, and the light non-melanic forms were abundantly present in natural populations. The rarity of black forms was essentially due to the higher rate of predation by birds. The

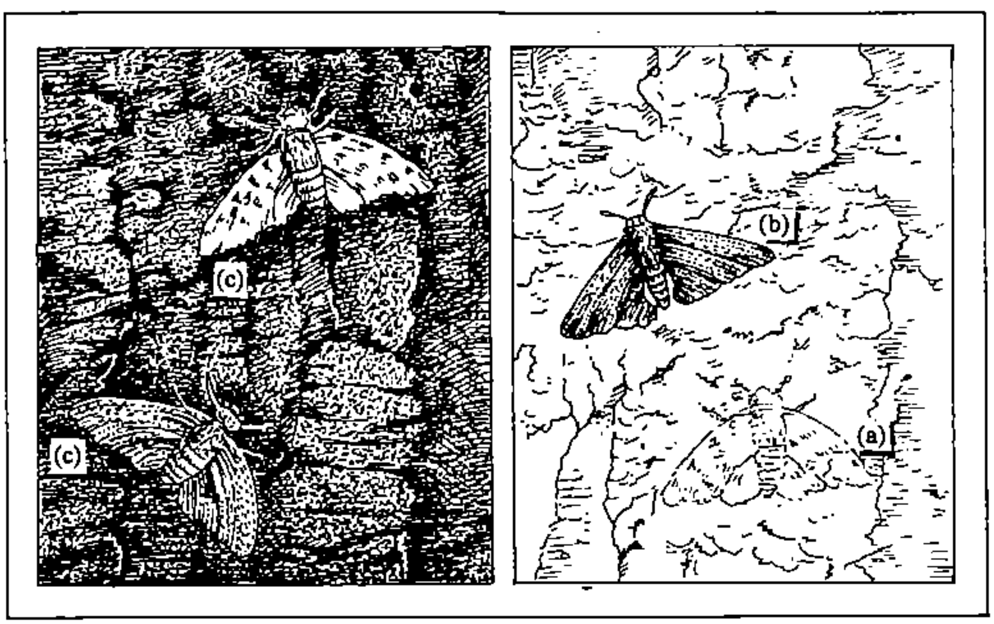

Fig. 12.1 : Industrial melanism in *B. betularia:* a) non-melanic on lichen covered tree; b) melanics on lichen covered tree; c) both melanics and non-melanics on soot-covered tree.

black forms resting on light coloured and lichen encrusted trees were the easy targets for the birds. The light coloured non-melanics blend with their background, and therefore, are not easily visible to the predators (Fig. 12.1). With the onset of the industrial revolution the distribution of melanic forms particularly in the industrial centres underwent a great change. An examination of museum collection of insects over the past 100 years showed that the melanic forms increased in numbers and the non-melanics were becoming rarer and rarer. What could be the possible reason for such an occurrence? In industrial regions, the sooty smoke emanating from factories blackened the bark of the trees and prevented the growth of lichens. This resulted in the black coloured forms resting on such trees becoming invisible to the predators and the light coloured ones being increasingly susceptible to the predator attack because of their contrast with the background. In industrial areas the birds predated upon non-melanics in extremely large numbers whereas in other areas melanics were preferentially eaten. Since the proportion of melanics increased due to industrial activity, the example is often referred to as industrial melanism.

Industrial melanism is a case in which the selection favoured in moths a specific character namely the protective coloration. H.B.D. Kettlewell and E.B. Ford who studied this phenomenon in England (refer to the results of their experiment in Table 12.1) explained that a single dominant gene for melanism is present in the population of *Biston betularia*. The frequency of the gene increased from a mere less than 1% in pre-industrial times to more than 90% with the onset of the industrial revolution in less than fifty generations of the insect.

Table 12.1 : The results of the marking and recapturing experiments of *B. betularia* in two different localities (Based on Ford 1964)

		Typical Form	Carbonlria
Unpolluted Woodland	Released	496	473
	Recaptured	62 (12.5%)	30(6.3%)
Soot-polluted Woodland	Released	137	447
	Recaptured	34(16%)	154(34%)

Biston betularia is not an isolated example for industrial melanism. The phenomenon was subsequently discovered in over 100 species of moths. More interestingly, strict pollution control measures implemented in several industrial cities have brought back the original environment, namely, the tree trunks free from soot deposits and lichens growing on them. In such places the natural selection has favoured the mottled-grey individuals as against the melanic forms.

Industrial melanism explained yet another concept of selection widely known as directional selection. Directional selection is one type of natural selection operating when the organisms have to adapt themselves to a changing environment. Changing environment would lead to changing genetic constitution of the population. This is because, in a changed environment, alleles that are favoured by selection are different from the ones found in the earlier environment. Industrial melanism is a good example of directional selection in action. In the changed environment, namely, the soot polluted trees, the gene for melanism is preferentially selected, thereby changing the genetic constitution of the peppered moth populations. Directional selection contrasts with another type of selection known as stabilising selection or normalising selection which favours an allele already well adapted to the environment by eliminating any marked changes from it. (Refer to unit 11 of Block 3 of LSE-07.)

"Major Leonard Darwin told E.B. Ford that his father (Charles Darwin) had once expressed the hope that it must be possible, on occasion, to observe the action of natural selection and the resultant evolutionary change during the lifetime of a human being. Here, in industrial melanism, the birds are the agents of natural selection eliminating the moths not adapted to the environment (melanic forms against lichen-covered barks, and the pale forms against the soot covered barks). One definition of evolution is systematic changes in gene frequencies and here we see the gene for melanism gradually and systematically changing from 1% to 98%. Darwin's prophetic hope was fulfilled with the demonstration of Industrial Melanism in a matter of a few decades."

J.C.B. Abraham (1990) *Bilogy Education* (Macmillan India) 7 (4), 248-250.

SAQ 1

Fill in the blanks

i) Natural selection always aims at .... those alleles which are ill-adopted to the environment.

ii) *Biston betularia* occurs in two forms, the .... and the ....

iii) After the commencement of .... , melanic forms .... in numbers and non-melanic forms were becoming ....

iv) Industrial melanism is a case in which the .... favoured a specific character namely ....

v) .... is one type of natural selection operating when the organisms have to adapt themselves to a changing environment.

vi) .... favours an allele already well adapted to the environment by eliminating marked changes from it.

12.3 INTERSPECIFIC COMPETITION

Darwin while evolving the concept of natural selection laid emphasis on competition among individuals belonging to a species, that is intraspecific competition. Here the individuals compete for almost identical requirements from the environment. Competition between individuals belonging to different species, that is interspecific competition is also observed in nature. In the following subsection we shall discuss the essential differences between the two types of competition, and subsequently highlight the role of natural selection in evolving coadapted communities of closely related species.

12.3.1 Distinction between Intraspecific and Interspecific Competition

In the preceding block you learnt the Darwinian premise of natural selection based on certain facts and deductions thereof. You would have noticed that one of the foundations for the concept of natural selection relates to competition among the individuals belonging to the same species — the intraspecific competition. You may also recall that intraspecific competition involves two components — (1) the individuals belonging to the same species compete among themselves for the same requisites from the environment which results in physical competition, including the competition for mates and (2) the individuals belonging to a species may compete as to which of them leaves behind a major share of descendents in the future populations. The second type of competition is more subtle, by which is meant that individuals do not compete directly or in any physical way. The success of the second type of competition is measured in terms of the survival of offsprings, and therefore alleles in the next generation. You might have by now deduced that the two types of competition are interrelated. Success in the first type of competition known as ecological intraspecific competition is a prerequisite for success in the second type of competition namely reproductive intraspecific competition. It does not mean that ecological success always ensures reproductive success, for ecologically successful individuals may be sterile; but ecological success is always necessary to achieve reproductive success. We may then summarise that intraspecific competition results in adaptations to a given environment and this helps to perpetuate the genotypes of successful individuals generation after generation.

Interspecific competition, on the other hand is between individuals belonging to different species, which do not interbreed. Closely related species do compete for similar requirements from the environment, especially when the niches they occupy tend to overlap. At these times there will be a pronounced competition at the ecological level. However, there is no competition for mates but each species would independently try to leave behind a major share of descendents in the population. In the following sub-section you will learn more about the interspecific competition and the resultant coadapted communities.

12.3.2 Coadapted Communities

From your studies in ecology, you must be aware that most ecosystems are quite complex consisting of several habitats and that habitats in turn are composed of microhabitats. Each microhabitat may accommodate diverse groups of organisms belonging to various species. Each species inhabiting a microhabitat has carved an ecological niche for itself. The ecological niche essentially tells you everything a species does and the relationships that the species enters into both with biotic and abiotic surroundings. Each species has an exclusive and a well defined niche and it can be said with any amount of certainty that no two species would have an identical ecological niche. This hypothesis was well explained by R.H. MacArthur, in an elegant study of five species of warbler birds of genus *Dendroica* living together in a single spruce tree. All the five species shared the same food insect, the spruce bud worms at the same time. But each species had a well defined niche in the spruce tree as shown in Fig. 12.2. The myrtle warbler was most time confined to the lichen covered branches, near the trunk of the tree. The black burnian warbler was always found on the other parts of the uppermost branches, whereas the black-throated green warbler fed mostly from branches of intermediate height. The other two warblers Cape May warbler and bay breasted warbler also fed on different parts of the same tree, but their feeding zones overlapped with those of the three species mentioned first. The last two species would visit the spruce tree only when there was an outbreak of a spruce bud worms, hence called fugitive or species a having nomadic existence. Essentially, the number of birds of these two species visiting the spruce bud trees depended on the availability of feed organisms, the spruce bud worms. If there were to be an outbreak of spruce bud worms, the two warblers, were found in appreciable numbers. The occurrence of all five species of warblers together depended on the increase in the carrying capacity of spruce trees, made possible by the increase in the number of spruce bud worms. Otherwise only three species were found, each occupying different part of the tree. The three different parts of the tree could be characterised as distinct ecological niche. Each one of them is characterised by its own microclimate, the components of which are temperature, light, relative humidity etc. For instance the lower branches may have less sunlight, lower temperature and high relative humidity as compared to the upper branches which may have more temperature, more light and less humidity. There might be a slight overlap in the niche of any of the three species. However, that does not imply that the entire ecological niche of any of the three species is identical with that of another. Although the spruce bud worms are the common food for all the species, each species also feeds on other insects characteristic of that part of the tree.

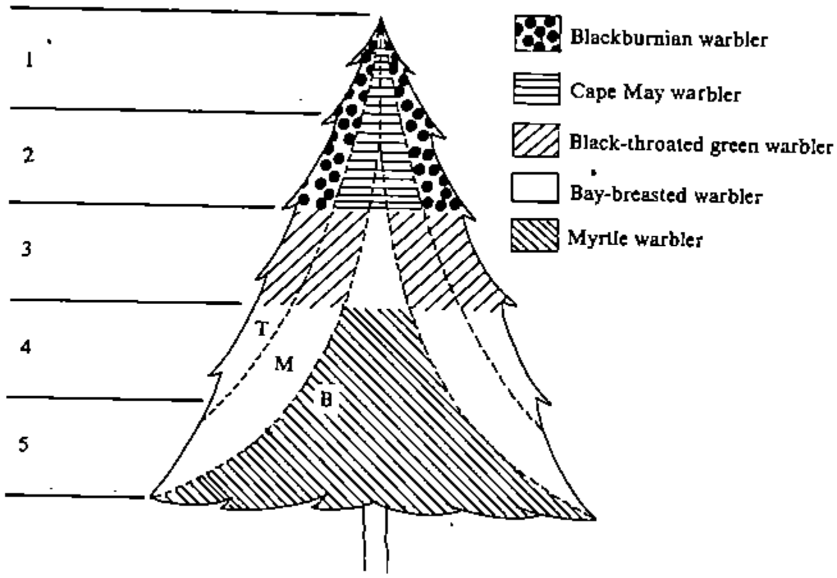

Fig. 12.2 : Diagram showing the distribution of five different species of warblers on spruce bud trees. B-bare lichen covered bases of the tree. M-middle zone of old needles. T-Terminal zone of new needles and buds.

This example brings forth one fact to light, that it is possible for members belonging to different species to occupy well defined adjacent niches, despite a small niche overlap. In other words, the different species of warblers live as a coadapted community. Precisely, this is the point we are trying to make in this section, namely that interspecific competition results in the evolution of coadapted communities. The different species of birds have carved out specific ecological niches for themselves, yet they feed on common food and thus have learnt to live as a community. When MacArthur studied warbler example, it is possible that the competition between the species had already resulted in a coadapted community.

We may also mention here that niche specialisation is a mechanism by which competition between the species is kept to a minimum or even totally avoided. But most of the times in natural environments individuals have not only to interact with the members of one's own species but with members of other species, as well as the physical environment. And the physical environment is a constantly changing one. The changes in the environment may bring individuals of one species close to another species resulting in competitive interaction. At such times the interspecific competition becomes an unavoidable feature and the net effect is character displacement in relation to ecological exclusion. The two terms, character displacement and ecological exclusion require further explanation and let us explain them with a suitable model system.

12.3.3 Character Displacement and Ecological Exclusion

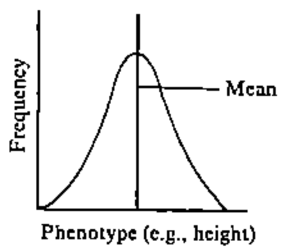

Fig. 12.3 : Normal distribution curve.

Consider two species of organisms, species A and species B. Species A has a population in a community. Another population species B arrives into the same community, rather suddenly, being brought into the community by man (there could be other ways by which the new species can enter into a community). Let us assume that the food organisms of the two species are identical (it can be insects or seeds etc.). The range of food particle size fed upon by each individual species falls into a normal curve. By normal curve we mean that there is a variation in the given trait, for example size of the seeds or insects in this case, or beak sizes which are all distributed in such a way that the largest number of individuals in the population has optimum or mean size or measurement and a very few individuals have extreme sizes or measurments (Fig. 12.3). The normal distribution as shown in Figure 12.3 takes the form of a bell shaped curve. For a more detailed discussion on normal distribution you may refer to any of the introductory statistics books or Block 3 of Mathematical Methods of IGNOU course material, MTE-03. You could observe from Figure 12.4(a) that there is a significant overlap in the normal curves of food capturing devices (mouth, beak or tooth sizes) of species A and B. The region of overlap implies that the members of the two species have to compete for their food over a larger area in the community. Essentially, there is an ecological interspecific competiton for food. You may also note in the figure that some food particles (food particles of both large and small sizes) are out of the reach of each species. Although the population as a whole can feed on a range of food particle size, any individual in the community is restricted in the size of the food particles it can feed on. Assuming that the number of food particles of each size is the same, then individuals outside the region of overlap have better accessibility to the food particles and they may have to expend only less energy in acquiring them. Compare these individuals with those which lie within the region of overlap. They have not only to compete with conspecific individuals for their food, but with those of the other species as well. The net result is that the individuals outside the region of overlap have more energy for reproduction, and naturally will tend to leave more offsprings to the next generation. These offsprings will essentially carry the alleles of their parents including those involved in the determination of food particle size. The effect of this natural selection process over a number of generations will be to move the normal curves of food particle size of the two species apart as shown in Fig. 12.4(b). The two species become adapted to each other's presence in the community — in other words, they become coadapted. Apart from evolving into a coadapted community, you must be able to appreciate in this example that the two sympatric species have shown divergence in a particular character (food particle size preference) owing to the competition between the species. This phenomenon of divergence in character is known as character displacement. Character displacement is accompanied by the carving out of an exclusive niche for each species and the displacement from the region of overlap. You can now understand that in the example given above natural selection has excluded each species from the niche of the other. This phenomenon of separation of niche is referred to as ecological exclusion. Character displacement and ecological exclusion are the basis for the evolution of coadapted communities.

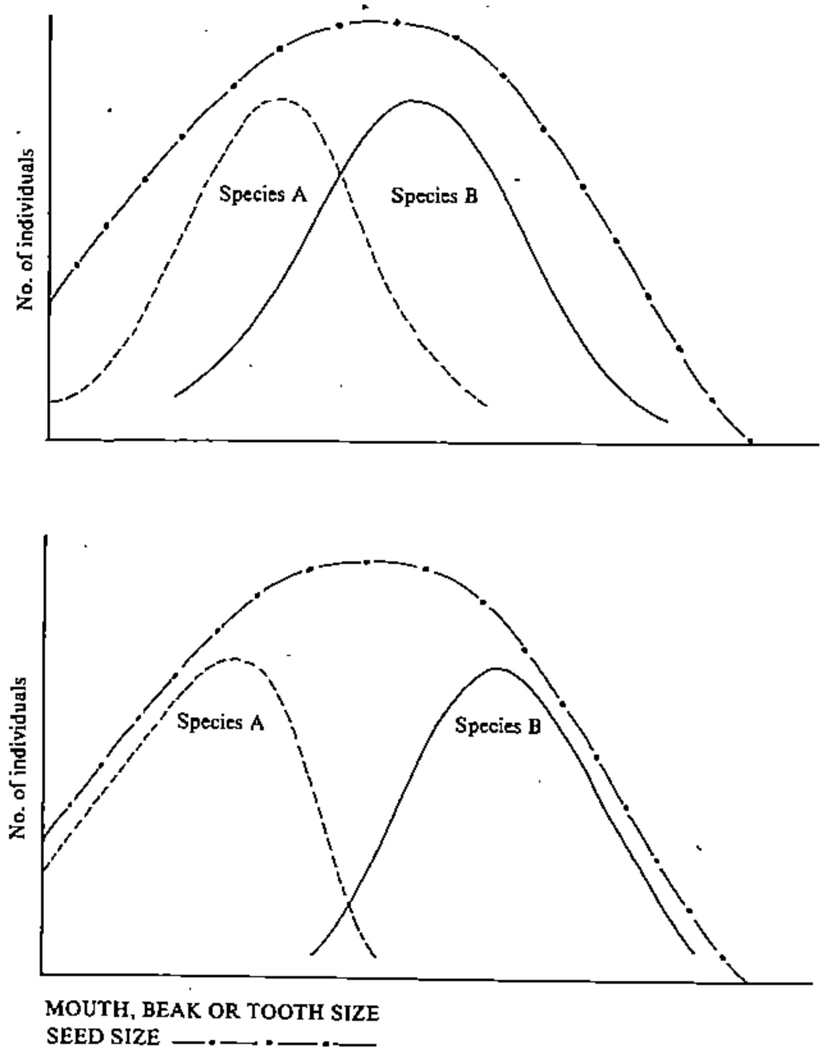

Fig. 12.4 : Character displacement. See text for explanation.

J.H. Connell, a Scottish biologist exemplified these two phenomena by an elegant study on two species of barnacles belonging to two different genera *Balanuns* and *Chthamalus*, living in the same intertidal zone of rocky shore. As shown in Fig. 12.5

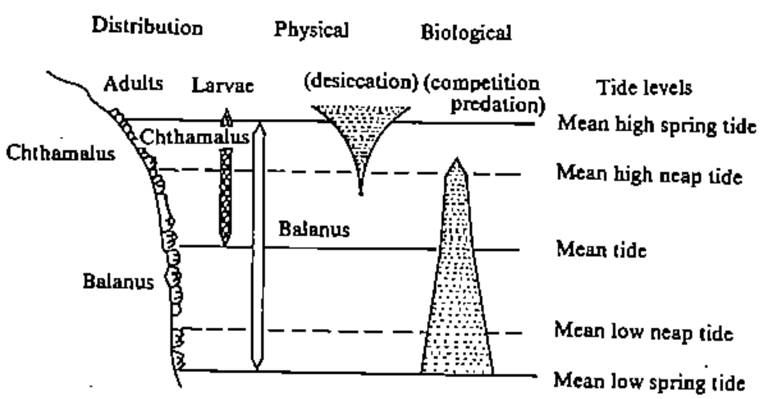

Fig. 12.5 : Distribution of two species of barnacles, *Balanus* and *Chthamalus* at the intertidal gradient. Although the larvae of two species settle over a wide range, their survival is restricted to narrow ranges. Physical factors such as desiccation control the distribution of *Balanus* while biological factors such as competition restrict the distribution of *Chthamalus*.

Chthamalus lives on the upper regions rocks and *Balanus* occupies all the deeper regions in the same shore. There is a region of broad overlap where only the swimming larvae of the two species settle down for the purpose of metamorphosis. In areas where *Balanus* is absent, above the mean tide level, *Chthamalus* can live and the larvae also transform into adults. But in the area of overlap, that is, in the zone where both kinds of larvae attach, *Balanus* outnumber *Chthamalus* and virtually crowd out them. This is because, the *Balanus* larvae are comparatively larger in number and their rate of growth is greater than the *Chthamalus* larvae. Here is an instance of interspecific competition for space, an actual physical struggle between the two species and in this competition *Balanus* always wins. But at the typical *Chthamalus* zone, above the mean tide level and high up in the rocks where some of the *Balanus* larvae do settle, none of them survives, for the simple reason that resistance to desiccation, an adaptation evolved by *Chthamalus* larvae is not characteristic of *Balanus*. It is now obvious to us as to how the two species of barnacles distribute themselves on the shore and that each species is adapted to survive in certain ranges of environmental conditions. The barnacle story illustrates the differences in the environmental ranges of sympatric populations. You should have learnt by this example that each species has a unique and exclusive ecological niche and that each species is optimally adapted to the niche.

SAQ 2

Say true or false. Tick the correct answer.

a) The competition among individuals of a species as to which of them leave behind a major share of descendents is intraspecific ecological competition. True/False

b) Individuals belonging to different species do not normally interbreed. True/False

c) Interspecific competition is more pronounced at reproductive level. True/False

d) Individuals belonging to two different species always occupy identical ecological niche. True/False

e) Interspecific competition results in the evolution of coadapted communities. True/False

f) Niche specialisation is a mechanism by which the competition between the species is enchanced. True/False

g) The divergence in a particular character observed in two sympatric species owing to competition between them is described as character displacement. True/False

h) Each species has an unique and exclusive ecological niche and each species is optimally adapted to that niche. True/False

12.4 PARASITISM, PREDATION AND COEVOLUTION

You now know that natural selection aims at evolving adaptations of organisms in response to environmental changes in the inanimate world. Also many adaptations arise due to interaction with or as a response to the presence of other organisms in the environment. So far we discussed the evolution of such interactions and adaptations between closely related species which more or less occupy the same level in the food chain. Such interspecific interactions may also occur between organisms at different levels in the food chain. The evolution of adaptations in response to such interactions has been largely responsible for the development of various associations — be it commensalism, mutalism, parasitism or predation. For instance, the claws, teeth, speed etc., found in carnivores are adaptations evolved in response to the kind of prey species which makes up their diet. Similarly, the toxins, protective coloration and chemical warfare devices are the adaptations evolved by the prey species to escape from the evil designs of the predator. Also selection is able to maintain and adjust the rate of reproduction of the prey species to that of predators. In short, interspecific relationships are a direct result of the coordination of the evolution of ecologically related species by the natural selection process. Very interestingly, of the two species that are involved in the evolution of such relationships, each one acts as the mutual agent of selection for the other. It is this process that is known as coevolution. In this section, we shall be analysing prey-predator, plant-herbivore and host-parasite relationships as coevolutionary processes.

12.4.1 Coevolution of Prey-Predators

Predation is a process by which one organism (predator) eats another organism (prey). If the prey population is abundant, the predator population also becomes abundant. If the predators are abundant and efficient, there will be a reduction in the abundance of the prey population. Prey-predator relationships can be visualised as a game in which each player tries to outwit the other. If you consider the prey population, only individuals better adapted to escape predation would survive and reproduce. So in a prey-predator population with varying degrees of efficiency (the variations are genetically determined), the prey species evolve at the avoidance of the predator and the predator species evolves towards maintaining predation and making it more efficient. Such a coevolution of the predator-prey relationship may continue indefinitely over long periods without causing extinction of both the species. This is achieved by improving the efficiency of the predator and the resistance of the prey in a balanced way. Natural selection aims at a faster improvement of the efficiency of an inefficient predator than the resistance in an already resistant prey. But in a vulnerable victim, the resistance is evolved faster than the efficiency of an already efficient predator. Such balancing acts by natural selection do not allow any one of the two species to win the race.

There are several examples of natural selection having produced complex adaptations as a consequence of long term evolutionary process. These adaptations manifest themselves both among the predators and prey organisms. Examples among the predators are: the long and slimy tongue and the accurate aim of insectivorous lizards; the elaborate webs of the spiders; the social hunting behaviour of the lions. Cryptic coloration, fleetness, noxious substances and toxins, alarm calls and posting of sentinels can be cited as instances of adaptations evolved by prey organisms as defensive measures.

12.4.2 Coevolution of Plant-Herbivores

There has been a perfect coevolution between plants and herbivorous animals. This has often developed into a mutually beneficial relationship. Whereas the plants have proved to be a good source of food for animals such as insects, birds and certain mammals, these animals in turn have been of great help to plants for dispersal of pollen and seeds. More specifically plants offer insects both nectar and pollen as food and insects in turn have developed olfactory, visual and structural adaptations for pollination as well as for seed dispersal. To attract pollinators, flowers have attractive colours and smell sweet as well. It is interesting to note that certain flies are attracted towards bad odours emanated by substances such as putrescin and cadaverine.

The relationship developed between insect pollinators and entomophilous plants is an excellent example of coevolutionary process. Several instances involving insect pollinators and plants belonging to the families Malvaceae, Papilionacea and Labiatae could be cited. One study related to the genus *Pedicularis* (louse wort) and its pollinators, the bumble bee (*Bombus*) stands out. Certain species of louse wort such as *P. canadensis* and *P. crenulata* are pollinated nototribically, which means that bumble bees pick up the pollen grains from the plant on their notum (the dorsal sclerite of the insect). The insects get a generous brushing on their dorsal side from the stamens of the flowers as shown in Fig. 12.6 and on their visit to a next flower deposit the pollen on the stigma. Certain other species such as *P. groenlandia* pollinate sternotribically which means that the pollen is picked up by insects on their sternum (ventral selerites of insects) as depicted in Fig. 12.7 and then transferred to the stigma of the flower. What is to be appreciated in the coevolutionary process is the close correspondence between the structure of the flower and the structure and behaviour of insects involved.

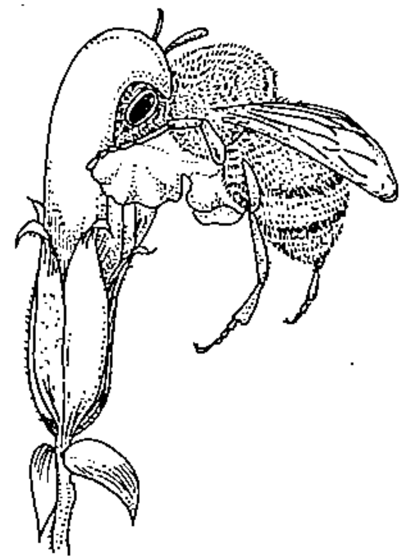

Fig. 12.6 : Nototribic pollination.

Similarly many animals help plants in return for the food they get from them by dispersing their seeds to far away places. Plants have evolved colourful, fleshy and nutritious fruits, and on being eaten and defecated by birds in environments favourable to the plants, the seeds germinate and grow. Apart from birds, large herbivores such as elephants, rhinos and giraffes living in forests consume fruits and disperse the seeds successfully. A study by D.H. Tarzer and A.S. Martin revealed that in Central America a large number of herbivores such as camels, horses, giant armadillos, elephants, bears and bisons were responsible for the dispersal of trees and shrubs during pleistocene times. But with the extinction of these animals, some 10,000 years ago, the trees also disappeared and only remnants survive today.

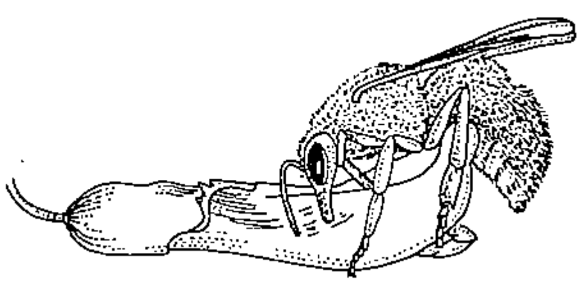

Fig. 12.7 : Sternotribic pollination.

Apart from such adaptations which promote mutualism, plants have also evolved adaptations that would protect them from the attack of herbivores. This is also a coevolutionary process. Plants tend to develop adaptations that would counter the adaptations developed by herbivores to feed on them. Many plants store toxic chemicals in their tissues that make them unpalatable to the potential eaters. A selective advantage is conferred on the plants which store toxins and thus protect them from insect attack. An interesting example is the identification of anti-juvenile hormone compounds in certain plants. Juvenile hormone is a terpenoid compound found in insects, being secreted by an endocrine gland the corpus allatum. The hormone regulates the metamorphosis of insects. The hormone circulates in the blood until the insect completes its larval development. Towards the end of larval development, the titre of circulating hormone decreases, probably due to the reduced secretion by the gland and the larva is transformed into a pupa. Towards the end of the pupal development, the hormone is no more in circulation and pupal-adult transformation takes place. Certain plants have developed chemicals which inactivate the corpus allatum. These chemicals are termed precocenes as they are capable of inducing a precocious metamorphosis in insects. Insects feeding on such plants have their corpus allatum "switched off" by the precocenes which enters into circulation. In the absence of the juvenile hormone, the insects instead of undergoing a gradual metamorphosis (larva-pupa-adult) develop into abnormal or precocious adults and die without reproducing. Precocenes thus provide a good defence mechanism against insect attack.

Another often cited example of chemicals acting as deterrants for those animals feeding on plants is that of monorch butterfly *Danaus plexippus* being despised by birds such as blue jays. The insect feeds on the milkweed plant *Asclepias* and accumulates in its body cardiac glycosides. The birds feeding on such insects experience severe vomitting provoked by the chemical. A similar example is that of grasshopper *Poecilocera picta* which is not predated by birds, for the insects feed on another member of the family Aselepediaceae *calotropis gigantia* and do accumulate the cardiac glycosides.

12.4.3 Coevolution of Host-Parasites

Coevolutionary relationships between parasites and their hosts can be more complicated than between predators and their prey. As in the case of prey-predator relationship, one can expect hosts to evolve more effective defences against the parasite, and the parasite in turn can evolve to be more virulent. A balancing act has to be done here also as the parasite cannot afford to increase its own reproductive efficiency at the expense of the host. The death of the host would mean the death of the parasite before it could be transmitted to another living host. If the parasite has to be transferred from one host to another the parasite must evolve a lower degree of virulence so as not to kill the host. Successful host-parasite relationships are evolved on the dictum of "live and let live".

The well known Australian example illustrates the coevolution concept between rabbit hosts and myxoma virus parasite. European rabbits *Oryctolagus cuniculus* were first introduced into the Australian continent in the middle of the 19th century. In less than ten years the population multiplied into enormous numbers occupying a wide variety of environments in Australia from subalpine to subtropical zones. Towards the middle of the 19th century there were several hundred million rabbits. The rabbits had attained the status of a serious pest population. In order to control very effectively the population size, a search of natural enemies for the rabbits was made. Such a search revealed that myxoma virus could multiply as an epizoite on rabbits and that mosquitoes could be the natural vectors for the mechanical transfer of the parasite. The virus causes a serious disease in rabbits, the myxomatosis (Fig. 12.8) leading to a high mortality rate in the population. In the winter of 1950 the

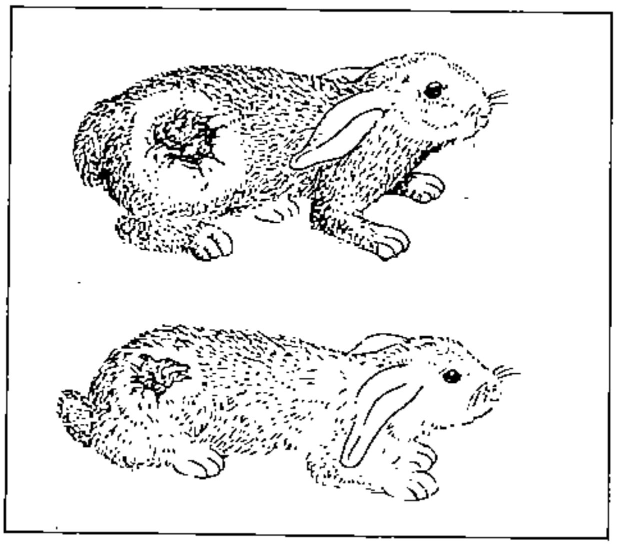

Fig. 12.8 : The rabbit afflicted with myxomatosis disease.

parasite was introduced into the wild rabbit populations and just before the Christmas of 1950, a wide spread outbreak of the disease became coexistent with the distribution of rabbits in Australia. Soon it was found that wherever myxomatosis occurred, there was a heavy mortality of rabbit populations and in certain areas the population appeared to be decimated.

In a particular study of natural infection of the virus, a rabbit population consisting of 5000 individuals dropped to 50 accounting for nearly 99% mortality. The survivors reproduced and the succeeding generation was again attacked by the virus. But this time the mortality was only 90% suggesting a basic change in the virulence of the virus. A study over the next 15 years suggested that there was a dramatic decrease in the virulence of the parasite. The virus which exhibited high virulence during 1950-51 transformed itself into a moderately virulent one during 1963-64. Myxoma of low virulence was also observed but they constituted only 5% of total viral population. It was found that low virulence virus did not reproduce successfully. You may ask the question as to why the introduced virus had lost its high virulence and attained moderate virulence. The answer lies in the mode of transmission, for upon this trait natural selection acts, and not upon the virulence as such. If the virus remains highly virulent and kills the rabbit quickly, there will be only a short time in which the mosquitoes can pick up the virus, as the mosquito bites only the living rabbits. Again, the virus with low virulence does not multiply rapidly with the result that there is not much chance for mosquitoes to pick up the virus. The maximum transmission rate therefore should occur when there is higher concentration of virus in the external skin leisions and when the rabbit does not die too quickly of the disease. This is accompanied by the development of relative resistance in the hosts for the parasitic attack. From only 1% survivors in the first epizootic attack the number of survivors increased to 10% in the next generation. There is a new population of rabbits every year with increased resistance and harboring viruses of decreasing virulence, as illustrated in Table. 12.2.

Table 12.2

Changes in the virulence of strains of myxoma virus in Australia between 1950 and 1964

Strain	1950-1951	1958-1959	1963-64
Strain I (high virulence)	● ● ● ● ● ● ● ● ● ● 100%	0%	0%
Strain II (quite high virulence)	0%	● ● ● 25%	0%
Stains III & IV (moderate virulence)	0%	● ● ● ● ● ● ● 70%	● ● ● ● ● ● ● ● ● ● 95%
Strain V (low virulence)	0%	● 5%	● 5%

The action of natural selection on two different species occupying different trophic levels can be regarded as an excellent model for the coevolutionary process. Such coevolutionary processes seem to have occurred innumerable times between a host and its new parasite. The parasite will maximise its chances of survival, successfully live in the host and do as little damage as possible to it. Host survival depends in parallel on its ability to resist the effect of the parasite. Natural selection favours the parasites that can maintain their infectivity, and the hosts that can become resistant to infections or resist toxic effects of the parasites once the infection has occurred.

SAQ 3

Fill in the blanks

a) .... arise not only because of the response of the organisms to the environmental changes in an inanimate world but also as a response to the presence of other organisms in the environment.

b) The interaction between species occupying different levels of food chain has been largely responsible for the development of associations such as .... and ....

c) The process of .... results in the development of an ecological association between two species, each of which acts as a mutual agent of selection for the other.

d) .... aims at a faster improvement of the efficiency of an inefficient .... than the resistance in an already resistant ....

e) Coevolution between plants and herbivores has often developed into .... relationships.

f) Successful host-parasite relationships are evolved on the dictum of ....

12.5 SEXUAL SELECTION

In this section you will be introduced to a variant of Darwinian concept of natural selection which he termed sexual selection. You may have observed very distinct and striking differences in appearance between opposite sexes of various animals groups, more prominently in birds and mammals. When differences in appearance occur between sexes, the animals are said to exhibit sexual dimorphism, the phrase simply meaning that the males and females are not uniform in appearance, but present two different forms. In general the males of the species are strikingly different from females although there may be exceptions to this rule. The male of the species may be more aggressive, brilliantly coloured or possess elaborate combs or bright plumage or extensive horns or ornamental hooks, tusks, spurs etc. Why are the male members different from the females? Is it not that the possession of such extra structures easily identify them to the enemies and make them more susceptible to their attack? Can these characters therefore be regarded as disadvantageous or ill-adaptations? If that be the case, is not the theory of natural selection contradicted?

As an answer to these questions, Darwin proposed the theory of sexual selection. According to the theory, the females of the species select their males and therefore a male which is more attractive or stronger than the other members of its sex has better chances of mating and leaving behind its offspring. In males there will be a constant evolution of such characters which are attractive to their female counterparts. Sexual selection can be regarded as competition among the members belonging to a sex to win the members of the opposite sex.

Sexual selection appears to be more pronounced in polygamous societies. An oft-cited example of sexual selection is the mating behaviour of the fur seal *Callorhinus ursinus* off Pribilof island near Alaska. The males of fur seals are at least one-and-a-half times as long and six times as heavy as the females. Prior to mating, the sea bulls meet in the breeding ground and engage in a fierce battle. Many males die in the encounter and some run away from the scene. The victor eventually settles down on a rocky shore with a "harem" of cows.

This example is from natural populations. There is not much experimental evidence to illustrate sexual selection. M. Anderson (1982) a Swedish biologist demonstrated sexual selection in African widow bird *Euplectus progne.* There is a marked sexual dimorphism in these birds with males having a half a meter long showy tail and prominent patches on the wings and the females have shorter tails and they are dull coloured. There is a strong territorial behaviour in males and in their specified territories they maintain a number of nesting females. Anderson created variations in tail lengths of male birds by cutting the tails of certain males to half their size and attaching them to normal males. As a result, he created three classes of male birds, males with short tails, normal tails and long tails. The three classes of birds when released into their natural habitat were able to successfully establish their own territories. But males with long tails were most successful in attracting the females to their territories and birds with short tails were least successful. The experiment demonstrated that certain characters do play an important role in maintaining the differences between the sexes and the female's choice of such characters confers adaptive advantage on the males.

While discussing sexual selection, one question that is often raised is, will an extrem specialisation of any character lead to the extinction of the species? In Anderson' experiment it was shown that the females, most of the time preferred males with long tails. This would result in the majority of the male progeny born with long tails. If the process were to continue, the gene for long tail is selected for and the population in the long run would consist of only long tailed birds and a few amo them having extreme development of the tail. We mentioned earlier that conspicuo characters such as long brightly coloured tails easily invite the attention of the predators and the birds are therefore vulnerable to the attack, as compared to birds with moderate tail lengths. Such characters may reduce the fitness and might possib result in the extinction of the species. R.A. Fisher termed this kind of selection process as runaway selection.

SAQ 4

State whether the following statements are true or false:

i) Animals with distinct and striking similarities in appearance between the opposite sexes are said to exhibit sexual dimorphism. True/Fa

ii) Sexual selection theory states that the females of the species select their mates and therefore a male which is more attractive or stronger than the other members of its sex has better chances of mating and leaving behind its offspring. True/Fa

iii) Extreme specialization of a character may reduce the fitness of the individual to a given environment and might possibly result in the extinction of a species. True/Fa

12.6 KIN AND GROUP SELECTION

While explaining the concept of natural selection, we have stressed the fact that natural selection is synonymous with differential or non-random reproduction. Natural selection aims at the multiplication of those genes that contribute to the reproductive success of the population. In other words, if any gene does not in a way contribute to the reproductive success of the species, the chances are it may eliminated from the population. Certain critics of Darwin pointed out that the common altruistic behaviour of individuals provided evidence contrary to the theor of natural selection. Whether it is so or not, will be discussed in the following subsections.

12.6.1 Kin Selection

Before we proceed to discuss kin selection we should define the term altruism. I refers to the behaviour pattern of an individual in the population for the benefit other members. Probably genes for altruism regulate the behaviour of such individuals. The local warning signal given by a bird to alert the other members the flock or a honey bee stinging an intruder in order to defend its hive, are a coupl of examples of altruism. In both the instances the altruistic individual may not survive: the signaller may invite the attention of the predator and the stinging b usually dies. It should be obvious to you that the death of these individuals wou result in the elimination of concerned genes for such behaviour. Critics of Darw argue that although altruism as a behaviour pattern is an adaptation, the fact th altruists are victims of such behaviour refutes the concept that natural selection wo promote favourable genes in the population.

A British biologist, W.D. Hamilton, effectively theorised that altruism is not an evidence against natural selection and proposed the term kin selection to explai altruistic behaviour. The term kin selection could be equated to natural selectio when we are considering the kin or relatives of an individual. For instance a mothe expending energy suckling or caring for her children, only ensures the reproduc success of her own genes through her progeny. Kin selection essentially favours su altruistic behaviour when the risk taken or energy spent by an individual is more th compensated by the benefits accrued by the relatives.

offspring. Let us assume that the parent meets with an altruistic death, say, that it died defending its children. Here is an instance where the selection would promote the gene for parental altruism through the progeny. J.B.S. Haldane tried to explain altruism and kin selection in the following statement — "I will lay down my life for two of my brothers or eight of my cousins". The sentence succinctly explains kin selection. The probability of one's genes shared by his brothers or sisters is one half and that of his cousins is one eighth. If the individual were to die because of altruistic behaviour, there are greater chances for his genes to spread in the population through his sibs or cousins. Contrarily if the individual remains "selfish", not only his own life may be lost but those of his relatives as well. For instance a warning call not given at the sight of a predator or an intruder may possibly wipe out the entire colony. The entire genome of the population may be lost.

Kin selection is one aspect of a broader area of study, viz. sociobiology. E.O. Wilson, a Harvard biologist and one of the pioneers in this field of biology surveyed various animal societies and demonstrated that altruistic behaviour can be understood within the Darwinian framework of natural selection. A hive of bees, a mound of termites, a pride of lions, a flock of crows, a troop of baboons can all be cited as examples of animals living mostly with their kin. Social insects such as honey bee present an interesting situation. A colony of honey bees consists of a queen, several haploid drones (males) and a large number of diploid, female sterile workers. Nearly 75% of the genome of workers is common. One among many workers in the colony is a potential queen. The drones and the queen are concerned only with reproduction; but the workers do a veriety of jobs ranging from foraging for food to colony defence. They are altruists in the real sense of the term. Being sterile, they have no chance of spreading their genes in the population directly, but by their altruistic behaviour they ensure the continuance of the colony and have greater probability of spreading their genes in the colony when they raise one of their sisters to the status of their queen. Thus natural selection explains the existence of sterile female workers in a beehive.

12.6.2 Group Selection

The effect of natural selection on colonies or population favouring one group in preference to other may be referred to as group selection. A group can be the smallest collection of individuals within a population or a colony. Group selection, it must be understood, is distinct from selection among individuals. The fitness of the genotypes between groups may vary within a population. The concept of altruism can be extended to groups as well. A colony consisting of many altruists has better chances of survival than a colony consisting of selfish individuals. Let us take a hypothetical situation where individuals of a colony, reproduce indiscriminately having no regard for the carrying capacity of the environment. On the other hand, consider a colony of individuals with genes restricting population growth, utilising optimally the food sources of the environment. The selection would essentially favour the latter group and the former may eventually face extinction.

SAQ 5

Fill in the blanks.

i) .... refers to a behaviour pattern of an individual in the population for the benefit of other members.

ii) .... favours altruistic behaviour when the risk taken or energy spent by an individual is more than compensated by the benefits accrued to the relatives.

iii) The effect of natural selection on colonies or population favouring one group in preference to other may be referred to as ....

12.7 SUMMARY

In this unit we discussed the role of natural selection as a guiding force of evolution. After you have studied this unit you should have learnt that:

- The example of industrial melanism provides an excellent insight into the operation of natural selection under natural conditions during our own life time.

gene from a population does not occur unless an alternate gene superior in terms of survival is present in the population. The example further highlights the concept of directional selection which defines the role of natural selection in evolving adaptations of organisms in a changing environment.

- Competition among individuals of a species for the various requisites of the environment results in the evolution of adaptations. Such a competition is sometimes witnessed among individuals belonging to different species. At such times there is an overlap of the niches of the two species. Such an overlap would frequently lead to character displacement and ecological exclusion. The net result of all these phenomena is the evolution of harmoniously interacting species living together in communities wherein the competition is kept to a minimum or even totally avoided. Such communities are known as coadapted communities.

- Coevolution is a concept related to the coordinated evolution of two or more species occupying different levels in a food chain. Often there is a biological interaction between the species and such interactions may be mutually beneficial or antogonistic to each other. Various forms of interspecific relationships arising out of coevolutionary process include plant-herbivore, host-parasitic and prey-predator associations.

- The theory of sexual selection states that competition among males for mates had led to the evolution of characters that are attractive to the female counterparts.

- And the theory of kin selection and group selection explains that altruism, a behaviour pattern of an individual that benefits the other members of the family or society and group does not contradict the theory of natural selection. Contrarily the kin selection theory form the genetic basis of Sociobiology.

12.8 TERMINAL QUESTIONS

1) Distinguish the terms intraspecific and interspecific competition. Briefly explain that interspecific competition results in the evolution of coadapted communities.

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2) What do you understand by the term character displacement? Describe with a suitable example that character displacement is the outcome of interspecific competition.

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3) Briefly explain the concept of coevolution and elaborate the concept with a suitable host-parasite relationship example.

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4) Industrial melanism is an excellent model to demonstrate the natural selection in action. Analyse the above statement critically.

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5) What do you understand by sexual selection. Illustrate your answer with a suitable example.

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6) How would you answer the criticism against Darwinism that common altruistic behaviour of individuals provided evidence contrary to the theory of natural selection?

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12.9 ANSWERS

Self-assessment Questions

1) a) Elimination
   b) Melanics, Non-melanics
   c) Industrial revolution, increased, rarer
   d) Selection, protective coloration
   e) Directional selection
   f) Stabilising selection.

2) a) False
   b) True
   c) False
   d) False
   e) True
   f) False
   g) True
   h) True.

3) a) Adaptations
   b) Commensalism, mutalism, predation and parasitism
   c) Coevolution
   d) Natural selection, predator, prey
   e) Mutually beneficial
   f) Live and let live.

4) a) False
   b) True
   c) True.

5) a) Altruism
   b) Natural Selection
   c) Group Selection.

Terminal Questions

1) **Intraspecific Competition :** Competition among individuals belonging to a single species, occur both at ecological and reproductive level. At ecological level, the competition is for the same requisites from the environment, including mates. At reproductive level the competition is for leaving behind the maximum number of their descendents.

   Interspecific Competition : Competition between individuals belonging to different species, more pronounced at ecological level. To explain that the interspecific competition results in the evolution of coadapted communities, you may refer to R.H. MacArther's study of warblers occupying different niches in the spruce tree. You may also discuss as to how a niche overlap is conveniently avoided by different species of warblers and yet these species live together in a single spruce tree without much of a competition for food and space.

2) Character displacement refers to the divergence of two species living in a niche with respect to a character owing to a competition between them. You may elaborate the concept with the barnacle example cited in subsection 12.2.3.

3) Coevolution signifies the coordinated evolution of two or more species and such a phenomenon results from a biological interaction between two species which occupy two different levels in a food chain. To illustrate coevolution with host-parasitic relationship, you may refer to subsection 12.3.3 in which coevolution between Australian rabbits an myxoma virus is discussed in detail. You may also discuss the phenomenon with any other suitable example that you have come across.

4) Industrial melanism relates to those species of moths which were earlier light coloured, but developed melanic variants during industrial revolution. The melanic variants have replaced the non-melanic forms in industrial regions. Essentially the industrial melanism describes the role of selection in replacing the non-melanics with melanics in soot polluted industrial areas. A more detailed discussion of the subject is provided in section 12.4.

The competition for mates (usually the competition among males to attract females) has resulted in the selection of certain secondary sexual characters. In males there is a constant evolution of such characters which are attractive to female counterparts. Brilliant colours, elaborate comb, bright plumage, extensive horns, ornamental tusks and aggressive behaviour are all secondary sexual characters evolved by males to attract females.

As example for sexual selection, courting behaviour of fur seals can be mentioned (see section 12.5). Anderson's study on widow birds is another example to show that female's choice of certain characters confers an adaptive advantage on males (see section 12.5).

Altruism refers to the behaviour pattern of an individual in a population for the benefit of other members. Probably the gene for altruism regulates the behaviour of such individuals. The altruistic individuals or the individuals exhibiting altruistic behaviour may not survive. For instance, a bird giving warning signal in order to alert the other individuals may itself invite the attention of the predator and die. The death of such individuals may also result the eliminations of concerned genes for such behaviour. Although altruism as a behaviour pattern is an adaptation, the fact is, that altruists are victims of such behaviour. In other words genes considered to be adaptive or favourable ones are eliminated, although natural selection is supposed to promote such favourable genes in the population. It is in this context, the British biologist Hamilton proposed the term kin selection to explain altruistic behaviour. You may refer to section 12.6 for a further discussion on the subject.

UNIT 13 SPECIATION

Structure

13.1 INTRODUCTION

In Unit 11 and 12 of the course on Evolution we explained to you that adaptations arise by gradual changes in genotypes, monitored by natural selection. We also pointed out that natural selection promotes different types of adaptations in different environmental conditions. Since environmental conditions tend to change from time to time, and from place to place, it is obvious that changes in genome also occur so that resulting phenotype is best adapted to the changed environment. Essentially the diversity of organisms and their characters are a result of natural processes. In this unit we extend this concept further and explain the origin of species. Also we shall ask the question 'What is species?' Species, as we shall show later are important that they represent a significant level of integration in living nature. We shall define the concept of biological species and then look into the process of speciation. Speciation is important in evolution because it adds to the diversity in nature, and in certain occcasions leads to progressive evolution.

Ernst Mayr, for whom, species and species problem have been the main concern of research, points out that speciation, the multiplication of species, that is division of one parent species into several daughter species is one process responsible for the evolutionary diversity of organic world. Darwin no where in his book *Origin of Species* defined the word species precisely although he interpreted speciation in terms of reproductive isolation (Darwin again did not use the term reproductive isolation in his book.) Darwin did emphasise that occupation of an unique ecological niche by each species could be a major characteristic of speciation. In this unit we shall briefly analyse the species concept laying emphasis on biological species and discuss in detail different types of mechanisms of speciation. Further we shall briefly look into how isolation brings about genetic repatterning and proceed to discuss the mechanisms of isolation with well chosen examples. As an illustration of how isolating mechanisms develop gradually, we shall explain the concept of ring species — the evolution of distinct new species. Finally there will also be a discussion on a phenomenon called genetic drift which however has no causal connection with speciation process but explains that in peripheral isolates gene frequencies drift due to smapling error.

Objectives

This unit should enable you to:

- comprehend the species concept and define species,
- describe the major types of speciation,
- explain the formation of ring species by the gradual development of isolating mechanism,
- explain the concept of genetic repatterning during isolation process,
- classify different types of isolating mechanisms, and
- discuss large scale change in gene frequencies in small populations — the genetic drift phenomenon.

13.2 CONCEPT OF SPECIES

We discussed in Unit 11 of Block 3 the universality of variations among organisms. In Unit 3 of Block 1, in taxonomical studies you have studied about the division of living organisms into different kingdoms. Also each kingdom is further divided into phylum, class and so on. Such classifications are made taking advantage of variations among different groups of organisms, although as we go down the ladder, that is at lower levels we require more refined methods to establish variations. Starting from microorganisms to man, although one could see an increasing complexity in organisation, such a complexity is not a continuous one. The discontinuities in organisation are illustrative of extinction of certain intermediates. And considering the fact that amount of extinction is so immense and the fossil record is so incomplete that it would never be possible to arrange all the organisms that live in this world into a single assemblage. At the same time we should remember that a classification of organisms is possible because discontinuities do exist between varying groups of organisms. There might be some differences of opinion as to the inclusion of a particular organism(s) into one group or another, but there is an overall agreement on the entire classification system. One may split an order into several families and the other may group these families into an order. But there is indeed an agreement on what should be split and what should be grouped. But such a taxonomic classification of organisms into specific groups is arbitrary rather than natural and is based on certain convenience. If this is so, then what is a species?

Many definitions of species have been offered, but none of them proved to be satisfactory. The definitions did not categorically provide the basis to decide whether two similar groups are distinct species or only sub-species. Again what is the criterion to decide the distinctness of a species? Some tried to specify the degree of difference that would distinguish a species from another. Apart from the difficulty in quantifying such differences, there are also other problems. Certain forms which show very little morphological differences proved to be very distinct species. In other cases, such as *Homo sapiens*, undoubtedly a single species, different races have pronounced differences. The discontinuity between groups, it appears, depends less on the degree of differences and more on the constancy of differences.

Another approach to define species was to distinguish related organisms on their inability to breed. Many definitions of species have relied upon such interspecific sterility and sterility of offsprings, that is hybrid sterility. This proposition also has certain inherent problems. It is not easy to identify cases in which organisms do not interbreed, and those which can breed, but do not do so for certain reasons. At these times, sterility cannot be deemed to be an appropriate criterion for defining species. Nevertheless, reproductive isolation or inability to breed has been the common element in the definition of species provided by many evolutionary biologists, be it Dobzhansky, Goldschmidt or Ernst Mayr. Reproductive isolation, the discussion of which follows later in this unit, has been the basis for defining the species and speciation. Such an isolating mechanism becomes a barrier for the flow of genes between related populations and the concept of biological species centres around this phenomenon.

More specifically, three types of species concept have been proposed so far. (1) The typological species concept (2) The nominalistic species concept and (3) The biological species concept. Let us briefly look into each one of them and find out why the biological species concept is more appealing for the definition of species than the other concepts.

1. The Typological Species Concept

The typological species concept was suggested by Plato more than 2000 years ago. According to this concept, the immense variety in nature can be reduced to a few "types". Individuals may vary but they belong to a single type. In practice this is just a morphological species concept. Most modern evolutionists find the typological species inadequate as it is a static concept. It fails to capture the dynamism of speciation as a significant evolutionary process.

2. The Nominalistic Species Concept

The nominalists deny the existence of Plato's "types". For them only individuals exist. Species are man-made artificial abstractions.

But naturalists, the biologists who have actually studied plants and animals in their natural conditions and have observed them closely for many years, claim that the nominalistic species concept is simply not true.

3. The Biological Species Concept

The biological species concept claims that species consist of natural populations and that species are real and objective. They are not man-made subjective abstraction. According to this concept, the members of a species are a reproductive community. The species is also an ecological unit. It interacts as a unit with other species with which it shares the resources of the environment. The species is also a gene pool. These aspects of the biological species concept are made clear in the famous definition of the Harvard evolutionist Ernst Mayr. According to Mayr, "Species are groups of interbreeding natural populations that are reproductively isolated from other such groups". The biological species is not only a distinct unit at any given time, but it also has the evolutionary capacity to change continuously over long periods of time, measured in millions of years.

SAQ 1

State whether the following statements are true or false.

i) The discontinuity between groups of organisms depends less on the degree of difference and more on the constancy of differences. (True/False)

ii) Reproductive isolating mechanism has been the basis for defining the species and speciation. (True/False)

iii) The typological species concept is most sound and dynamic concept of speciation. (True/False)

iv) Species are groups of interbreeding natural propulations that are reproductively isolated from other such groups. (True/False)

13.3 MECHANISMS OF SPECIATION

In the previous section we discussed the concept of species in detail and concluded that the concept of biological species and Mayr's definition of species have a wide acceptance among biologists. In this section we shall proceed to discuss the mechanisms of speciation or the mode of formation of a species. Mayr's definition of species amply makes it clear that to qualify for the title of the species, the individuals must be reproductively isolated from other groups. This naturally raises a question whether a new species could arise from populations occupying the same territory. In other words, should the populations of parent species live in quite separate territories in the formation of new species? In our earlier discussions on natural selection, you have learnt that origin of adaptations is a gradual process. This is much more true of speciation. Biologists recognise three different kinds of speciation.

- Sympatric speciation
- Peripatric speciation
- Allopatric speciation.

As we shall see later, peripatric and allopatric speciation can be grouped into a single type, namely *geographic speciation.* We shall now discuss the different types of speciation.

13.3.1 Sympatric Speciation

Sympatric speciation can be regarded as speciation where parent species gives rise to a daughter species without the individuals of a species being separated by space or territory. Both instantaneous and gradual models of sympatric speciation have been proposed. Barring one mode of instantaneous speciation by a mechanism known as polyploidy, other modes of sympatric speciation have remained quite controversial.

Polyploidy is quite common among plants. (For a detailed discussion on polyploidy refer to Unit 10 of Block 2 of LSE-03 of Genetics course). A cross between two diploid plants could result in a tetraploid hybrid. The hybrid would remain largely reproductively isolated from its diploid parents. The reason for such isolation is that due to back-crossing if a triploid individual were to be formed, it will produce a high proportion of nonviable gametes. There is also a possibility that interbreeding between deploid and tetraploid forms or between different tetraploids may give rise to other polyploids.

Polyploidy is rare or virtually non-existent in sexually reproducing organisms which include almost all animals. In sexually reproducing organisms, if a single mutational event or chromosomal change such as polyploidy results in reproductive isolation, the organism will not successfully reproduce unless there is close inbreeding. Among animals, close inbreeding is quite uncommon. But in a group of hymenopterous parasites chalcidoidea, there is mating between brothers and sisters that emerge from a single host. Such matings have facilitated a high species diversity in this group. But instances of instantaneous speciation in animals is a very rare phenomenon. Speciation in general is a gradual process and whether or not such speciation can occur within the confines of a single interbreeding population is a debatable point. Nevertheless, the possibility of such a speciation is not totally ruled out, as we would see from the following discussion.

It has been pointed out that sympatric speciation may occur whenever disruptive or diversifying selection is active (For a detailed discussion on disruptive selection refer to Unit 11 of Block 3 of Evolution). For example, take a population of individuals with genotypes AA and A'A', each of which is adapted to live specifically on plant species 1 and 2 respectively. The heterozygote AA' is not well adapted to either species of plants. Essentially it means that each homozygote would have a higher fitness if it mated assortatively or non-randomly. By assortative or non-random mating it is meant that males and females of similar phenotypes (hence genotypes) tend to mate with each other. Such an assortative mating would very much minimise the production of unfit heterozygous progeny. Also the selection process would tend to establish two different populations, each composed of a distinct genotype. You may recall from your studies on Unit 11 that this is precisely the role of disruptive or diversifying selection. Another locus B may be conferrring the assortative mating trait on the two genotypes. This locus may influence the mating behaviour or impel the organism to choose a specific host species, to find a mate and lay eggs. Genotypes BB and Bb may mate and lay egg on host 1 and bb mates and lays eggs on host 2. You may observe here that difference in the selection of specific host species isolates the two genotypes from one another and a reproductive isolation sets in. In many groups of phytophygous insects such as treehoppers, it is observed that closely related species are confined to different host plants for feeding and breeding.

13.3.2 Geographic Speciation

In almost all animal groups, the mode of speciation is geographic speciation. It is essential that a population which is a prospective new species is geographically isolated from the parental species. Geographical isolation, according to Ernst Mayr, is almost invariably necessary for speciation to occur. Geographic speciation, as we pointed out earlier, in turn can be typed into two categories:

i) Allopatric Speciation

Speciation by populations of parent species which occupy quite separate territories is the most common mode of species formation among animals. Allopatric speciation occurs in large continental areas, and perhaps, also in the vast continental slopes and ocean floors. A once continuous series of population may be divided into two parts by a new barrier. The barrier may be a newly formed desert or river or mountain range. The population on other side of new barrier becomes geographically isolated. The separation may be gradual as shown in Fig. 13.1. This model of allopatric speciation is known as dumb-bell model.

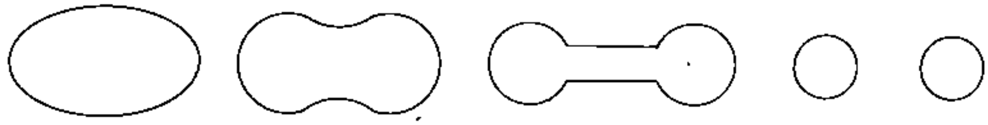

Fig. 13.1 : Illustration of allopatric speciation.

Essentially in allopatric system, speciation occurs by the more or less equal subdivision of a large population. It is believed that allopatric speciation is characteristic of K strategists (see marginal remarks on K strategy) which are highly mobile, long lived and high in competitive ability.

ii) Peripatric Speciation

K strategy : Populations living in nearly saturated environments are said to be K selected. In such populations selection favours the fine tuning of adaptations. The reproductive rate of the population may not be high and the emphasis is on developing better adaptations. Individuals on which K selection is active are known as K strategists.

Speciation by small populations isolated on the periphery of the distribution of the parent population can be described as peripatric speciation. Small, peripheral populations occupy ecological niches not occupied by parental population and these founder populations can carry only a small part of the genetic variability of the parent population. Origin of species by peripatric speciation can be explained as follows:

Initially species consists of uniformly distributed individuals (Fig. 13.2a). The individuals are grouped as populations between which there is a limited gene flow. This gene flow keeps the populations as an integrated species. As long as there is a free flow of genes, even if it were to be limited, a new species cannot be formed.

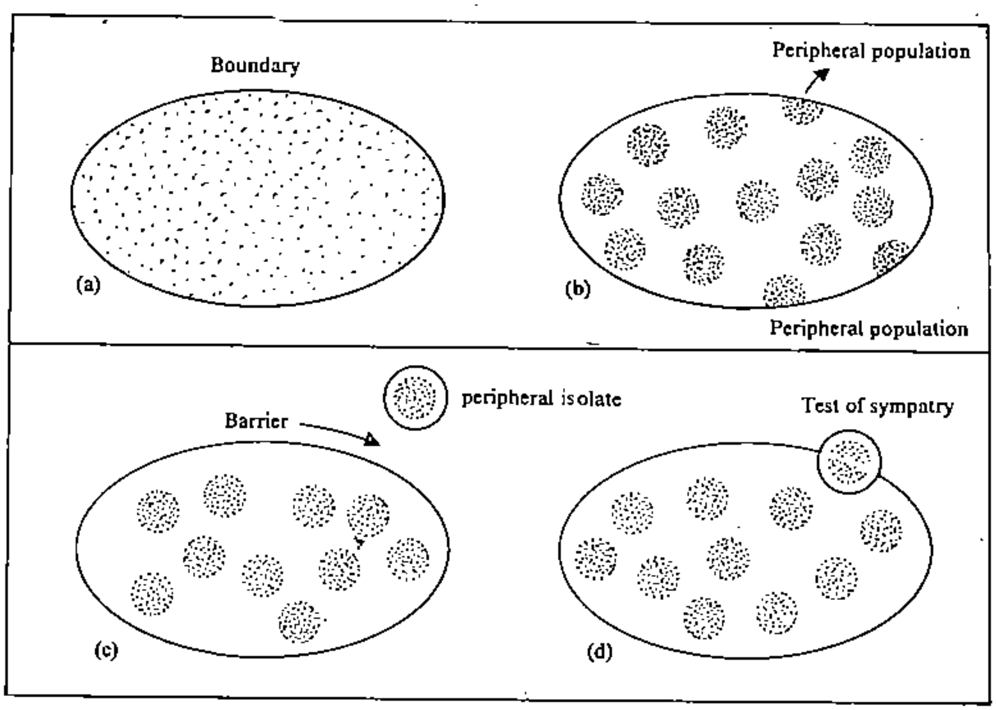

Fig. 13.2 : Illustration of peripatric speciation

Peripheral populations (13.2b) (individuals living in the periphery of a population) may experience less gene flow than central populations. But still they will form an integral part of the species. Only when the population is a peripheral isolate (13.2c) and not just a peripheral population, that it has the possibility of becoming a new species (13.2d).

A peripheral isolate can be formed in different environments. For instance it may be formed on an island off the coast of a large subcontinent. The finches that Darwin observed during his voyage on the ship H.M.S. Beagle were evolved from peripheral isolates on the Galapagos island, off the west coast of South America.

Before we start discussing in detail the various mechanisms of isolation that in turn were instrumental for the formation of a new species, we shall look into two concepts: (1) The concept of ring species — an example which shows beautifully how isolation of population develops gradually resulting in distinct new species, and (2) the concept of genetic repatterning during isolation. And prior to that, attempt the following SAQs.

SAQ 2

Fill in the blanks with suitable words from the text.

i) To qualify for the title of species the individual must be .... from other groups.

ii) .... refers to the speciation process where the individuals of a species are not separated by space or territory.

iii) .... is a common mechanism of speciation in plants.

iv) Sympatric speciation may occur wherever .... is active.

v) It is essential that a population which is a prospective new species is .... from the parental species.

vi) .... speciation refers to speciation by populations of parent species which occupy quite separate territories.

vii) Speciation by small populations isolated on the periphery of the distribution of parent population is ....

13.4 RASSENKREIS AND SPECIATION

According to the current concept of speciation, a widely distributed species should break up into partially isolated rule species. The different subspecies become differentiated further due to the action of selection and other factors. This would result in a circle or group of races or Rassenkreis. And the terminal members of such a circle will be sufficiently different from others, so that a sterility barrier sets in. We shall try to explain the concept with an example of an amphibian species.

In the west coast of USA there are two high mountain ranges, the Coastal Range and the Sierra Nevada. At their northern ends, near the Canadian border they are united (Fig. 13.3). Proceeding south, they are separated by a hot and arid desert. Further south, close to the Mexican border, these high mountains meet again. There is an amphibian species *Ensatina eschscholtzii* at the place marked as A in Fig. 13.3. It is supposed that this original species split into two populations, B and G, which then moved down the two respective mountain ranges. On one range the populations can be seen to change gradually from B to C to D to E and on to F. On the other mountain range the population G, like B derived from A, gradually moved south changing into H, I, J and K. While these changes were taking place the two series were isolated from each other by the desert, and isolating mechanisms were gradually developing. Since this amphibian *Ensatina* has poor locomotor powers, it must have taken hundreds of thousands of years for them to proceed from the Canadian border to the Mexican border. It stands to reason that populations B and G will have the least amount of isolating mechanisms. The isolating mechanisms will be more between D and I. They will be greater between E and J. Remember, both the series, BCDE and GHIJ, are derived from a single species, *Ensatina eschscholtzii*, designated in Fig. 13.3 as A. But when they reach the Mexican border, the two populations F and K are able to overlap, as seen in the cross-hatched area, **without mating. They have passed the test of sympatry.** F and K are now two distinct species. Similar ring species have been shown to occur in sea-gulls forming a circumpolar ring around the world.

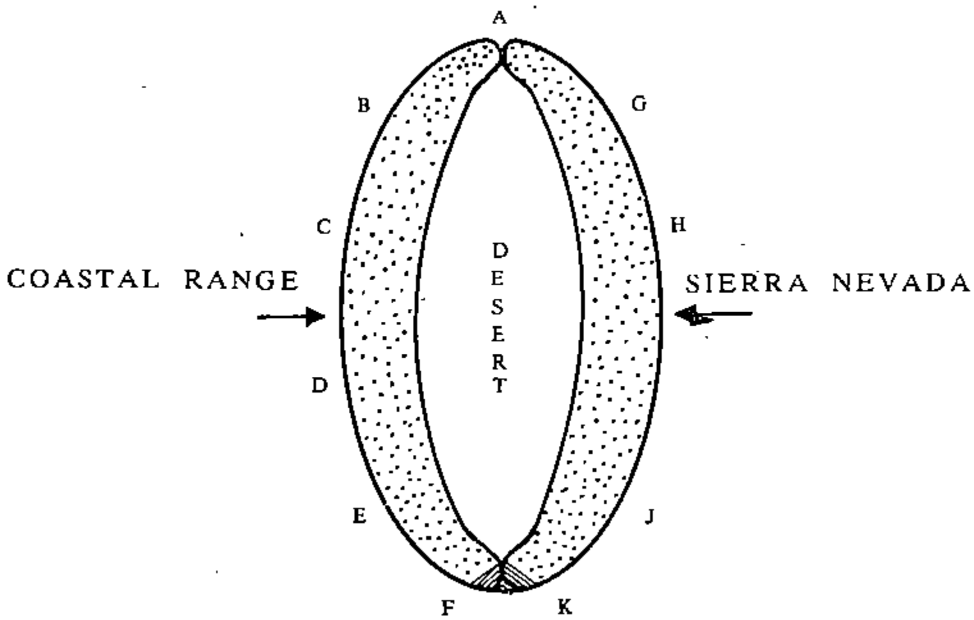

Fig. 13.3 : Formation of ring species.

13.5 GENETIC REPATTERNING DURING ISOLATION

An island may be colonised by just a few individuals, or just a pair, or even a single gravid female. When a new population develops from these early colonisers of the island, they undergo drastic genetic repatterning. This is sometimes described as a genetic revolution. The founder being small in number, the first major change in the colonisers is a drastic reduction in the variability (Fig. 13.4 A to B). Inbreeding further reduces variability (Fig. 13.4 C). Imbreeding eliminates recessives as homozygotes and the genetic load is reduced. The decisive change is from a large open population to a small closed population. In the closed population, overdominance, that is the superior fitness of the heterozygote (say, Aa) over the other two homozygotes (AA and aa), increases. Non-allelic epistatic interactions of genes greatly alter the functioning of the gene complexes. As a result the genetic cohesiveness is broken and the founder population becomes plastic and pliable enough to be moulded into a newer one with better adaptations. This, in essence, is the genetic repatterning or the genetic revolution.

The founder population, the peripheral isolate, usually becomes extinct due to the greatly reduced variability (Fig. 13.4 C) However, if it survives the genetic revolution, the population builds up to greater variability and better adaptedness (Fig. 13.4D). It may even acquire greater variability than the original parental population and stabilise at a higher level of genetic cohesion as a new species (Fig. 13.4E). This status of a new species, distinct from the parental species is made possible by the development of isolating mechanisms during the genetic revolution.

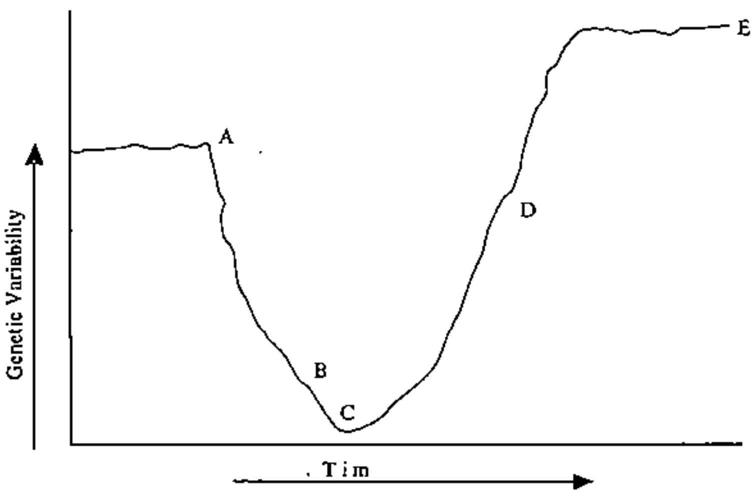

Fig. 13.4 : Genetic revolution.

SAQ 3

Answer in about 50 words each.

i) Explain briefly the term ring species.

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ii) Explain the concept of genetic repatterning during isolation.

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13.6 ISOLATING MECHANISMS

In this section we are to discuss the means by which populations get separated or isolated from each other, first gain the status of sub-species and finally evolve mechanisms which prevent them from mating with local populations to be called as a distinct species. In short, we are to discuss the mechanisms that are responsible for keeping populations from the access of each other that in turn leads to origin of new species. You are aware that local populations generally interbreed among themselves with only rare cases of outbreeding. Therefore, the genotypes of different populations of a single species may show differences in some or many loci. The resulting phenotypes could be classified into sub-species based on the differences in parts. These subspecies because of their proximity to other populations tend to meet the other members with the result that a single generally intermediate and variable population is formed. This would result in the loss of the status of subspecies for the population. However, if a sub-species is isolated over a long period of time and the breeding with its relations is prevented, then by continuing to accumulate the genetic differences it may lose its ability to interbreed with the parental species. Under such circumstances, the sub-species gets elevated to the status of a species, satisfying Mayr's definition of a species. When two groups are geographically separated from each other, it is often difficult to determine whether they do not interbreed any more. In other words, could they be referred to as allopatric species? Once they move into the same territory, fail to interbreed and form intermediates, they may said to have passed the test of sympatry or they could be regarded as sympatric species. In many cases it has been noticed that once the species status has been established, selection tends to promote those characters which act as a deterrent for the formation of hybrids, since usually hybrid progeny have a reduced fitness.

George Romanes, an American neurologist who evinced a very keen interest in evolutionary problems once wrote, "without isolation or the prevention of interbreeding, organic evolution is in no case possible". Many recent studies on origin of new species have proved that Romanes was largely true in his assessment of the problem. Let us now look into the details of mechanisms of isolation.

Ernst Mayr classified isolating mechanisms into two major types. The *pre-mating isolating mechanisms* and *the post-mating ones*. The difference between the two types of mechanisms is as follows. Pre-mating isolating mechanisms prevent the occurrence of mating and the post-mating ones ensure failure of such matings once they occur. In the discussion on pre-mating isolating mechanisms, besides the biological barriers evolved by the organisms which prevent effectively mating between the individuals, isolation by space will also be included. We shall also examine how the ecology, seasons and even the behaviour of individuals could be instrumental in bringing about the isolation of populations leading to species formation. We shall also look into the details of post-mating isolating mechanisms which prevent the formation of successful hybrids, thereby ensuring the distinctness and identity of a species.

13.7 PRE-MATING ISOLATING MECHANISMS

We mentioned earlier that pre-mating mechanisms are concerned with the prevention of occurrence of interspecific crosses. In such cases,

a) the potential mates do not meet in which case the isolation is due to either geographical, seasonal or habitat reasons.

b) the potential mates do meet but fail to mate in which case the isolation is due to ethological reasons.

c) the potential mates meet and mate but no transfer of sperm takes place in which case the isolation is due to mechanical reasons.

Let us have each one of these mechanisms examined in detail.

13.7.1 Geographical Isolation

Many species of organisms are restricted in their distribution even as they may be found over a vast geographical regions. Studies using distribution maps of organisms have shown that although species may be continuously found over vast areas, a close scrutiny would reveal that the distribution is rather restricted to those regions with suitable ecological features. For instance, the American plane tree, *Platanus occidentalis* although distributed over more than half the United States, the natural groves of the plants are confined to bottom lands and stream banks. This is true of several species of organisms whose populations are separated by barriers of territory which they cannot use for ecological reasons. For instance, take the case of amphibians. A small body of salt water could be a barrier for their dispersal. Oceanic islands are not inhabited by amphibians except as in the case of Hawaii where they are introduced by man. Salt water is also a barrier for fresh water fishes. Pacific ocean receives many parallel streams of fresh water each of which had its own sub-species or species of fishes. Only the flooding during the rainy season join the streams and the fishes may be found together.

Similarly populations of land birds are separated by large bodies of water. Normally species and sub-species of birds living on opposite banks of rivers are different. Mayr observed that different sub-species of birds occupy different tropical islands despite that distances between these islands are not very far. Darwin reported that 21 of the 26 species of land birds and only 2 of the 11 species of marine birds are endemic to Galapagos islands. This is a significant finding in that the land birds could not migrate to either direction because of the water barrier and were confined to their territories. More than the birds, it is the mammals which are often stopped by water barriers. Rodents living in opposite banks of rivers usually belong to different sub-species.

Mountains often separate organisms occupying low lands. Studies on the distribution of different species of rabbits showed their restricted distribution to specific geographical regions. *Sylvilagus floridanus* confines itself to planes while its cousin the jack rabbit *Lepus americanus* is found only in mountains in United States. Similarly the white footed mouse *Peromyscus leucopus* is found in priaries and its close relative *P. maniculatus* has invaded the mountains. Thus every natural feature could be a barrier to either a plant or an animal paving the way for sub-speciation and ultimately the speciation process.

13.7.2 Ecological Isolation

Ecological isolation is based on the fact that population shows preference to one habitat over the other. This extensive forests become barriers to the dispersal of organims living in grasslands. The reverse that priaries being barriers to forest organisms is also true. The red tree mouse *phenocomys longicaudus* lives on fir needle trees and feeds on fir needle. It is understandable that for these mice not only priaries but the non-fir forests will also be a barrier for dispersal.

You may recall that in unit 11 of this block we discussed extensively MacArthur's study of five species of warbler birds living in spruce trees. The five species of *Dendroica* are effectively isolated by ecological factors although they have a similar distribution. As a matter of fact, the ecological and food preference of the different species of warblers are very similar. Under such circumstances one would have expected a severe competition among them. But each species has carved a well defined niche and forages at a particular level in the trees. Differences in breeding dates and occupation of different habitats outside the breeding season are the contributing factors for the minimum competition and niche overlap among the species. There are other instances where potential mates keep away from each other because of their habitat preferences. In these cases there might even be a broad niche overlap and the individuals may exist in the same general area, but the distinctness of sub-species and species is maintained. Dice cited an example from United States where the two sub-species of mice *Peromyscus maniculatus* have overlapping niches and do not interbreed in nature, although there is interbreeding in the laboratory. Similarly another study showed that the fresh water and salt water races of the water snake *Natrix sipedon* may come close together but may not interbreed because of their habitat preferences.

An interesting study was reported by A. Pictet in Swiss moths *Nemeophila plantaginis*. Two races of the moth are known, one living at an altitude of above 2700 meters and the other below 1700 meters. The two races differ by a single gene. Midway at an altitude of 2200 meters a hybrid population of the two races is found and all the moths living here are heterozygous. When the two races are brought to the laboratory and bred, the offsprings exhibit typical Mendelian inheritance, namely that the F_2 consisted of both homozygotes and the heterozygote. The fact that at 2200 meters only heterozygous genotypes are found showed that there is a severe selection pressure against the homozygotes at this altitude and they are all eliminated. You may observe here that differences in habitat requirements act as barriers to random mating.

Breeding between populations or races or sub-species may be effectively prevented if the seasons in which they breed are to be different. This phenomenon appears to be quite common among plants. A good example comes from the study of five species of cypress trees belonging to the genes *Cupressus*. The five species of trees have distributed themselves as ten groups each one of which could be called a sub-species. Each group has a limited distribution and may be represented by a few trees. Very rarely hybrids are formed between any two groups despite the closeness of their existence. The reason appears to be that the groups shed their pollen at different times or seasons preventing the occurrence of cross pollination. The rare occurrence of hybrids is explained by the fact that some trees shed their pollen earlier than or later than the usual time.

Seasonal isolation is very effective among the animal groups which have a highly restricted breeding seasons. This is true of all poikilothermic vertebrates and invertebrates. A revealing example comes from the study of three species of frogs living and breeding in the same pond in north eastern United States. The three species *R. clamitans, R. pipiens* and *R. sylvatica* have staggered breeding seasons. *R. sylvatica* completes breeding before others arrive at the pond and *R. clamitans* begins breeding only when all others have completed. The breeding time of each species appears to be determined by the temperature of the waters of the pond which they occupy. The following table gives you temperature of the water at which the frogs begin their breeding.

Species of frog	Water temperature at which breeding commences
Rana sylvatica	44°F
R. pipiens	55°F
R. clamitans	>60°F

Further each species has developed specific and elaborate mating call and this again prevents breeding between sympatric forms. Finally even if mating takes place between species, the development fails beyond the embryonic stage. Thus the seasonal isolation has led to sterility barrier and the three species have no chance of forming hybrids.

13.7.3 Ethological Isolation

Members belonging to different species refrain from mating because of the behavioural differences between them. Such behavioural differences usually centre around specific courtship patterns which the species have evolved. The behaviour patterns are more conspicuous in animals rather than in plants. And among animals, once again, the courtship behaviour is more pronounced among terrestrial and fresh water organisms than in marine forms. Mayr points out that in those forms where there is an elaborate courtship behaviour the interspecific hybrids are rare. Closely related species that do not have pair-binding courtship rituals do commonly give rise to hybrids. Mayr is of the opinion that in species where there is a courtship behaviour pattern, the "engagement" may be broken if the pairs do not belong to the same species.

A detailed study of the courtship behaviour of six species of Drosophila showed that courtship and mating could be divided into six phases. If there is incompatibility at any one of these six phases, the potential mates break off and the courtship is discontinued. Under laboratory conditions, the interspecific crosses have not been successful and the courtship was terminated even in the first stage. What is more interesting here is that even to a trained observer differences in courtship behaviour exhibited by different species may appear to be trivial and insignificant. But the species recognise the specific signals and respond suitably. In certain other forms differences in courtship behaviour between species could be very pronounced. The courtship dances of the different species of Uca (shore crab) could be recognised from a distance. This is also true of mating dances of salamanders, turtles and birds.

Earlier it appeared that *Rana pipiens* consisted of a single species. This assumption was based on morphological considerations. But today researches have shown that there are a number of species and the frogs have no difficulty in recognising their own species. Both the frogs and researchers could distinguish the characteristic mating song of each species. Some species of birds which show only minor morphological differences can be easily differentiated by their songs.

Apart from the species specific dances and songs evolved by organisms to attract their mates, specific scents are produced by certain organisms for purposes of species recognition. These scents, otherwise known as pheromones have been proved to elicit selective response from males when left with females of two closely related species in the same area. A study by B. Patterson in Scandinavian valley has shown that nearly thirty seven species of moths belonging to a single genus live together without any interbreeding among them. The author has concluded that despite all minor morphological differences among the species, conspecific matings are assured because of the specific scent produced by each species. Essentially the above account tells you that specific behaviour patterns play a vital role in species recognition and serve as a powerful isolating mechanism.

13.7.4 Mechanical Isolation

In certain instances differences in the morphology of genitalia between species make it impossible for normal mating to occur, and sympatric species tend to remain isolated. When there is no correspondence between the male and female external genitalia for copulation to occur, the members belonging to different species are reproductively isolated. When interspecific crosses occur between individuals having no exact correspondence in their genitalia, it resulted in the death of copulating pairs. Insects and snails are usually quoted as examples of such fatal matings which occur due to mechanical differences in their genitalia. It must alao be stated that differences in copulatory organs, in many instances, have not proved to be a barrier for interbreeding. Breeding between dogs belonging to different races is an often cited example.

Mechanical isolation appears to play a more important role in the speciation of plants. Since many plants are aided by insects and birds in cross pollination, a morphological compatibility is required between the plants and the pollinating agents. You may recall the example that has been cited in unit 11 in which the flowers of different species of **Pedicularis** plant are pollinated differently by bumble bees. Further, queen bees with their long mouth parts pollinate the nector producing species of **Pedicularis** and the other species of the plants are pollinated sternotribically or nototribically.

13.8 POST-MATING ISOLATING MECHANISMS

The second category of isolating mechanism that may permit interspecific mating but ensures reduced viability is called post-mating isolating mechanism. This category could be subdivided into two types.

- **Interspecific sterility :** Organisms belonging to different species may mate, but may not produce any offspring.
- **Hybrid sterility :** Here the interspecific cross may result in an F_1 offspring but the offspring is invariably sterile.

We shall now briefly look into each one of these sterility mechanisms with plant and animal examples.

13.8.1 Interspecific Sterility

In interspecific sterility, the failure in mating occurs because of inability of the sperm to reach the egg in animals and the pollen to reach ovules in plants. In plants interspecific crosses usually result in the non-growing of the pollen tubes or the slowing down of the growth. If pollen from another species is transferred to a plant along with the pollen from conspecific individuals, the growth of the pollen tube of the latter is much faster than the former and all the fertilisation is conspecific.

In certain cases of interspecific crosses the pollen tube begins to grow but then bursts ensuring that no fertilisation occurs. Such an event occurs when the chromosome number of the male parent is higher than female parent. For instance, three species of tobacco plants are known to occur: *Nicotiana tabacum, N. sylvestris* and *N. tomentosa*. *N. tabacum* has 48 chromosomes and the other two species have 24 each. Probably *N. tabacum* is a tetraploid produced by a cross between the other two species. A cross between either of the two species and *N. tabacum* is successful only if the latter is used as a female parent. In such a cross the style tissues have 48 chromosomes and the pollen tube has only 12 chromosome, giving a ratio of 4:1. When the cross is between *N. sylvestris* and *N. tomentosa,* the style tissue of both the species has 24 chromosomes and the pollen tube has 12 chromosomes giving a 2:1 ratio. But if *N. tabacum* were to be a male parent, and the either of the other two species a female, then the style tissue has 24 chromosomes and the pollen tube has 24 chromosomes giving 1:1 ratio. It is only under these circumstances, that is when the ratio is close to 1:1 the bursting of pollen tube occurs. It is assumed that a high osmotic pressure in the pollen tube causes it to burst and that this trait is controlled by a gene. Essentially a genetically coupled physiological mechanism prevents interspecific crosses in the tobacco plant.

There are other instances where a zygote may be formed but its further development may not occur beyond a stage. Thus in interspecific crosses of jimson weed plant, the embryo dies around the eight cell stage. In the case of hybrid plants, it is believed that there is an inadequate nutritional relationship between the developing embryos and the endosperm resulting in the death of the embryos.

The genetic basis of interspecific sterility is not clearly understood in many cases. Yet, one good example comes from studies on the tropical fish of the genus *Xiphophorus*. *X. maculatus* (moon fish) carries a dominant gene (Sd) responsible for a dark spot on its dorsal fin. The gene produces macromelanophores which are potential tumors. In a closely related species *X.helleri* (swordtail), the gene occurs in recesive form (sd). A cross between the two species produced fertile F_1 offspring. The hybrid offspring has the heterozygous genotype Sdsd and in such a condition the fins are more heavily pigmented than the homozygous (SdSd) genotype. The Sdsd progeny always have lethal tumors. A backcross of Sdsd fish with the recessive genotype (sdsd) have shown that half the progeny have lethal genotype (Sdsd). Thus in *Xiphophorus* interspecific sterility manifests in the form of production of offsprings with lethal genes in them.

13.8.2 Hybrid Sterility

Hybrid sterility can be regarded as yet another form of interspecific sterility. The offspring of the interspecific crosses are mainly sterile. Geological studies have shown that the chromosomes of the hybrid individuals fail to synapse at the time of meiosis and thus result in either non-production of gametes or defective gametes. Unless the chromosomes of parents are accurately separated which might result in viable gametes, in most cases the gametes are not produced and if produced they may not be fertile. The commonly cited example is the mule, a sterile animal the product of a cross between a donkey and a horse. Further, the hybrid species in general are found to have grossly abnormal reproductive system. If normal reproductive system is present, then meiosis is abnormal and non-viable gametes are produced.

Thus various types of reproductive isolating mechanisms are at work in different groups of organisms to maintain the distinctness and uniqueness of species.

SAQ 4

1) Match the following:

Column I	Column II
a) Non-meeting of the potential mates	i) Ethological isolation
b) Potential mates do meet but fail to mate	ii) Mechanical isolation
c) Potential mates meet and mate but no transfer of sperms	iii) Geographical, seasonal or habitat isolation

2) Answer in about 50 words each.

a) Explain the concept of geographical isolation with suitable examples.

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b) How does habitat preference of organisms promote speciation process?

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c) Cite an example to show that highly restricted breeding seasons of populations contribute to isolation process.

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d) Discuss the role played by courtship behaviour and scents in the isolation process.

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e) Distinguish the terms interspecific sterility and hybrid sterility.

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13.9 GENETIC DRIFT

In this section we shall be discussing a phenomenon associated with small populations. You may recall from your studies in Genetics (LSE-03, Block 4, Unit 2) that in large populations the frequencies of alleles tend to remain constant generation after generation provided the populations do not experience any mutation, genetic recombination, gene migration and selection. You may further recall that this phenomenon is known as Hardy-Weinburg equilibrium. But evolution essentially depends on changing gene frequencies. In the unit on 'Behaviour of Genes in Populations' in Block 4 of LSE-03 Course, you may find illustrations of how gene frequencies are altered in natural populations by factors such as mutations and natural selection. Such factors although they affect gene frequencies, do it in a small way. But genetic drift is a phenomenon that causes a large change or a drift in the frequencies of genes in small populations. The phenomenon was first investigated by the American population geneticist Sewall Wright and therefore is also known as Sewall Wright effect.

It is generally believed that genetic drift occurs as a result of sampling error. As we said earlier it occurs in small populations such as peripheral isolates. We may demonstrate genetic drift by a small experiment. Take beads of same size but different colours, say blue, red, green and yellow. Take a thousand of each colour and mix them well in a bag or mug. The 4000 beads now constitute a population. Now put your hand in without looking, pick up just four beads with your finger tips. Let us say that you get two blues, one red and one green. This will mean that the blues have increased from 25% to 50% but the yellows are reduced to zero. You could see that the random drifting or large scale changes in the frequencies of coloured beads is a result of sampling error. Just as the frequencies of coloured beads drift randomly in the experiment, in small populations or peripheral isolates gene frequencies may drift due to sampling error. Hence the phenomenon is known as genetic drift.

Can such drift be observed in natural populations? The answer appears to be yes. Let us take a small population of mice living in the rice barn of a farmer as four or five extended families. The farmer tries a variety of methods like setting up of traps, use of a shot gun, surprise visits, cats etc. to eradicate them. Such acts of the farmer exert a severe selection pressure on the mice. Under such circumstances the traits that would be selected are the swiftness, short tail, hearing acuity, cautiousness etc. Naturally the frequencies of the alleles that control these traits would tend to be high in the population as only those mice which possess such traits can survive in an hostile environment. After a couple of months, let us say there is an environmental change and a severe winter sets in. The farmer confines himself to a fire place and as a result the selection pressure on those traits we mentioned earlier is now lifted. And in order to survive in a changed environment, the mice need to possess totally a different set of traits and essentially mice with such traits would be selected for. Thus swiftness and visual acuity are no more the traits that would be selected for, but the mice with a thick fur on them and similar such traits which would protect them from the severity of the winter would be selected. The net result is that the frequencies of the alleles that controlled the traits in the earlier environment undergo a drift — (i.e.) their frequencies become significantly low in the new environment. It should be emphasised that such a drift is characteristic of only small populations.

Sewall Wright suggested that genetic drift may have important consequences for evolution. At one time he even seemed to have suggested that, in special circumstances, genetic drift may override Darwinian natural selection. This view was criticised by the Oxford biologists R.A. Fisher and E.B. Ford who showed that natural selection is the chief agent of evolutionary change not only in large and medium populations, but also in very small populations. E.B. Ford demonstrated the occurrence of wingspot polymorphism in small populations of Meadow Brown butterflies in the Isles of Scylly, at the South Western tip of England. For, where the polymorphism occurs, it is the surest indication that natural selection is operating at its highest potential. Sewall Wright also found such arguments to be true and has now modified his genetic drift theory into a more acceptable shifting balance theory.

SAQ 5

Fill in the blanks with appropriate words.

i) In large populations the factors which tend to alter the gene frequencies are ...., ..., ... and ...., ...

ii) .... that causes a large change in gene frequencies is characteristic of small populations.

iii) In small populations or peripheral isolates the genetic drift usually occurs because of ....

iv) The genetic drift is also come to be known as .... effect.

v) Sewell Wright has modified his genetic drift theory into .... theory.

13.10 SUMMARY

In this unit you have learnt:

- The concept of species and the definition that the species are a group of interbreeding natural populations that are reproductively isolated from other such groups. The biological species concept is more realistic than the typological or nominalistic species concept. It explains species as a distinct unit of time, with a capacity to change continuously over long periods of time. In short, species has an evolutionary capacity.
- The different modes of speciation. (a) The sympatric speciation refers to speciation among populations living together. (b) Allopatric speciation refers to speciation in populations separated by space and (c) Peripatric speciation refers to speciation of individuals isolated as a peripheral population.
- Concept of ring species in which a population becomes isolated, changes gradually, passes the test of sympatry and becomes a distinct species.
- The concept of genetic repatterning in which a new population develops from the early colonisers of the island by a process of genetic revolution. Reduction in variability, elimination of homozygote recessives by inbreeding process, overdominance resulting in heterozygote superiority and non-allelic epistatic interactions are some of the genetic events that break the genetic cohesiveness of populations. Such events render the founder population more plastic and pliable and move it into a new species with better adaptations.
- The different types of isolating mechanisms—the geographical, ecological, mechanical, ethological and reproductive (both pre-mating and post-mating) all of which promote the formation and distinctness of species.
- That genetic drift is a process that may operate in small populations bringing about large scale changes in gene frequencies. Also known as Sewall Wright effect, in small populations the drift is due to sampling error.

13.11 TERMINAL QUESTIONS

1) Briefly comment on the three types of species concept.

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2) Distinguish the terms sympatric, peripatric and allopatric speciation.

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3) What do you understand by the term ring species? Illustrate your answer with suitable example.

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4) To what type of isolation the following barriers contribute to?
   a) Oceanic islands inhabited by amphibians ....
   b) Salt water as a barrier for fresh water organisms ....
   c) Large bodies of water as barrier for land birds ....
   d) Priaries as barrier for forest organisms ....
   e) Mountains as barriers for low land organisms ....
   f) Restricted breeding seasons ....
   g) Courtship patterns ....
   h) Specific mating calls ....
   i) Specific scents ....
   j) Distinct morphology of genitalia ....
   k) Hybrid sterility ....
   l) Higher chromosome number of male parent ....

5) In small populations the gene frequencies often tend to drift. Justify the logic of the statement with a suitable example.

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13.12 ANSWERS

Self-assessment Questions

1) i) T, iii) T, iii) F, iv) T.

2) i) Reproductively isolated
   ii) Sympatric speciation

iii) Polyploidy
iv) Disruptive selection
v) Geographically isolated
vi) Allopatric
vii) Peripatric speciation.

3) i) It is quite possible that the action of selection could differentiate the different sub-species further resulting in a circle or group of races. The terminal members of such a ring or circle sufficiently different from others evolve into a species — the ring species.

ii) When a new population develops from early colonisers of the islands they undergo a variety of genetic changes by way of reduced variability, elimination of recessive homozygotes, reduction in genetic load, superior fitness of heterozygotes and non-allelic epistatic interactions, all of which result in a genetic revolution or more precisely the genetic repattering.

4) i) a) iii), b) i), c) ii)

ii) a) The concept of geographical isolation refers to the restriction of organisms to certain specific geographical regions with suitable ecological features. For instance oceanic islands are not inhabited by amphibians. Pacific ocean receives many parallel streams of fresh water each of which has its own species or sub-species of fishes which live isolated.

b) Habitat preference do promote speciation process. In Swiss moth *Nemeophila plantagenis* the habitat preference of the two races appears to contribute to the speciation process. One race of the moth lives at an altitude of about 2700 meters and the other race below 1700 meters. Although the two races breed in the laboratory the hybrid population is confined at an altitude of 2200 meters.

c) The five species of cypress trees of the genus *Cupressus* are divided into 10 groups. Each one of these could be called as sub-species. Very rarely hybrids are formed between two groups although the groups live close enough. The reason appears to be that the groups shed their pollens at different times or season, preventing the occurrence of cross pollination.

d) Courtship behaviour patterns which are very specific for each species act as a deterrent for the members belonging to different species. Mayr opines that where there is courtship behaviour pattern the engagement may be broken if the pairs do not belong to the same species. Similarly specific scents produced by certain organisms to attract their mates help in the process of species recognition.

e) Interspecific sterility: Organisms belonging to two different species may mate but may not produce any offspring.

Hybrid sterility : The interspecific cross may result in a sterile F_1 offspring.

5) i) Selection, mutation, genetic recombination and gene migration.
ii) Genetic drift
iii) Sampling error
iv) Sewall wright
v) Shifting balance.

Terminal Questions

1) Three types of species concept have been proposed.

a) The typological species concent, as suggested by Plato, reduces the immense variety of organisms in nature to a few "types". It proposed that individuals might vary but belonged to a single type.

b) The nominalistic species concept regarded species as man-made abstraction.

c) The biological species concept, a more realistic and objective approach to the problem of species conceived species as members belonging to a reproductive community and as an ecological unit. It also regarded species as a genetic unit where individuals are held as a large, strongly united gene pool.

2) Sympatric speciation refers to speciation where parent species give rise to a daughter species without the individuals of the species being separated.

Speciation by populations of parent species which occupy quite separate territories is the allopatric speciation and the most common mode of species formation. Speciation by small populations isolated on the periphery of the distribution of the parent population can be described as peripatric speciation.

3) Ring species refers to a concept of speciation in which a widely distributed species breaks up into partially isolated species and then acted by selection and other factors results in a circle or group of races or Rassenkreise. For the example refer to section 13.4.

4) a) Geographic isolation
   b) Geographic isolation
   c) Geographic isolation
   d) Ecological isolation
   e) Ecological isolation
   f) Ecological isolation
   g) Ethological isolation
   h) Ethological isolation
   i) Ethological isolation
   j) Mechanical isolation
   k) Reproductive isolation
   l) Reproductive isolation

5) In small populations genetic drift occurs due to sampling error. It refers to accidental but pronounced fluctuations in the frequency of a particular allele. In a population consisting of 100 individuals, assuming an allele is present only in one individual, the chances are that either the allele is irrevocably eliminated from the population in one or two generations or the frequency of allele may increase by 10%. In other words, due to genetic drift, the genes may be consequently lost or completely fixed in small populations. For an example refer to section 14.3.

UNIT 14 HUMAN EVOLUTION-I

Structure

14.1 INTRODUCTION

The evolution of human kind can be regarded as the climax of phylogenic history of organisms. In the previous units of this block as well as the previous block we have detailed for you the mechanisms and the processes of evolutionary change. In such discussions, specific examples from both the animal and the plant situations were chosen and explained. However, it should be conceded that in this course on Evolution, it was not possible for us to discuss the evolution of various groups beyond the species level. Nevertheless the evolution of the lineage that eventually produced man is indeed important. Since we are the current end products of the process and are capable, we can look back into the history and at the remains of the organisms that have been a part and parcel of this lineage.

The fossil record of the human history, although rudimentary, has been quite helpful in determining largely what we are seeking, namely a coherent history and evolution of human species. It is rather difficult to say that natural selection also sought and directed the evolution of man. It could be that the selection process operated mechanically to produce populations of organisms adapted to produce more organisms. This observation is obvious if one looks at the fossil history from early primates to the present man. In this unit we will be analysing the trends in human evolution starting from early primates. Such trends are a reality only for us. The last unit of this block will be concerned with certain aspects of cultural and social evolution of man with a special emphasis on his future course of evolution. Some of the questions we would like to raise in the next unit are what direction the human evolution is taking and whether man is capable of steering his own evolution. The answers for such questions may not readily be forthcoming but an attempt will still be made.

Objectives

After studying this unit you should be able to:

- trace the fossil history of the mankind,
- bring out the common ancestory of humans and apes by highlighting the similarities and differences between the groups,
- reason out the uniqueness of man in the animal kingdom as a whole, and
- discuss that concepts like culture, religion and ethics evolved with humans.

14.2 PRIMATE HERITAGE

Table 14.1 provides you the classification of the living primates. The primate fossil history dates back to 60 million years i.e. to paleocene times, more specifically to the cretaceous age. The fossils of mammals of this period, their teeth, jaws and skulls bear affinities with Lemuroids.

Table 14.1 : A brief summary of the classification of primates

Order Primates
Suborder Prosimii
Superfamily Lemuriformes — lemurs, indriids, aye-ayes
Superfamily Lorisiformes — lorises, pottos, bush babies
Superfamily Tarsiiformes — tarsiers
Suborder Anthropoidea
Superfamily Ceboidea — New World monkeys
Superfamily Cercopithecoidea — Old World monkeys
Superfamily Hominoidea
Family Hylobatidae — lesser apes: gibbons, siamangs
Family Pongidae — great apes: orangutan, gorilla, chimpanzee
Family Hominidae — humans

In all these fossils apart from the structure of the molar teeth which is of primate character, there is a tendency in the skulls towards the expansion of the brain. Further there is a shortening of the face in these skulls, and the eyes which were initially laterally placed get a frontal position. Also, there is a relative increase in the size of the cranium to accommodate a larger volume of brain (see Fig. 14.1).

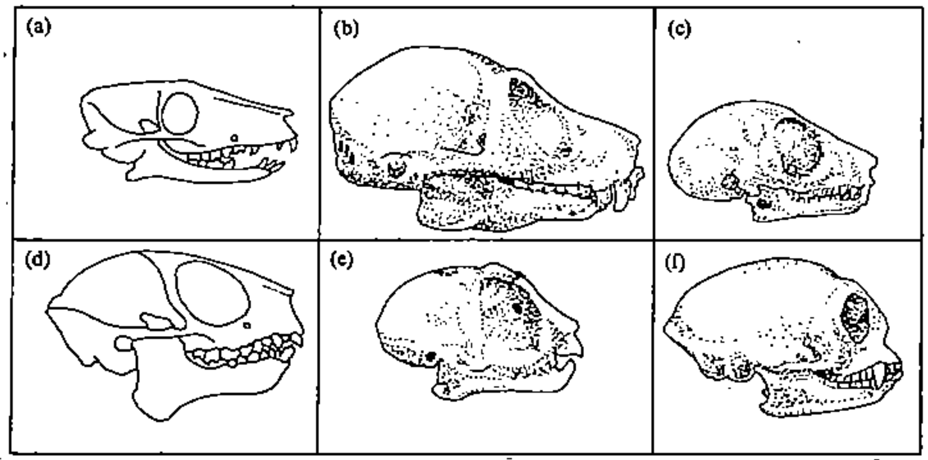


Fig. 14.1 : Comparison of the morphological features of the skulls of some prosimians. a) tree strew; b) & c) Lemuriforms; d) & e) tarsiers; f) the primitive monkey.

The Lemurs (Fig. 14.2a) found in the fossil records of the eocene times were comparable to modern lemurs except that their brain was smaller and teeth specialisations were not found. Eocene times also showed tarsiers (Fig. 14.2b), the fossils of which showed primitive skulls, brain and limbs. Significantly the number of teeth were reduced from 44 to 32, which is an anthropoid characteristic. Besides the numbers, the structure of the teeth with bicuspid premolars and tricuspid-molars were typically anthropoidian in nature. Primates were abundant in North America and Europe until the end of eocene and then disappeared completely.

There is a poor fossil record of primates in oligocene times i.e. some 30 million years ago. In Egypt, in a place called Fayum a considerable diversity of primate remains were obtained. These primates belong to the genera *Aegyptopithecus, Apidium, Aelopithecus* and *Oligopithecus*. These fossils were clearly distinct from lemuroid fossils of eocene times. All of them were small mammals and anthropoid in their characters. A nearly complete fossil of the skull jaws and other skeletal parts were obtained for *Aegyptopithecus*. The skeleton resembled that of a tree dweller, possessed a tail and was not a brachiator. The fossil suggested that the animal had a long snout, small bony eye sockets, sexual dimorphism of the canine and its teeth resembled those of apes. Possibly this animal was an ancestor of gibbons.

Some 20 million years ago during miocene times the fossils of cecropithecoids and hominoids appeared. And towards the end of miocene it was the period of old world monkeys. Old world monkeys fell into two groups, the leaf eating colobines and fruit eating cecropithecines. These animals extended from Africa to India and Pakistan.

Oreopithecus, a late miocene primate had very close resemblances to those of gibbons (Fig. 14.2c), although the tooth structure showed that the animal was only a monkey and not a hominoid. Another group of hominoids that were present in moiocene in Europe, Africa and Asia were Pongids.

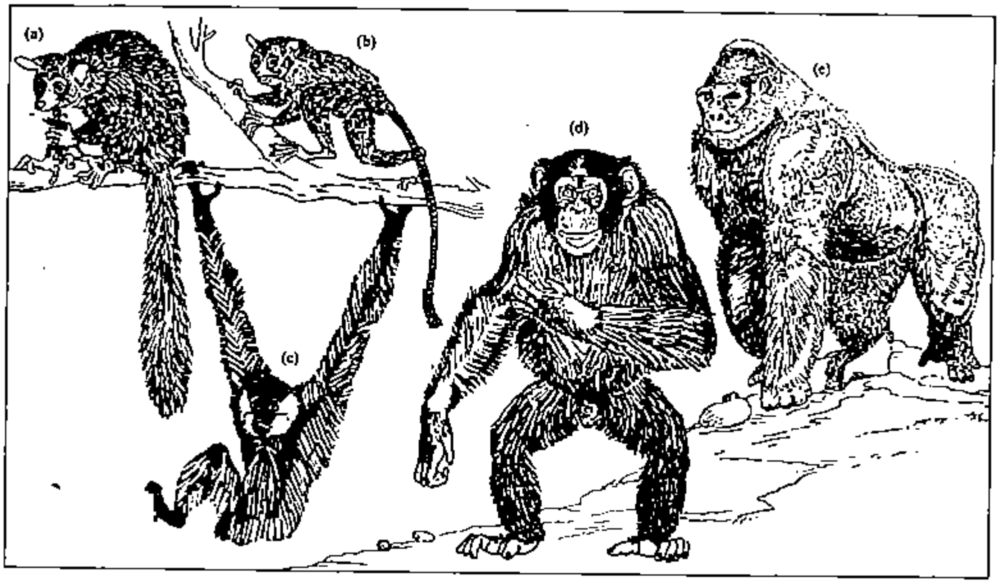


Fig. 14.2 : a) Lemur, b) tarsier, c) gibbon , d) chimpanzee, e) gorilla.

The oldest of the Pongids was the genus *Proconsul*. This fossil was dated at 17 to 21 million years before the present. Several species of *Proconsul* weighed between twenty kilograms (20 kg) to hundred kilograms (100 kg), had premolars and molars similar to those of hominoids but lacked the tusk like canines of modern Pongids. The next major fossil and a descendent of *Proconsul* was *Dryopithecus*. This fossil had a teeth like those of living apes, and long limb bones. The long limb bones were suggestive of beginnings of brachiation. *Dryopithecus* belongs to the subfamily Dryopithecinae and family Pongidae which included chimpanzees (Fig. 14.2d), gorillas (Fig. 14.2e) and orangutans.

The next major fossil finds belong to pliocene age dating back to 10 million years. Such fossils also belong to the late miocene age. These rare fossils of subfamily Dryopithecinae belong to the genera *Sivapithecus* and *Ramapithecus* and were discovered in Siwalik hills of northern India. These fossils were the earliest recognisable hominid fossils along with those discovered in Kenya and Hungary. Subsequently, the genus *Gigantopithecus* was found both in Siwalik hills and pleistocene deposits of South China. All these fossils had a mixture of hominid and pongid characters. The hominid traits were the shortening of the face, thickening of molar enamel and modest development of canines. The pongid characters included the parallel rows of premolar and molars, a gap between incisors and canines called diastema and a sharpening surface on the first premolars on which the canine is honed. The hominid nature of such fossils became obvious with the discovery of a beautifully preserved partial skull of a *Sivapithecus* discovered in 1982 by Pilbeam. The skull resembled that of orangutan. By way of summarising it could be said that although several late miocene and pliocene fossils were found there was no real consensus that they belonged to hominids. The real hominid fossils did not appear until pleistocene times, that is until eight million years before the present. In our next section we will be discussing the hominid fossils that were ancestral to the genus *Homo* and provided evidence for the evolution of modern man; but before that try the following SAQ.

SAQ 1

Fill in the blanks in the following sentences.

i) Lemurs and tarsiers belong to the suborder .... of order primates.

ii) The characters of Aegyptopithecus suggested that it had affinities with ....

iii) The earliest recognisable hominid fossil is ....

iv) .... is the oldest pongid-hominoid genus discovered from the Miocene beds of Kenya.

14.3 TRENDS IN HUMAN EVOLUTION

Before we further proceed to discuss the fossil history of the humans we shall briefly look into what distinguishes humans or genus *Homo* from his ancestors namely the apes. These differences are clearly indicative of the trends in human evolution which are to a certain extent supported by the available fossil evidence. Is it possible to specify certain criteria for assigning an organism to the family hominidae and the genus Homo? The answer to this question will also indicate certain definite trends in human evolution. Some of the general trends in human evolution which would often come into discussion even as this unit progresses are:

i) The development of bipedalism so that the forelimbs are set free for performing specific tasks (Fig. 14.3).

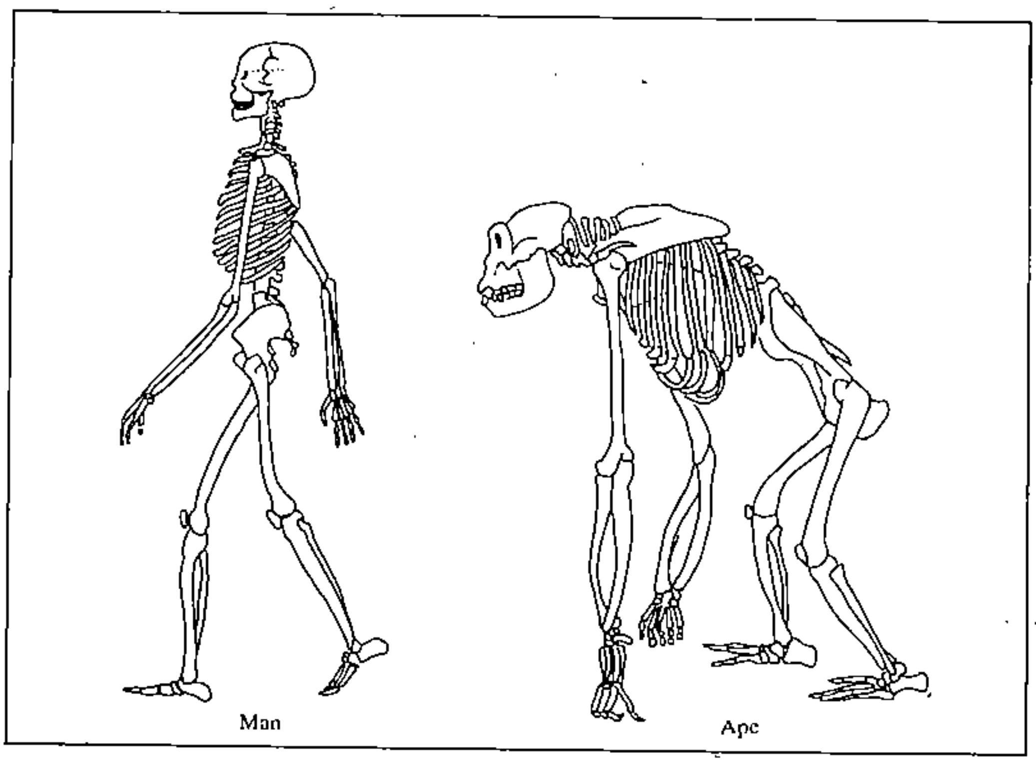


Fig. 14.3 : The evolution of bipedalism.

ii) The development of visual acquity which has been perfected by the evolution of a binocular stereoscopic vision.

iii) An increase in cranial capacity in order to accommodate a larger volume of brain (Fig. 14.4).

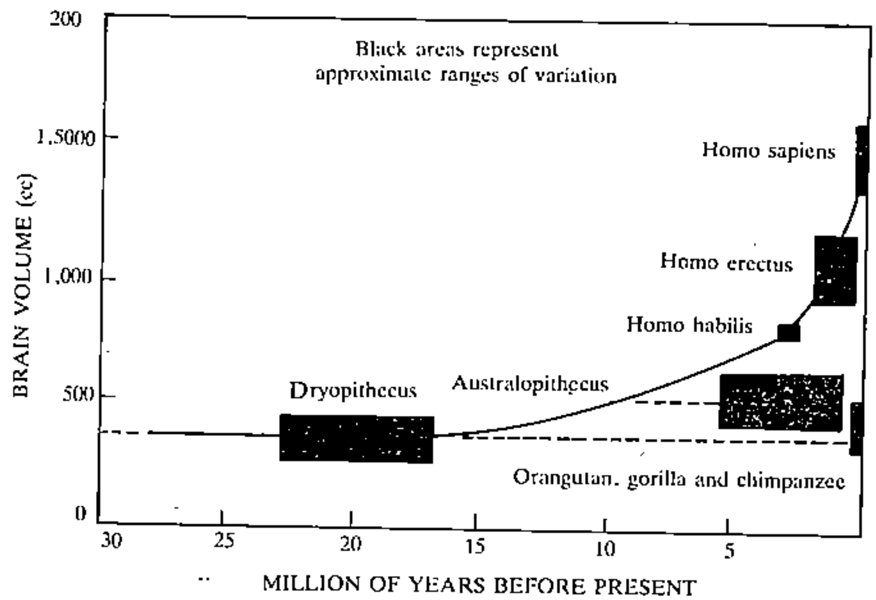
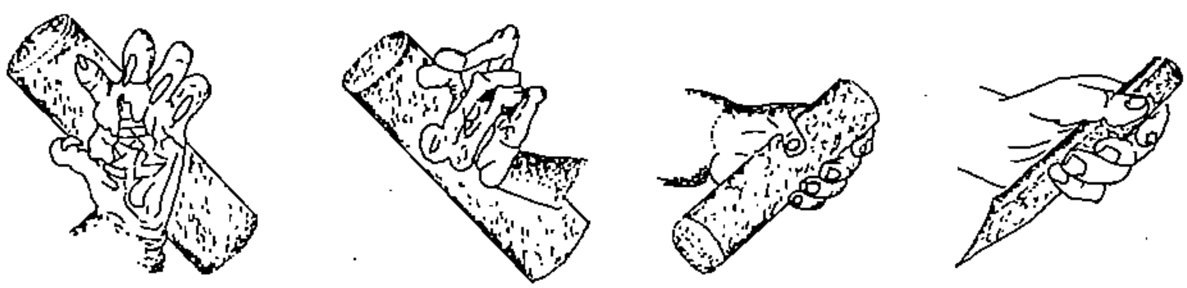


Fig. 14.4 : The brain volume in different species of primates.

iv) A receding forehead.

v) Development of opposable thumb (Fig. 14.5).



(a) Tree shrew (b) Tarsier (c) macaque (d) Human

Fig. 14.5 : Evolutionary changes in the structure of the hands of primates leading to the development of a opposable thumb.

vi) The development of arched feet.

Along with the above mentioned anatomical changes other important factors that were responsible for delimiting the genus Homo are:

i) Evolution of culture by which it is meant that individuals in a society formulate concepts and communicate them to the other members of the society;

ii) By communication it is meant that language has to be developed as a fundamental medium of culture.

In subsequent sections, our analysis of human evolution would focus the trends we mentioned above in relation to fossil records. Whereas it is possible to obtain the fossil evidence for the anatomical traits we mentioned and to a certain extent to depict cultural evolution, the language is not a fossilizable one. We shall briefly discuss later in this unit and more elaborately in the next unit the evolution of communication skills in human societies.

14.4 AUSTRALOPITHECINES

The first ever australopithecine fossil was found in 1924 at Taung, South Africa. It was the skull of a 6 year old child showing a mixture of human and ape like features.

This abnormal fossil was termed as *Australopithecus* (southern ape). Subsequent to this finding several additional skeletons, most of which were incomplete, were found. All such finds fell into two groups: i) a lighter more progressive group and ii) a heavier less progressive group. The former were named as **gracile** type and the latter the **robustus** type.

The earliest known undisputed hominid fossils came from two separate sites from East Africa. The one site Laetoli is located 50 kms south of Olduvai Gorge in Tanzania. In this site M. Leaky found in volcanic ash a twenty meter trail of footprints of three hominids of 3.75 million years age. Also fossil fragments of 13 individuals, mostly teeth and jaws with a few post-cranial bones were found. The second site is from Hadar in the remote Afar region of Ethiopia. In 1974 D.C. Johanson, an American anthropologist discovered a remarkable hominid fossil which consisted of 40% of the skeleton of a 0.9 meter tall female australopithecine.

The fact that we could obtain the fossil footprints of 3.75 million years old essentially suggests that upright walking had already developed to a great degree. This observation has to be viewed in relation to the brain size. Australopithecines had a cranial capacity which was only slightly in excess of 400 cubic centimetres. This finding was further confirmed from the Hadar findings which were four million years old. Precisely, it was 4 million years ago that the branching of the African apes and hominids could have possibly taken place (Fig. 14.6). Let us briefly discuss the characters of the australopithecines that suggest a hominid ancestory in them.

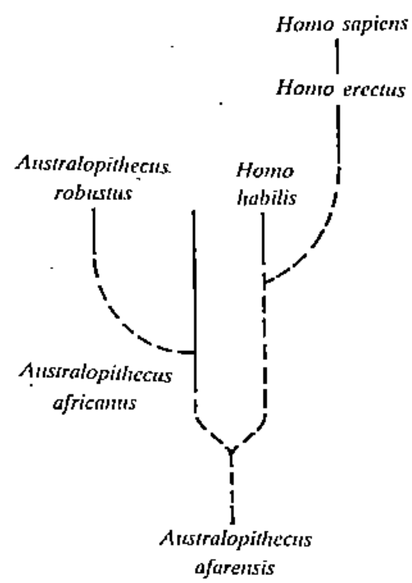


Fig. 14.6 : The branching of the hominid and the australopithecine lines nearly 4 million years ago.

Mostly the brain case of australopithecines ranged from 400 to 600 c.c. and was in fact much larger in proportion to that of the body which was about 1.2 meters tall and weighed around 23 kilograms. Most of the fossils were found in cave sites which means that by 2 million years ago the use of caves as shelter has begun. There is evidence to suggest that these forms made stone tools. Johanson while explaining the bipedalism in *Australopithecus afarensis* (this fossil of the female ape was named as Lucy) suggested that the males while collecting and bringing in the food for the families should have got their forelimbs freed. In other words bipedalism evolved in relation to the concept of provisioning for the family. The forehead was more rounded than chimpanzees and eyebrow ridges were still very prominent but less so than in chimpanzees. The jaws protrude prominently but less than those of modern apes. The dental arcade of australopithecines were intermediate between the apes and other advanced hominids in overall shape, in the size of the canines and in the prominence of cusps of premolars and molars (Fig. 14.7).

Also, there were differences in the shape of the tooth rows between apes on one hand and australopithecines and humans on the other hand. In apes the canines, premolars and molars form parallel rows on either side of the jaw and the incisors are at right angles to them. In the other two groups the teeth are arranged in a parabolic row as

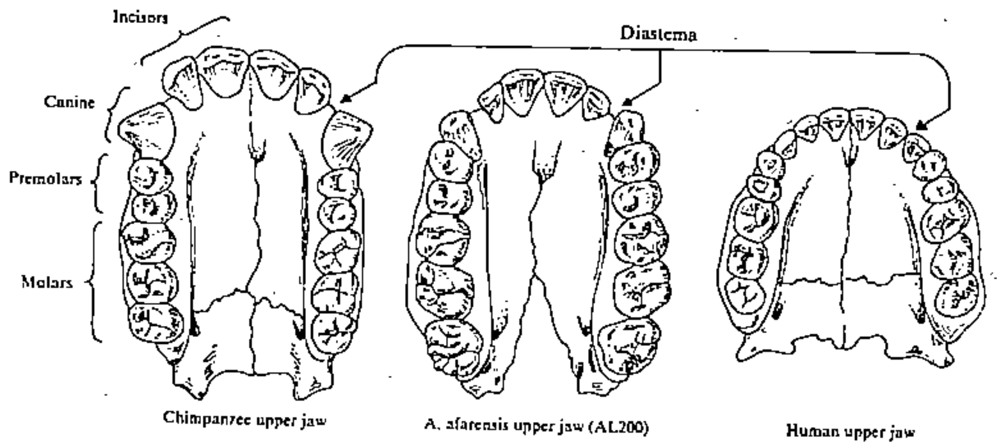


Fig. 14.7 : Comparison of the dental arcade of a chimpanzee, an australopithecine and a human.

you can see in Fig. 14.7. Finally, the occipital condyle by which the skull articulates with the spinal cord resembles more of humans than of apes suggesting an erect posture.

Also there are similarities in other skeletal parts between humans and australopithecines. The limb bones, overdevelopment of arms, the hip bones, the arrangement of the big toe and the development of arches all of which are suggestive of an erect posture and bipedal walking. Apart from skeletal details, evidence from anatomical and biochemical studies as well as the karyotype analysis and DNA hybridization techniques indicate that humans and African apes may share as much as 98% of their genetic material.

From the available fossil evidence it cannot be precisely said the point of time at which the branching of the genus *Homo* from australopithecines took place. *A robustus* to which we referred to earlier and *A. boisei* are highly specialised forms and can be regarded as the terminal members off australopithecines. As on date, there is reason to believe that *A. africanus* could be the point from which the genus *Homo* bifurcated. This hypothesis seems to be reasonable until new fossils suggesting a different line of bifurcation is discovered. Our discussion on the australopithecines, the immediate ancestors of genus *Homo* ends here. In the next section, you will study the fossils of humans belonging to other species and trace the evolution of *Homo sapiens* through these fossils.

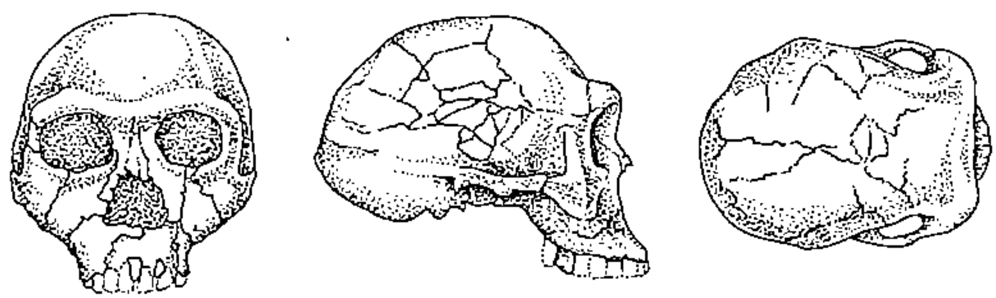
SAQ 2

Match the items given in column I with those of column II.

Column I		Column II	
i)	Canines, Premolars, molars in parallel rows and incisors at right angles	a)	Human dental arrangement
ii)	*Australopithecus afarensis*	b)	Tanzania
iii)	*Australopithecus robustus*	c)	Terminal member of australopithecines
iv)	Fossils of trail of footprints	d)	Hadar
v)	Parabolic arrangement of teeth	e)	Characteristic of apes

14.5 HOMO HABILIS AND HOMO ERECTUS

Two important human fossils that throw much light on the human ancestory were discovered in Olduvai beds in Africa and in central Java respectively. Although the development of bipedalism and the resultant freeing of hands are being regarded as the first happening towards the evolution of the genus Homo, subsequent human evolution essentially depended on the dramatic expansion in the brain size. This development in brain size began about 2 million years ago. Fossils discovered in Kenya and Tanzania suggested that individuals had cranial capacities more than 650 c.c. and close to 800 c.c. The fossils represented the first appearance of the human kind and termed *Homo habilis* which meant 'handy man' a term coined by Louis Leakey and his colleagues in 1964. *Homo habilis* had several features common to *A. africanus* such as similar height and weight and bipedal walking. But a closer scrutiny showed distinct differences in having a larger head (Fig. 14.8) and shorter rounder neck, relatively flat and less protruding face. Further, this *Homo* genus showed teeth less massive than southern apes. The name handy man suggests that he is a maker of tools. New discoveries from 1972 by Richard Leakey at Koobi fora in Kenya showed fossil hominid skulls with cranial capacities of 800 c.c. More importantly along with the skulls, tools were also found there which justified the specific name *habilis* for the species and the inclusion of species under *Homo*.



(a) (b) (c)

Fig. 14.8 : The frontal (a) lateral (b) and top (c) view of the skull of *Homo habilis*

Homo erectus first arose about 1.6 million years ago and is believed to have lived for atleast 600,000 years at a time when the transition to *Homo sapiens* took place. The fossil finds of *Homo erectus* indicate several first happenings in the human history. For the first time man became from being an opportunistic scavenger to a cooperative and big game hunter. For the first time he had come to know the use of fire. From being a mere stone scrapper, he became a systematic tool maker. There is evidence to indicate that he had home bases or campsites from where he operated. And also for the first time we had such fossils from outside Africa, in Eurasia.

Homo erectus variously named as *Pithecanthropus, Sinanthropus* and *Atlanthropus,* first appeared during the pleistocene interglacial period. Natural selection, it appears acted on specific characters which favoured the accumulated wisdom, such as increased body size, increased longivity, symbolic human-style culture, and loss of body heat. The cranial capacity of the pithecanthropine man ranged between 800 c.c. to 1125 c.c. (Fig. 14.9). The later populations of *Homo erectus* were known as **cave man** or **ape man**. The pithecanthropine fossils showed several characters which gave a fair picture of the primitive humans.

They were of moderate height, with straight limb bones, broad hip bones and occipital condyle positioned more or less like a modern man. These traits showed that they stood erect or nearly so. The proportion of arms and legs resembled that of modern man. The forehead was receding but the jaws were still projecting although much less than those of the apes. They possessed large jaws and teeth and there was no chin. The teeth, their size and arrangement agreed more with humans rather than

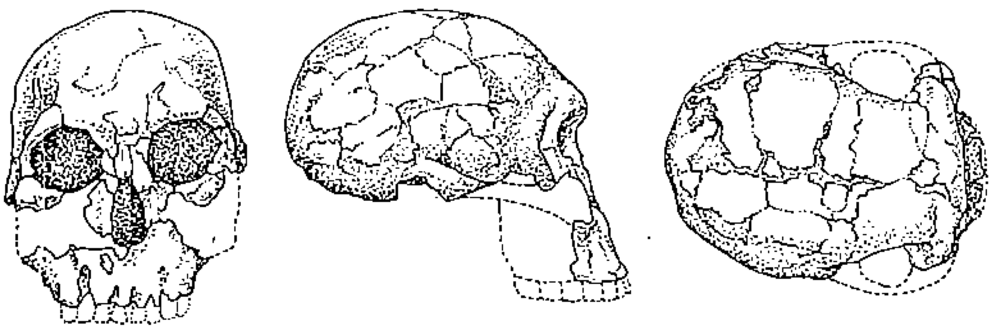


Fig. 14.9 : The frontal a) lateral b) and top c) views of the skull of *Homo erectus*.

with those of apes. The brain case showed variations in different fossils of pithecanthropines. **Java man** had a cranial capacity ranging from 775 to 900 c.c. with an average of 860 c.c. **Peking man** had a cranial capacity varying from 850 to 1225 c.c. with an average of 1075 c.c. These measurements are intermediate between those of gorilla (500 c.c.) and the modern humans (1350 c.c.). Although a direct correlation between the brain size and intelligence cannot be made, the fossil evidence did suggest that *Homo erectus* was very clever as compared to the apes but dull as compared to the modern man.

As we mentioned earlier two specific skills of *Homo erectus* make him stand apart from all his predecessors: i) skills as an efficient tool maker ii) skills as a cooperative game hunter. Both the skills could be associated with the larger brains they had. The earliest tools usually associated with australopithecines were the pebble tools. In such tools, the stone had one edge sharpened by chipping either on one side or on both sides. This basic style of tool making is also found in advanced forms which made more variety of better tools. In fact some of the ancestors of Australian aborigines resorted to this basic style of tool making. This suggested that there was no change in tool making when transition from *Homo erectus* to *Homo sapiens* took place. Nevertheless the tools made by *Homo sapiens* were more refined than those of their immediate ancestors. The chopper tradition of tool making witnessed in Java and Peking man (Chinaman) evolved in two directions in Eurasia and Africa. One direction was the **flake tool** tradition in which stone flakes struck off a core were prepared by further chipping on one side. In another direction it was the development of **biface core tool** or hand axe. In the second tradition the central core from which the flakes were chipped away was shaped on both sides to form a chopping or cutting tool. Fossil finds suggest that the hand axe was present in tropical sites while the flake tools were abundant in more boreal regions. For example, during the last glaciation hand axes disappeared from Europe indicating the migration of the species towards south. The flake tools are better tools for skinning animals and preparing skins than the hand axes. Such tools were favoured by northern people who wore furs. To summarise *Homo erectus* was the characteristic species of lower Paleolithic age. Stone tool making industry can be said to fall into two categories: i) tools of Olduwan industry (Fig. 14.10a) which were simple, unspecialised and geographically restricted. Subsequently, the Olduwan industry developed more skill and sophistication as is known in South and East Africa. ii) The Acheulian industry (Fig. 14.10b) is characterised by large hand axes with fine workmanship. Such tools were abundant in regions from France to India. The Acheulian industry lasted almost a million years and probably *Homo sapiens* also used these tools .

The most important event that led to the evolution of modern man is his tranisition from being a hunter-gatherer to that of a big game hunter. During the middle

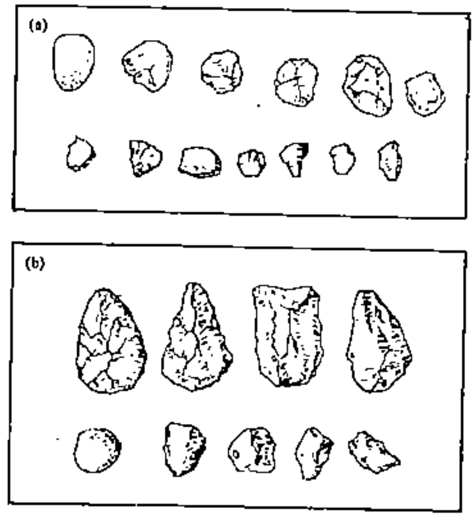


Fig. 14.10 : The tools of lower paleolithic age. a) Olduwan industry. b) Acheulian industry.

Pleistocene times there were huge herds of very large mammals. Bones of such large mammals were found associated with the human fossil finds and the contemporary fossil tools. It is even suggested that it is the large scale hunting by man that led to the eventual extinction of many of the large pleistocene mammals in Eurasia. Such animals included mammoths, mastodons, wooly rhinoceros, cave bears and giant deer. Initially the big game hunting was probably not carried out on a large scale and might have been cooperative venture. Here, several males surrounded a selected individual and killed it by the handiest method. The important point is that the whole process was a cooperative venture. It could be true that although the hunting was a cooperative venture, *Homo erectus* could not have detailed any specific plan in advance because of the lack of communication skills. But the cooperative venture served one big purpose namely it enabled the formation of multi-family groups and socialising tendencies. Also, it could be postulated that in such situations there was more than one male. And this could have led to the evolution of dominance hierarchies. The cooperative hunting also became necessary so that not only the hunting could be done together but also the sharing of the hunted food was possible. A mastadon would contain more meat than could be consumed by a single family and therefore the sharing occurred. This tendency also favoured the development of socialisation and formation of different families. Further, big game hunting appears to have excluded the females as they were involved in bearing and nursing children. In other words, big game hunting could have been the reason for the development of different social roles for males and females. This means the division of labour was being established and the role of female was getting confined mostly to child bearing and rearing children along with gathering of vegetal matter and slow game.

The big game hunting brought certain changes in the physical structure of the human beings. Man hunted the animals during the day time. This meant that the hard work of chasing and killing animals had to be done in the hot sun. Selection during these times favoured individuals that lost the metabolic heat faster than their fellow individuals. Possibly man had lost the thick body hair during these times and developed a high density of sweat glands in the skin. Man could effectively evaporate and cool all over the body.

Another tool that *Homo erectus* has learnt to use was fire and in fact man had multiple uses for fire. It is not very clearly known how man had learnt to tame the fire but he understood that it was a source of warmth at a time when the thick hair from the body was being eliminated. Man also found use in fire in scaring of large carnivores. With a generalised tooth row that he was now developing, it became important for him to soften the tough meat and vegetables. Fire was also usd to harden the pointed wooden stakes so that it [illegible] converted into a spear. Finally fire also contributed to the development of soc[illegible]. It would make the home a warm place where women and children stayed together as a unit when male hunters were away.

The era of *Homo erectus* should have probably come to an end some 275 thousand years ago, but by that time all those salient characters that are found in modern man had come to be established in *Homo erectus*. It has not been possible for the palaeontologists and anthropologists to determine precisely the time of transition from *Homo erectus* to *Homo sapiens* although the first fossils of *Homo sapiens* were atleast 300,000 years old. Let us now look at the trends in the evolution of *Homo sapiens*.

SAQ 3

Give brief answers for the following in the space provided below.

a) List major trends in the evolution of genus *Homo*.

....

....

....

....

b) Based on fossil findings how do the pithecanthropines differ from the australopithecines?

....

....

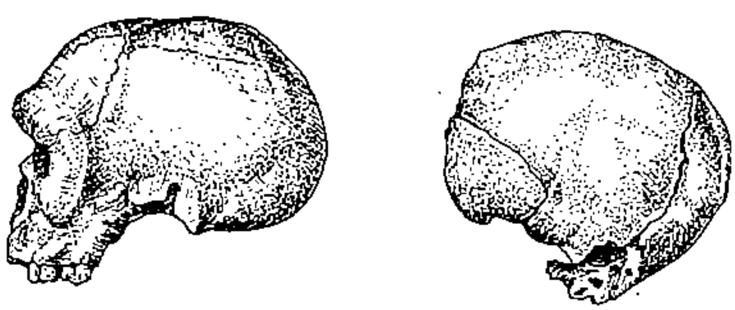
c) What are the two skills developed by *Homo erectus* that led to the development of socialising tendencies and family patterns?

....

....

14.6 HOMO SAPIENS

Homo sapiens first appeared in the fossil record between 200,000 to 300,000 years ago. The fossils were the Swanscomb man (Fig. 14.11a) from England and Steinheim man (Fig. 14.11b) from Germany.



(a) (b)

Fig. 14.11 : a) The Swanscomb skull, b) The Steinheim skull

There are only slight physical differences between *Homo erectus* and *Homo sapiens* and the transition between the two species is obvious from the earliest known groups of *Homo sapiens*, the Neanderthal man. For this reason some authorities prefer to place Neanderthal man under *H. erectus*. Whereas *H. sapiens* is characterised by large and round brain case, smaller brow ridges and a more pronounced chin as compared to pithecanthropines, Neanderthalers were more or less intermediate (Fig. 14.12).

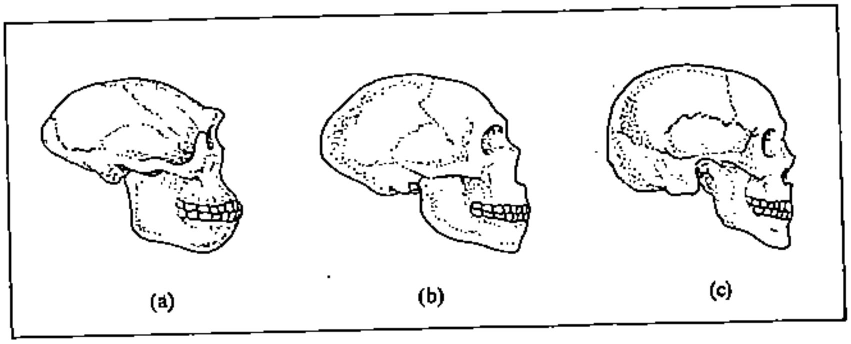


Fig. 14.12 : Comparison of the skull of Neanderthal man b) with a pithecanthropine man a) and a mode man c).

Glaciation : The dating of the human fossils is done with respect to some of the important climatic events that has taken place on the earth. There appears to have been four important ice advances separated by warm interglacial periods. Tentatively the first glaciation lasted for 600,000 years and began 1.3 million years ago. The second glaciation began about 500,000 years ago and lasted 250,000 years. The third glaciation period commenced 225,000 years ago and lasted 100,000 years. The ice last advanced 100,000 years ago and existed until some 11,000 years ago. The last glaciation is the Wurm glaciation.

Neanderthal man was distributed all over Europe, Asia and Africa. Their cranial capacity was larger than that of modern man. It is not very clear whether Neanderthalers represent a stage in the evolution of modern man or whether they represent another race of modern man. Available evidence indicates that the second proposition may be correct. Both modern man and Neanderthalers were found together during the later part of **Wurm glaciation** and since this is so at one point, it indicates that the Neanderthalers represent only another modern race. Neanderthalers are known for their fine tool industry, the Mousterian industry (Fig. 14.13) in which the hand axe was slowly replaced by various tools.

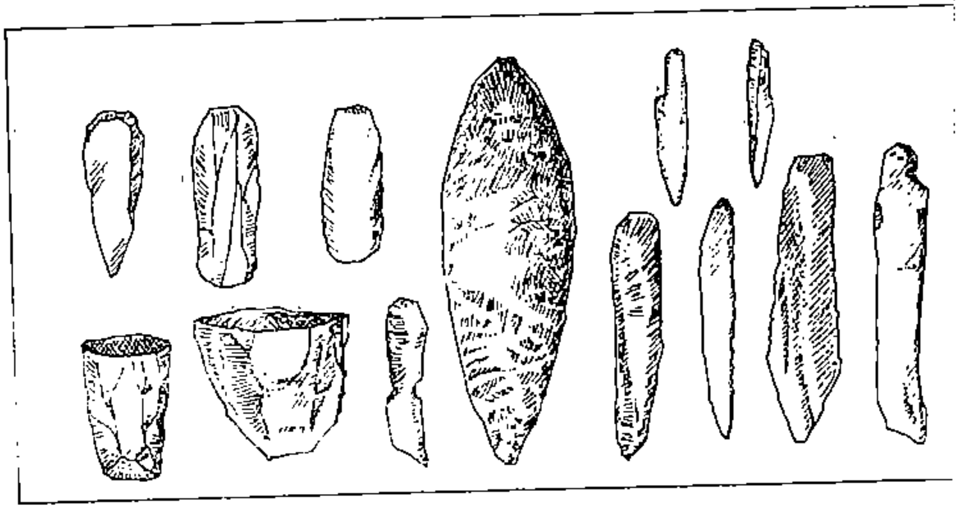


Fig. 14.13 : A sample of Mousterian tools.

Neanderthalers were characterised by a large thick boned skull and moderately prominent eyebrow ridges. They had a receding forehead and the cranial capaci was greater than that of modern man averaging about 1450 c.c. The teeth and ja were large and heavy as compared to modern man and he had a receding chin. Indications are that he had a powerful neck musculature, robust limb bones and skeleton more adapted to higher levels of activity and stress. Anatomy of the ha indicated a powerful grip. The stature was 1.5 meters and he was a cave dweller Culturally Neanderthalers appeared to be more advanced. They had the habit o burying dead ones with reverance as was evidenced by the presence of flowers in th burial centres. This group was biologically very successful and consisted of a homogeneous and widely distributed people.

Modern humans, *Homo sapiens sapiens* appeared in fossils some 33 thousand ye ago. The first fossil was discovered from the Cromagnon shelter in France and hen the fossil was known as Cromagnon man (Fig. 14.14).

Fig. 14.14 : A Cromagnon skull.

Subsequently many such fossils were known from France, Italy and middle East. All such fossils exhibited reduced brow ridges, steep forehead, high rounded cranial vault, short face and pronounced chin. Being bulky, they were not as tall as Neanderthalers. Structurally the Cromagnon man had a lot of resemblance to modern Europeans. It appears that the stone implements of Cromagnon's man had a high technological perfection. One could obtain in fossils long thin blades of various types. Further, Cromagnons had a taste for art. They made beads, carved statues and even engraved pictures. The cave paintings made by these men are a record of their aesthetic sense. Their burials were ceremonial and gave an indication of their cultured life. It could be said that with the appearance of Cromagnon, the modern human, the morphological evolution of humans is more or less complete and any further progress is related to culture and language. We shall be looking into the details of this aspect in our next unit. Nevertheless, we briefly outline here some of the important landmarks in the human progress.

A significant shift in the pattern of the human activity has occurred beginning about 10,000 years ago. This shift manifested itself in various aspects of his life. For instance, there was a shift from hunting and gathering to agriculture. There was a shift in the tool making process also. From the paleolithic age which was marked by making stone tools, he began to make his implements first in bronze and then in iron. And beginning 5,000 years ago special occupations developed, the cities began to be formed and the development of various aspects of culture such as writing, history, wealth, leisure, science and arts took place. This can briefly be the evolution of modern humans.

SAQ 4

Write (T) for true statements and (F) for false statements.

i) Neanderthal man and modern man belong to two distinct species. [ ]

ii) Mousterian tool industry belonged to *H. erectus*. [ ]

iii) The cranial capacity of Neanderthalers averaged about 1450 c.c. [ ]

iv) Neanderthalers were biologically very successful and widely distributed. [ ]

v) Structurally Cromagnon man had a lot of resemblance to modern Europeans. [ ]

vi) A significant shift in the pattern of human activity has occurred beginning about 35,000 years ago. [ ]

14.7 AN OVERVIEW OF HOMINID PHYLOGENY

In the above sections we discussed in detail the fossil record of primates in general and more particularly those of apes and the humans. Despite the fact that in recent years a number of hominid fossils have been discovered, the fossil history of humans is not complete and the evidence is only fragmentary. Therefore, it has become necessary that based on the available evidence we need to synthesise an acceptable path of human ancestory. The hominid family had its origin from the dryopithecine ancestors. The fossil record suggests that genus *Proconsul* and *Ramapithecus* could be the near point of the origin of the family Hominidae. There is a consensus among the paleontologists and anthropologists at one time that Ramapithecus was the earliest recognisable hominid. But now evidence is available that Ramapithecus was more close to orangutans than to hominids. Late miocene and early pliocene period were short of primate fossils. It is only during the late pliocene period the first remarkable hominid *Australopithecus afarensis* (Lucy) appeared. The australopithecines were a separate side branch of the hominid evolution and have no survivors in the modern world. This means the genus *Homo* derives its ancestory from an australopithecine species whose fossils could not be found. This species probably gave rise to *Homo habilis,* and subsequently through *Homo erectus* to *Homo sapiens.* There is also another viewpoint. The *A. afarensis* led to *A. africanus* which divided into two lineages: 1) to *Australopithecus robustus* and *A. boisei* which represented the termination of the australopithecine lineage. 2) the more progressive branch gave rise to *Homo habilis* to *H. erectus* and finally to *H. sapiens.*

The fossil history of humans makes one thing clear. At any given time not more than one species of *Homo* existed, although many contemporary sub-species could have lived. The fossil evidence suggests that the origin of *Homo sapiens* from *H. erectus* could have occurred during the middle pleistocene times.

While discussing the origin of modern man we mentioned that the Neanderthalers were a separate race by themselves. The classical Neanderthal fossils of later date were found from Western Europe although the skeletons of early Neanderthals were found in Eastern Europe and Asia. Obviously the Neanderthal race, a modern but a distinct race from *H. sapiens* occupied the old world as early the second interglacial period. By around the fourth glaciation the classical Neanderthal man got separated from the main population. The *Homo sapiens sapiens,* it is believed, should have arisen from the main population and developed into a more progressive Cromagnon man. From the eastern Europe the Cromagnon man invaded the West and replaced his Neanderthal cousins. Neanderthal fossils are at least 45,000 years old and are associated with mousterian tools. About 40,000 years before the present skeletons of both Neanderthals and modern man could be found. Considering the fact that these fossils were found in eastern Europe it is suggested that modern humans made their appearance in the middle east Europe, moved out from there and replaced the Neanderthals. At such times intermating could have occurred between Neanderthals and Cromagnon man and the latter inherited the genes of the former.

On this note we end our discussion on one aspect of human evolution. But evolution is an ever continuing process. Currently man is evolving by adapting biologically to his own cultures. Or is it that biological and cultural evolution are two different aspects of human evolution? The evolution of symbolism, language and culture and what the future evolution holds for man will be the subject matter of our next unit. We will look in detail into the development of symbolising ability and the invention of symbolic culture that projected man into a new adaptive zone involving adaptation to cultural evolution.

SAQ 5

Tick mark (√) the correct option in the following sentences.

i) The fossil history of humans is complete/fragmentary. ( )

ii) The hominid family had its origin from *Ramapithecus/ Australopithecus afarensis.* ( )

iii) The first remarkable hominid fossil was that of *H. habilis/ A. afarensis.* ( )

iv) The origin of *Homo sapiens* from *Homo erectus* would have occurred during late miocene/middle pleistocene times. ( )

v) Evolution is an ever continuing/abruptly ending process. ( )

14.8 SUMMARY

In this unit we attempted to reconstruct certain aspects of human evolution based on the scantly fossil evidence that is available. You have studied that:

- The human evolutionary history can be traced back to 60 million years that is to the cretaceous age of the paleocene times. The paleocene primates possessed several of anthropoid characters such as the size of the body, the number of teeth, and the structure of the canines.

- Towards the miocene times the hominoids started making their appearance and the old world monkeys dominated the late miocene times. The fossil of the genus *Proconsul*, a pongid dating back to 17 to 21 million years before the present had several of the hominoid characters and was the direct ancestor of *Dryopithecus*.

- About 10 million years before the present during the late miocene stage the fossils of the genera *Sivapithecus* and *Ramapithecus* were found from the Siwalik hills of northern India. These were the earliest recognisable hominid fossils with characters which were a mixture of hominids and pongids. The shortening of the face, thickening of the molar enamel and the modest development of canines were the characters that were responsible for including them under the hominid category.

- The human evolutionary history begins with the discovery of the hominid fossils. The trends that were observed in these fossils leading to the evolution of modern man were the development of bipedalism, increased cranial capacity, receding forehead and brow ridges, development of stereoscopic binocular vision, development of an opposable thumb and the development of an arched feet.

- Based on fossil evidence it is observed that the hominid lineage separated from the australopithecines some 3.5 million years ago. The australopithecines became extinct with *A. robustus* and *A. boisei*. The hominid lineage passed through different stages such as *H. habilis* and *H. erectus* before the modern man evolved. A race of modern human species, the Neanderthalers were possibly the connecting link between *H. erectus* and *H. sapiens*. The first *Homo sapiens sapiens*, the Cromagnon man possibly represented the transition between the Neanderthal man and the modern man.

14.9 TERMINAL QUESTIONS

1) Write briefly on the primate lineage of hominid ancestory.

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2) How would you justify that australopithecines were human ancestors?

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3) Make a comparison of the characters of *Homo erectus* and *Homo sapiens* based on fossil evidence.

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4) Briefly comment on the possible hominid phylogeny.

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14.10 ANSWERS

Self-assessment Questions

1) i) prosimii
   ii) apes
   iii) *Ramapithecus*
   iv) *Proconsul*

2) i) e, ii) d, iii) c, iv) b, v) a

3) i) The major trends in the evolution of genus *Homo* were:
   1) Development of bipedalism
   2) Development of binocular stereoscopic vision
   3) Increase in cranial capacity
   4) Receding forehead
   5) Development of opposable thumb
   6) Development of arched feet.

   ii) The australopithecine fossils were roughly 3 million years old and the upright walking had just begun. The cranial capacity was in excess of 400 c.c. The body was 1.2 metres tall and weighed around 23 kg. They made stone tools. They were mostly scavengers.

   Pithecanthropines, on the contrary appeared during the pleistocene period around 1.75 million years ago. Their cranial capacity ranged from 800 c.c. to 1125 c.c. They were of moderate height with straight limb bones, broad hip bones and the occipital condyle positioned more or less like a modern man. They stood erect. They were systematic tool makers and more of hunter gatherers.

   iii) The two skills developed by *H. erectus* that led to the development of family groups and socialising tendencies were:

   1) The transition from being a hunter-gatherer to that of a big game hunter. This skill involved a cooperative venture where several males surrounded a selected individual and killed it by handiest method.

2) Big game hunting involved making of biface core tools or the hand axe. Such tools were useful for skinning animals and preparing skins, which also brought the males together.

4) i) F, ii) F, iii) T, iv) T, v) T, vi) F

5) i) Fragmentary.
   ii) *Ramapithecus*
   iii) *A. afarensis*
   iv) Middle pleistocene
   v) Continuing

Terminal Questions

1) The primate lineage of the hominid ancestory dates back to 60 million years to the paleocene times. The fossils of the prosimians found between 60 million years before the present had several characters which were anthropoidian in nature. The primate remains obtained from Egypt showed that the mammals were small, had a long snout, small bony eye sockets, sexual dimorphism of the canine and the resemblance of the teeth to apes. For a detailed discussion see section 14.2.

2) There is lot of evidence to suggest a hominid ancestory in australopithecines. They had developed upright walking and an increased cranial capacity relative to their primate ancestors. They had a cave dwelling habit and there is evidence to suggest that they made stone tools. They had already developed a social life as well.

3) *Homo erectus* arose about 1.6 million years ago. The cranial capacity ranged between 800 c.c. to 1125 c.c. They were of moderate height, straight limb bones and broad hip bones. The forehead was receding but jaws were protruding. They possessed large jaws and teeth and there was no chin. He was an efficient tool maker and had a well defined social life. *Homo sapiens* appeared in fossils 33 thousand years ago. The fossils exhibited reduced brow ridges, steep forehead, high rounded cranial vault, short face and pronounced chin. He made stone implements of high technological perfection, had a taste for art as exemplified by cave paintings and had ceremonial burial indicating a cultured life.

4) The hominid family had its origin from the Dryopithecine ancestors. Fossil record suggests that *Proconsul* and *Ramapithecus* could be the near point of origin of the family Hominidae. During pliocene period the first hominoid fossil *Australopithecus afarensis* was discovered. Australopithecines were a separate side branch of the hominid evolution and have no survivors in the modern world. Essentially the genus *Homo* derives its ancestory from an australopithecine species.

UNIT 15 HUMAN EVOLUTION-II

Structure

15.1 INTRODUCTION

In the last unit we traced the human evolutionary history mostly from a palaeontological viewpoint. Although still fragmentary, the available fossil evidence makes it possible to construct a more or less coherent story of human origin and its development. Besides suggesting a primate ancestory, fossil evidence has indicated various trends in human evolution. Today the modern man is regarded as a climax of the evolutionary process. But several questions are raised as to which direction the human evolution is proceeding now and what direction will it take in the future. Is the be-all and end-all of all the evolutionary process? Or do human beings continue to evolve biologically? It may not be possible to provide a direct answer to these questions since evolution is a long term process and the effects could be visualised only after tens of thousands of years.

In this unit we will deal in detail with the cultural evolution of man. Communication skills and development of language have been the most important aspects of cultural evolution. This unit will also dwell on the evolution of the families and societies. There will also be a discussion on whether natural selection is active as ever on the present day man. Towards the end of the unit we will discuss the trends in the future evolution of man.

Objectives

After studying this unit you shall be able to:

- discuss the role of the language in the evolution of human culture,
- describe the evoluton of various cultures in human societies,
- raise questions whether natural selection continues to act on man and what is its effect, and
- draw your own conclusions regarding the direction of the future evolution of man.

15.2 SYMBOLISING AND LANGUAGE SKILLS

Language, a powerful tool for communication should have played a very important part in the evolutionary history of human species. Two relevant questions that could be asked of human language in an evolutionary context are : i) when did it originate and ii) what were the selection pressures that led to its development as a powerful facility for the exchange of ideas? There cannot be definitive answers for either of these questions. Yet we can do some knowledgeable speculations.

One of the man's major adaptations is symbolic thinking and its expression through a symbolic language. Language is the foundation of human culture and this adaptation has distinguished man from other animals and in fact has made him superior to them. Other organisms, however, can also learn a few things, for instance birds can learn to do new things with their beaks by observing another bird. A chimpanzee can put together two sticks to make a long one to obtain a fruit placed out of its reach. But even here the animal can do this only if all the elements are together in one place. In other words, the chimpanzee may not be able to think and go in search of the stick in order to obtain fruit. But recent studies have indeed shown the chimpanzees, our closest relatives do have the ability to symbolise to some degree.

It is a fact that ability to symbolise has made man enter a new adaptive zone. Also, it was big jump for man from the world of symbolising to a world of words. The development of a spoken language should have been a response to the direct stimuli from the external environment. We earlier raised a question regarding the time of emergence of the language. Unfortunately the products of language facility cannot enter into the fossil record. Therefore, we have to deal indirectly with the question of when the facility arose. Human brain as distinct from those of other animals provides a reasonable answer to this question. Also, a more careful analysis of the tools and art objects, the hominid products, do indicate of the type of cognitive capabilities necessary for spoken language.

Language abilities could be directly related to the brain size. In most people language centres are located within the left cerebral hemisphere which is slightly larger than the right. The structure and the sense of human speech as well as the coordination of the throat and the mouth muscles are controlled by specific centres in the brain. Two centres, Wernich's area and Broca's area (Fig. 15.1) located in the side and front of the brain appear as slight swellings on the left hemisphere. Again it cannot be certainly said that dominance of left hemisphere and the occurrence of the centres are diagnostic of language skills, since it appears that even chimpanzees possess them, although to a lesser extent.

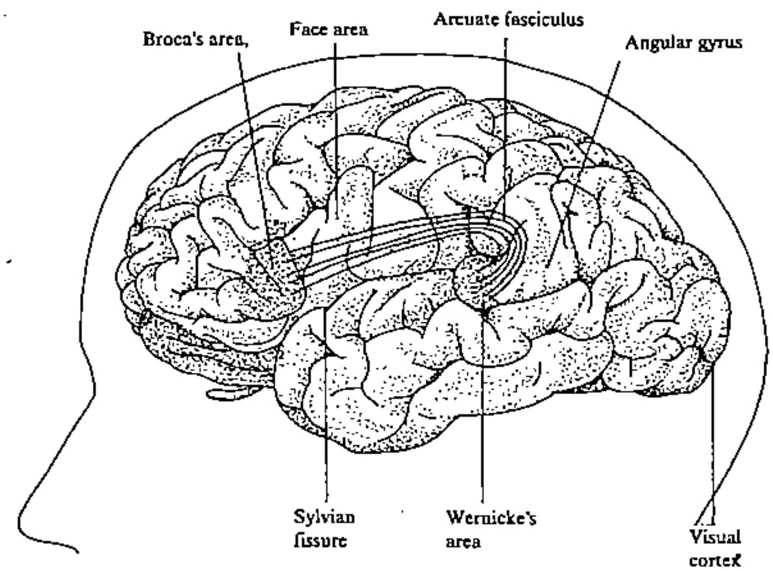

Fig. 15.1 : Language centres in the brain of humans.

Yet another anatomical feature of the modern human cranium is its flexed or vaulted appearance to accommodate the vocal apparatus. The basicranium of apes is much flatter. The basicranium of australopithecines resembles those of apes and in *Homo erectus* it is incompletely humanlike.

Two other skills, both of which are non-language products, seem to have played a significant role in the evolution of the communication abilities of humans. The first of these is the systematic and orderly progress the man-made in tool making. An analysis of the stone tool making over the past 2.5 million years suggests that there has been an increasing standardisation of tool types over the years. The transition that brought about the sophistication in tool making coincided with the dates of appearance of *Homo erectus*, Neanderthal man and modern man. In other words, the transition took place 1.5 million years, 150,000 years and 40,000 years before the present respectively.

The standardisation of tool making is a reflection of the nature of the societies which made the tools as well as used them. Glynn Isaac, an eminent archeologist suggests that the progressive orderliness seen in stone tool kits is an expression of an increasingly ordered society. Isaac further argues that it is not possible to conceive such well structured societies without the emergence of a complex spoken language. Fossil evidence indicate well established social relationships, an effective exploitation of the resources and a strong expression of group identity, all of which speak about highly ordered societies. Both the processes, the tool making and the spoken language involve sequential elaboration of component parts. In other words, they have to be developed in a specific order. If the order is not followed, then the final product makes no sense. Gordon Hewes, an anthroplogist concurs that the speech and tool making have several things in common. The tongue and the mouth movements are commonly associated with precise hand work. Hand gestures should have pre-dated the spoken language as a form of communication. Non-verbal communication or the symbolic language should have played a vital role in the early hominid evolution and in fact this is true of even today.

The second of the non-language product of the prehuman brain is his ability to do, art work. The art work should have been created with a view to symbolise and should have had a high utility value for him. The symbolic culture should have developed in relation to a cultural context. The oldest artifact available is at least 300,000 years old. It is an ox rib in which a series of festooned double archs are carved (Fig. 15.2a). A similar such pattern is available some 40,000 years before the present. In between we do not have anything comparable to such structures. From mousterian one could obtain engraved bone and ivory. And starting from upper paleolithic culture several such structures both in terms of number as well as variety have been obtained (Fig. 15.2b & c). The increase both in terms of number and elaboration is suggestive of an incremental leap in the facility for spoken language. It is not that the spoken language was the first innovation of these times but rather a substantial refinement of it. Harry Jerison a neurobiologist at the University of California is of the view that the evolution of language might have been a response to the ever expanding need to create an improved model of the world in one's brain. Language emerged specifically within the social context of an economically interdependent society.

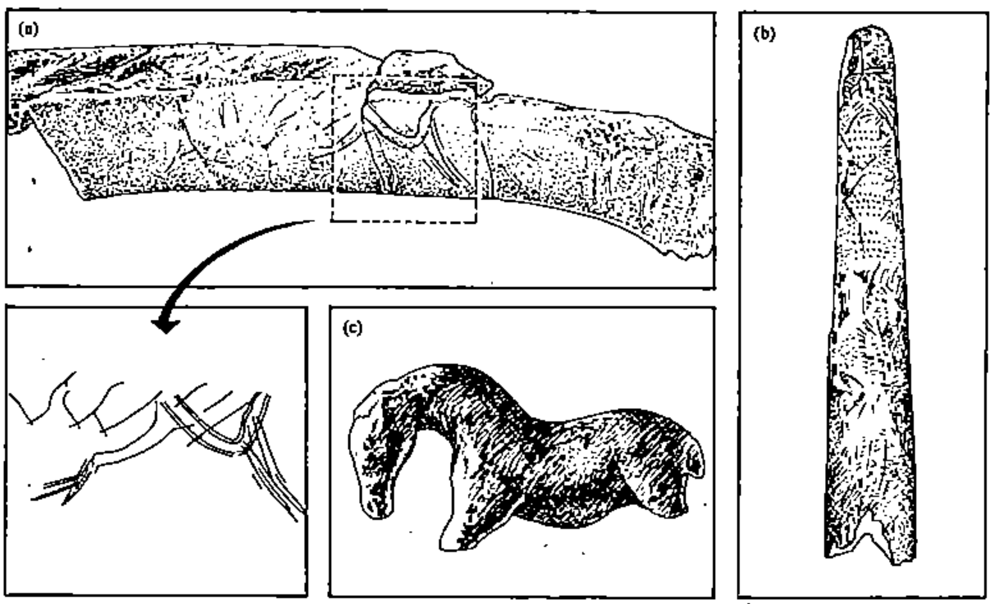

Fig. 15.2 : a) Oldest art work (dating back to 300,000 years back) showing festooned arches carved on an ox rib; b) Fragment of reindeer antler (12000 years old) showing an engraved pregnant mare; c) 300,000 years old horse carving from Mammoth ivory.

Is man unique in having evolved an efficient communication system? Is he therefore, to be distanced from his biological relatives, the apes? Some evolutionists believe that language is unique to man. G.G. Simpson is of that view. Dobzhansky believes that man has an exalted position over all other living organisms. J.C.B. Abraham (1990) refuses to accept the claims of such great evolutionists. He is of the view that if there were to be an "unbroken continuity in morphology, anatomy and physiology of apes and mankind, then that continuity must be recognised also in language, self-awareness and the higher faculties such as the aesthetics, the ethical and the behavioural — both individual and social". The Darwinian revolution, observes J.C.B. Abraham, must be pushed to its logical conclusion. Citing examples in favour of his argument, he points out that chimpanzees may not vocalise words but do use the American sign language effectively. A female chimpanzee, Washoe could use a vocabulary of 160 words by the age of 5. Washoe could even transfer her abilities to the novices who became familiar with the sign language. The situation is similar to the one witnessed in human society where the children acquire their mother tongue by imitating the parents and learning from them. Other workers have shown that these animals besides their capacity for human language with proper syntax were also capable of cultural transmission of the language. It, therefore, appears that it is not possible to maintain the hypothesis that the chimpanzees are divided by unbridgable gap from humans.

Symbolic and spoken languages most often come to be written. One advantage of writing is that things can be written down, forgotten and retrieved again. Such a methodology improves the content of any culture and promotes accuracy. With the knowledge explosion it became increasingly difficult to transmute, condense and generalise knowledge in the minds of men. Therefore, authority passes from living men to books. In fact, the creation of new knowledge itself does not depend on a single person but rather it is collective task. Writing became a significant milestone in the cultural evolution of man and the accessibility of the books to all people was responsible for the spread of the knowledge.

SAQ 1

Write (T) for true statements and (F) for false statements.

i) Language, a tool for communication played relatively a less significant role in the evolutionary history of human species. [ ]

ii) Symbolic thinking and its expression through a symbolic language are one of the major adaptations of human beings. [ ]

iii) Chimpanzees have the ability to symbolise to some degree. [ ]

iv) There is abundant fossil record as evidence for the products of language facility. [ ]

v) Language centres are located on the right cerebral hemisphere which is slightly larger than the left. [ ]

vi) The modern human cranium has flexed or vaulted appearance to accommodate the vocal apparatus. [ ]

vii) The progressive orderliness seen in stone tool kits is an expression of an increasingly ordered society. [ ]

viii) Hand gestures should have predated the spoken language as a form of communication. [ ]

15.3 EVOLUTION OF CULTURE

A general agreement among all the human evolutionists who may have a very radical philosophical background and convictions is that man is the result of an extraordinary evolutionary process. Whereas evidence is available from fossil remains of our ancestors and relatives for the comparative morphology and even anatomy to structure a biological classification, fossil forms do not record the behavioural aspects of man. Essentially the artifacts or the environment in which the fossils were found have to be examined judiciously to draw inferences, relating to the behaviour and cultural aspects. For instance, aggressiveness is a behaviour pattern but this behaviour pattern cannot be fossilised. On the other hand, the environment in which the sharp fossil tools and the fossils of big animals killed by game hunting speak volumes of the aggressive behaviour of the men of the times. The uniqueness of man can be attributed to the instinctive culture that he has evolved. Culture is sum total of a store of information and behaviour patterns. This is inherited by one generation from the other by instruction and learning and by examples and imitation. In other words, although the culture by itself may not be controlled by genes, the capacity to acquire it is determined genetically. As we discussed in our earlier section, the symbol systems should have played a significant role in the transmission of cultures. Because of this difference that the culture is not transmitted by genes, it is called "superorganic". This notion is not necessarily true. After all it is only the possessors of the human genotype who can acquire, transmit, innovate or transmute culture. In other words, human genotypes are indispensible for culture although the genotypes themselves do not decide which one of the variants of the existing cultures they will acquire. It amounts to saying that there are no genes for Hindu, Islamic, Sikh, American, Chinese or European cultures. The acquiring of a particular culture depends on the environment in which a child is brought up. The same argument can be extended to the concept of the learning and using of a language. Such acts although are decided by genes, the genes do not decide which particular language will be learnt.

In the last unit we looked into the complexities in human evolution based on palaeontological data. The complexities manifested themselves in the morphological and anatomical details. The question is, whether the cultural evolution is as complex as other aspects of evolution. Is it possible to define progress in cultural evolution as we defined progress in cranial capacity or bipedal walking? Is there any way by which a particular culture is more or less well adapted than the other cultures? Does culture actually progress from a lower to higher state?

The answers to these questions may not be simple. What could be the possible criterion on which the culture could be measured? Western scientists have chosen the efficiency as a measure of culture. The efficiency refers to an increase in the energy gained in respect to the energy expended. Thus, when man switched from scavenging to big game hunting, there was a surplus of energy. Once the agriculture was discovered he grew more. Modern industrial technology allows greater surpluses. Future depends on the use of new fuels, solar energy and other non-conventional sources, all of which are expected to bring greater returns on the energy expended. But there is also the criticism that the trend we describe occurs only in small portion of the total culture and does not reflect the entire culture. Also, the efficiency aspect of the culture may not be the most important one in terms of survival at any moment. Also, this aspect of culture may lead itself ultimately to inadaptiveness.

Another aspect of cultural evolution is that it could potentially be self-destructive if the adaptation is to the culture itself and not to the external environment. For instance, with all the modern industrial and technological development man of today is beseiged with major ecological and emotional problems. The factors which led to such situation involved appropriate adaptations to the changed cultural conditions. The acquired cultural adaptations may in turn bring further critical problems. What we are trying to impress upon here is that man's adaptations to changing culture may not have any relevance to his biological needs and his associated flora and fauna. As a matter of fact the newly acquired cultural adaptation may be limited by his biological needs. For instance, man may become adapted to an ever expanding automobile culture, but the biological adaptation (need) namely the ability of the lungs to withstand pollution may be limited. However, it should be conceded that there is a definite advantage by replacing the biological evolution with cultural evolution in that it leads to a faster rate of change.

Biological evolution is a slow and tedious process as compared to cultural evolution which at times progresses by quantum leaps. The differences in the rates of the two evolutionary processes allows man to adjust temporarily to temporary changes in climate and other environmental parameters. It could even be argued that in case of man the biological evolution could not keep pace with cultural evolution. If a cultural adjustment is made before a biological one, the latter has no way of occurring. It could be said that culture has very subtly delinked the genome of man from his geophysical environment.

We shall discuss this aspect further in detail when we are to discuss natural selection and man in our next section.

SAQ 2

Fill in the blanks with suitable words.

i) The uniqueness of man can be attributed to .... that he has evolved.

ii) Culture being not transmitted by genes is called ....

iii) The acquiring of a particular culture depends on the .... in which a child is brought up.

iv) If the adaptation is confined to culture and not to external environment, then it would prove to be ....

v) In man .... evolution could not keep pace with .... evolution.

15.4 NATURAL SELECTION AND FUTURE OF MAN

Natural selection is a process which directs all biological evolution. It is a process that directs genetic changes which when proved to be adapted to the environment are retained in the genome. In other words, man like any other organism may have to passively adapt to changing ecological circumstances through a slow, generation by generation change in gene complexes. The question is, does natural selection act in the same way in man as it is acting on other organisms. The major difference between man and other organism is that man is capable of steering his own evolution whereas the other organisms cannot. Teilhard de Chardin, an eminent human paleontologist and anthropologist says "the evoluton of life on earth, far from having come to a stop, is on the contrary now entering a new phase. The Darwinian era of survival by natural selection is thus succeeded by a Lamarkian era of super life brought about by calculated invention". Such a statement gives credence to the hypothesis that man can monitor his own evolution in future.

There is evidence to suggest that man through the technological revolution has modified the role of natural selection. As an example one may mention the cancer of the eye, the retinoblastoma caused by a dominant mutation. The disease develops as a tumor in one of the eyes of the affected child, spreads to the other eye and then extends to the brain causing the death before the individual reaches the adulthood. Today, if the condition is detected sufficiently early, it is possible to remove the tumor surgically despite the loss of one eye. The child can grow into a near normal-adult, marry and give birth to children. But there is a 50% chance for his children to be born with retinoblastoma. And inturn they have to be treated for the disease. Here is an instance where, through a surgical treatment a lethal gene is permitted to be preserved and passed on to the subsequent generations. Natural selection in normal course would have aimed to eliminate the gene from the population. But if the lethal condition were to be completely cured in every patient the frequency of the gene would increase slowly in the population.

Certain authors advance the argument that there is a deterioration in the genetic endowment of man. This may be due to ever improving conditions of life as well as to the improvements made in modern medicine. For example, the availability of insulin inexpensively allows the diabetic genotypes to breed although they would not have done so in the past. Similarly, the invention of eye glass has allowed the accumulation of those alleles which are inimical to good vision. These are the cases where the improvement in the quality of life has led to the accumulation of unwanted genes in the population. In other words, certain alleles have their selection coefficients reduced on account of improved medical practices. At the same time the modern civilization has also increased the selection coefficient of certain other alleles. For instance, as the civilised life became more faster, predisposition to tendencies like schizophrenia greatly increased. All these examples are suggestive of an increasingly modified role of natural selection in the future evolution of man.

There is some truth in the statement that the progress in health care is responsible to a certain extent for the rate of genetic deterioration of mankind. Can this genetic decay be stopped? The answer to this question lies in the science of eugenics, the science that seeks to improve the genetic stock of mankind. While the positive eugencies aims at the multiplication of desired alleles, the negative eugenics is concerned with avoiding the spread of undesirable genes.

Genetic counselling is a practice which informs prospective parents about the genetic nature of a given condition that may exist in one of them or in the families, and about the chance of its transmission to the offspring. Genetic engineering is a method of direct manipulation of genetic material. Germinal selection is a technique that involves the use of sperm and egg cells from individuals with desirable genetic constitutions through artificial fertilisation. Cloning is a process that ensures that an offspring is a true genetic copy of an individual. Cloning has been successful in frogs and toads.

There are four different ways by which the improvement in the genetic endowment of man is attempted to be made. They are; genetic counselling, genetic engineering, germinal selection and cloning. Without going into the details we may mention here that the eugenic procedures have enormous ethical and sociological implications. Not all the four methods we mentioned here could be put into practice. Methods like genetic counselling are quite desirable and the genetic engineering techniques to correct serious genetic defects appear to be socially and ethically unobjectionable. Anyhow the human species will continue to evolve genetically whether the man chooses to interfere in the process or not. Both positive and negative eugenics will be put to test in the process. It is only for the future generations to say whether the man has acted correctly or not in steering his own evolution.

One other aspect of future evolution of man relates to the pathway in which his culture would evolve because human experience is now within the realm of culture and not in basic biology. As far as the change is concerned, the human experience has telescoped it to be measured in hundreds of days, what was once measured in hundreds of million years ago. Further, as compared to many organisms, the human being has become one of the least specialised of the species. In other words, in terms of habitat and food specialisation man has adapted himself to varying conditions. He feeds on a broad diet and has distributed himself worldwide. The technology that he has evolved has taught him to dive beneath the oceans, fly successfully and even burrow under the ground. In short, man is a supremely adaptable species and this has been the reason for his enormous success on this planet.

Further, the continuous learning process which is an element of his social and economic activities has made man extremely different from all other organisms. Clifford Geertz observes that man is extremely dependent on "a certain sort of learning; the attainment of concepts, the apprehension and applications of systems of social meaning". It is these aspects that have led to the evolution of culture, a trait about which man alone can be proud of. Geertz further observes, "Man without culture is like apes who had somehow failed to find themselves". Man without culture "would be unworkable monstrosities with very few instincts, fewer recognisable sentiments and no intellect". Tautomerically, one could ask whether humans produce culture or the culture produces humans. The sociobiologist E.O. Wilson in a landmark study believes a kind of coevolution between genes and culture as a result of which virtually every wrinkle in human behaviour is explicable in terms of genetics.

SAQ 3

Choose the correct answers.

i) Man is capable/incapable of steering his own course of evolution.

ii) Technological advances may lead to a deterioration/an improvement in the genetic endowment of man.

iii) Availability of insulin allows/does not allow diabetic genotypes to breed successfully.

iv) Positive/negative eugenics is concerned with avoiding the spread of undesirable genes.

v) Genetic engineering techniques developed to correct serious, genetic defects are socially and ethically objectionable/unobjectionable.

vi) Every wrinkle in human behaviour could be/could not be explained in terms of genetics.

15.5 SUMMARY

In this unit you have studied the following:

- The concept of symbolising and the evolution of language skills in human societies. The symbolic language found its expression through symbolic thinking. The language has been the foundation of human culture. Ability to symbolise and develop language skill have led man to a new adaptive zone. The evolution of the language facility in human species is closely related to the evolution of human brains and the specific centres located in the brain. Also, the anatomy of the human cranium is adapted to accommodate the vocal apparatus. Tool making abilities and ability to do artwork appear to be two other skills that have played a significant role in the evolution of communication ability in humans. Controversy still exists as to whether man is distinct from his biological relatives because of the efficient communication abilities. Ability to write seemed to have followed the. symbolic and spoken language ability.

- Behaviour and culture are two other domains which are unique to man. Culture is something instinctive and is sum total of a store of information and behaviour patterns. Environment along with the genotype plays a significant role in the evolution of culture. Although it is difficult to quantify and measure culture, efficiency which refers to an increase in the energy gained in respect to the energy expended is regarded as a measure of culture. Switchovers from scavenging to big game hunting to agriculture and to modern industrial technology — all have led to an increase in the energy and thus inefficiency. Future evolution depends on the use of solar and other nonconventional sources of energy.
- Natural selection which is concerned with the nature of the genetic change through time and specifically with the differential survival of genotypes continues to act on man. But man responds to the challanges posed by the environment by changing his behaviour or by changing the environment itself. It appears that man has started to steer the course of his own evolution. Various eugenic processes such as genetic counselling, genetic engineering, germ selection and cloning may be attempted to improve the genetic endowment of man. Although some of these processes may have ethical and sociological implications, it appears that the future genetic evolution of man may depend in the application of such procedures. The present human evolution can be measured in much shorter time element as compared to his past evolution. Also the present day man is a supremely adaptable species mostly because of the extensive technologies that he has evolved. Only man could be identified as having evolved the learning process, a special sort of learning process namely the attainment of concepts. Man is endowed with the unique trait, the culture, which distinguishes him from all other species, more particularly his close relatives. There appears to have been a coevolution between human genes and the cultural process.

15.6 TERMINAL QUESTIONS

1) Do you think that ability to express has distinguished man from other animal groups and made him superior to them? Briefly substantiate your claim.

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2) How is the tool making ability linked with the development of communication abilities in humans?

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3) Is evolution of culture distinct from biological evolution of man? Justify your answer.

4) Do you believe that natural selection plays relatively a lesser role in evolving adaptation in man as compared to other groups of organisms?

15.7 ANSWERS

Self-Assessment Questions

1) i) F, ii) T, iii) T, iv) F, v) F, vi) T, vii) T, viii) T
2) i) culture, ii) superorganic, iii) environment, iv) self-destructive, v) biological
3) i) capable, ii) deterioration, iii) allows, iv) positive, v) unobjectionable, vi) could not be.

Terminal Questions

1) There are two opinions regarding the superiority of human species in terms of their ability to express as distinct from those of animals. Dobzhansky and Simpson are of the view that language is unique to man and it has made him to achieve an exalted position over other organisms. Another school of thought is of the view that there is indeed a continuity in morphology, anatomy and physiology of apes and mankind and that this continuity should recognised in language, self-awareness and other faculties as well. (You may express your opinion on the subject).

2) There appears to be a correlation between tool making ability and the development of communication abilities in humans as speech and tool making have several things in common. The tongue and mouth movements are commonly associated with precise hand work. Hand gestures appear to have predated the spoken language as a form of communication. Both tool making and spoken language involve sequential elaboration of their component parts and have to be developed in a specific order.

3) The answer appears to be yes. While biological evolution is strictly regulated by the changes in gene frequencies, the culture it appears is not transmitted by genes and therefore, superorganic. But it remains a fact that it is only the possessors of human genotype who can acquire, transmit, innovate or transmute culture. Also, the cultural evolution could be potentially self-destructive if the adaptation is to culture itself and not to the external environment. To distinguish cultural evolution from biological evolution it could be said that man may become adapted to an ever expanding automobile culture but at the same time he should also evolve the biological adaptation of his lungs withstanding the pollution problem.

4) It appears that the present day man is capable of steering the course of his own evolution. More particularly at a time when he is capable of improving his genetic endowment by phenomenon such as genetic counselling and genetic engineering. (The student may list his own conclusions on the possible role of natural selection and the extent to which it plays a role in evolving adaptations in man).

GLOSSARY

Acheulian industry : this stone tool industry presents a slight advance over the Olduwan tool industry and dates back to 1.5 million years. The industry is characterised by the presence of tear drop shaped hand axes.

Allopatry : organisms belonging to same species are separated by space and occupy different territories.

Altruism : a behavioural trait probably genetically controlled responsible for the benefits provided to the other members of the species.

Basicranium : the region relating to the underside of the cranium.

Carrying capacity : the capacity of the environment to sustain an optimal population size.

Character displacement : the tendency of the two species of organism to evolve differences in their characters when there is a broad niche overlap. To begin with the two species may share a larger area of the niche but with the action of natural selection the niche overlap diminishes.

Coadaptation : adaptations evolved by two different species occupying the same niche to specific needs from the environment that minimises the interspecific competition.

Coevolution : simultaneous evolution of two or more ecologically related species.

Conspecific : individuals belonging to same species.

Directional selection : selection favouring adaptations to new environmental conditions so that change is produced.

Genetic drift : changes in gene frequency in small populations because of random processes.

Genetic repatterning : the mechanism by which a new population develops from the early colonisers of a habitat by various genetic mechanisms that break the genetic cohesiveness. This results in a plastic and pliable population that could be moulded into a new species.

Group selection : a selection which aims the extinction of certain populations so that other populations could be propagated. This concept of selection suggests that population is the unit of selection and not the individual.

Hybrid sterility : the sterility of the offsprings of the interspecific crosses.

Interspecific sterility : failure in mating because of the inability of the sperm of one species to reach the egg of another species in animals and that of pollen to reach the ovules in plants.

Kin selection : selection favouring the altruistic behaviour of an individual towards its own relatives or individuals having some of its own gene.

Mousterian industry : the products of the *Homo sapiens neanderthalensis* culture. The mousterian culture continued through to around 35,000 to 40,000 years ago and led to the emergence of fully modern humans *Homo sapiens*.

Niche : the sum total of the ecological requirements of a species.

Olduwan industry : the earliest stone tool industry discovered from Ethiopia dating back to 2.5 million years. They are a collection of extremely crude scrapers, choppers and flakes.

Peripatry : populations living in isolation at the peripheral territory of a parent population.

Post-mating isolating mechanism : the isolating mechanism taking effect after mating.

Pre-mating isolating mechanism : the isolating mechanism taking effect before mating.

Rassenkreis : the mechanism by which a sub-species slowlv evolves and becomes a new species by geographical isolation.

Speciation : formation of new species from parent population.

Stabilising selection : natural selection which maintains a well-adapted condition by eliminating any marked deviations from it (it is also called normalising selection).

Sympatry : individuals belonging to a species living in the same area.

FURTHER READINGS

1) Dodson, E.O. (1985) *Evolution : Process and Product*, Wadsworth Publishing Company, California, USA.
2) Lull, R.S. (1984) *Organic Evolution* (Revised edition), Seema Publications, Delhi.
3) Moody, P.A. (1978) *Introduction to Evolution* (Third edition), Kalyani Publishers, Delhi.
4) Stebbins G.L. Jr. (1968) *Variation and Evolution in Plants*, Oxford and IBH Publishing Co. Calcutta.

Dear Student,

While studying these units you may have found certain portions of the text difficult to comprehend. We wish to know your difficulties and suggestions, in order to improve the course. Therefore, we request you to fill and send us the following questionnaire, which pertains to this block.

QUESTIONNAIRE

LSE-07
Block-4

Enrolment No. | | | | | | | | | | |

1) How many hours did you need for studying the units?

Unit Number					
No. of hours					

2) How many hours (approximately) did you take to do the assignments pertaining to this block?

Assignment Number		
No. of hours		

3) In the following table we have listed 4 kinds of difficulties that we thought you might have come across. Kindly tick (✓) the type of difficulty and give the relevant page number in the appropriate columns.

Page Number	Types of difficulties			
	Presentation is not clear	Language is difficult	Diagram is not clear	Terms are not explained

4) It is possible that you could not attempt some SAQs and TQs.
In the following table are listed the possible difficulties. Kindly tick (✓) the type of difficulty and the relevant unit and question numbers in the appropriate columns.

Unit No.	SAQ No.	TQ No.	Types of difficulties			
			Not clearly posed	Cannot answer on basis of information given	Answer given (at end of Unit) not clear	Answer given is not sufficient

5) Were all the difficult terms included in the glossary. If not, please list in the space given below.

6) Any other suggestion(s)

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To

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