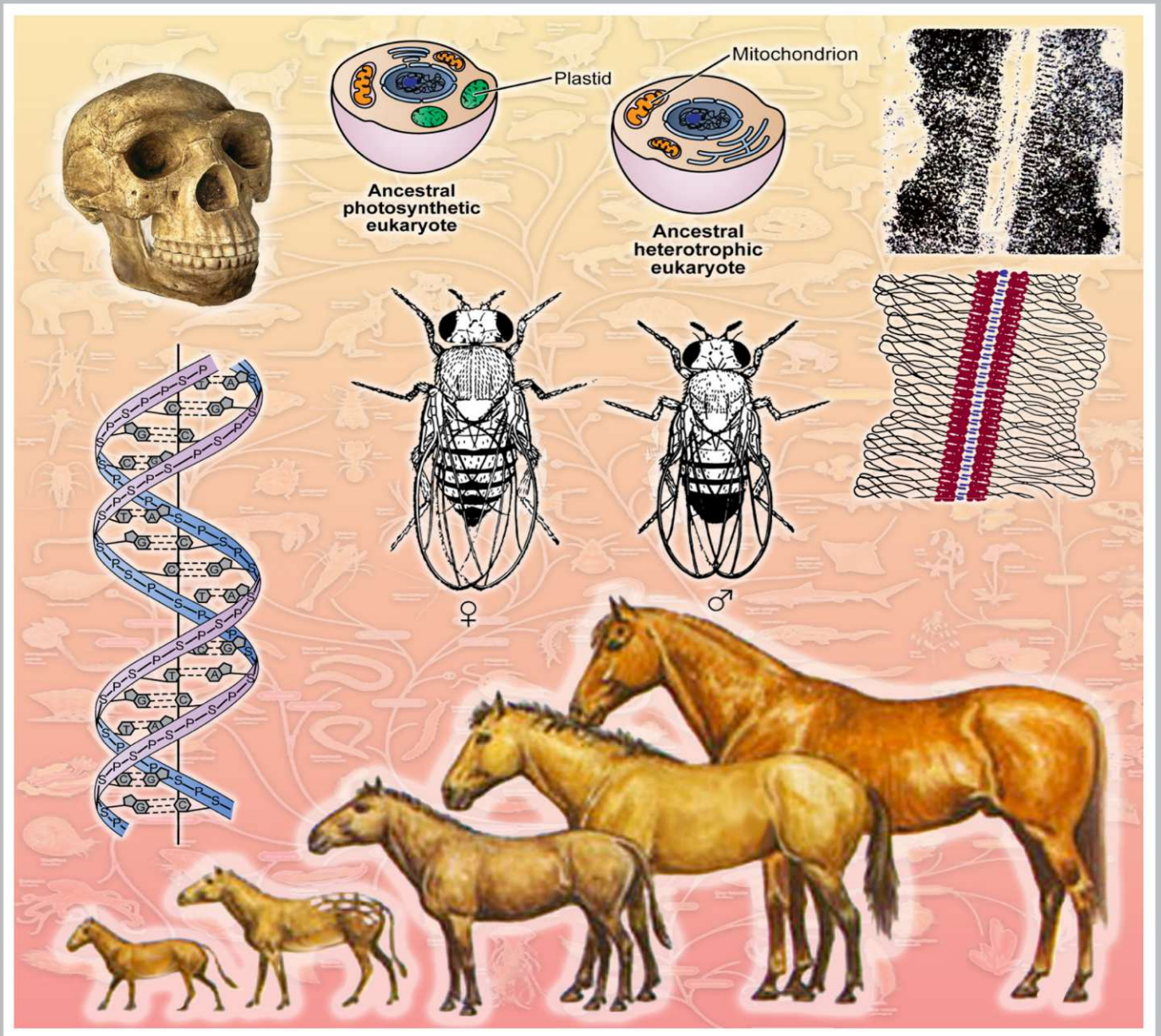


BZYCT-137 GENETICS AND EVOLUTIONARY BIOLOGY



VOLUME 2

EVOLUTIONARY BIOLOGY
Blocks 3 and 4

BZYCT-137 GENETICS AND EVOLUTIONARY BIOLOGY

VOL

2

EVOLUTIONARY BIOLOGY

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EVOLUTIONARY BIOLOGY

Genetics and Evolutionary Biology is a four credit core course and consists of four blocks. Blocks 1 and 2 are concerned with Genetics and Blocks 3 and 4 with Evolution. There are specific reasons as to why we have clubbed these two subjects together into one course. Evolutionary biology cannot be explained without basic understanding of genetics, paleontology and molecular biology.

The general agreement today is that life originated about 4 billion years ago, from spontaneous chemical reaction whose ingredients were molecules of non-living substance. This theory is supported by the remarkable fact that all living organisms on the Earth have a similar composition and basic molecular structure. During the pre-Christian era the existence of different life forms was being related to the supernatural powers. Later with the intellectual insights of Linnaeus and Buffon provided the scientific foundation for the idea that species can evolve. At first Lamarck conceptualized the theory of evolution, although his laws of use and disuse and inheritance of acquired characters could not be verified and therefore, discredited. Later in 1859 the study of evolution was revolutionized by the publication of the 'Origin of Species' by Charles Darwin and his idea of "descent with modification" caught the attention of the contemporary scientific community.

With 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 the theory of natural selection strengthened. At present we have several lines of evidence supporting the concept of organic evolution and theory of natural selection which are discussed later in this course. Fossil record documents the succession of life over an immense period of time—"the geological time scale", which is divided into eras, periods and epochs. The evolution of horses can be traced back from its origin, diversification, extinction and trends with the help of fossil records.

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. The embryonic development of invertebrates and vertebrates shows us that developmental stages of various related organisms resemble each other and suggests "**ontogeny repeats phylogeny**". The evidence from comparative physiology confirms that the same physiological processes occur throughout the living world. With biochemical studies it is well evident that the degree of molecular differentiation and taxonomic separation of species are co-related.

Darwin observed that in nature organisms have enormous potential to reproduce however, only few competitive ones survive. The genetic variations which make organism survive in a given environment are heritable; become adaptations and raise their reproductive efficiency in comparison to others. Thus the essence of natural selection is related to differential reproduction of the species. Mutations and genetic combinations (which you have already studied in the previous blocks) account for 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. Recombination ensures reshuffling of chromosomes thus creating variations.

The reproductive efficiency of genotypes is measured quantitatively as fitness value. The converse of fitness is selection coefficient which is a measure of selection pressure acting on

a genotype. Based on the distribution pattern of a population in an environment the selection can be either directional or disruptive or stabilizing. The various forms of selection pressure are seen in nature like sexual selection and kin selection.

The well accepted biological species concept given by Mayr is that the species are a group of interbreeding natural populations that are reproductively isolated from other such groups and it has an evolutionary capacity. There are sympatric and allopatric modes of speciation which are discussed in detail in the fourth block of this course.

Evolutionary changes occur due to many progressive events which will be discussed in the last two units of this course. One of these processes is reproductive Isolation. It is a mechanism by which individuals are able to maintain the species genotype. It can be divided into pre -mating and post-mating isolating mechanism. Another process of evolution is genetic drift that may operate in small populations bringing about large scale changes in gene frequencies through either Bottleneck or Founder Effect.

The process of evolutionary change has been also found associated with extinction of a species and its environment. The term Pseudo-extinction is introduced which occurs when all the members of the species are extinct but members of daughter species are alive. There are several reasons of species extinction both natural and man-made. Some of the natural causes are change in climate, disease, and spread of invasive species; extermination, and ecological imbalance. Overexploitation, pollution and loss of habitat are man-made causes of extinction. The two types of extinctions are background extinction and mass extinction. Background extinction is a natural regular event in the process of evolution. It is caused by the poor adaptation to the ongoing changes in the environment and the rate of the background extinction is steady over geological time. A mass extinction is a relatively sudden, global decrease in the diversity of life forms within a short period of geological time. Every mass extinction was followed by speciation. There have been five episodes of natural mass extinctions in the fossil record- Ordovician-Silurian, Devonian, Permian-Triassic, Triassic-Jurassic and Cretaceous–Paleogene extinction. The Sixth/Holocene Extinction is also called the Anthropocene, or Age of Man extinction since it is directly linked to human involvement to the changes of the planet. Humans have become the top predator both on land and across the sea. The impacts of a still-avoidable sixth mass extinction would be catastrophic, widespread and, of course, irreversible.

Genetics is the science of heredity that relates to the study of the structure and function of genes and the mechanisms of the transmission from generation to the next. The difference in many a characteristic among organisms are a direct result of differences in their genetic makeup. These differences have resulted into the evolutionary processes.

This course of Genetics and Evolutionary Biology introduces you to the concept of genetics and as to how it has developed unto full-fledged discipline with the Mendel's work on garden pea. Mendel's laws of inheritance give a base to understand genes and their transmission. However there are modifications of Mendelian genetics involving various intragenic and intergenic interactions, they influence and produce a new phenotype.

The experiments of Bateson et al. and of Morgan introduced the concept of linkage. Now we know how to construct linkage maps and their utility in genetic analysis. We also appreciate the cytological and molecular mechanisms of crossing over which is basis of the recombination process that serves as a raw material for natural selection.

The general dogma of genetics states that the **genes are the hereditary material of an organism and they reside in the nucleus of a eukaryotic cell**. However, exception of this general dogma is evident and understood as extra-nuclear, extra chromosomal, cytoplasmic, uniparental or maternal inheritance which involves chloroplast and mitochondria of a cell.

At present new sub-branch of genetics called cytogenetics has emerged which deals with the various structural abnormalities (like deletions, duplications, inversions and translocations) and numerical abnormalities (like polyploidy, trisomy, monosomy etc.) in the chromosomes and their phenotypes. With the use of new technologies, now it is possible to establish the causes of mental retardation, developmental disabilities, birth defects, Down's syndrome, Patau syndrome in our population.

The field of molecular genetics emerged with the discovery of DNA structure which enhanced our present information on genes, their expression and evolutionary selection.

Objectives

After studying the course on Genetics and Evolutionary Biology you should be able to:

- interpret and explain the results of mono-, di- and tri-hybrid crosses based on Mendel's laws of inheritance,
- recognise and describe giving examples the existence and modification of Mendelian genetic analysis,
- illustrate and explain the concepts of linkage, crossing over and genetic mapping,
- discuss extra nuclear genetic systems present in chloroplast and mitochondria of eukaryotic cell and their cooperation with nuclear genetic system,
- describe the techniques employed to study the various aspects of human chromosomes,
- describe the normal human chromosome at morphological and molecular levels,
- recognise and explain the various kinds of structural chromosomal anomalies in humans and their resultant effects,
- discuss nature and structure of genetic material,
- describe the mechanism of recombination and complementation in a bacteriophage,
- describe the various types of mutations that arise in the genetic material and the rates at which they occur,
- distinguish between the spontaneous and induced mutations and list the various mutagenic agents,
- present a brief history of the origin and development of the evolutionary thought from the time of the early Greek philosophers to the present,
- interpret the evolution of adaptation through natural selection based on the Darwinian tenets,
- describe the sources of heritable variations and the manifestations of variability,
- discuss the characteristics of different kind of selective forces,
- discuss the concept of species and modes of speciation,
- discuss the various reproductive isolating mechanisms and their role in speciation, and
- the concept of mass extinction and its causes.

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 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 TQs 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 13, 14 and 15 more than once in order to comprehend them.
- viii) To understand the evolutionary concept a basic understanding of the mechanism of inheritance is necessary. The concepts of genetics would be of great help in understanding the evolutionary biology.
- ix) We have suggested a number of books at the end of the block. These books are available in your study centre. These books will be of help 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.

BZYCT-137
GENETICS AND
EVOLUTIONARY BIOLOGY

Block

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Acknowledgement:

- Prof. Neera Kapoor and Mr. Ajit Kumar, Suggestions for figures and Cover Design.
- Mr. Vikas Kumar, JAT for word processing and CRC preparation.

February, 2021

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ISBN : 978-93-89969-15-3

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Printed and published on behalf of Indira Gandhi National Open University, New Delhi by the Registrar, MPDD, IGNOU.

Printed at:

BLOCK 3: EVOLUTION: CONCEPT, EVIDENCE AND MECHANISMS

The previous two blocks (Volume 1) of this course dealt with the genetics. Now we will deal with the second aspect of this course, namely evolution.

Evolution is defined by Darwin as 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 generation to the next. Although Darwin had no knowledge of genetics, he could predict that variability in a population is responsible for the origin of adaptations. Today, we know that variability is generated continuously in populations by mutations and further enhanced by genetic recombination. These processes, together with the action of natural selection, bring about changes in gene frequencies in population. In this block you will be introduced to the concept of evolution, the evidence of evolution in nature and the mechanism of evolution through natural selection.

This block consists of four units. In Unit 10, you will study to answer the basic question that of how life originated on the Earth. You will study the theories related to the origin of the Universe, the Earth, the cell and evolution of complex life forms from simpler life forms. The unit discusses the Oparin –Haldane theory of chemical evolution and its scientific basis, the theory of biological evolution and the diversity of life forms. You will come to know that there is a general agreement today that life originated about 4 billion years ago, from spontaneous chemical reaction whose ingredients were molecules of non-living substance. This theory is supported by the remarkable fact that all living organisms on the Earth have a similar composition and basic molecular structure.

In Unit 11, 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 biochemical genetics and molecular evolution. The unit discusses the early Greek views on evolution and the implications of the biblical doctrine of 'Genesis' for a theory of evolution. It traces the evolution or unfolding of notions on the origin and diversification of species in the century preceding the celebrated formulation of Darwin's views. It also explains that 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 the relevance of 'creationism' in today's world.

The evolution is a time taking process and it cannot be repeated in a laboratory. Therefore, the evolutionary evidences found in nature are of great importance to understand the process of evolution. In Unit 12, the evidence of evolution will be described in detail. These evidences include the geological time records, biogeography, comparative anatomy, comparative embryology, comparative physiology and biochemistry. You will understand how the knowledge of fossils on the earth's crust serves as strong evidence of organic evolution. You will also study the link between geographical distribution of various species of contemporary plants and animals to the course of evolution. This unit also introduces the concepts of homology and analogy with their significance in correlating structure to function in light of evolution. It ends with a description of the contributions of developmental biology to the evolutionary argument, leading to generalizations such as Haeckel's and von Baer's laws and explains evolution from the stand point of physiology and biochemistry.

In Unit 13, you will study that the evolution is a simple fact of nature and the Darwinian concept of evolution through "natural selection" has stood the test of time. This unit describes the details of the mechanism of evolutionary change through natural selection. It 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 introduce the concept of Darwinian fitness and its relation to the reproductive success of organisms. Finally you will be made 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. Thus, this unit will explain the basis of natural selection and how it works under different environmental conditions.

In the next block we shall proceed to a discussion on concept of species, mode of speciation, concept of mass extinction and other modes of evolution like a genetic drift, mutation and isolation.

Objectives

After reading this block you should be able to:

- present a brief history of the origin of the universe, the Earth and the evolution of organic life from inorganic substances,
- appreciate a brief history of origin and development of evolutionary thought from the time of early Greek philosophers up-to the present situation,
- document the fact of occurrence of evolution by lining up evidence available from the various disciplines of biology, and
- interpret the Darwinian concept of evolution by natural selection and its implications under different environmental conditions.

UNIT 10

MAJOR EVENTS IN HISTORY OF LIFE

Structure

10.1	Introduction Objectives	10.5	Evolution of Living Organisms Origin of Self Replicating Genetic Material Origin of Procaryotes Origin of Eukaryotes The Origin of Multicellularity
10.2	Origin of the Universe The Expanding Universe Closing in on Creation (Big Bang Theory)	10.6	Geological Time Scale
10.3	Origin of Solar System Origin of Sun Origin of Planets Origin of Earth	10.7	Summary
10.4	Biochemical Origin of Life Oparin-Haldane Theory of Origin of Life Organic Molecules or Prebiotic Molecules	10.8	Terminal Questions
		10.9	Answers

10.1 INTRODUCTION

How life originated on the earth with origin of universe. You know that the universe has a structure. Seen on a large distance scale, it is made up of superclusters which are groups of large clusters. Clusters contain anything from a few, to a few thousand galaxies. The galaxies are, in turn, made up of stars and clouds of gas and dust. Our own star, the Sun, is an ordinary star in the Milky Way Galaxy, one among 100 billion stars. It is surrounded by nine planets including the Earth, that move around it. While reading all this, did you not wonder how we came to know about the structure of the universe in such detail? Because, all we can see by our unaided eyes are the few thousand stars scattered in the sky.

This unit proposes to take you back to a distant past when there was no life on our planet and helps you to imagine how life originated and how plants and animals came into existence. Naturally, in discussing things which must have happened billions of years ago, there is a certain amount of guess work and uncertainty. But the guess or conjecture has to conform to a good deal of available evidence as well as to basic laws of physical sciences. This creates a certain amount of confidence in the suggested theory of the origin of life on our planet. Thus, there is general agreement today that **life originated about 4 billion years ago, from spontaneous chemical reaction whose ingredients were molecules of non-living substance**. This theory is supported by the remarkable fact that all living organisms on the Earth have a similar composition and basic molecular structure.

Objectives

After studying this unit you should be able to:

- ❖ describe the origin and evolution of the universe alongwith the supporting evidence, if any,
- ❖ describe the various theories regarding the origin of life, and Pasteur's contribution in this context,
- ❖ explain the theory of chemical evolution and its scientific basis, and
- ❖ discuss the theory of biological evolution and the diversity of life forms.

10.2 ORIGIN OF THE UNIVERSE

So far you have studied how information about the universe is collected. It is stored mainly in the form of photographs of the cosmic objects, and spectra of their light. The other radiations coming in from space are recorded in various ways. This information is analysed and interpreted to construct theories about the universe and the objects that constitute it.

The hypotheses and theories about the universe and its constituents are always open to change in the light of new discoveries. Quite often a given theory may turn out to be wrong. Observed data may also be misinterpreted. In fact, a given theory may never agree hundred percent with the observations about the universe. A good scientific theory about the universe is one that is extremely close to all relevant observation. At the other extreme are tentative and speculative theories. We will now present some theories and concepts which represent the best possible understanding of stars, galaxies and the universe as a whole. Let us see what can be known about stars on the basis of the information obtained.

10.2.1 The Expanding Universe

As of today, a huge optical telescope called the Hubble space telescope, after Edwin Hubble is in orbit around the earth. Several large telescope are stationed in USA and several european countries and in India the major optical observatories are located at various places like Nainital, Udaipur, Hyderabad

and Kodaikanal. Hubble's observations have proved the existence of galaxies. After mapping as many galaxies as could be seen by the telescopes then available, he turned his attention to the motion of galaxies. He was motivated to do this by a puzzling report of V.M. Slipher, an American astronomer. He had discovered in 1912 that many of the faint nebulae were moving away from the Earth at very great speeds. Their spectral lines exhibited large shifts towards the red end (what is called as red shift). This seemed peculiar because stars in the Milky Way Galaxy move at much smaller speeds, some moving away from us while others moving towards us. Slipher had made these observations a decade before galaxies were discovered. Then it was thought that the nebulae were objects in our own galaxy. He did not know what to make of this observations.

But as Hubble knew that these nebulae were galaxies, he began a systematic study of the relation between their speeds and their distances along with his colleague M.L. Humason. What they found was very interesting. To put it simply, his observations showed that;

- i) all galaxies were moving away from us;
- ii) the farther away a galaxy was from our Galaxy, the greater was the speed at which it moved away.

Hubble's discovery put forth the picture of an expanding universe. But if all the galaxies are moving away from us, are we at the centre of the Universe? No. If we were situated in another galaxy, even then the other galaxies would seem to move away from us. You can understand this picture of an expanding universe if you study Fig. 10.1 and also perform a simple activity.

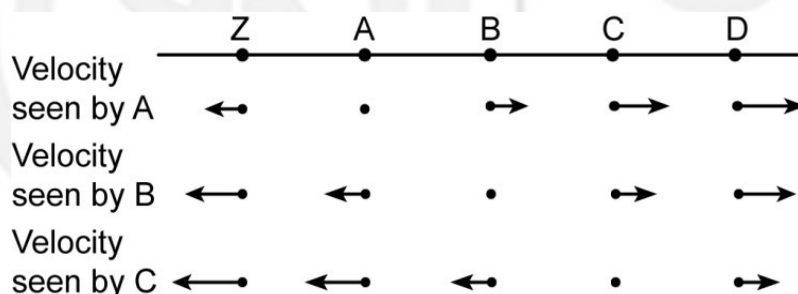


Fig. 10.1: A string of equally spaced galaxies Z, A, B, C, etc. are shown. Their speeds as measured from A or B or C are indicated by the lengths of arrows: The directions of arrows indicate the directions in which the galaxies would appear to move. Seen from any galaxy, any other galaxy would appear to move away with a speed proportional to the distance between them.

10.2.2 Closing in on Creation (Big Bang Theory)

The most important current theory for the origin of the universe is the **Big Bang** theory. According to this theory, the universe started with a huge explosion (Fig. 10.2). It was not an explosion like the ones with which we are familiar, which start from a definite centre and spread out. It was an explosion which occurred everywhere in space at the same time. It filled all space from the beginning with every particle of matter rushing apart from every other particle. This was not a burst of matter into space but rather an explosion of

space itself. Every particle of matter rushed away from every other particle. It is so far impossible to 'picture' the first moment of 'creation' of the universe.

Positrons: Positron is the antiparticle of electron. It has an electric charge of + i.e, spin of $\frac{1}{2}$ and same mass as that of electron. When it collides with an electron, annihilation occurs.

One-hundredth of a second after the creation of the universe is the earliest time about which scientists can speak with any confidence. At this instant, the temperature of the universe was about a hundred billion degrees centigrade. This is much hotter than in the centre of even the hottest star. At such temperatures none of the components of ordinary matter, atoms, molecules, or even nuclei of atoms, could have held together. Instead, the matter rushing apart in the explosion consisted of various types of elementary particles. The particles most abundant in the early universe were the electrons, positrons and neutrinos. There were also some protons and neutrons. The rest of the universe was filled with energy. It was a kind of a cosmic soup.

Neutrino: Neutrino is a subatomic particle, very similar to an electron, but has no electrical charge and mass equivalent to zero. They are incredibly difficult to detect as they have very little interaction with matter.

As the explosion continued, matter and energy rushed, apart, the universe expanded and the temperatures dropped, reaching 30 billion (3×10^{10}) degrees centigrade after about one-tenth of a second; 10 billion degrees after about one second; and 3 billion degrees after about fourteen seconds. At the end of the first three minutes, the universe became cool enough (about 1 billion °C). Protons and neutrons begin to form simple nuclei. The first to be formed was the nucleus of heavy hydrogen which was made up of one proton and one neutron. There were also helium nuclei made of two protons and two neutrons. It was still too hot for atoms to hold together, they were ripped apart as soon as they were created. This matter continued to rush apart, becoming steadily cooler and less dense.

Many thousands of years later, it became cool enough for electrons to join with nuclei to form atoms of hydrogen and helium. Soon, the resulting gas began to form clumps under the influence of gravitation. These clumps ultimately condensed to form the galaxies and stars of the present-day universe, almost 5 billion years after the Big Bang.

Quasar: A quasar is an extremely luminous active galactic nucleus (AGN) in which a super massive black hole is surrounded by a gaseous accretion disc. This is also called as a quasi stellar object (QSO).

There is another theory about the origin of the universe known as the **steady state** theory was proposed by Siger of Brabant in the 13th century. This theory holds that the universe has always been just about the same as it is now. As it expands, new matter is created continuously to fill up the gaps between the galaxies. Thus, the problem of the origin and early moments of the universe is banished: there was no early universe.

However, the Big Bang theory is the most favoured by the astronomers and astrophysicists. Why is it so? This is due to the evidence based on observations which lend support to the 'Big Bang' universe.

Evidence Favouring the Big Bang

One piece of evidence comes from the expansion of the universe which we have already described. The expanding universe suggests that the matter was packed much more densely in the early stages of the universe. The proof for this also comes from the distant objects quasars. When we 'look' at quasars situated 6 to 8 billion light years away, we are looking at them as they existed then. If the universe were more dense in that epoch, we should be able to see some evidence of that density in the quasars. We do see such high density among the quasar.

Another substantial bit of evidence for the Big Bang theory comes from the **cosmic background radiation**. For many years the astronomers believed that if there was a cosmic explosion long ago, radiation from that event should still exist within the universe. This radiation may be weak, it may have lost its energy due to the expansion and cooling of the universe, but it should exist. Radio-astronomers have, indeed, discovered faint signals-a constantly present background radio noise that pervades all space. Calculations done by astrophysicists show that this radiation, called the cosmic microwave background radiation, is a relic of the ancient past when the universe was in its first throes (agility) of creation in the Big Bang.

An additional discovery made by astronomers during the past is that of the **primordial abundance of elements**, i.e. the elements hydrogen and helium first created in the aftermath of creation are found to be most abundant in the universe. By examining the light coming from the various parts of the universe, astronomers have found out that, out of every 100 atoms, almost 93 are hydrogen atoms and seven are helium atoms. Elements heavier than helium are present in traces only. This suggests that the universe started out with a Big Bang from a very hot and dense state and quickly cooled as it expanded. The hot and dense conditions lasted long enough for some hydrogen to fuse into helium. But they did not last long to allow other heavier elements to form in significant amounts. These were made much later in the interior of massive stars.

In conclusion, we find ourselves amidst an expanding universe which throws up puzzles with amazing regularity. With each question answered many more questions arise. For example, an important question today is about the future of the universe. Will it go on expanding like this? Or, will its expansion stop some day? What will happen then? Will the universe remain as it were then or will it start contracting? We also find ourselves amidst an explosion of ideas and techniques being applied to study the universe. In this unit we have tried to give you a brief glimpse of the enigmatic nature of the universe and our undaunted efforts to understand it. Don't you feel that this brief insight was worthwhile? We end this section with a quote of Edwin Hubble from his last paper:

"From our home on Earth we look out into distances and strive to imagine the sort of world into which we are born. Today we have reached far out into space. Our immediate neighbourhood we know rather intimately. But with increasing distance our knowledge fades until at the last dim horizon we search among ghostly errors of observations for landmarks that are scarcely more substantial. The search will continue. The urge is older than history. It is not satisfied and it will not be suppressed".

SAQ 1

Which three among the following observations support the Big Bang theory of the origin of the universe? Tick (✓) the correct answer:

- i) Stellar spectra show the shift as well as red shift in the spectral lines.
- ii) The elements hydrogen and helium are the most abundant in cosmic matter with other heavier elements occurring in traces only.

- iii) The spectra of light from galaxies shows a red shift suggesting that the universe is expanding.
- iv) There is a cosmic radiation pervading the entire space.

10.3 ORIGIN OF SOLAR SYSTEM

Kuiper Belt: It is a circumstellar disc in the outer Solar System extending from the orbit of Neptune. (at 30 AU) to approximately 50 AU from the Sun.

Sednoid: A sednoid is a trans-Neptunian object with a perihelion well beyond the Kuiper cliff at 47.8 AU. Only 3 objects are known from this population, but it is suspected that there are many more.

The Solar System is gravitationally bound system of Sun along with all the objects that orbit around it. The Sun is orbited by planets, asteroids, comets and other things. A planet is a large object such as Jupiter or Earth that orbits a star. Planets are smaller than stars, and they do not produce light. A star and everything which orbits it are called a star system. There are eight planets in our Solar system. The solar system consists of a medium size star, the Sun along with eight planets orbiting it. There are two types of planets. The four planets nearest to the Sun are **Mercury, Venus, Earth, and Mars**. They are called as **inner planets** or terrestrial planets. They are comparatively smaller compared to other four and composed of mainly metals and rocks. The other four planets, **Jupiter, Saturn, Uranus and Neptune** are **giant planets** substantially bigger than terrestrial planets and are far away from the Sun. the two largest planets, Jupiter and Saturn are gas giants composed of hydrogen and helium mainly whereas the two other outermost plants, Uranus and Neptune are ice giants composed of substances with relatively high melting points compared with hydrogen and helium called volatiles, such as water, ammonia and methane. All the eight planets have almost circular orbits that lie within a nearly flat disc called the ecliptic. The Solar System also contains smaller objects. Between the orbits of Mars and Jupiter lies the asteroid belt which mostly contains rock and metal. Beyond Neptune's orbit is the **Kuiper belt** and scattered disc which is composed of trans-Neptunian objects, mostly ices, and beyond them lies as newly discovered population of **sednoids** which are also trans-Nuption objects. Within these populations, some objects are large enough, have a round structure under their own gravity. There is considerable disagreement as to how many such objects are present. These objects are categorized as dwarf planets. The dwarf planets include the asteroid Ceres, and the trans-Neptunian objects like Pluto and Eris. A number of other small populations like comets, centaurs and inter planetary dust clouds, freely travel between regions.

10.3.1 Origin of Sun

Billions of years ago, conditions were near perfect for the formation of earth and the other planets in our Solar System. 5.6 billion year ago a huge cloud of dust and gas floated in one of the spiral arms of the Milky Way galaxy. This cloud, called a nebula by astronomers was made up of dust, hydrogen and helium with a small percentage of heavier atoms. These heavier atoms had been formed earlier in the history of the Universe when other stars collided and perished. This cloud/nebula began to contract and condensed collapsing on itself. The atoms once separated began to jostle each other generating tremendous heat. With the rising heat atoms collided more frequently and more violently. Eventually they reached a temperature at which the protons at the centers of the atoms began to fuse by a process called nuclear fusion. Due to nuclear fusion a tiny bit of matter transformed into a whole lot of energy and a star was born. In this way our Sun came into existence.

10.3.2 Origin of Planets

The planets were born from the cloud of gases and dust that orbited the new stars. The material in the nebula not absorbed into the Sun swirled around it in the form of a flat disk of dust and gas by the Sun's gravity. This disk is called an **accretion disk**. This material accumulated in the disk by sticking together or accretion. Each planet began as a microscopic grain of the dust in the accretion disk. The atoms and molecules began to stick together or accrete into larger particles. By gentle collisions some grains built up into balls and then into much bigger objects, more than a mile in diameter called **planetesimals**. These objects were big enough to attract others by gravity rather than by chance. When collisions of planetesimals occurred at high speeds, they shattered the objects. But when impacts were not strong or gentle, the objects combined and increased in the size. For about 10-100 million years these protoplanets orbited the Sun in an egg-shaped orbits that helped more frequent collisions. Protoplanets collided, combined and evolved for a dramatic period of time. When this stage was over there remained eight stable planets that had swept their orbits clean. A planet is defined as a body that orbits the Sun, is massive enough for its own gravity to make it spherical and has cleaned its neighborhood of smaller objects. In 2007, researchers at the University of California determined that our Solar System was fully formed at 4.568 billion years ago. They did this by determining the age of stony materials from the asteroid belt. The Sun released energy and particles in a steady stream, called as stellar winds. These winds proved so strong that they blew off most of the gases of the four planets closest to the Sun leaving them smaller with their rocks and metals only. That's why they are called as rocky or terrestrial planets. The other four planets were so far away from the Sun that its winds could not blow away their ice and gases. They remained gaseous with a small rocky core. Between the inner and outer planets lies an area filled with millions of asteroids which are small rocky, icy or metallic bodies left over during the formation of the Solar System. No planet formed in this area. Astronomers concluded that Jupiter's gravity influenced this region so much that no large planet could take shape. Jupiter is eleven times bigger than earth and more than twice as big as all the other planets combined. It is almost large enough to have become a star. Among the four rocky planets Mercury is the smallest, about two-fifths of the size of Earth.

10.3.3 Origin of Earth

Earth and Venus are of almost same size whereas the Mars is about half in size of Earth. Astronomers speculate that a smaller objects must have hit Mercury, vaporizing its crust and leaving only the iron core.

When the rocky planets were formed, they were largely molten rocks. Over hundreds of millions of years they cooled down slowly and slowly. Mercury and Mars due to their small size solidified early and became rigid.

Earth, along with the other planets, is believed to have been born 4.5 billion years ago as a solidified cloud of dust and gases left over from the creation of the Sun. For perhaps 500 million years, the interior of earth stayed solid and relatively cool, perhaps 2,000°F. The main ingredients, according to the best

available evidence, were iron and silicates, with small amounts of other elements, some of them radioactive. Earth became molten due to generation of huge amount of heat by collisions. As millions of years passed, energy released by radioactive decay mostly of uranium, thorium, and potassium gradually heated the earth, melting some of its constituents. The iron melted before the silicates and being heavier sank toward the center due to gravitational pull and formed the inner core while the outer core was molten with lighter elements like aluminum and silicates (Fig. 10.2). Around it, a thin but fairly stable crust of solid rock formed as Earth cooled. Depressions in the crust formed natural basins.

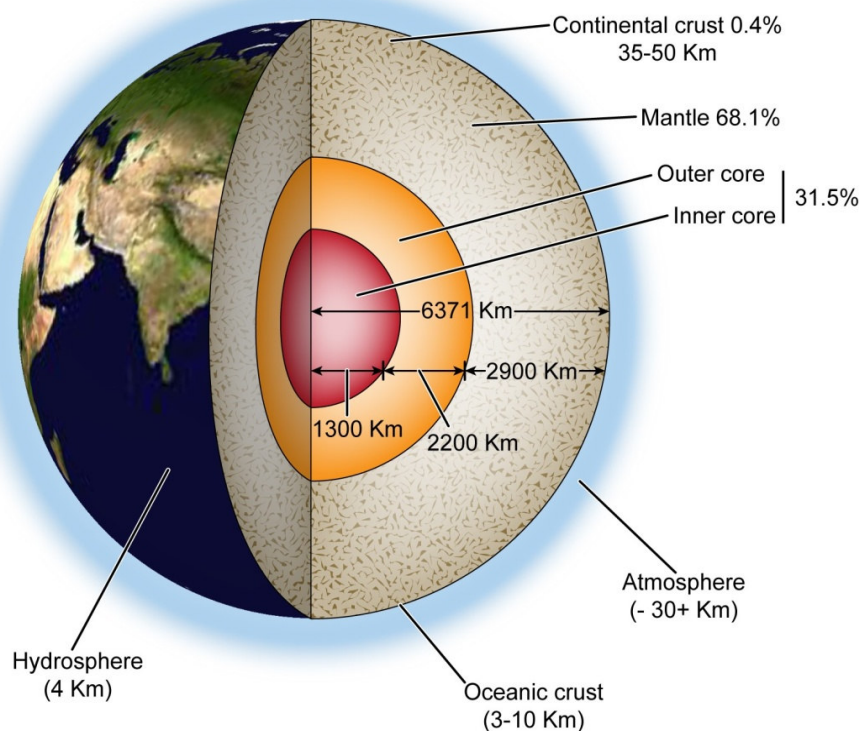


Fig. 10.2: A section through Earth.

Primary atmosphere of earth had hydrogen and helium. These light gases were replaced with the growth and development of solar system which exerted its effect on earth atmosphere.

Secondary atmosphere developed between 4.2 to 3.8 Billion years ago due to gases liberated by volcanoes and strike of meteorite and comets on earth. This atmosphere had water vapours, carbon dioxide, methane. The green house gases (CO_2 and methane) prevented cold conditions as they provided warmer conditions. The atmosphere in secondary atmosphere was reducing as evidenced in river deposits present in South Africa (3 Billion years ago). It has compounds (FeS , ZnS) which are highly unstable in the presence of oxygen. These deposits also indicate unavailability of oxygen at that time.

Tertiary and present atmosphere originated 2.3 billion years ago and contains nitrogen and oxygen. Ozone layer was formed during this period with the irradiation of oxygen. Presence of optimal level of oxygen helped the evolution of life on the earth.

SAQ 2

- a) Fill in the blanks:
- i) A huge cloud of dust and gas condensed to form
 - ii) Earth came into existence billion years ago.
 - iii) When the earth temperature started falling, the earth metallic core gave birth to
 - iv) Cyanobacteria helped to supply for the air.
 - v) The secondary atmosphere of the earth was as evidenced in river deposits present in South Africa.
- b) Answer the following:
- i) Name the eight planets of solar system.
 - ii) Which compounds were highly unstable in the presence of oxygen?

10.4 BIOCHEMICAL ORIGIN OF LIFE

The question of how life came into being in the first place still remained unanswered. To find an answer of this question means looking back billions of years in time and trying to imagine what the condition on the earth could have been like when life first appeared.

The origin of life on the earth was possible due to certain conditions:

- a) Origin of solar system including Sun.
- b) Chemical diversity (hydrogen, nitrogen, sulphur and phosphorus) including carbon-containing molecules.
- c) Presence of water.
- d) Cooling of earth from original 5000-6000° C.
- e) Availability of energy provided by solar radiations, Cosmic rays, heat generated by volcanic eruptions, layered clays etc. on primitive earth.
- f) Presence of reducing atmosphere.

10.4.1 Oparin-Haldane Theory of Origin of Life

Alexander I Oparin, a Russian Biochemist and J.B.S. Haldane, a British Biologist proposed in 1920 that the life originated on early earth through physico-chemical processes of atoms combining to form molecules. Molecules in turn reacted to produce inorganic and organic compounds. Organic compounds interacted to produce all types of macromolecules which later on organized themselves to form the first living system or cell. According to this theory, life originated on the earth spontaneously from non-living matters.

Inorganic compounds were formed first followed by organic compounds in accordance with ever-changing environmental conditions. This is called chemical evolution which cannot occur under present environmental conditions on the earth. Conditions suitable for origin of life existed only on the primitive earth.

The Chemical Evolution of life can be divided into 4 phases:

- (i) Atomic Phase
- (ii) Formation of Inorganic molecules
- (iii) Formation of simple Organic molecules (Monomers) and
- (iv) Formation of complex organic molecules (macromolecules).

1. Atomic Phase

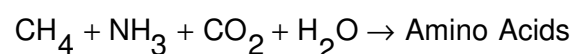
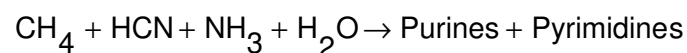
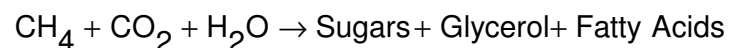
Early earth was rich in atoms like hydrogen, oxygen, carbon, nitrogen, sulphur, phosphorus, etc. which were essential for the formation of protoplasm. Atoms were segregated in three concentric masses according to their weights. The heaviest atoms of iron, nickel, copper were concentrated in the centre of the earth. Medium weight atoms of sodium, sulphur, phosphorus, potassium, silicon, magnesium, aluminium, chlorine, fluorine etc. were concentrated in the core of the earth. The lightest atoms of nitrogen, hydrogen, oxygen, carbon etc. were prevalent in the primitive atmosphere.

2. Formation of Inorganic molecules

Free atoms combined to form simple inorganic molecules like Hydrogen (H_2), Nitrogen (N_2), water vapour (H_2O), Methane (CH_4), Carbon dioxide (CO_2) and Ammonia (NH_3). Hydrogen atoms were most abundant and most reactive in primitive atmosphere. They reacted with all oxygen atoms to form water thereby leaving no free oxygen. So, the primitive atmosphere was reducing atmosphere (without free oxygen) unlike the present oxidizing atmosphere (with free oxygen). Hydrogen atoms also combined with nitrogen and formed ammonia (NH_3). So water and ammonia were probably the first molecules of primitive earth.

3. Formation of Simple Organic Molecules (Monomers)

Early inorganic molecules interacted to produce simple organic molecules like simple sugars (glucose, ribose, deoxyribose etc.), nitrogenous bases (purines and pyrimidines), amino acids, glycerol and fatty acids.



When it rained and the water rushed down, it dissolved and carried away salts and minerals with it and ultimately accumulated in the form of oceans. The ancient oceanic thus contained large amounts of dissolved NH_3 , CH_4 nitrides, carbides, various gases and elements. The source of energy required for such

chemical reaction might be either solar radiations such as UV light, X-rays, energy from electrical discharges like lightning, high energy radiations or energy from unstable isotopes on the primitive earth. There was no ozone layer in the atmosphere.

A soup-like broth of chemicals called as Prebiotic Soup or Hot Dilute Soup formed in the oceans of early earth from which living cells are believed to have originated. Now the stage was set for combination of various chemical elements. Once the organic molecules formed they accumulated in the water because their degradation was extremely slow in the absence of any life or enzyme catalysts. Absence of oxygen during this period was also helpful to keep the synthesized organic molecules without being oxidized and degraded into smaller molecules.

Experimental Evidence for Biochemical origin of Life was provided by Miller in 1953 at the University of Chicago. He demonstrated clearly that UV radiation or electrical discharges or heat or a combination of these can produce complex organic compounds from a mixture of methane, ammonia, water and hydrogen. The ratio of methane, ammonia and hydrogen in Miller's experiment was found to be in the ratio of 2:1:2 (Fig. 10.3).

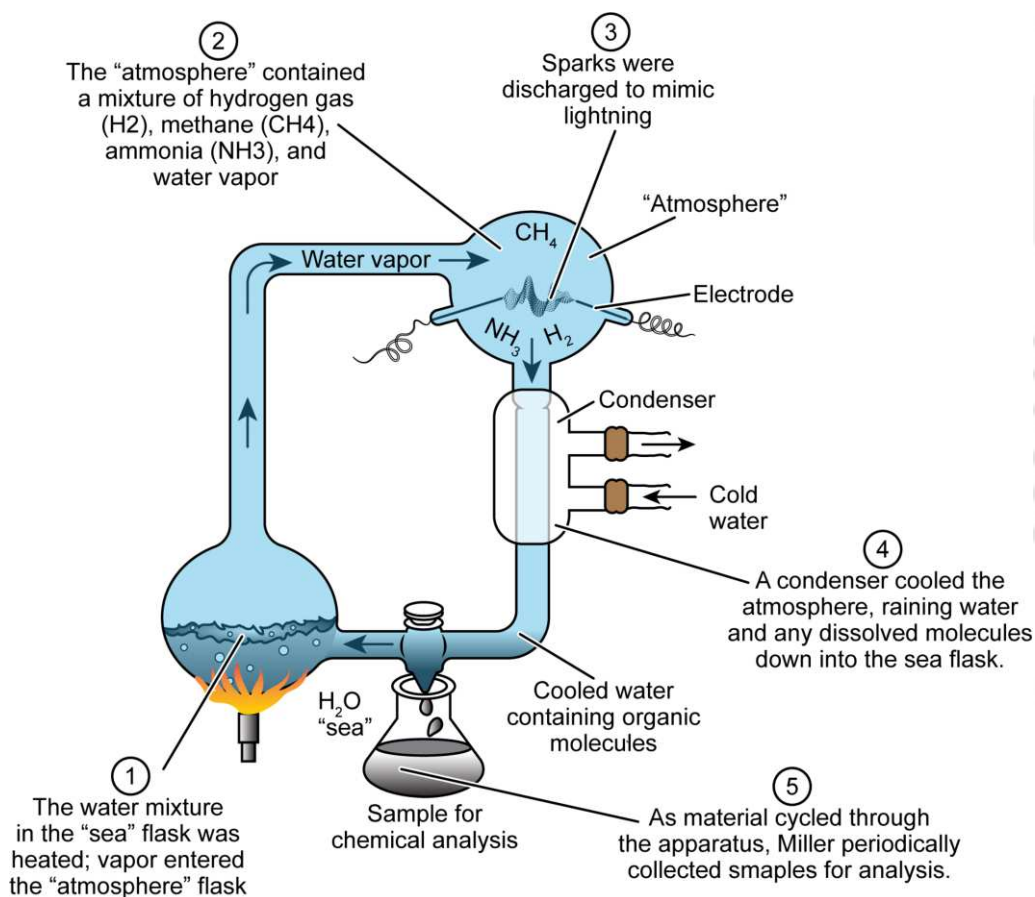


Fig. 10.3: Stanley Miller experiment to show abiotic synthesis of organic molecules on early earth.

Miller circulated four gases methane, ammonia, hydrogen and water vapour in an air tight apparatus and sparks were discharged from electrodes at $800^{\circ}C$ to mimic the lightening. He passed the mixture through a condenser. He circulated the gases continuously for one week and then analysed the chemical composition of the liquid inside the apparatus and found that a large

number of simple organic compounds including some amino acids such as alanine, glycine and aspartic acids were present in the reaction mixture. Other substances like urea, hydrogen cyanide, formaldehyde, lactic acid and acetic acid were also present. In another experiment Miller circulated the mixture of the gases in the same way but he did not discharge the electrical spark. He failed to get the significant yield of organic compounds.

Later on a number of investigators synthesized a great variety of organic compounds including purines, pyrimidines and simple sugars etc. It is believed that the essential 'building blocks such as amino acids, purines, pyrimidines, nucleotides of living organisms could have formed in this way on the primitive earth.

Miller performed this experiment to test whether organic molecules could be synthesized in a reducing environment. It is still debatable whether the early environment on earth was reducing environment. It is still debatable whether the early environment on earth was reducing because it contained nitrogen and carbon which make it neither reducing nor oxidizing.

4. Formation of Complex Organic Molecules (Macromolecules)

A variety of amino acids, simple sugars, purines and pyrimidine bases, fatty acids, hydrocarbons and other organic compounds accumulated in the ancient seas. Solar energy, electrical discharge, lightning, ATP and polyphosphates might have provided the source of energy for polymerization reactions of organic synthesis.

S.W. Fox demonstrated that if a dry mixture of amino acids is heated, polypeptide molecules are synthesized. Polypeptides can unite to produce different kinds of proteins. Likewise, simple sugars could produce polysaccharides and fatty acids can be converted to fats. Finally sugars, nitrogenous bases and phosphates combined into nucleotides which polymerized into nucleic acids in the ancient oceans.

Sugar + Sugar $\longrightarrow$ Polysaccharides

Fatty Acides + Glycerol $\longrightarrow$ Fats

Aminoacids + Aminoacids $\longrightarrow$ Proteins

Nitrogenous Bases + Pentose Sugars + Phosphates $\longrightarrow$ Nucleotides

Nucleotides + Nucleotides $\longrightarrow$ Nucleic acids

10.4.2 Organic Molecules or Prebiotic Molecules

The fossilized evidences of photosynthetic bacteria suggest that it took half a billion years to form primitive cells from macromolecules. It is speculated that prebionts (non-living aggregates) which contained carbohydrates, proteins, lipids and nucleic acids formed (coacervates droplets surrounded by film of water). Coacervates can selectively absorb water molecules. They can divide and increase in number. Coacervates were able to perform primitive metabolic functions like synthesis and hydrolysis of starch. Coacervates appear to be boundary between non-living and living.

Oparin proposed that early prebiotic cell structures were protenoid microspheres. They had double layered. Outer membrane in which organic macromolecules were trapped. Microsphere works like a primitive cell. Some of the protenoid (protein like molecules made of branched chain amino acids) performed the functions of enzymes. They were able to make small microspheres by budding.

Sydney Fox was able to obtain microspheres from Protenoids. These molecules can be synthesized from a reaction of amino acids at 180°C when boiling water containing protenoid is allowed to cool slowly can form microspheres. Protenoid microspheres have double layer membrane but do not contain lipids.

Another hypothesis is the formation of Protobionts, abiotically produced structures with primitive lipid bilayer membrane. Protobionts can also be called as **liposomes**. These (liposomes) can form in water in the presence of lipids and organic macromolecules. The outer membrane of liposomes can give rise to small liposomes and metabolic reactions can occur depending upon the organic molecules present in it (see Fig. 10.4).

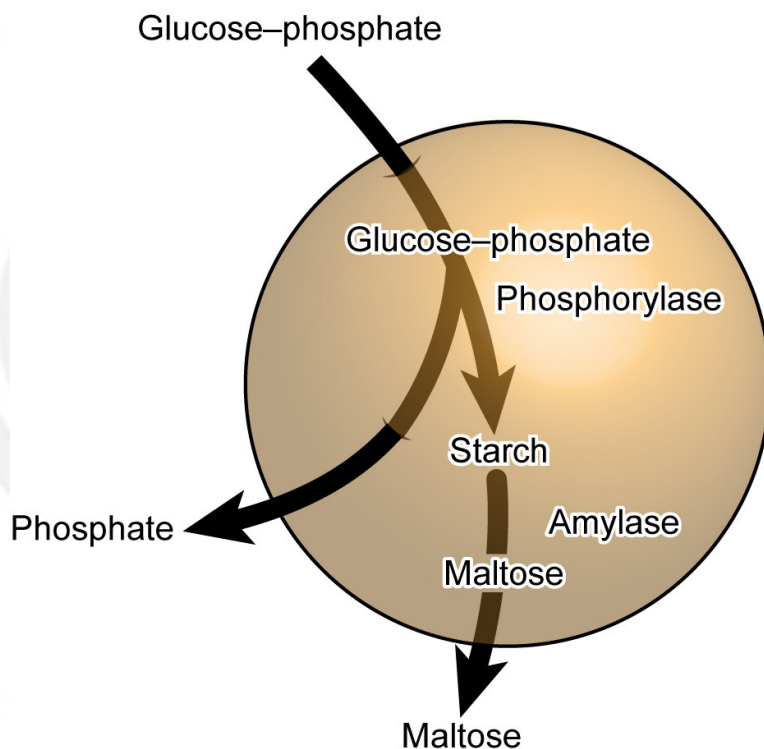


Fig. 10.4: Simple metabolism: Simple metabolic reaction and export of products by liposome. (Role of phosphatase and amylase enzymes shown).

The hypotheses described above are speculative. They may represent a necessary structure because the origin of **protocell** requires separation of complex organic molecules from the hot watery soup. These models may represent an important step towards origin of life.

SAQ 3

Elaborate upon four phases of chemical evolution of life.

10.5 EVOLUTION OF LIVING ORGANISMS

10.5.1 Origin of Self Replicating Genetic Material

As described earlier, the primitive earth which was hot dilute soup formed complex organic substances as a product of condensation and polymerization. For the origin of life at least three conditions were essential. (i) formation of polymers that can make copies of themselves steady supply of replicators or self producing molecules (ii) Copying of these replicators must have been subject to error through mutation and (iii) continuous supply of free energy for self replicators and partial isolation from general environment.

The high temperature of early earth might have fulfilled the requirement of mutation. Self replications might have created variants by mistake. Nucleic acids appears to be the earlier replicators (Fig. 10.5). The origin of primitive living cell is supported by the evidence for the synthesis of Coacervates, Protoid microspheres and Protobionts like liposomes in the laboratory. The hypothesis was further strengthened on the basis of origin of RNA which acted as enzyme and genetic material, DNA originated. The evidence suggests RNA molecule originated first. RNA could reproduce itself and has the capability to function as enzyme (Ribozyme).

Copying error may produce stable self replicating molecule. In the existing organisms RNA has multifunctional nature and diversity of roles as evidenced in **translation** by RNA primers in DNA replication, RNA interference, splicing and RNA processing etc. These functions might have played key roles in the primitive evolutionary process.

Nucleotide sequences of primitive RNA (stored information) were capable of coding polypeptides. The ancient RNA were carried by protobionts. Protobionts could split and pass the information to daughter cells. Possibly, natural selection would have advantageous generation.

The possible reasons for the replacement of RNA to DNA are the following:

- i) DNA is stable carrier of genetic information because of lower reactivity.
- ii) It was not possible for RNA for rapid replication as required in complex organisms. RNA could be damaged by chemicals.

The possible development of DNA occurred on RNA as template to assemble DNA nucleotide. The necessity for accurate replications of DNA and stable repository for genetic information led to the development of double stranded DNA. The genetic code evolved due to selection pressure between RNA and DNA.

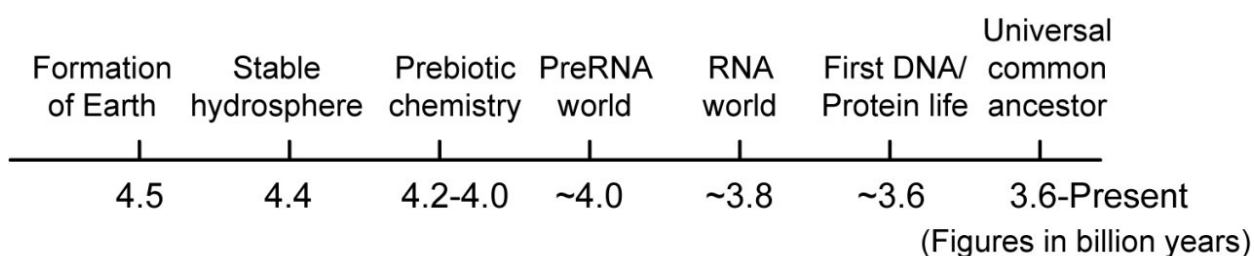


Fig. 10.5: Steps in the origin of Life.

10.5.1 Origin of Prokaryotes

As described earlier, evidences support the change over of earth atmosphere from primary (which lacked oxygen) to secondary (small amount of oxygen) in the history of life.

The first primitive Anaerobic living cell (Prokaryotes) can be thought to have originated in the following way.

1. Formation of primitive membrane bound vesicles having short chain molecules.
2. RNA acted as hereditary material and ribozyme.
3. Simple metabolic machinery led to simple biochemical reactions in the protocell or protobionts.
4. Natural selection played the role for further evolution of protocell.

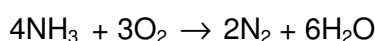
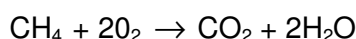
Prokaryotes are predicted to have originated 3.5 to 3.8 Billion years ago which lacked nuclear membrane and organelles. The atmosphere was anaerobic due to absence of free oxygen in atmosphere. These prokaryotes don't have nuclear membrane, cytoskeleton or complex organelles. They divided by binary fission.

Earliest prokaryotes utilized energy produced by fermentation of organic molecules of the sea broth in oxygen free (reducing) atmosphere. They required readymade organic material as food, as a result they were **Heterotrophs**.

Due to rapid increase in the number of heterotrophs the nutrient from sea water started depleting and exhausted gradually. This led to the evolution of autotrophs. **Autotrophs** were capable of producing their own organic molecules by chemosynthesis or photosynthesis. Due to Drop in temperature, synthesis of organic molecules in the sea water stopped. Some of the early prokaryotes evolved to chemoautotrophs which were able to produce organic food utilizing the energy released during inorganic chemical reactions. These **anaerobic chemoautotrophs** resembled present day anaerobic bacteria. They released CO₂ in the atmosphere.

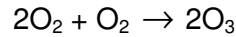
Aerobic photoautotrophs used water as a source of hydrogen and carbon dioxide as source of carbon for the synthesis of carbohydrates in presence of solar energy. The first aerobic photoautotrophs were cyanobacteria (blue green algae) like forms which had chlorophyll. They released oxygen in the atmosphere as a by product of photosynthesis. The main source of genetic variation was mutation.

As the number of photoautotrophs increased, oxygen was released into the sea and atmosphere. Free oxygen reacted with methane and ammonia present in the primitive atmosphere to produce carbon dioxide and free nitrogen.



The oldest fossil belonging to blue green algae, named *Archaeosphaeroides barbertonensis* is 3.2 billion years old. Oxygen releasing prokaryotes first appeared at least 2.5 billion years ago.

As oxygen accumulated in the atmosphere, the UV light converted some oxygen into ozone.



This ozone formed a layer in the atmosphere blocking the UV light and leaving the visible light as main source of energy.

The protection of earth surface from UV rays and increasing level of oxygen helped the development of new forms. Oxidizing atmosphere also breaks organic molecules which was not very suitable for the first primitive living cell. Alternately the mutation, selection and evolution played role in the formation of aerobic organisms and aerobic respiration.

Aerobic organisms had advantage over anaerobic organisms as they make ATP (Adenosine triphosphate) molecules in large numbers from the eaten (engulfed) food material (see Fig. 10.6).

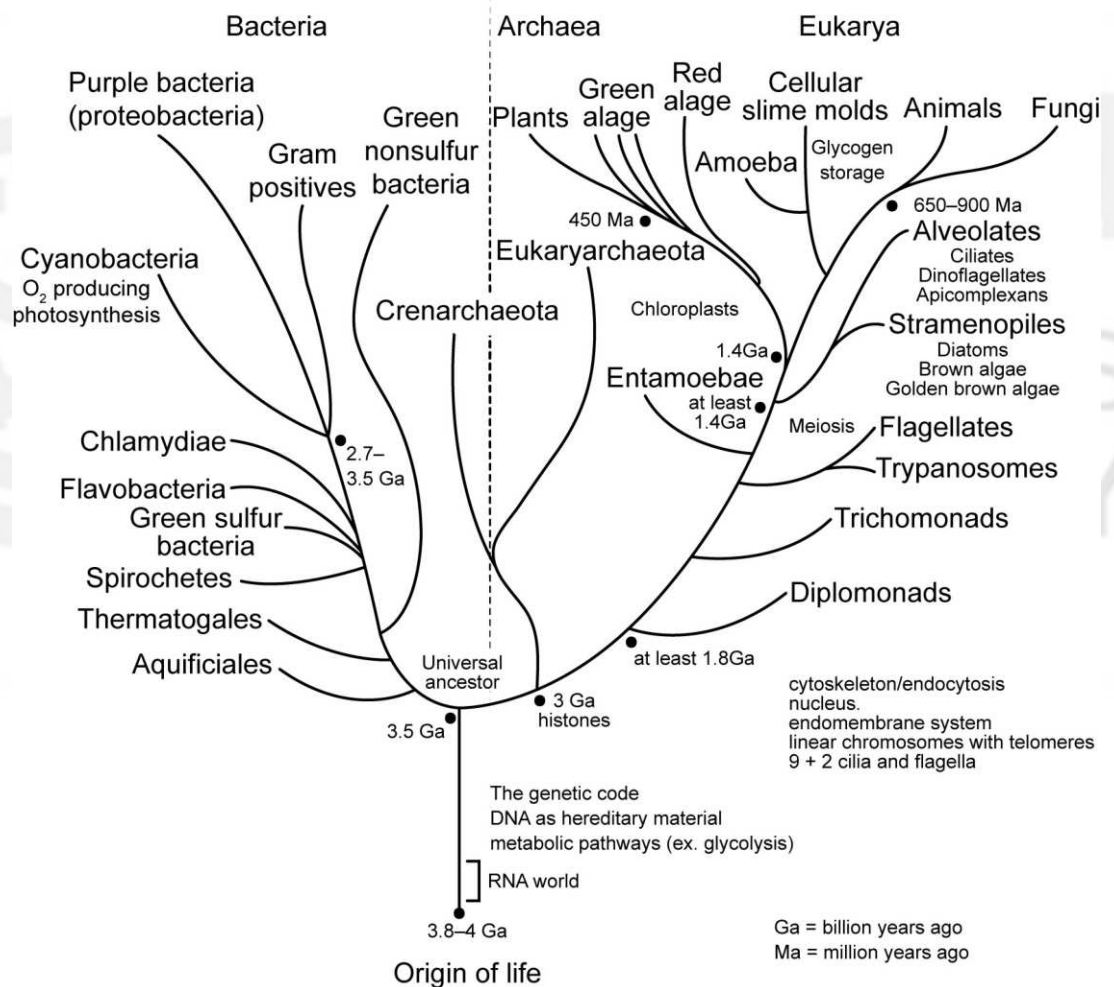


Fig. 10.6: A phylogenetic tree based on small subunit of ribosomal RNA.

10.5.3 Origin of Eukaryotes

The eukaryotes developed about 1.5 billion years ago from the primitive prokaryotic cells. There are two theories regarding the origin of eukaryotes.

(a) Symbiotic Origin

Margulis (1970-1981) of Boston University proposed that some anaerobic predator host cells engulfed primitive aerobic bacteria but failed to digest them. These aerobic bacteria established themselves inside the host cells as a symbiont. This anaerobic predator host cell became the first eukaryotic cells.

The anaerobic predator host cells that engulfed aerobic bacteria evolved into animal cells while those engulfing both aerobic bacteria and blue-green algae became the eukaryotic plant cell. The aerobic bacteria established itself as mitochondria and blue green algae as chloroplast.

(b) Origin by Invagination

According to this view cell organelles of eukaryotic cells might have originated by invagination of surface membrane of primitive prokaryotic cells.

The first eukaryotic common ancestor acquired the genes for its nucleus and mitochondria by endosymbiosis of Archaeobacteria and Eubacteria (See Fig. 10.7).

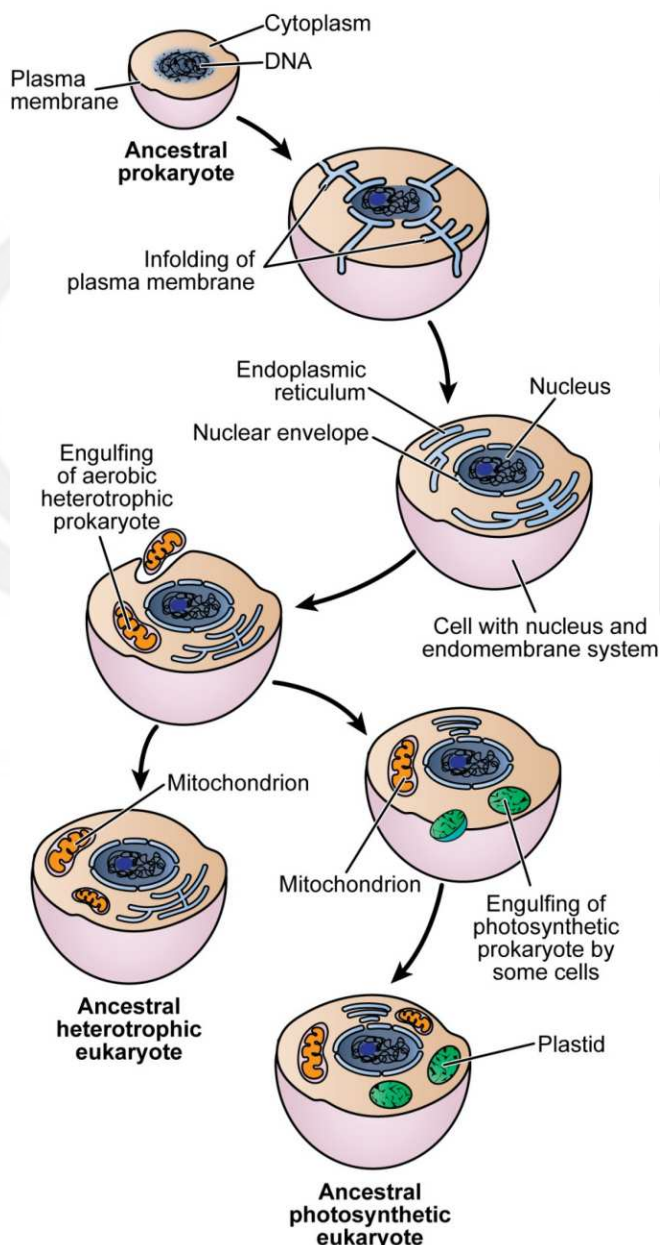


Fig. 10.7: A model to show the origin of eukaryotes through endosymbiosis.

These ancestral eukaryotes further diverged by endosymbiosis of cyanobacteria. This led to the development of chloroplast and ultimately different lower and higher plants.

The evidences are based on:

- (a) Fossil Records
- (b) Computational Phylogenetic Technique
- (c) Biophysical Approaches
- (d) Radioactive record of Zircon fragments

10.5.4 The Origin of Multicellularity

It is still debatable how multicellular life originated. It is estimated that these multicellular organisms originated 600 to 700 million years ago (Pre-Cambrian period) in the following ways.

- (i) Cell division occurred in single cell organisms but daughter cells did not separate.
- (ii) Single cell organisms acquired multiple nuclei and made boundaries for two cells/multiple cells together.
- (iii) Permanent associates of cells led to specialized function of each cell like absorbing nutrients, reproduction etc. Cellular specialization might have been the key to increase in size.

The origin of complexity in primitive eukaryotic cells favoured evolution of structured and functional diversity (see Table 10.2 & Fig. 10.8). Fossil record and DNA sequences comparisons suggest the presence of earlier eukaryotes as algae which originated about 1.2 billion years ago. Further complexity gave rise to soft bodied organisms. The ice age (about 750 million years ago) slowed the evolutionary process.

Several living animal phyla (Porifera, Coelenterata, Mollusca) appeared during Cambrian period (About 530 million years ago). This is based on paleontological record. There are also exceptions based on a fossil from China which suggests complex animals might have originated earlier.

The appearance of microbes, plants and animals on land was the another landmark in the history of life. Tetrapods appeared about 360 million years ago. The process of divergence of tetrapods specially hominoids (apes) from the phylogenetic tree gave the foundation of earlier humans about 6-7 million years ago. The humans appear to have originated about 200,000 years ago.

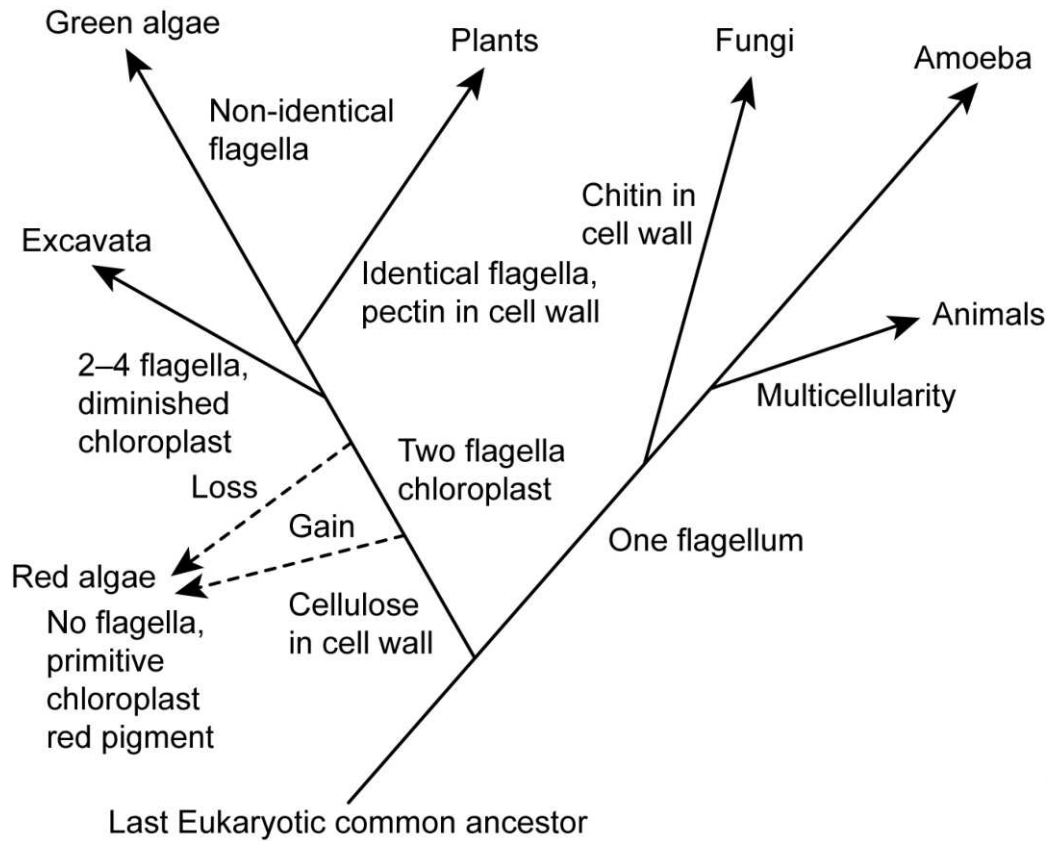


Fig. 10.8: A cladogram based on the Table 10.2 showing how the last eukaryotic common ancestor gave rise to major group of organisms.

Table 10.2: Properties of the major groups of organisms.

	Nucleus	Mitochondrion	Chloroplast	Flagella or cilla ^a	Main cell wall polysaccharides ^b	Centriole	Type
Eubacteria	N	N	N	1-many	Murein	N	Single cell
Archaeobacteria	N	N	N	1	Pseudomurein	N	Single cell
Amebae	Y	Y	N	0 or 1	None	Y	Single cell
Animals	Y	Y	N	1	None (but chitin is the main constituent of exoskeletons)	Y	Multicellular
Fungi	Y	Y	N	1	Chitin	Y	Both
Red algae	Y	Y	Rhodoplast	0	Cellulose, agarose, carrageenan	Centroplast	Both
Green algae	Y	Y	Y	2 (heterokont – the flagella are different)	Polysaccharides (cellulose) and glycoproteins	Y	Both
Plants	Y	Y	Y	2 (dikont – the two flagella are the same)	Cellulose + pectin	Y	Multicellular
Excavates (for example, slime mold, <i>Euglena</i>)	Y	Y or partial	Some	2-4	Polysaccharides (for example, cellulose), glucans	Y	Single cell + aggregate

N: no; Y: yes.

- a) The three different whip-like appendages of eukaryotic cilia and eubacteria and archaeobacteria flagella are defined by function, not structure. Eukaryotes with one or two cilia are referred to as unikonts or dikonts (or heterokonts if the flagella are different). Note that the figures here exclude cells such as those of the respiratory tract in animals that have mats of cilia.
- b) This list is not comprehensive but is intended to note the most important constituents.

(Source: Principles of Evolution by Jonathan Bard ©2016, Publishers: Garland Science)

SAQ 4

i) Evidence to support history of life on earth are based on:

- | | |
|----------|----------|
| a) | b) |
| c) | d) |

ii) Define the following terms:

- | | |
|----------------|--------------------|
| a) Prokaryote | b) Archaeobacteria |
| c) Coacervates | d) Protenoid |
| e) Ribozyme | f) Palaentology |
| g) Autotroph | |

SAQ 5

How multicellularity originated on Earth 600-700 million years ago?

10.6 GEOLOGICAL TIME SCALE

History of earth is based on geological records created on the basis of study of fossils. It is divided into three eons i.e., Archaean, Proterozoic and Phanerozoic (See Fig. 10.9 & Table 10.3).

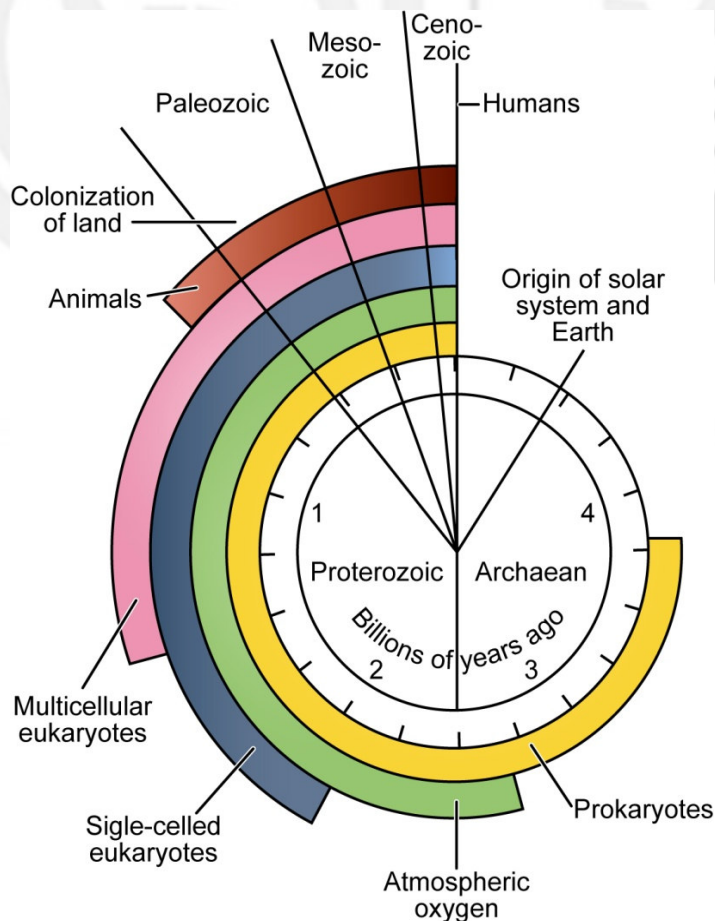


Fig. 10.9: Clock analogy of some key events in Earth's history.

Table 10.3: The Geological Record.

Relative Duration of Eons	Era	Period	Epoch	Age (Millions of Year Ago)	Some Important Events in the History of Life	
Phanerozoic	Cenozoic	Neogene	Holocene		Historical time	
			Pleistocene	0.01	Ice ages, humans appear	
			Pliocene	1.8	Origin of genus <i>Homo</i>	
			Miocene	5.3	Continued radiation of mammals and angiosperms; apelike ancestors of humans appear	
		Paleogene	Oligocene	23	Origin of many primate groups, including apes	
			Eocene	33.9	Angiosperm dominance increases; continued radiation of most present-day mammalian orders	
			Paleocene	55.8	Major radiation of mammals, birds, and pollinating insects	
				65.5		
		Mesozoic	Cretaceous		Flowering plants (angiosperms) appear and diversify; many groups of organisms, including most dinosaurs, become extinct at end of period	
			Jurassic	145.5	Gymnosperms continue as dominant plant; dinosaurs abundant and diverse	
Proterozoic	Paleozoic	Triassic		199.6	Cone-bearing plants (gymnosperms) dominate landscape; dinosaurs evolve and radiate; origin of mammals	
				251	Radiation of reptiles; origin of most present-day groups of insects; extinction of many marine and terrestrial organisms at end of period	
				299	Extensive forests of vascular plants form; first seed plants appear; origin of reptiles; amphibians dominant	
		Devonian		359.2	Diversification of bony fishes; first tetrapods and insects appear	  
				416	Diversification of early vascular plants	
				443.7	Marine algae abundant; colonization of land by diverse fungi, plants and animals	 
		Cambrian		488.3	Sudden increase in diversity of many animal phyla (Cambrian explosion)	  
				542	Diverse algae and soft-bodied invertebrate animals appear	 
				635		
Archaean	Ediacaran			2,100	Oldest fossils of eukaryotic cells appear	
				2,500		
				2,700	Concentration of atmospheric oxygen begins to increase	
				3,500	Oldest fossils of cells (prokaryotes) appear	
				3,800	Oldest known rocks on Earth's surface	
				Approx. 4,600	Origin of Earth	

The phanerozoic eon represents last half billion years when the multicellular eukaryotic life dominated the earth.

Phanerozoic eon is divided into three eras:

1. Paleozoic
2. Mesozoic
3. Cenozoic

The boundaries between the Era's represent major extinctions events based on fossil records. The organisms which survived during extinction period were replaced by evolved organisms.

10.7 SUMMARY

In this Unit you have studied that:

- How the universe, solar system and Earth came into existence and the role of Big Bang in their creation.
- The primary atmosphere of the earth had hydrogen and helium. It was replaced by secondary atmosphere which was reducing with unavailability of oxygen. Finally the tertiary and present atmosphere contained nitrogen and oxygen.
- Origin of life had non-biological origin based on organic molecules. Presence of water in primitive earth acted as solvent for the formation of complex organic molecules.
- The evidence suggests RNA molecule originated first. RNA could reproduce itself. It has the capability to function as enzyme (Ribozyme).
- Origin of RNA, DNA proteins, lipids and sugars gave life its form and structure.
- Earlier molecules were linear which form the membrane based vesicles, the Protobionts. This led to the origin of protocell.
- Variation and selection played important role in different types of vesicles which gave rise to first cells.
- The primitive cell was probably similar to existing prokaryotes. The cells acquired different distinct characteristics as a result of mutation and changing environment.
- Endosymbiosis of Eubacteria by archaeobacteria and engulfing of eubacteria or cyanobacteria by primitive eukaryotic cell gave rise to mitochondria and chloroplast respectively.
- Ultimately multicellular life originated where cell division, mutations, selection and evolution played the role.
- The appearance of microbes, plants and animals on land was the another landmark in the history of life.

- History of Earth is divided into three eons (i.e. Archaean, Proterozoic and Phanerozoic) based on geological records. Multicellular Eukaryotic organisms dominated the phanerozoic eon which is divided into three eras (i.e. Paleozoic, Mesozoic and Cenozoic).
- Evidences for the history of life are based on fossil record, computational phylogenetic technique, biophysical approaches and radioactive record of zircon fragments.

10.8 TERMINAL QUESTIONS

1. Explain briefly the impacts of Miller's experiment on the theory of origin of life.
2. Why is it accepted that life evolved with RNA as hereditary material?
3. What is endosymbiosis?
4. What were the favourable conditions for the origin of molecules and life on primitive earth?
5. Why is it proposed the first organism on earth were anaerobic?

10.9 ANSWERS

Self Assessment Questions

1. (ii), (iii) and (iv).
2. (A) i) The Solar System
ii) 4.5
iii) Magnetic shield
iv) Oxygen
v) Reducing
(B) a) Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune
b) FeS, ZnS
3. i) Atomic phase
ii) Formation of Inorganic molecules
iii) Formation of Simple Organic molecules
iv) Formation of complex organic molecules
4. i) a) Fossil Record
b) Computational phylogenetic technique
c) Biophysical Approaches
d) Radioactive record of Zircon fragments

- ii)
 - a) A unicellular organism that lacks a membrane bound nucleus and organelles.
 - b) A type of bacterial group which includes bacteria that live in harsh environment. The environment resembles the early earth environment.
 - c) A body which has organic macromolecules surrounded by water molecule.
 - d) The protein like structure which represents the basic structure of microsphere.
 - e) It is a RNA enzyme that catalyzes a chemical reaction in a similar way to protein enzyme.
 - f) Study of extinct fossil organisms.
 - g) Organisms that can synthesize carbohydrates (Food molecule) using inorganic raw material and sunlight.
- 5.
 - i) Cell division occurred in single cell organisms but daughter cells did not separate.
 - ii) Single cell organisms acquired multiple nuclei and made boundaries for two cells/multiple cells together.
 - iii) Permanent association of cells led to specialized functions of each cell like absorbing nutrients, reproduction etc. Cellular specialization might have been the key to increase in size.

Terminal Questions

1. Refer to Sub-Section 10.4.2.
2. Refer to Sub-Section 10.4.2.
3. Endosymbiosis is a symbiotic relationship between two organisms. One organism lives within the cell of another organism. Endosymbiotic theory in the context of history of life refers to the origin of eukaryotic cell from prokaryotic cell. The probable way of the existence of mitochondria and plastids (chloroplast) is explained as “endosymbiosis of Eubacteria of archaeobacteria and engulfing of Eubacteria or cyanobacteria by primitive eukaryotic cell gave rise to mitochondria and chloroplast respectively”.

The evidences support that mitochondria and chloroplast are from bacteria. These can be explained as:

- i) Mitochondria and plastid divide like bacteria i.e. by binary fission.
 - ii) Both contain single circular DNA molecule like bacteria.
 - iii) Genome comparisons show similarity between plastid and cyanobacteria.
 - iv) Ribosomes present in mitochondria and plastids are 70S.
4. Refer to Sub-Section 10.4.1.
 5. Refer to Sub-Section 10.5.1.

INTRODUCTION OF EVOLUTIONARY THEORIES

Structure

11.1	Introduction	Criticism of Darwin's Theory
	Objectives	11.4 Biochemical Genetics and Molecular Evolution
11.2	Pre-Darwinian Evolutionary Thinking	Mendelian Genetics-Modern Evolutionary Theory
	Greek Contribution	The Chromosome Theory
	The Origin of Species According to Genesis	Hugo de Vries Theory of Saltation
	The Post-Renaissance Period	Biochemical Genetics
	Lamarckism	Molecular Evolution
	Criticism of Lamarck's theory	11.5 Challenges to Darwinism
	Neo-Lamarckism	Neo-Darwinism
	The Pioneers of Geology and Pre-Darwinian Evolution	11.6 Summary
	Baron Cuvier and Comparative Anatomy	11.7 Terminal Questions
11.3	Darwin's theory of Evolution	11.8 Answers
	Postulates of Darwin's Work	
	Significance of Darwin's Contribution	

11.1 INTRODUCTION

In the previous unit you have studied about origin of solar system and you have also learnt as to how life came into being and consequently led to biological evolution. From the time human took the first step moving towards civilized living, primitive human – much like his modern counterpart – must

have wondered about his own origin as well as the origin of the many different kinds of living forms around him. On the one hand, he would have noted diversity and on the other, the unmistakable relatedness between seemingly different organism. After all, while there are a whole lot of different kinds of birds, they are all birds and, as such are clearly distinct from one another, distinct from other such groups like the fishes or the quadrupeds. Therefore, plants and animals can be grouped into or classified into recognizable bunches.

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. Curiously enough, Indian thinkers apparently did not feel the need to go beyond this metaphorical view of the origin of living forms.

In this Unit, we shall be tracing, in broad outline, the history of thinking on organic evolution.

The unit speaks about Pre Darwinian evolutionary thinking and how Darwinism came into existence Further it elaborates on challenges to Darwinism and how it led to Neo-Darwinism the subsequent modern synthesis.

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 the relevance of 'creationism' in today's world.

11.2 PRE-DARWINIAN EVOLUTIONARY THINKING

Early notions on the origin of species were, in reality, mere speculation – that is, products of imaginative thinking. Surprisingly, however, some of the early Greek philosophers were fairly down to earth and their views on evolution were based on certain facts and observations.

11.2.1 Greek Contribution

In the pre-Christian Western world, some of the early Greek philosophers were apparently good observers. Based on their observations on relatedness of many animal species, they raised up the question of evolution; how the 'higher' forms of life evolved from the 'lower'. Anaximander (612-547 B.C.)

You may perhaps be aware that in the middle ages (in Europe), alchemists were attempting to *transmute* baser metals into gold.

considered that life arose by spontaneous generation and the first animals were fish, produced in moisture and provided with a spiny skin. During the course of time, their descendants left the water and reached dry land. The various other animals came into being through a series of transmutations – that is, transformations. Human, 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.

11.2.2 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.

11.2.3 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 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 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 about the natives in parts of 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.

Swedish naturalist, Carl Linnaeus (1707-1778) 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". He adhered to the notion of God-generated species. Nevertheless, he talked about the role of nature and proposed that. Nature acting over a period of time produced minor variations in species.

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, called it 'the unity of body plan' and made 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 resulted in the death of many and the survival of a few in each generation. It is interesting to note after ten years of Buffon's death, Thomas Malthus (1766-1834) published his famous essay on the same theme. His work was raised to the status of a law known as Malthusian Law.

Before proceeding further attempt 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 and hierarchical classification system.
ii) Carl Linnaeus	b) He was 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 spontaneous generation and the first animals, the fish were produced in moisture and provided with spiny skin.

11.2.4 Lamarckism

Jean Baptiste Lamarck (1744-1829, Fig. 11.1) began as a botanist and settled 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 known as Lamarckism.



Fig. 11.1: Jean Baptiste de Lamarck (1744-1829).

To Lamarck, evolution was a continuous search for perfection on the part of God's creations. He believed in the Aristotle's notion of scale and indeed made it the foundation for his theory of evolution. According to him, life originated all the time as a simple form. It then proceeded to unfold over many generations and, due to its own inner drive, achieved complexity. Thus, through a series of intermediate gradations, it ascended [the scala naturae!] to higher levels of organisation.

Lamarck recognised that the physical environment changed with time and argued, that organism is obliged to alter its way of life in order to survive. How does this happened. According to Lamarck, organisms as a whole as well as their constituent parts, such as organs, showed a tendency to increase continually in size. New organs developed in order to meet the need. Thirdly, organs that were in constant use became highly developed; on the other hand, disuse caused their degeneration. Organisms thus responded to changes in the environment by undergoing changes – brought about by slow degrees – in their bodily structure. Every such change, no matter how small, was 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.

No doubt, the most significant pre-Darwinian evolutionary hypothesis was made by the French naturalist Jean Baptist-Lamarck, a professor of Zoology in Paris. He published his theory of organic evolution in the book titled *Philosophique – Zoologique* which earned wide publicity in the year 1809.

Lamarck's theory was based on the assumption that species differed from one another because they had different needs. Due to their different needs that some organs and appendages were used more than the others. His evolutionary thought was based on four assumptions:

i. Inner urge of organisms

Organisms tend to grow and increase in size. According to Lamarck this increase in size, in form and structure is due to an inner urge of life.

ii. New needs arise due to ever changing Environment

Lamarck observed that the environment was not static. It was changing continuously and led to creation of a new habitat. The organisms then tried to

adapt themselves to survive in the changed environment. This consequently brought about structural modifications as well as behavioral changes in them.

As a matter of fact organism develop adaptive structural modifications to cope with the new environment.

iii. Use and disuse of organs

Lamarck was of the view that as the environment changed, some organs/appendages of the body were more frequently used than the others. The more frequently used organs/appendages have the tendency to grow and develop efficiently, whereas the organs/appendages which are less used in the changed environment become vestigial or reduced.

iv. Inheritance of acquired characters

Lamarck observed that new adaptive characters develop in organisms in response to the environmental changes during its life time. He called them as **acquired characters**. These acquired characters are not found in its immediate ancestor. According to Lamarck these acquired characters are passed on to the next generation leading to morphological, physiological and behavioral changes in a species (Fig. 11.2).

Basically, we can say that Lamarck's theory consists of two parts:

1. New structures appear because of inner urge of an organism.
2. These new structures are acquired in response to need which are passed on to the next generations.

Lamarck cited many examples in various group of animals in support of his arguments or theories. Here we shall be talking about two classical examples.

i. Lengthening of fore limbs and long neck of giraffe

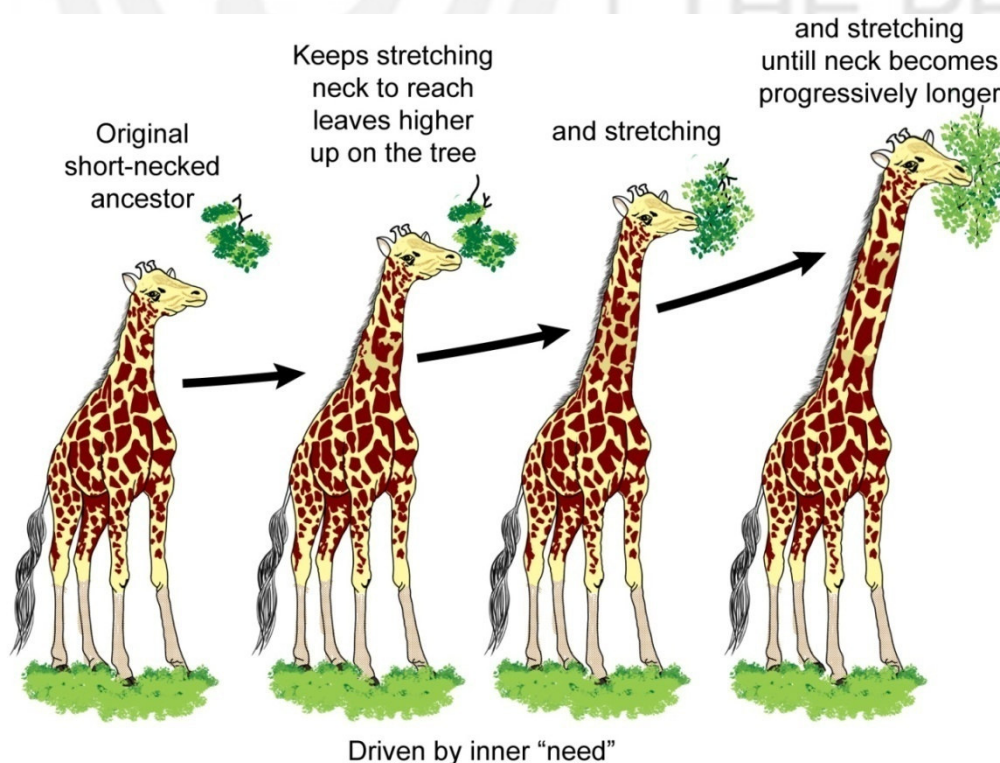


Fig. 11.2: Lamarck's view: Inheritance of acquired characters driven by inner need.

According to Lamarck the ancestors of giraffes were with short necks and short legs which enabled them to graze on the grass. There was a climatic change and the rich green vegetation of the habitat was gradually replaced by tall trees. Now there was scarcity of grass and the ancestors of present day giraffes stretched their neck and forelimbs to obtain food from the tall trees. Their neck and forelimbs lengthened and it was the long neck and forelimbs of the giraffe that was inherited. In the next generation also, the giraffe faced the same problem and further stretched their neck and forelimbs to get their food from the tall trees. Lamarck's observation was that continuous stretching of the neck and forelimbs of giraffes to reach the higher branches of the trees resulted in the elongation of the neck and forelimbs after several generations.

Another example is flightless birds. According to Lamarck, the flightless birds like Ostrich from Africa, Emu from Australia and Kiwi of New Zealand have descended from flying birds. They had plenty of food and no enemies in the various habitats they were living. So, they did not feel the need to fly. According to Lamarck these birds did not use their wings and because of disuse of the wings, the wings got degenerated. After several generations these birds lost the ability to fly.

Lamarck cited many more examples to prove his theory. However, he did not give any example of plants in support of his theory.

11.2.5 Criticism of Lamarck's Theory

There was strong criticism of the theory of evolution proposed by Lamarck. Several evolutionists were forced to put forth their view points against the Lamarck's theory of evolution. According to Darlington the Lamarck's theory is an evergreen superstition. Many objectives were raised against Lamarkism.

1. Tendency to Increase in Size

First law of Lamark states that all the organisms have tendency to increase in their size. It is not universally acceptable. Some poriferans are much bigger compared to coelenterates. Many fishes are bigger than some amphibians, reptiles, birds and even mammals.

2. Inheritance of Acquired Characters

August Weisman (1904) disproved Lamarck's theory that anything acquired during the life time of an individual is passed on to the next generation. He cut off tails of rats for several generations (about 22 generations) and allowed them to breed. Weisman observed that there was not even a single rat without a tail in any generation. Only the characters which influence the germ cells are passed on to the next generation. Any changes taking place in the somatic cells are not passed on to the next generation. This was known as the "**theory of germplasm**".

3. Use and Disuse of Organs

Lamarck's use and disuse theory was also not accepted as it brought about changes in the somatic cells which cannot be inherited by the offsprings. Organs like heart and eye are continuously used however, no changes in their size or musculature has been reported so far.

4. Formation of New Organ at Will

Evolutionists argued that if Lamarck's theory "new organs develop because of need and inner urge of an organism" was true then why humans who have always wanted to fly could not develop wings till today.

According to Lamarck, evolution took place in a linear manner. Straight-line evolution means that species evolve in a pre-determined direction which may drive the species towards extinction.

11.2.6 Neo-Lamarckism

In spite of great objections raised against Lamarck's theory, a number of followers of Lamarck attempted to revive his theory by contributing their own ideas. This revised theory of Lamarck is known as Neo-Lamarckism.

According to Neo-Lamarckism, although the inheritance of effect of use and disuse have not been proved, it is also true that possibilities are there. A number of experiments were performed by Neo-Lamarckians to prove that acquired characters are inherited by offsprings. Griffith and Detleoson reared the rats on a rotating table for many months and rats were adapted to this changed environment to such an extent that when rotation was stopped, the animals felt dizziness and changed physiological condition. When these rats reproduced among themselves, their offsprings also exhibited dizziness when rotation was stopped. In another experiment Guyer and Smith crushed the lens of rabbit and inoculated in a fowl to develop antibodies the antiserum of fowl was injected to a pregnant rabbit and it was found that some of the offsprings had defective eye. This character was inherited in successive generations.

The latest attempt to prove the validity of Lamarckism was made by Steele and Gorchynski 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 so 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 Gorchynski 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.

- T.H. Morgan and Cope proposed that any changes acquired by an organism in its life time if incorporated in the germplasm are heritable and accumulation of these generation after generation results in the formation of new species.

- Neo-Lamarckism stresses on the direct effect of changed environment on the organisms.
- Only those variations are passed on to the next generation which effect the germ cells.

Although Lamarck's ideas on how evolution works were not correct but credit should be given to him for being the first to conceive a coherent theory of evolution.

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.

11.2.7 The Pioneers of Geology and Pre-Darwinian Evolution

The age of Buffon and Lamarck was also the age that saw the contribution of geology to the undermining of the tenets of Genesis as well as to pave the way for a truly scientific understanding of the origin of species. There are two major contributors to 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 contributed to make 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 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? Main forces are, 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 from and deposition of silt into the sea.

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.

11.2.8 Baron Cuvier and Comparative Anatomy

Fossils consist 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 a significant conclusion that, in the animal kingdom, there were 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 them flight-worthy. Clearly, no 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. Rarely 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 evolution in the complexity of living forms. You will study more about the fossil records.

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, ...

11.3 DARWIN'S THEORY OF EVOLUTION

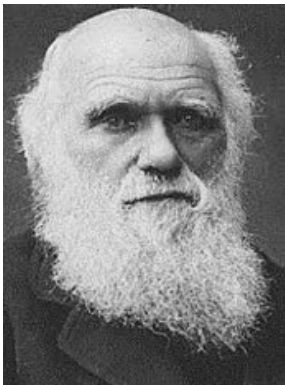


Fig. 11.3: Charles Robert Darwin (1809-1882).

Charles Darwin, a naturalist was born in England (1809-1882) and is known for his theory of natural selection (Fig. 11.3). Darwin in 1831 at the age of 22 got an opportunity to travel by HMS Beagle around the world (Fig. 11.4). This voyage around the world lasted for five years (1831-1836) and during this period the ship visited many places of the world like South-East Asia, Southern tip of Africa, coast of South America, some of the islands of Atlantic ocean and some islands of South Pacific.



Fig 11.4: Charles Darwin's voyage on HMS Beagle (1831-1836).

During his voyage, Charles Darwin studied the geology of these islands, their flora and fauna. He observed that different islands which were widely separated from each other but had similar climate and topography had

different flora and fauna. The flora and fauna of nearby islands was related, however, they differed amongst themselves and from plants and animals that were found on the mainland. When HMS Beagle sailed to Galápagos Islands about 600 miles away from the west coast of South America, he came across various plants and animals which were different from one island to another. He observed that the Galápagos Islands had various species of birds which were not found in any other part of the world, though similar ones existed on the west coast of South America. He observed 13 different kind of birds, each species occupying a different island and slightly different from one island to another. He found that the difference was in their beak size and shape. He also noted that the different type of beaks was associated with the type of food they ate. These birds also differed from the birds of the mainland of South America. Today, these birds are popularly known as **Darwin's finches** (Fig. 11.5).

Darwin found that the fossils of the Galápagos Islands were similar to the living species of South America.

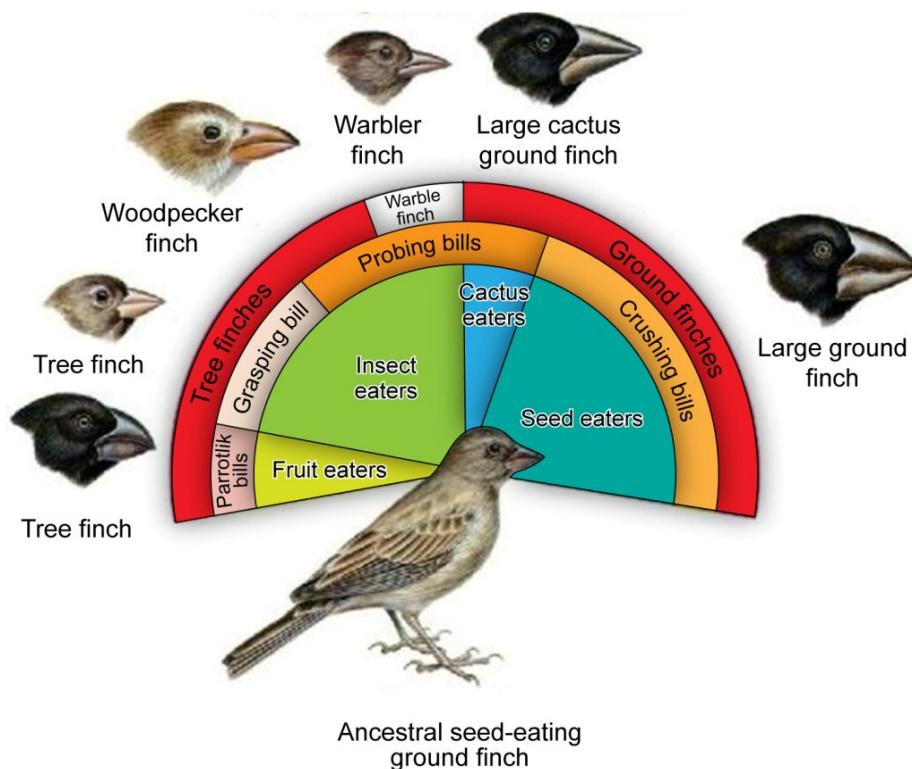


Fig. 11.5: Darwin's finches.

According to Darwin, the finches of the Galápagos Islands must have migrated from the mainland of South America. The ancestral forms then adapted themselves to the environmental conditions of the different islands and diversified into different species.

Darwin observed that the giant tortoise too differed from each other on different Islands.

Later in 1838 Darwin was inspired by the work of Thomas Malthus "Principles of population" (Fig. 11.6).

Malthus said that the rate of reproduction in plants and animals is very high. The rate of population growth takes place in geometric progression, but, the



Fig. 11.6: Thomas Robert Malthus.

food supply increases in arithmetic ratio. So, there is obviously scarcity for food which leads to competition among the living organisms for their survival. Darwin's idea of natural selection was greatly influenced by Malthus essay.

Darwin's theory is based on two facts:

5. All organisms exhibit variability
6. All organisms reproduce many more offspring than can survive

11.3.1 Postulates of Darwin's work

According to Darwin, natural selection is based on five postulates:

- Overproduction
- Competition
- Natural Selection and Survival of the fittest
- Variation
- Speciation

Overproduction: All living organisms reproduce in a geometric progression for the perpetuation of their species. The number of offspring produced is much more than the available food and space and if not checked will soon exhaust the available space and food. For example: elephants which are the slowest breeders start breeding at the age of 30 and during its life-time of 90 years produces only 6 offspring. If all the offspring were to survive then a single pair of elephant would produce about nineteen million of descendants in 750 years. Similarly, a single evening primrose plant produces an average of 1,18,000 seeds. Imagine what will happen if all the seeds were to give rise to evening primrose plant!!!! *Paramecium* divides three times in 48 hours. If all its offspring survive and multiply then one can imagine the consequences.

Competition: Darwin observed that space more or less remains constant. As stated earlier, food supply increases in arithmetic ratio whereas population size increases in geometric ratio. Thus, overpopulation results in struggle for existence for space and food. The struggle for existence can be:

- ❖ **Intraspecific:** Competition among the individuals of the same species or closely related species.
- ❖ **Interspecific:** Struggle between organisms of different species living together for food and breeding places.
- ❖ **Environmental struggle:** Struggle against physical factors like extreme temperatures, shortage or absence of space, shortage of food and water, drought, earthquake, volcanic eruption etc.
- ❖ **Variation:** Competitions among organisms compel them to change and adapt themselves to the existing conditions. If these changes are inherited, then the average character of the species will be altered. Darwin gave the name **variation** to these changes. He has also observed that not all the variations are significant from the evolution

point of view. Some variations become advantageous in the struggle for survival and are passed on to the next generation. These are **heritable variations**. Some variations are harmful and are not passed on to the next generation. These variations finally lead to the extermination of the species.

- ❖ Thus, he found no two individuals to be alike. Even the progeny of the same parents were not alike. Darwin observed that variation exists in living organisms, however, small these variations may be.
- ❖ Today we know that variation is the key factor in evolution. Without variation evolution cannot take place.

Natural selection and Survival of the fittest: In the fight for struggle for existence, Darwin found that individuals of a species with superior characteristics which were better adapted to the existing and changing environmental conditions survived and reproduced more successfully than the individuals with inferior characteristics. The unfit or the less fit organisms with inferior characteristics perished in this struggle for existence.

Nature selects only those individuals which have more favorable variations to adapt themselves to the environment.

Origin of species: Useful variations are passed on to the next generation. These variations get accumulated in the individuals of a species. However, our environment is not stable and is always changing and this leads to further changes and appearance of new adaptations in the organisms. As natural selection continues these organisms after several generations become quite different from their ancestors resulting in the origin of new species.

Let us now once again study the example of giraffe from Darwin's point of view. According to Darwin, the ancestral population of giraffes had neck of variable size. As the environment changed, there was also a change in the vegetation of the habitat. The grasses and the shrubs reduced and replaced by the tall trees. Nature favoured giraffe with the long necks as they had better chances to reach higher tree branches/foilage and thus have access to more food. This gave them more energy and an advantage in reproduction as compared to the giraffes with shorter and medium sized necks. In the subsequent generations therefore, more giraffe off-springs longer necks were produced. These long-necked giraffes outcompeted with the shorter-necked ones over many generations. According to Darwin this is how the long-necked giraffe would have evolved. Major tenets of Darwinism are provided in Table 11.1.

Table 11.1: Facts and inference deduced from Darwinis work.

	FACTS	INFERENCE
A	1. Rapid multiplication 2. Limited space	Struggle for existence
B	1. Struggle for existence 2. Variation	Survival of the fittest and Natural selection
C	1. Survival of the fittest 2. Adaptation	Origin of new species

11.3.2 Significance of Darwin's contribution

Darwin's theory of natural selection removed all conventional old myths and beliefs. He gave a more rational explanation of the formation of new species. Darwin's theory of "Descent with modification" gave an insight to evolutionary biology. He said that evolution was a slow, gradual process and that **lineages descend from a common ancestor uninterrupted**, undergoing various modifications as they descend. The initial species that diverge from the common ancestor are at first very similar but accumulate differences in several generations and finally come to differ radically from each other. **Thus, it was Darwin who first convincingly said that characteristics of lineages of organisms change over time.**

His theory of natural selection and the proposition that changes which take place in different individuals is because of their ability to survive, reproduce and adapt themselves to their environment.

Evolution took place in a branched manner according to Darwin in contrast to the linear concept of Lamarck (Fig. 11.7).

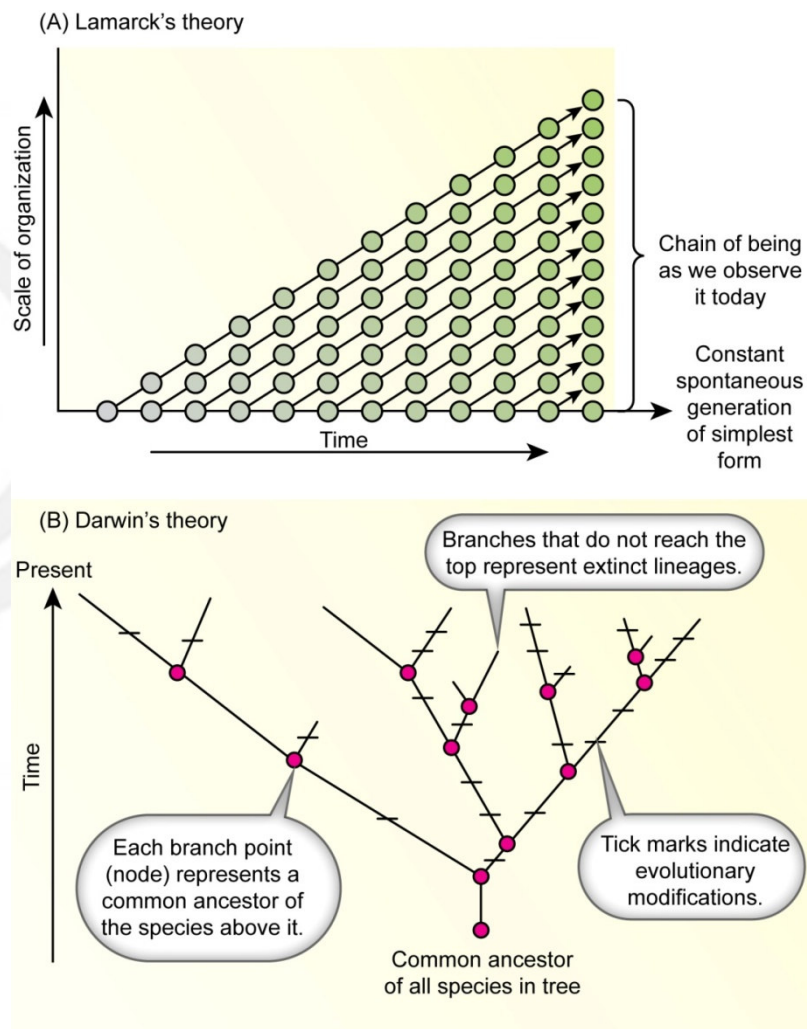


Fig. 11.7: A) Lamarck's theory of organic progression---Evolution takes place in a linear manner. B) Darwin's theory of Descent with modification---lineages descend from a common ancestor; evolution takes place in a branched manner.

Darwin in 1868 proposed the theory of pangenesis to explain the mechanism of inheritance. According to this theory, every somatic cell of the body produces minute heredity particles which he called **pangenes** or **gemmules**.

He said that these pangenes were carried by blood from the somatic cells of the body and collected in the germ cells. The gemmules according to Darwin are produced continuously at all stages of development. However, Weisman had already proposed the “theory of germplasm” which clearly refutes the theory of pangenesis.

It must be mentioned here that Darwin was not the only one working on natural selection, there were other evolutionary biologists too who were working on the same aspects during that time. Alfred Russell Wallace (Fig. 11.8) was also inspired by the essay on “Principle of population” written by Thomas Malthus. He studied many different species in Asia and Amazon River basin in South America and came to the same conclusion as Darwin. The difference between the work of these two scientists was that Darwin thought evolution was driven by competition between individuals while Wallace believed that the environment was the driving force. He said that species changed over time so that they can fit into the new environment.

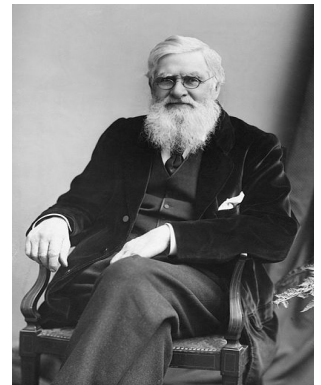


Fig. 11.8: Alfred Russell Wallace (1823-1913).

11.3.3 Criticism of Darwin's theory

- ❖ Darwin had no knowledge about heredity. He could not explain where these hereditary variations came from? He could not explain the origin of variation.
- ❖ Darwin talked about survival of the fittest but could not explain arrival of the fittest.
- ❖ He could only explain the inheritance of useful variations but was not able to explain the inheritance of non-useful variations.
- ❖ Natural selection is not the only cause of origin of new species. He had no idea about mutations.
- ❖ He emphasized on small and cumulative variations and said that these variations were directional.

SAQ 3

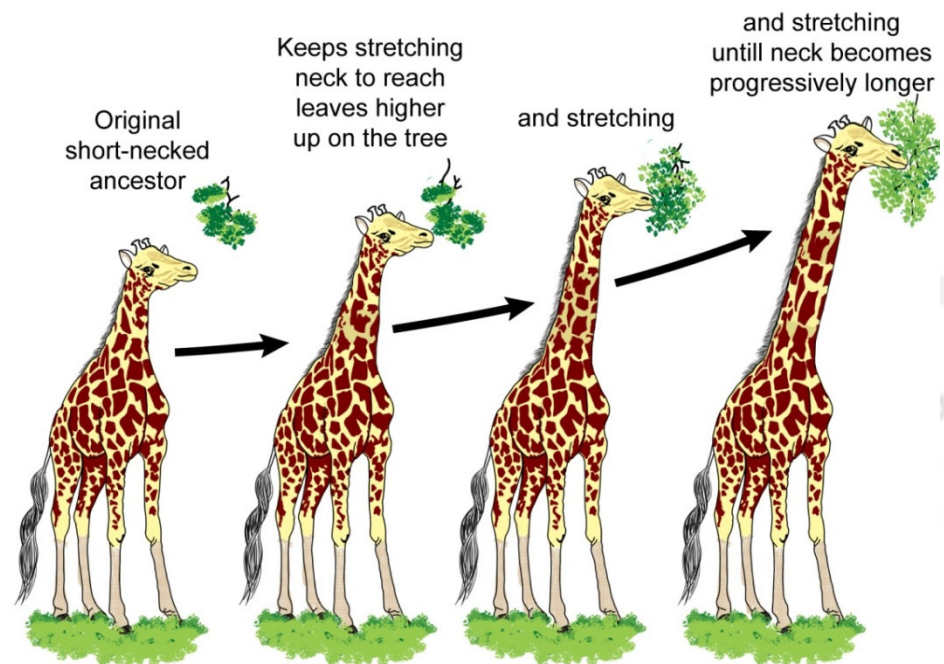
- a. Fill in the blanks:
 1. The theory “Descent with modification” was given by
 2. The paper “Principles of population” was written by
 3. The book entitled *Philosophique Zoologique* was written by
 4. Theory of germplasm was given by
- b. State whether true or false:
 1. The “use and disuse theory” was given by Wallace.
 2. Variation is a key factor in evolution.
 3. Darwin said that lineages descend in a linear manner from a common ancestor uninterrupted.
 4. Birds of Galápagos Islands are now popularly known as Darwin's finches.
 5. According to the concept of biological evolution, all organisms are related through ancestry.

11.4 BIOCHEMICAL GENETICS AND MOLECULAR EVOLUTION

The origin of species as proposed by Darwin raised a lot of controversy. Darwin's theory lacked an input of modern concept of Genetics and molecular biology. He was unable to explain how characters appear and persist in a population.

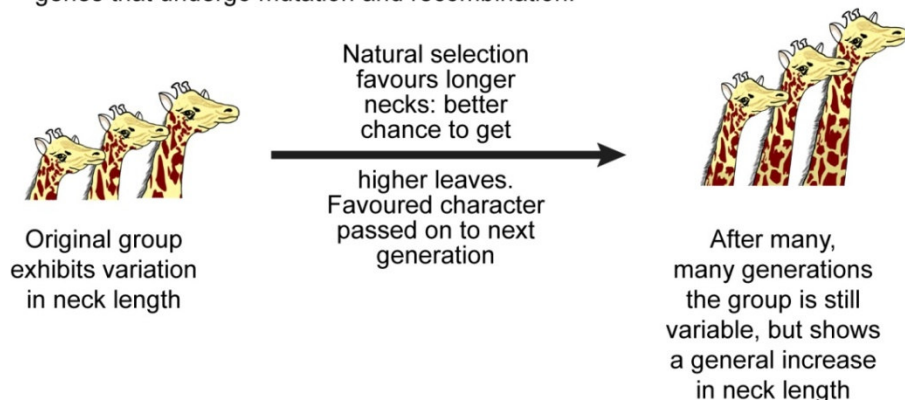
11.4.1 Mendelian Genetics—Modern Evolutionary Theory

J. Gregor Mendel (1822-1884) worked on the Inheritance of acquired characters but his work received no recognition till 1900. The concept of evolutionary change was further understood when Mendel's work on "Inheritance of Acquired characters" was rediscovered in 1900. The basis of biological reproduction and heredity was established only after the rediscovery of Mendel's principles. There was a rapid, explosive growth of the field in genetics in 1900s.



Lamarckian view: Inheritance of acquired characteristics driven by inner need

Mendelian view: Inheritance of intrinsic characteristics controlled by particulate genes that undergo mutation and recombination.



Darwinian view: Inheritance of acquired characters by natural selection

Fig 11.9: Comparison among Lamarck's view and Darwin's view.

11.4.2 The Chromosome Theory

Thomas Hunt Morgan (1866-1945) found the theory of natural selection proposed by Darwin to be incomplete as it was difficult for him to accept that complex adaptations developed in an organism simply by accumulation of slight chance variations. Darwin provided no mechanism to account for the origin or inheritance of variations. Morgan found Mendel's theory to be purely hypothetical. He agreed that Mendel's theory could account for and predict breeding results but Mendel was not able to explain the process of heredity. He argued that no single chromosome could carry specific heredity traits. He did experimental studies on *Drosophila* and gave his classical "Chromosome theory of heredity". Morgan from his work on *Drosophila* gave the sex-limited (now called sex-linked) hypothesis. He said that these sex-limited characters were a part of X-chromosome of females and that X-chromosome carried a number of discrete heredity units. He called these heredity units as **genes** (term gene was coined by Danish botanist Wilhelm Johannsen in 1909). He said that genes are possibly linked in series on the chromosome and are responsible for hereditary traits.

Morgan played a key role in the field of genetics.

Boveri-Sutton identified chromosomes as the carrier of genetic material.

11.4.3 Hugo de Vries theory of saltation

It was Hugo de Vries (Fig. 11.10) who said that natural selection was not necessary for the origin of new species. He said that sudden drastic changes can reorganize the whole genome giving rise to new phenotypes. He called these sudden changes as **mutations** or **saltations**.

His idea of mutation was based on many experiments performed on Evening Primrose (*Oenothera lamarckiana*) for several generations. He was fascinated by the sudden appearance of seven new varieties of Evening Primrose in his garden and he observed that all these varieties were heritable. He observed that the new types of inherited characteristics in Evening Primrose that appeared suddenly gave no indication of their presence in previous generations. He called these individuals of Evening Primrose with new characters as **mutants** and the sudden changes as **saltatory mutations**.

According to Hugo de Vries:

- ❖ Mutations are sudden, large heritable changes. Darwin on the contrary had emphasized on small cumulative variations.
- ❖ According to Hugo de-Vries mutations are random and can occur in all directions.
- ❖ Mutations can appear in different members of the same species thus giving rise to many new related species.
- ❖ They may be useful or harmful. When subjected to natural selection, the beneficial mutations are favored and selected by nature while the harmful ones are eliminated (death of the mutants). The less harmful mutations can however persist in the progeny.



Fig. 11.10: Hugo de Vries (1848-1935).

- ❖ Mutations though rare are of common occurrence.
- ❖ Mutations can accumulate in natural populations and contain enough genetic variations to evolve rapidly when environmental conditions change.

Note: Mutation is the raw material for evolution and not a substitute to natural selection. Mutations can have evolutionary significance only if they are transmitted to succeeding generations.

Recall the different types of mutations and the molecular basis of mutations that you have already studied and try to co-relate it with the concept of evolution.

Ronald A. Fisher and John B. S. Haldane in England and Sewall Wright in United States proposed the mathematical theory of population genetics which shows that natural selection and mutation together cause adaptive evolution.

SAQ 4

- i). Variations during mutations are:
- a) random and directional
 - b) random and directionless
 - c) random, small and directional
 - d) small and directional
- ii). Match the scientists listed in **Column A** with the concept listed in **Column B**:

Column A	Column B
a) Darwin	v) Chromosomes as the carrier of genetic material
b) Hugo de Vries	vi) Sex limited inheritance
c) Boveri-Sutton	vii) Descent with modification
d) Morgan	viii) Saltation

11.4.4 Biochemical 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.

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 the 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.

11.4.5 Molecular Evolution

Molecular evolution came into existence as you can readily see, with the advent of the study of the amino acid sequences – what is called the primary 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 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 5

Tick mark (✓) the correct alternative in the following sentence:

i)	Population genetics is concerned with changes in the gene frequencies in population/smooth and gradual changes in the characteristics of populations.	()
ii)	Sytematics 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.	()

11.5 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 amino acid sequencing there were challenges to the synthetic theory of evolution from molecular geneticists. They were discovering in the genomes of humans and other organisms so 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 protagonists 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 during course of evolution organisms pass through 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.

11.5.1 Neo-Darwinism

Darwin's theory of natural selection was strongly supported by Wallace, Huxley, Haeckel, and Weismann. Darwin's theory lacked an input of modern concepts of genetics and was unable to explain how characters appear and persist in a population. In the light of recent researches in genetics and molecular biology the theory was modified. This is known as modified theory of Darwinism or Neo-Darwinism. The Synthetic theory emerged by combining the original idea by Charles Darwin and addition of new knowledge of genetics, population dynamics, statistics, and heredity to the theory. This is the most

modern theory of evolution and has been constantly improved during 20th century by the contribution of many scientists. R.A. Fischer, J.B.S. Haldane, Ernst Mayr, Julian Huxley, and G.G. Simpson contributed with their studies on population dynamics. T. Dobzhansky, H.J. Muller, H. DeVries, G.L. Stebbins added information on genetics and mutation. G.H. Hardy, W. Weinberg, Sewall Wright did extensive work on population genetics and statistics, which helped to understand the mechanism of heredity.

Darwinism considers all favourable variation are inheritable, does not explain the reason for variation, believe that basic unit of evolution is an individual, does not consider reproductive isolation as a major factor in the formation of new species and propose that Natural selection is responsible for the survival of the fittest and removal of the unfit ones during the course of time.

Neo-Darwinism is the modification of original concept of Darwin and Wallace based on data obtained from genetic research. It considers the inheritable genetic variation (mutations) for evolution, explains the reason for variations, consider population as a basic unit of evolution, consider reproductive isolation as a major essential factor in speciation and natural selection leads to the changes in gene frequency. Neo-Darwinism in fact is the fusion of Mendelian genetics and Darwin's natural selection that Produce a more comprehensive evolutionary theory. Darwin showed that evolution involves selection interacting with variation within populations, whereas Mendel on the basis of his studies concluded that the basis of the variations are discrete units of heredity (genes).

According to Neo-Darwinism the following factors are responsible for the evolution. (1) Gene mutations (2) Variation (Recombination) (3) Heredity (4) Natural selection (5) Isolation:

- 1. Gene Mutation:** A sudden alteration in the chemistry of gene (DNA) has the capability to change its phenotypic effect. Any change in the nucleotide of gene (DNA) has the capability to change its phenotypic effect. Any change in the nucleotide sequence of DNA or if one pair of nucleotides is replaced mutations will arise. This is called as point mutation or gene mutation. These are caused spontaneously in nature. Mutation may be due to induction, Mustard gas, x-rays, gamma rays, electric shocks, temperature shocks etc.. These mutations are rare. They are sudden and heritable. Mutation can produce drastic changes and may be deleterious, harmful, lethal or may be insignificant. There are equal chances of a gene to mutate back to normal. Most of the mutant genes are recessive to the normal gene and are able to express phenotypically only in homozygous condition. So the gene mutation has ability to produce variations in the offspring that can be inherited. In small inter breeding population heterozygous gene pairs will tend to become homozygous. Because of this, disadvantage characters may be expressed and those organisms will be weeded out. Such genetic drifts are not theoretical. They operate in small populations of Islands. This genetic drift provide a way to determine the line of evolution.
- 2. Variations:** During Darwin's time little was known about genetic variations. During Meiosis and crossing over synapsis take place. Due to

this regrouping of genes take place due to which genetic variation will appear or chromosomal aberrations will take place. The chromosomes may lose or gain a bit or order of genes may be changed, or the chromosomal bits may be exchanged between the two chromosomes. These aberrations will become heritable variations. Number of sets of chromosomes may also increase or decrease. This is called Polyploidy which is a heritable variation and when occurs will be carried to number of generations. This may result in the origin of new species.

3. **Heredity:** The transmission of variations from parent to offspring is an important mechanism of evolution. Organisms possessing helpful hereditary characteristics are favored in the struggle for existence. The offspring's are able to benefit from the advantageous characteristics of their parents.
4. **Natural Selection:** Natural selection brings evolutionary change by favouring differential reproduction of genes. It produces changes in gene frequency from one generation to the next. It does not produce genetic change, but once it has occurred it acts to encourage some genes over others. It also creates new adaptive relations between population and environment by favouring some gene combinations, rejecting others and constantly modifying and molding the gene pool.
5. **Isolation:** In Darwin's time nothing was known about isolation. Isolation is a very important part in evolution. Usually the organisms of a population are segregated into several populations because of physiological or geographical isolation. Members of these populations are unable to breed with the members of other population and get reproductively isolated. An isolated population independently develops different types of mutations. The latter accumulate in its gene pool. After several generations, the isolated population becomes genetically and reproductively different from others so as to constitute a new species.

SAQ 6

- a) Comment briefly on the following :
 - i) Neutralists' theory of evolution.
 - ii) Punctuated equilibrium.
 - b) Having gone through this unit, do you think that life could have been created on this planet earth?
-

11.6 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'.

11.7 TERMINAL QUESTIONS

- 1) Critically evaluate the Lamarckian concept of evolution.
- 2) What do you understand by the term struggle for existence?
- 3) How do biochemical genetics helped in the understanding of the evolutionary process?
- 4) What do you understand by the term Modern synthesis?

11.8 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. a) i) Darwin
ii) Malthus

- iii) Lamarck
 - iv) Weisman
 - b) i) F, ii) T, iii) F, iv) T, v) T
4. i) b,
ii) d.
5. i) Change in gene frequencies in population
ii) Ernst Mayr
iii) Phenotypic
iv) Biochemical genetics
v) Morgan
6. a) i) The neutralists' theory stated that since many sequences of nucleotides are found duplicated several thousand times in our genome 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 of the question.

Terminal Questions

1. 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 practice 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 prominence 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.

Acknowledgment of Figures

Fig. 11.1: <http://www.bio.miami.edu/ecosummer/lectures/lecevolution.html>



EVOLUTIONARY EVIDENCES |

Structure

12.1	Introduction	12.5	Comparative Embryology
	Objectives		Haeckel's Law
12.2	The Geological Record		Von Baer's Principles
	Relative Dating	12.6	Comparative Physiology and Biochemistry
	Absolute Dating		Physiology
	The Geological Time Scale		Biochemistry
	Fossils	12.7	Summary
	Evolution of the Horse	12.8	Terminal Questions
12.3	Biogeography	12.9	Answers
	Biogeographical Regions		
	Discontinuous Distribution		
	Life in Islands		
	Life in Oceans		
12.4	Comparative Anatomy		
	Homologous Organs		
	Analogous Organs		
	Vestigial Organs		

12.1 INTRODUCTION

The history of the development of the idea of organic evolution was traced in Unit 12. 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 beginning to end. Therefore, scientists have brought in indirect evidences from a variety of disciplines that, taken together, support the view 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 these aspects shall be examined 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.

12.2 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 were transported to the floor of depressions, lakes or oceans and accumulate there. Sometimes various organisms also died and get buried at the bottom of such water bodies. Material so deposited later became 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:

12.2.1 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 settled in the oceans and other large bodies of water. At the bottom, they were gradually compacted into layer upon layer of rock. Of the sedimentary rocks which remained undisturbed, the deepest strata should be the oldest and the most superficial the most recent. However, there are complications. Although all strata were 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, was a civil engineer who worked out the principles of relative dating.

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 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.

12.2.2 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 proportion of their organic carbon in the radioactive form. The half-life of radioactive carbon is $5,760 \pm 30$ 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 is calculated from the known half-life.

Some rocks underwent melting during their formation. Such 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 is 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

12.2.3 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 12.1. 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 12.1: 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 4 th 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.
		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,	Dominance of archaic

			climate cool to moderate	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.
	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 glaciations, cool dry climate	Extinction of many marine invertebrates; Rise of modern insects, spread of reptiles.
	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 glaciations, 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.

12.2.4 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. 12.1 a, b & c you can see some examples of fossil records.

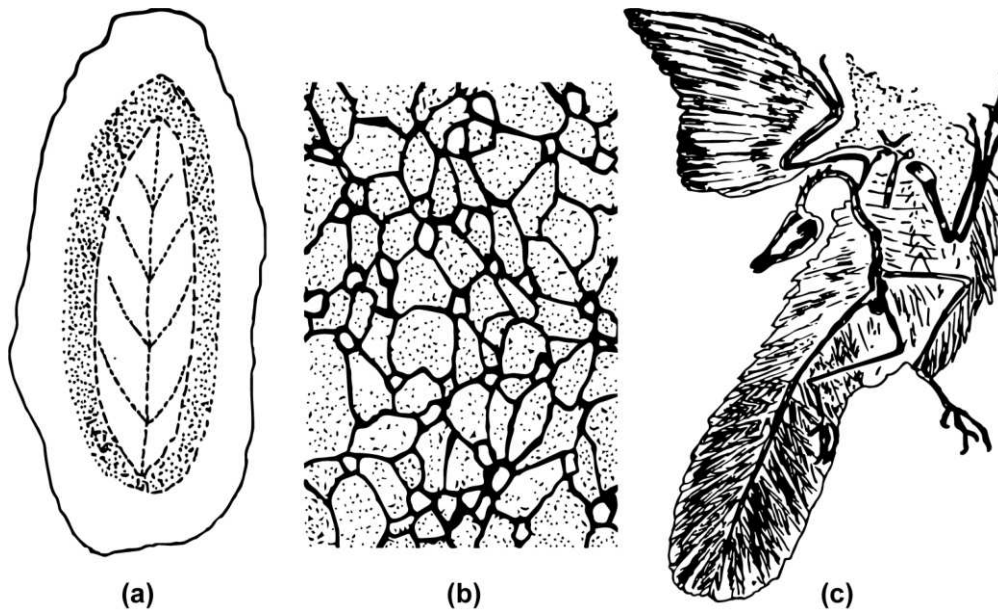


Fig. 12.1: Examples of fossil records: a) an impression of a leaf; b) cuticle of the lower epidermis of a leaf; c) *Archaeopteryx*—a fossil bird.

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.

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.

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.

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.

12.2.5 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 to grind tough grassy vegetation.

You can see in Fig. 12.2, 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.

12.3 BIOGEOGRAPHY

An important line of evidence that Darwin carefully built up in support of his theory 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.

12.3.1 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 — 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 orangutan, 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.

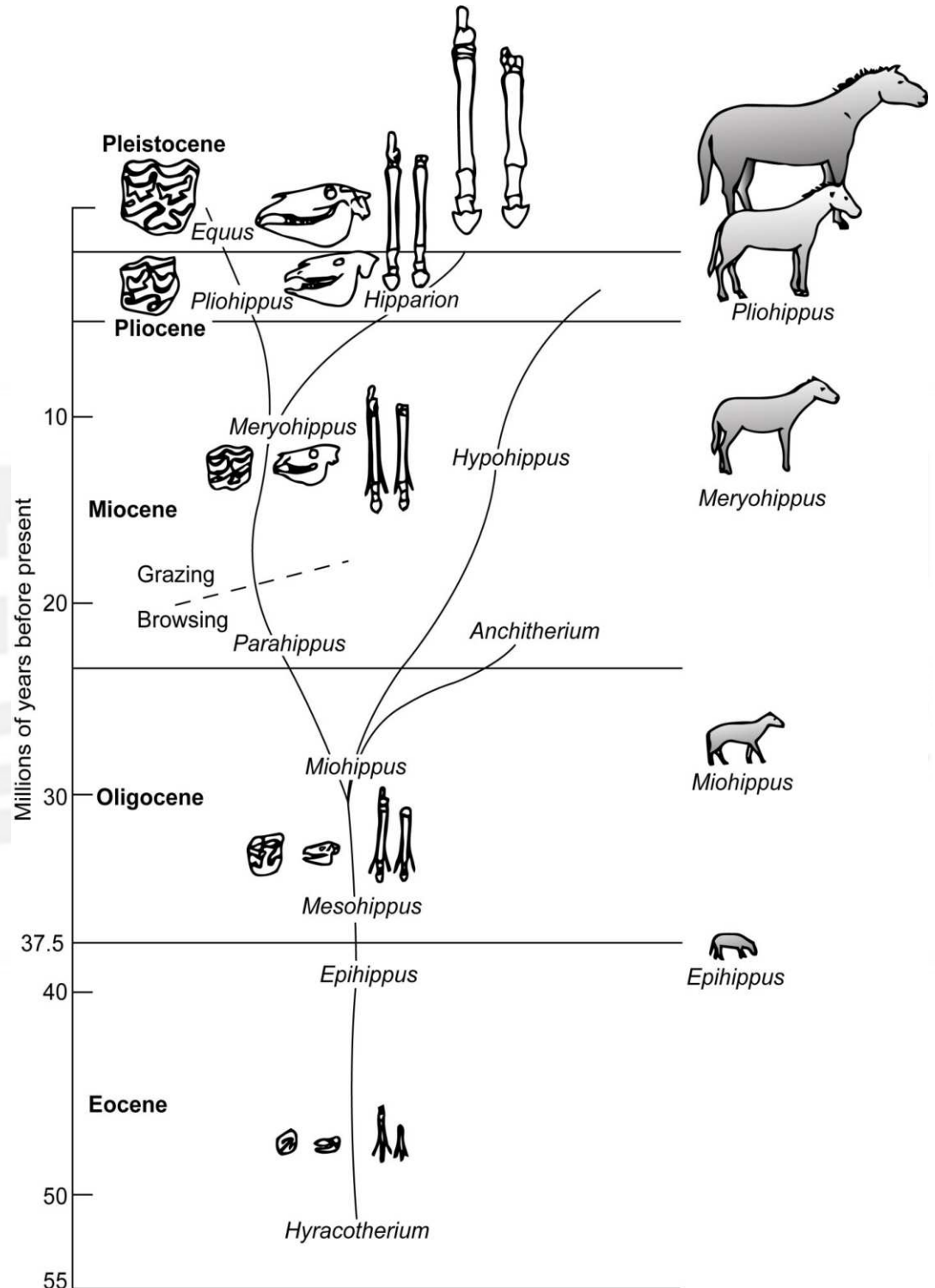


Fig. 12.2: Schematic diagram showing the evolutionary trends in horses within a span of 60 million years. Note the diversity of horses during Miocene and pliocene period and extinction of all other horses except for single toed species by the end of pliocene.

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.

Look for all these different regions of the world in Fig. 12.3.

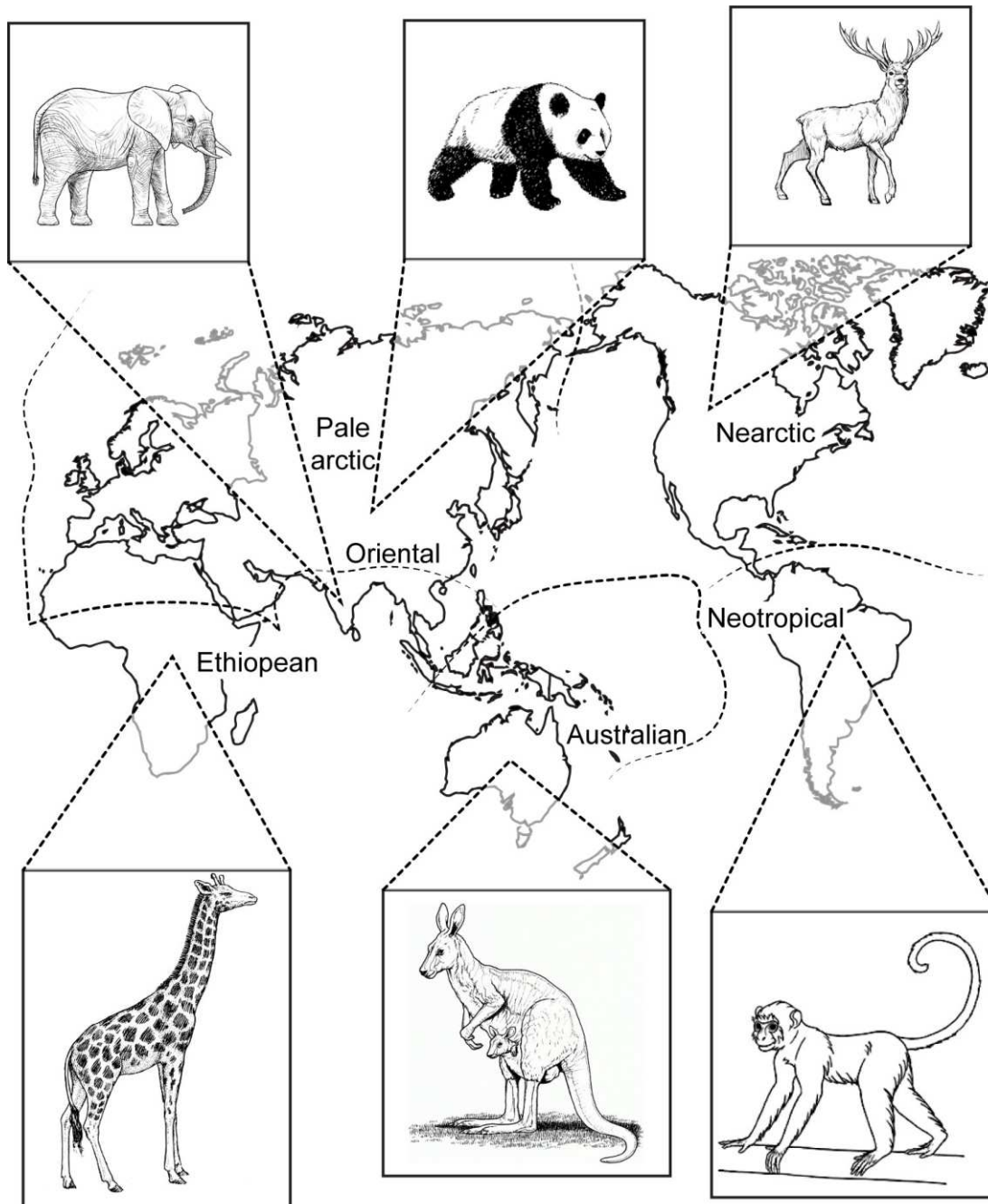


Fig. 12.3: Biogeographical regions of the world. Each region is marked by its typical flora and fauna.

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.

12.3.2 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. 12.4).

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**.

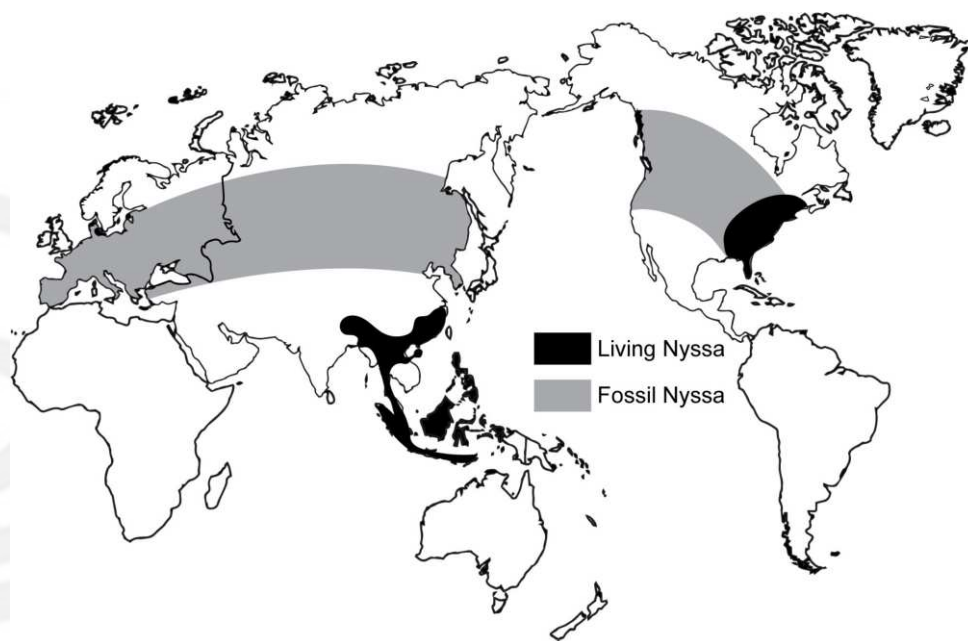


Fig. 12.4: Distribution of *Nyssa*. The shaded area indicates the distribution of fossils and the dark area indicates the distribution of the living forms.

12.3.3 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. 12.5, 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 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.

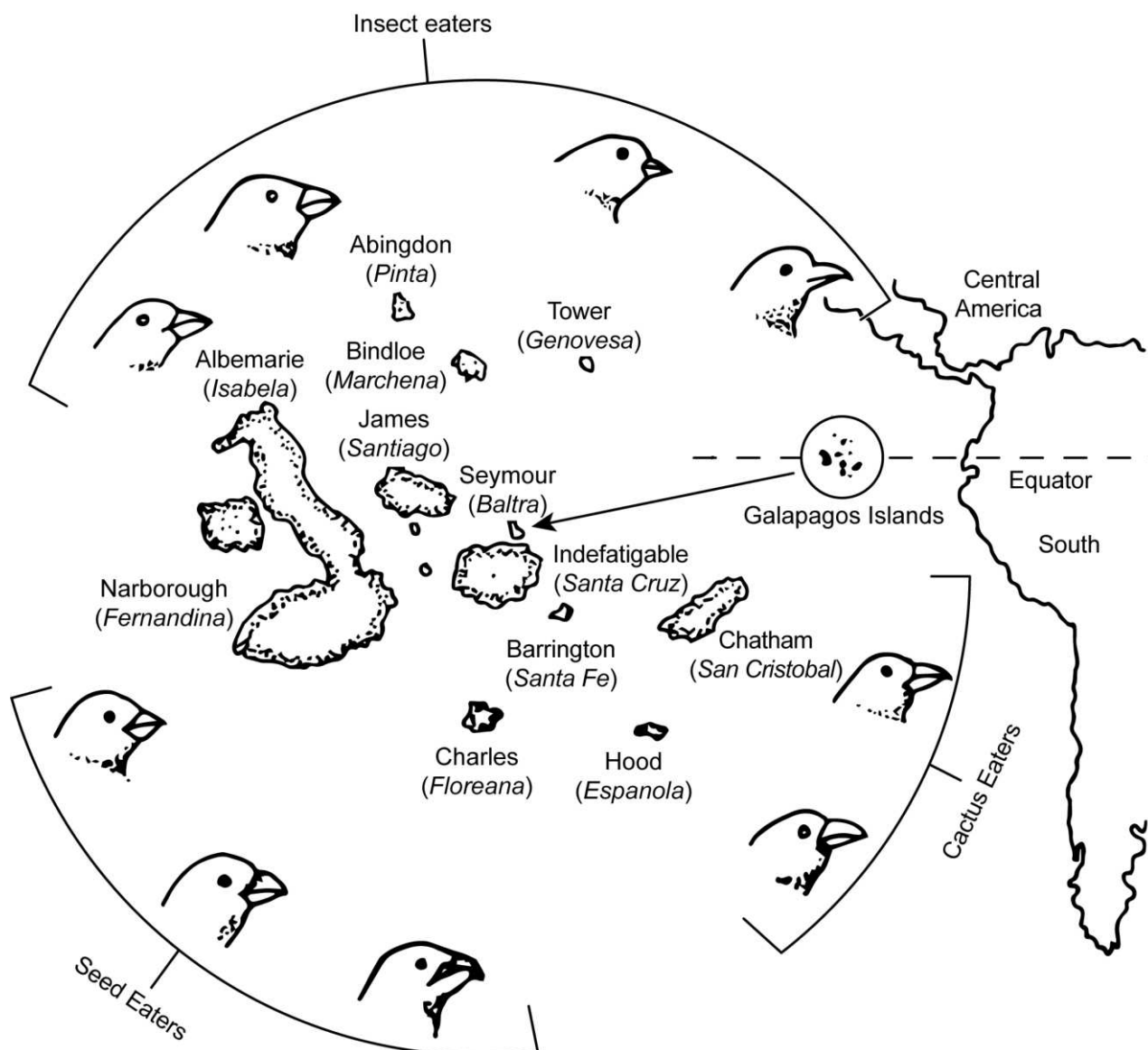


Fig. 12.5: Galapagos and different beak structures of birds of subfamily Geospizinae, owing to different feeding habits. Galapagos islands are situated between 500 and 600 miles west of South America.

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.

12.3.4 Life in the Oceans

Oceans, like lands have distinct biotic regions which offer different kinds of habitats. As shown in Fig. 12.6 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.

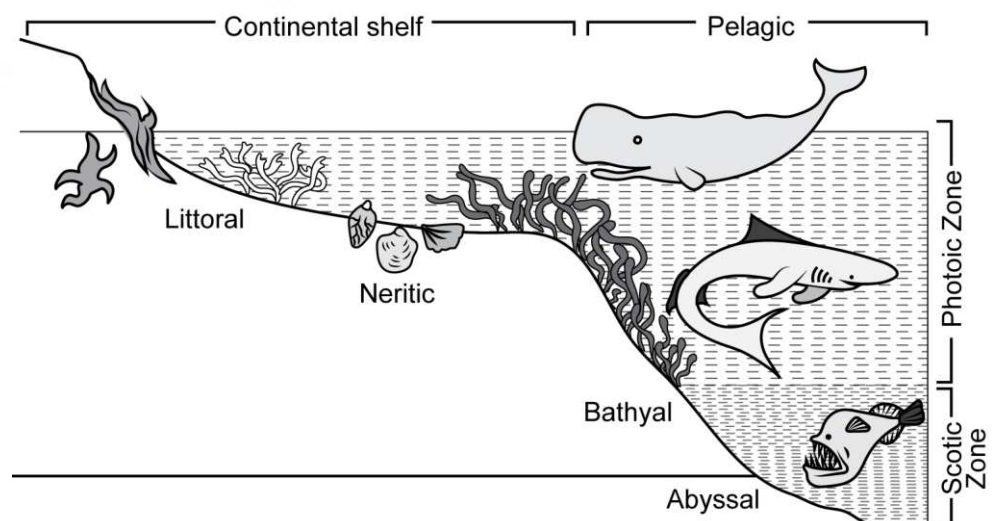


Fig. 12.6: Different ecological zones of an ocean. Each one is the barrier for the organism of another zone.

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 fauna. 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 ()
- v) Oceans like lands have distinct regions which are ecologically different. ()

12.4 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.

12.4.1 Homologous Organs

Homology is the similarity of structures in various related organisms arising from common ancestry 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. 12.7, you can see some examples of vertebrate forelimbs, modified to suit various functions.

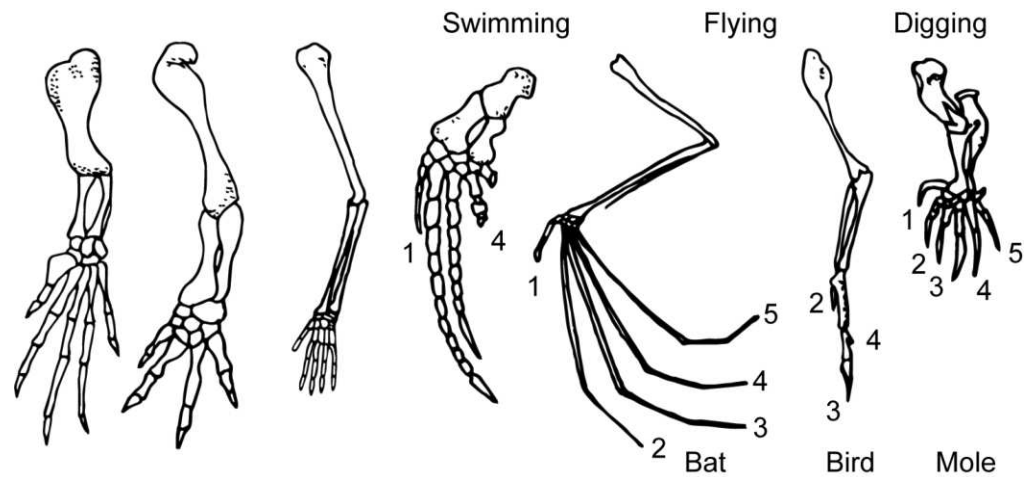


Fig. 12.7: Homology in the bones of the left forelimb in the vertebrates. Similar bones in each animal are adapted for special use by differences in length, shape and bulk of various bones.

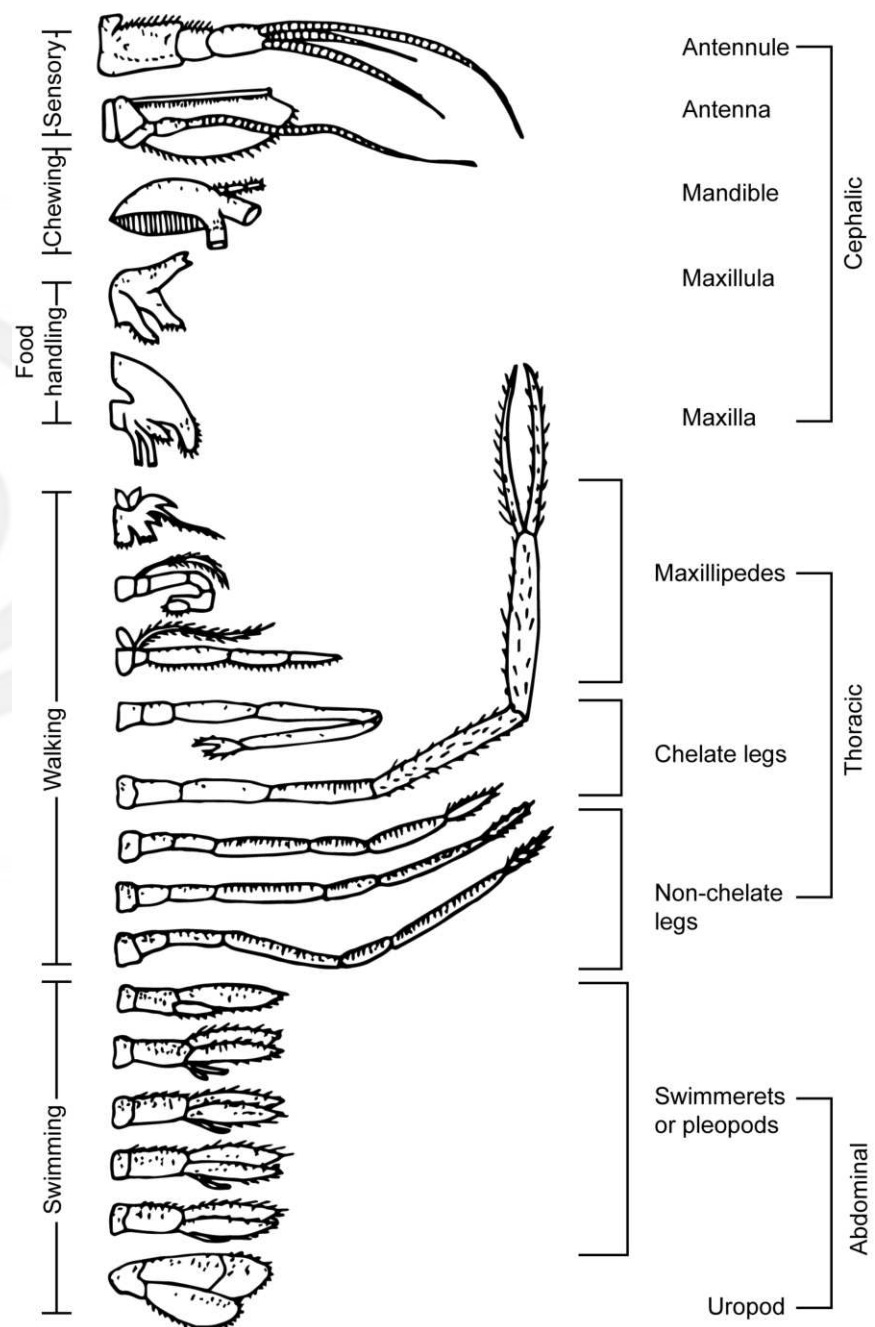


Fig. 12.8: Serially homologous appendages of prawn. Note the structural modifications to suit the various functions performed.

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. 12.8, 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. 12.9 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.

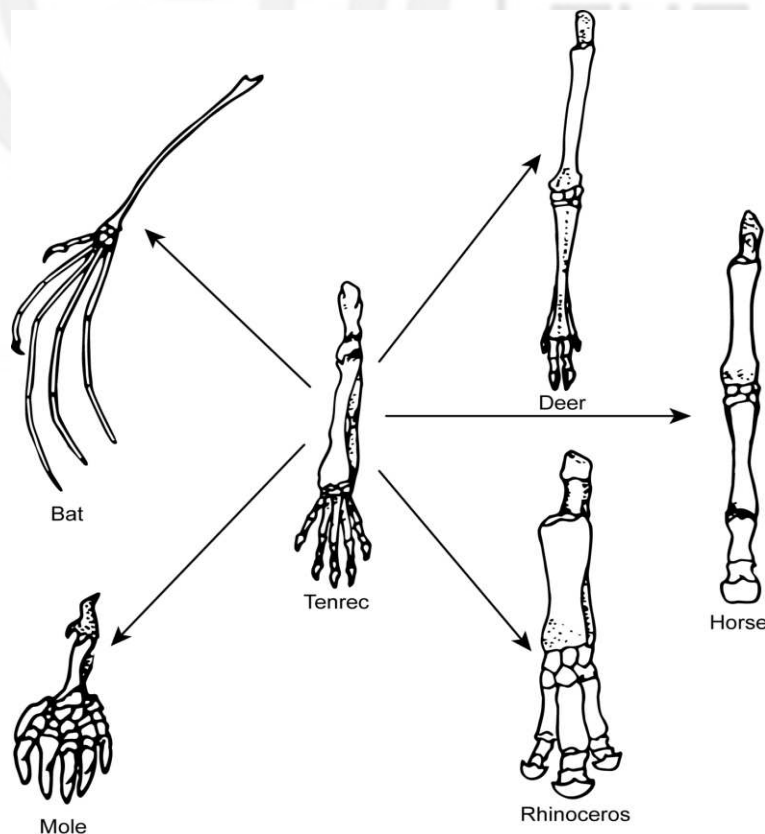


Fig. 12.9: Adaptive radiation in the forelimbs of mammals.

You can find homologous structures in plants also. For example, a thorn in a bougainvillea or a rose and a tendril in the cucurbits, are homologous, arising as they do in the axillary position.

There are many such examples, showing us that though there is a great range of variation, the basic pattern is same. Within any taxonomic category, all of the members appear to be built on a common plan, with variations among members that adapt each to its specific mode of life.

The higher the taxonomic category, the greater is the variation. Since Darwin's time, a great majority of biologists have been convinced that close anatomical similarity must be based on close genetic relationship and that more remote resemblances reflect more remote genetic relationship.

12.4.2 Analogous Organs

Analogous organs are morphologically different structures which develop in various unrelated organisms serving similar functions. However, there are a certain similarities in these structures which are based on adaptations to perform the same functions. These organs, called analogous organs, are the consequence of convergent evolution.

A classical example of analogous organs is the set of wings developed independently by insects, some extinct reptiles as well as birds and bats. As shown in Fig. 12.10, the insect wing is a membrane supported by chitinous veins. The entire wing is a lifeless structure operated by muscles attached to its base. The wings of pterosaurs, extinct flying reptiles, were formed by a fold of skin supported by an enormously enlarged fourth digit of the forelimb. In birds, the planing surface of the wing is composed of feathers.

The feathers are supported by an internal skeleton of bones of the forelimb. In bats the wing is formed by a membrane modified from skin. The wing in the bat is supported by the elongated and outspread phalanges of the last four digits of the forelimbs.

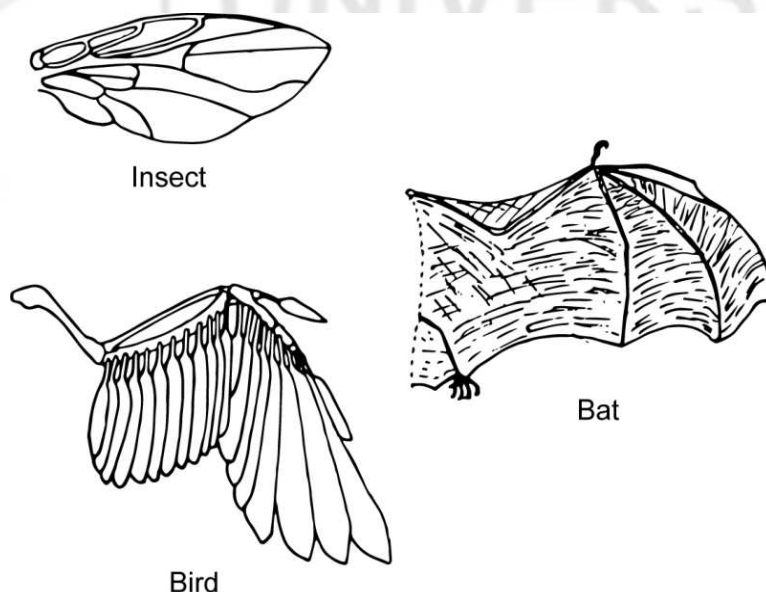


Fig. 12.10: Analogy between wings of insect, a bird, bat and pterosaur. In each the planning surface is formed from different materials and the resemblances are only due to functional adaptations.

In plants you have the example of tendrils. The tendrils of pea and vine have different origins. The former is a modified leaf and the latter is a modified stem. You can think of other examples in plants and animals to show that superficial resemblances are a result of functional adaptations in response to identical environmental situations.

12.4.3 Vestigial Organs

Another very important aspect of comparative anatomy is the study of **vestigial** or **rudimentary organs**. The presence of vestigial organs further strengthens our notion of speciation through evolution. The vestiges represent structures that were once useful to the ancestors and in course of evolution got modified in the descendents. Such modifications during evolution are produced as a result of adaptations to changed environmental conditions. In many cases the reduced organ has assumed a new function, completely unlike that for which it was originally adapted. In other cases it is apparently useless.

The most widely known example of vestiges is the human vermiform appendix. This is a small structure, wormlike in appearance (vermiform) and is the constricted terminal portion of the caecum of the large intestine. In some mammals that live on coarse fibrous diet, made up of a considerable amount of cellulose, the caecum and appendix are considerably larger. This enables the bacteria lodged therein to enzymatically digest the cellulose. However, in humans with changed dietary habits (cellulose intake is much reduced) the appendix has been rendered superfluous and therefore, remains rudimentary (see Fig. 12.11). Sometimes it is the source of . nuisance because its enlargement results in appendicitis. In man, it can be removed by surgery without dire consequences.

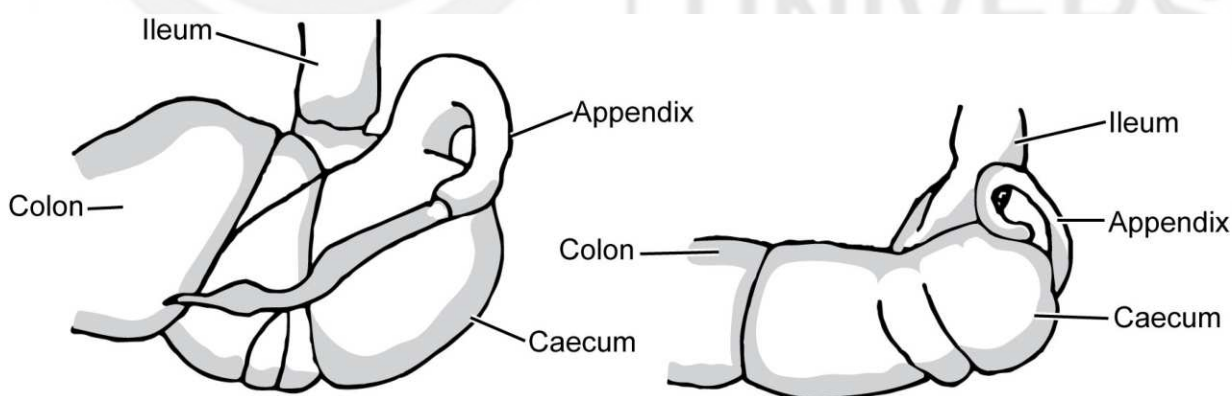


Fig. 12.11: The appendix in orangutan and in man.

There are numerous other examples of vestigial organs in animals and plants. The nictitating membrane of the eye, the external ear muscles and the wisdom teeth in humans, the vestigial caudal vertebrae (embryonic tail) in higher primates, the pelvic girdle in whales, boas and pythons, degenerated eyes in cave dwelling vertebrates and invertebrates are such examples in animals. In plants some of the examples of vestiges are covered stomata on the stem of

cactus, vestigial leaves in prickly pears, the abortive stamens of Labiatae and the abortive pistillodes of male flowers in Cucurbitaceae. Similarly, in some members of the family Compositae, the ray florets have an abortive pistil devoid of any stigma and therefore fail to be fertilised. This results in abortive ovules.

With this conclude our discussion of the evidence from comparative anatomy in support of organic evolution. Before we proceed further try the following SAQ:

SAQ 4

- a) Distinguish between homologous and analogous organs.
 - b) Why is the vermiform appendix reduced to a rudimentary form in man?
-

12.5 COMPARATIVE EMBRYOLOGY

Each sexually reproducing organism begins its life as a unicellular zygote and develops into an adult as a result of cell division and differentiation. The early 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 during the developmental history of an organism there is a remembering or 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 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. 12.12 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.

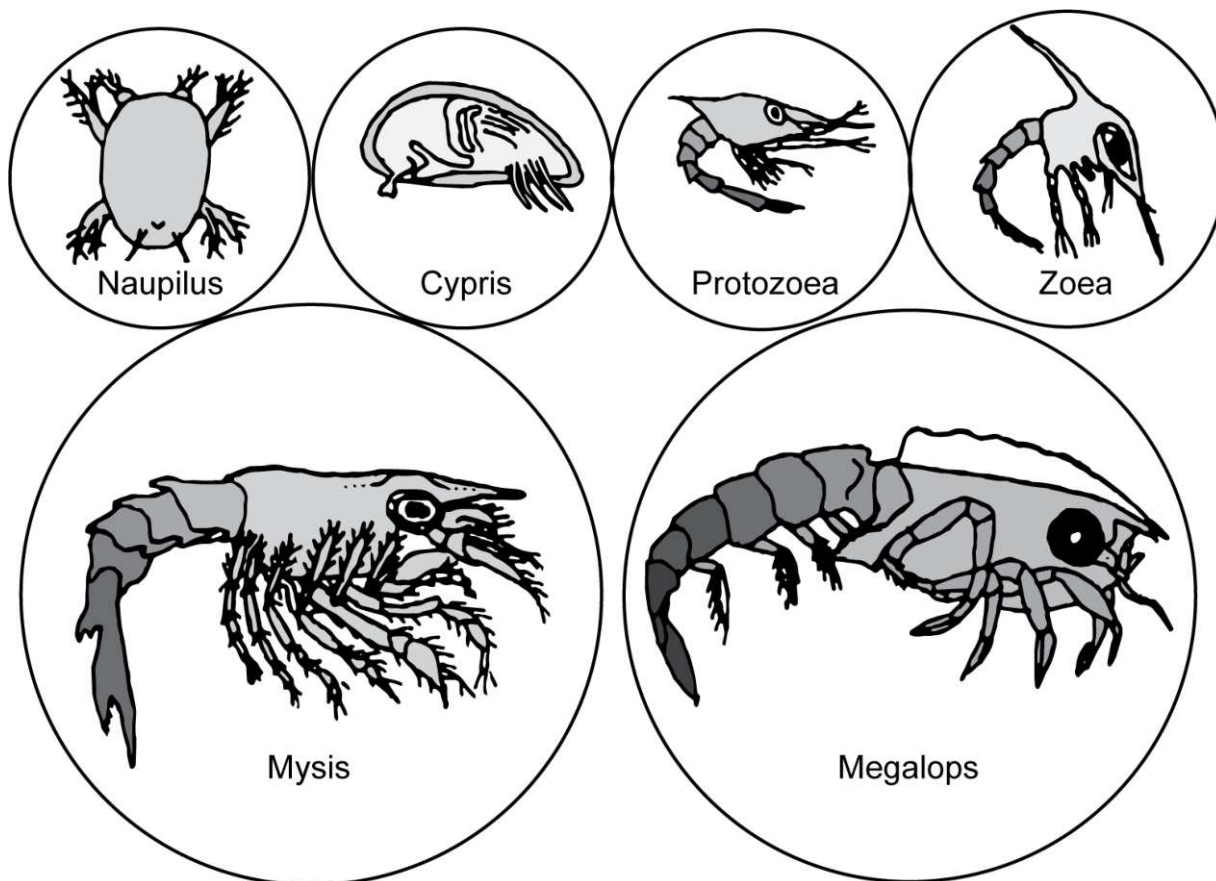


Fig. 12.12: Six larval stages during development of crustaceans. Larval stages often resemble adults of the groups with corresponding names.

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. 12.13. 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.

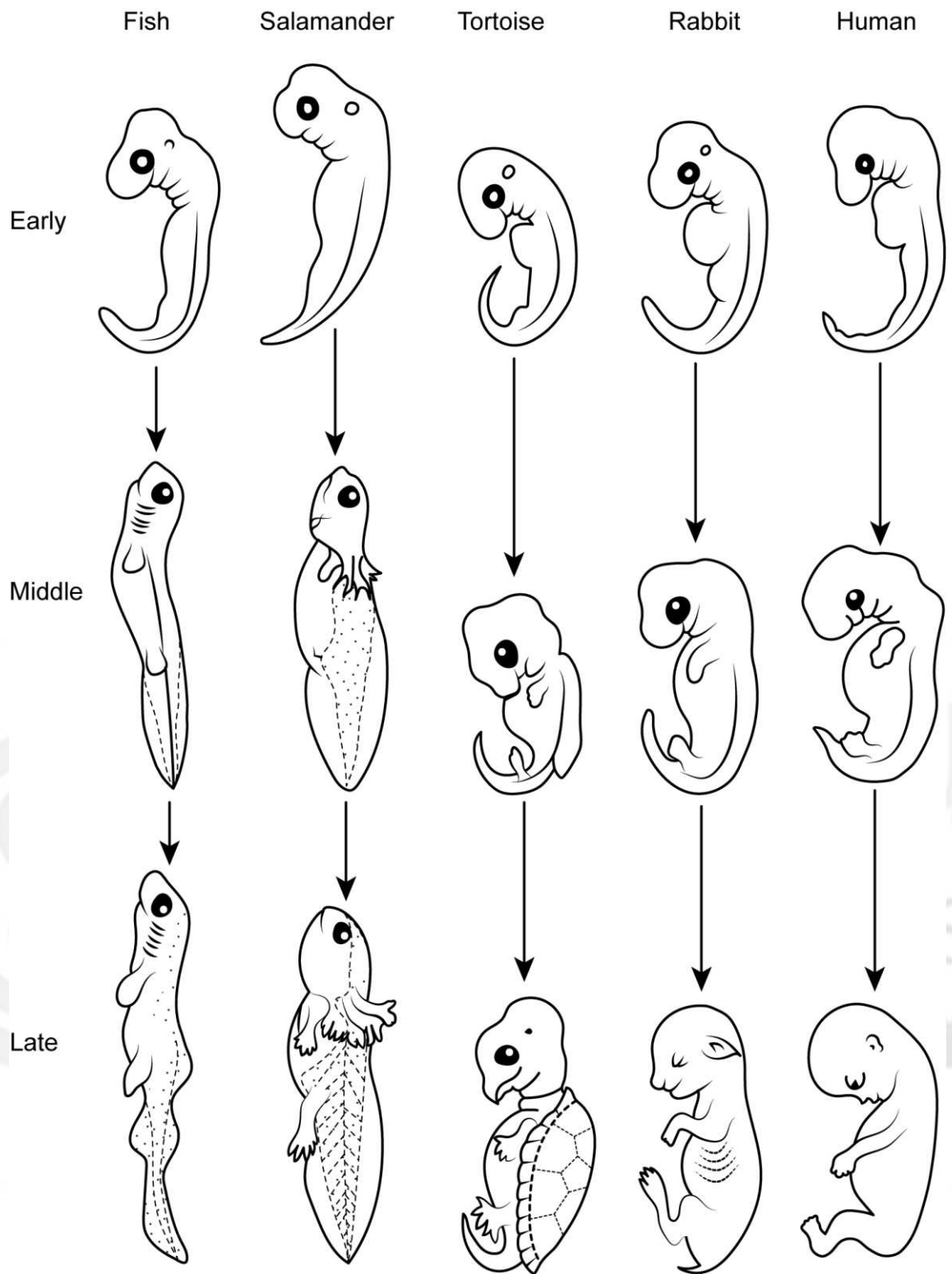


Fig. 12.13: Embryos of series of vertebrates compared at three stages in development. The series has been used as evidence for recapitulation.

In plants, recapitulation is not so evident as their embryology is much simpler, yet good examples are available. *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. 12.14, 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.

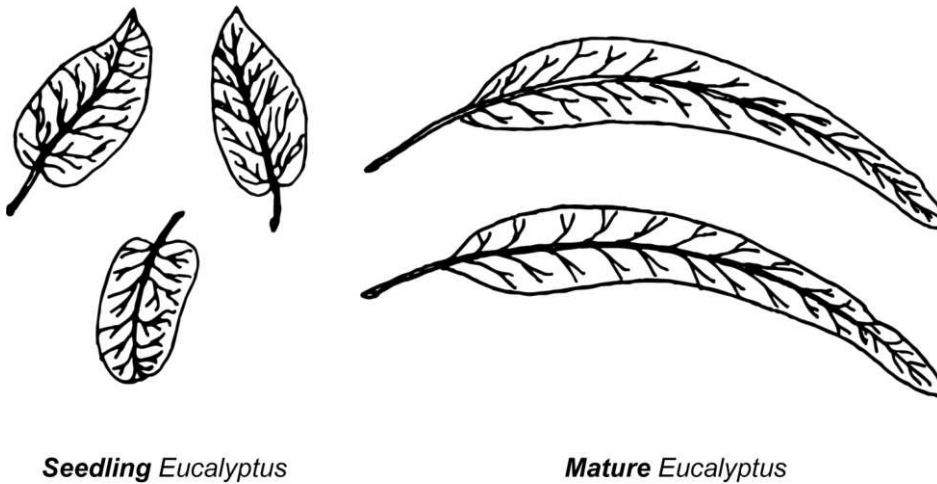


Fig. 12.14: The mature *Eucalyptus* plant exhibits long narrow leaves. The seedlings have leaves similar to those of less specialised trees.

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.

12.5.2 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

12.6 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.

12.6.1 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 animals are 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.

12.6.2 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.

Serum is the fluid portion of blood that remains after clotting has been allowed to take place and consists of a mixture of proteins.

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.

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. 12.15, 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.

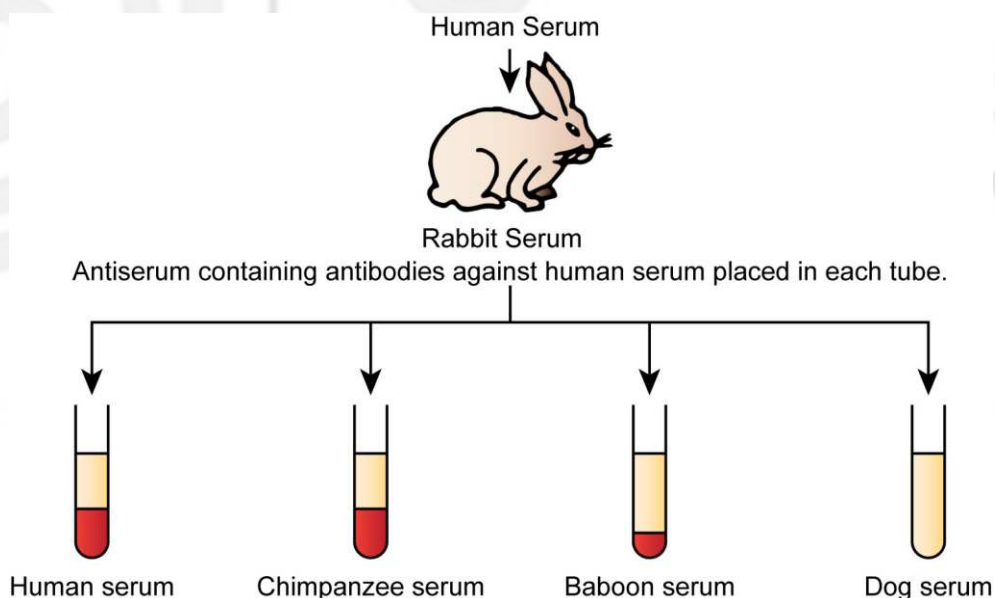


Fig. 12.15: Principles of antigen-antibody reaction test (precipitin test) used to establish the animal relationships. Antigen antibody reaction will be more intense in closely related species compared to distantly related.

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.

Cytochrome 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 40 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 cytochrome C in all these life forms indicates the common ancestry. You can see in Fig. 12.16. 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.

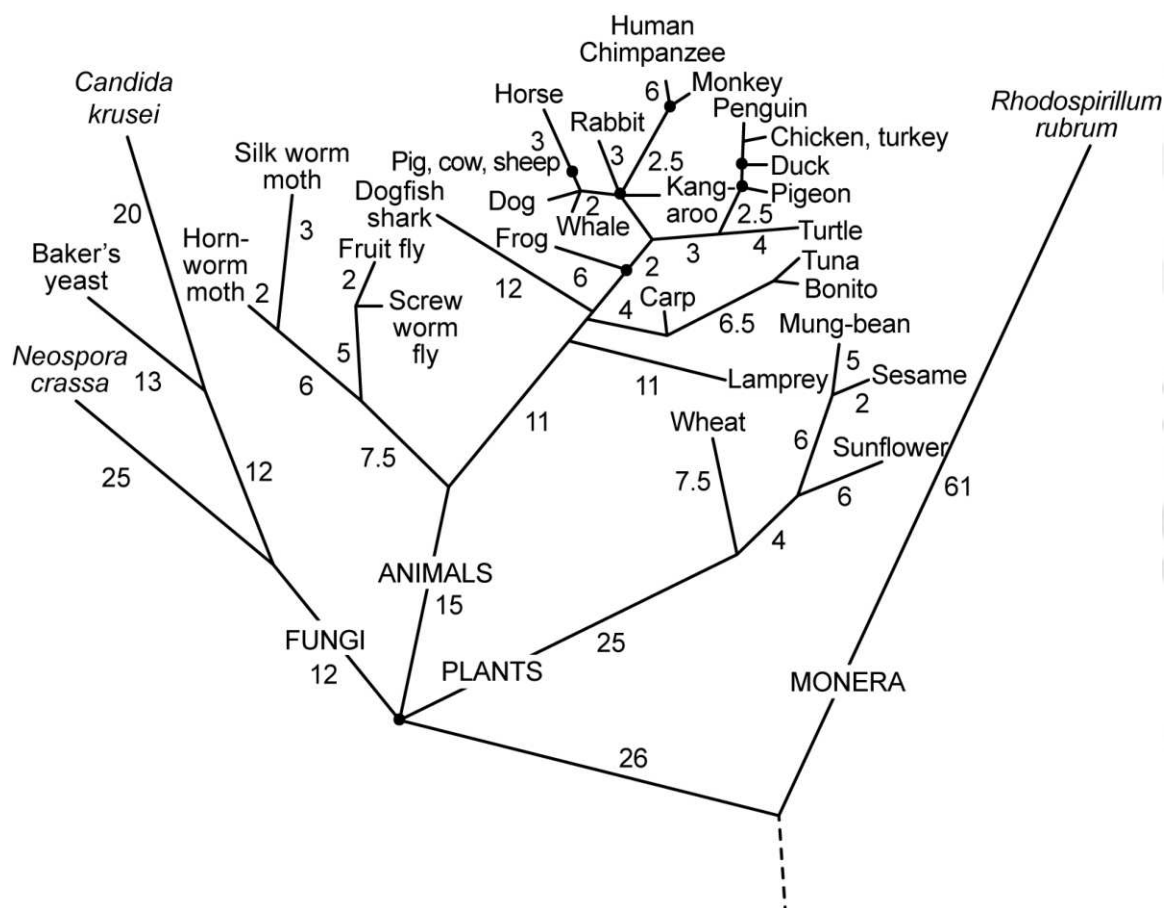


Fig. 12.16: Evolutionary tree of the species based on the structure of cytochrome C in various organisms. Numbers indicate the changes in the percentage of amino acid composition.

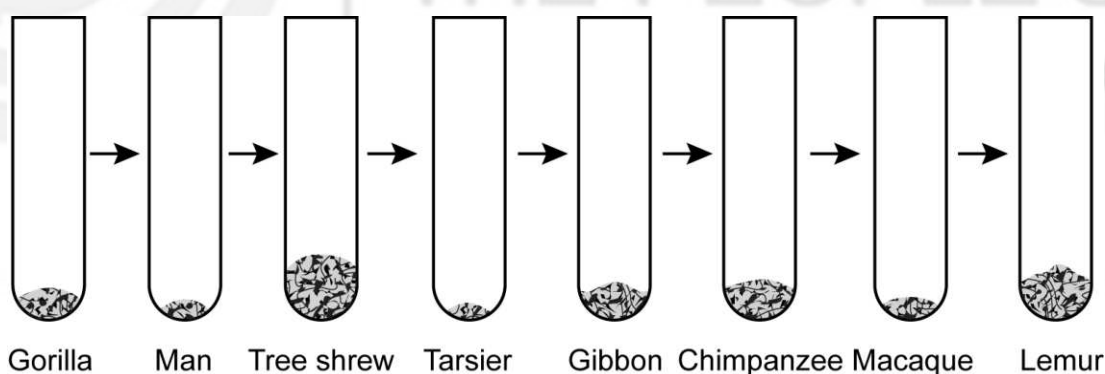
The other method in biochemical studies is **nucleic acid hybridisation** to trace molecular phylogeny. In this method DNA is extracted from a test species, say a human volunteer. The double stranded molecule is then separated into single strands by heating. These single strands are then trapped into 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 between 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?
- 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?
- 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. Interpret the following data.



12.7 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 various 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 for 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.

12.8 TERMINAL QUESTIONS

1. Do you think that fossil record is incomplete? If so justify your answer with examples.
2. Explain with the help of an example, why there is a marked discontinuity in the geographic distribution of some species.
3. The presence of vestigial vermiform appendix in humans provides evidence for evolution. Explain briefly how?
4. What is the major criticism of Haeckel's law?
5. Outline the major steps involved in a precipitin test.

12.9 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) pronephric
 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 fossil *Nyssa* (Refer to Section 12.3.2).
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.



EVOLUTIONARY CHANGE: NATURAL SELECTION

Structure

13.1	Introduction	Action of Natural Selection in Changing Environments (Directional Selection)
	Objectives	
13.2	The Basis for Natural Selection	Action of Natural Selection in Heterogenous Environments (Disruptive Selection)
	The Prodigality of Nature	
	Factors the Limit the Reproductive Potential	13.6 Sexual Selection
	Variability in Populations	13.7 Kin and Group Selection
	Natural Selection	Kin Selection
13.3	Sources and Expression of Variability	Group Selection
	Sources of Variability	13.8 Summary
	Expression of Variability	13.9 Terminal Questions
		13.10 Answers
13.4	Concept of Fitness	
13.5	Natural Selection Under Different Environmental Conditions	
	Action of Natural Selection in Uniform Environments (Normalising Selection)	

13.1 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.

13.2 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 argument 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.

13.2.1 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.

13.2.2 Factors the Limit the Reproductive Potential

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 logarithmic 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 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. 13.1). 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 size in animals, as mentioned earlier can be limited by food supply. Here the number of individuals, increase 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.

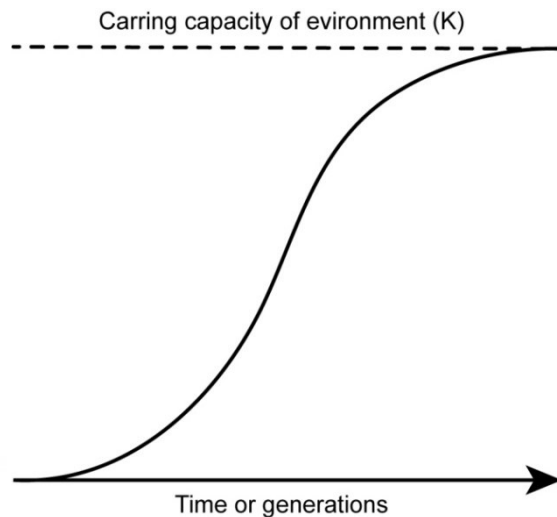


Fig. 13.1: The graph showing the sigmoid growth curve of population.

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 “mature 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.

13.2.3 Variability in Population

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

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.

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 and so forth. Sweet peas may have either red flowers or white ones; *Drosophila* 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 and genetic recombination. Also the subtle effects of environment add another dimension to the variability of traits in natural populations. An often 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.

13.2.4 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 a 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 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 $(p + q)^2$; 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 frequencies. 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 SAQ 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:

1.	Darwin and Wallace were the coauthors of the book 'Origin of Species'.	()
2.	It was Dobzhansky who said that 'nothing in biology makes sense except in the light of evolution'.	()
3.	Variations are rare in nature.	()
4.	By 'struggle for existence', Darwin meant fighting among the individuals of a species with weapons.	()
5.	One way to describe natural selection is that it refers to changes in gene frequencies in a population.	()
6.	Adaptations evolve because of the interaction between the genotype and environment.	()

13.3 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 absence 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.

13.3.1 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.

Mutations

The term mutation is used to designate the process by which changes arise in the genetic material. There are two categories of mutations. (1) Chromosomal mutations which affect the number of chromosomes 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:

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*: When one or more chromosomes of a normal set may be lacking or present in excess it is called Aneuploidy. 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.

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.

13.3.2 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 roan 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. 13.2. Individuals who are homozygous (HbS/HbS) for the gene usually die early in life. In heterozygotes (HbA/HbS) some proportion of red cells lyses periodically but this does not cause any serious harm to the individual and in any case the survival is not affected.

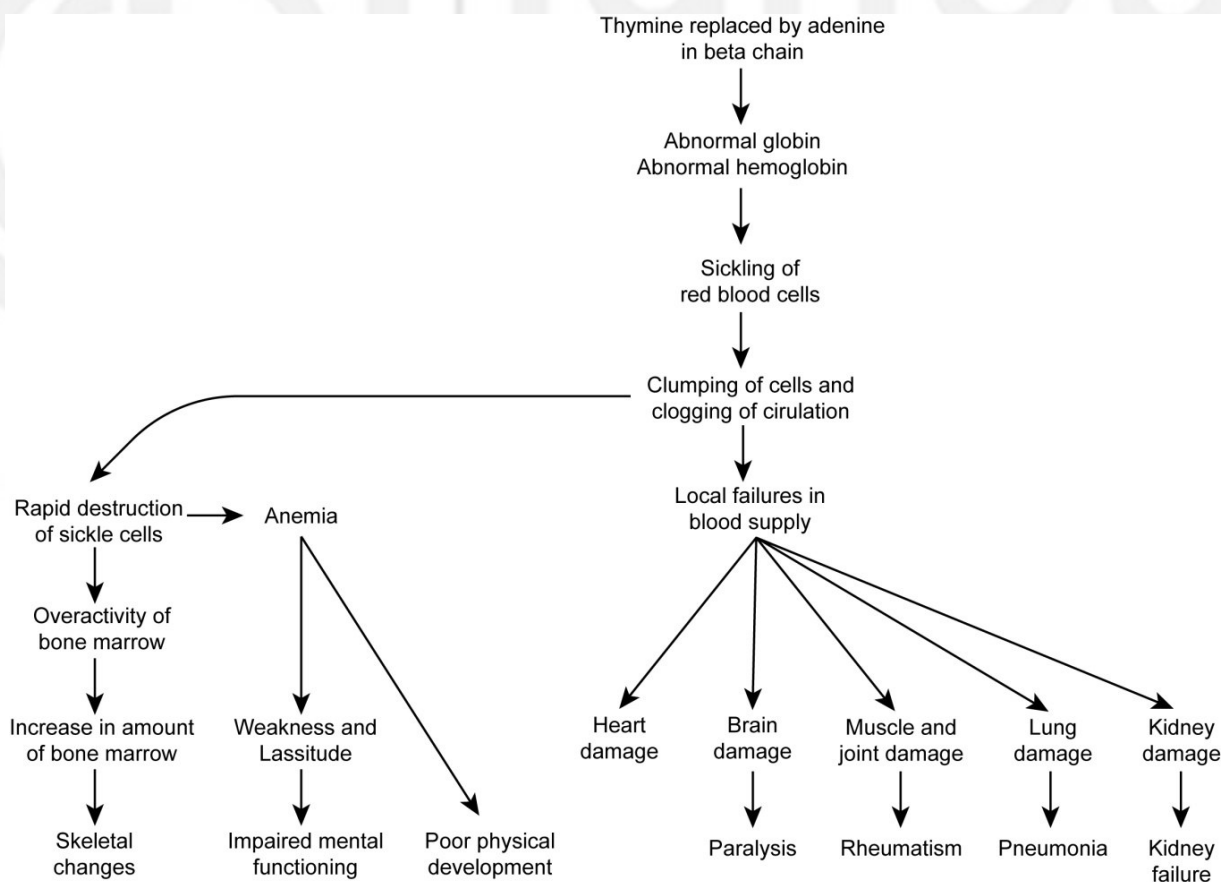


Fig. 13.2: Effects of sickle cell anaemia. The figure shows that a substitution of a nitrogenous base by another, triggers a variety of responses that nearly affect several aspects of organism's physiology.

In other mammals sickle cells do appear in population, but do not lead to the lyses 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 lyses 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 SAQ.

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, ...
-

13.4 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 13.1 explains to you the method of calculating the fitness value for the various genotypes.

Table 13.1: 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 2 nd 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 coefficients = $(1 - w)$	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 13.1 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.

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.

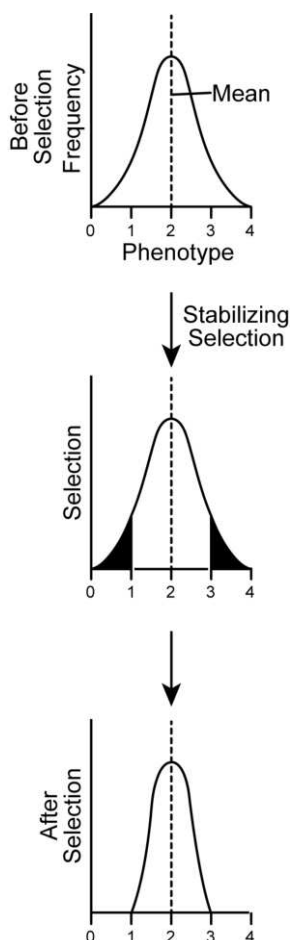


Fig. 13.3: Normalising selection a) Before selection the population has a normal distribution of individuals for a specific trait. You may observe that more individuals in the population has a mean measurement (dotted line) for the trait. b) Selection acts on individuals with extremes of measurements (shaded areas). c) As a result, the variability of the population has narrowed but the mean has remained the same.

13.5 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.

13.5.1 Action of Natural Selection in Uniform Environments (Normalising Selection)

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. 13.3a. As stated earlier, normalising selection occurs when individuals with intermediate phenotypes are favoured and those with extremes are under selection pressure (13.3b). 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. 13.3c). 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.

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 pseudoobscura*. 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 artificial 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. 13.4.

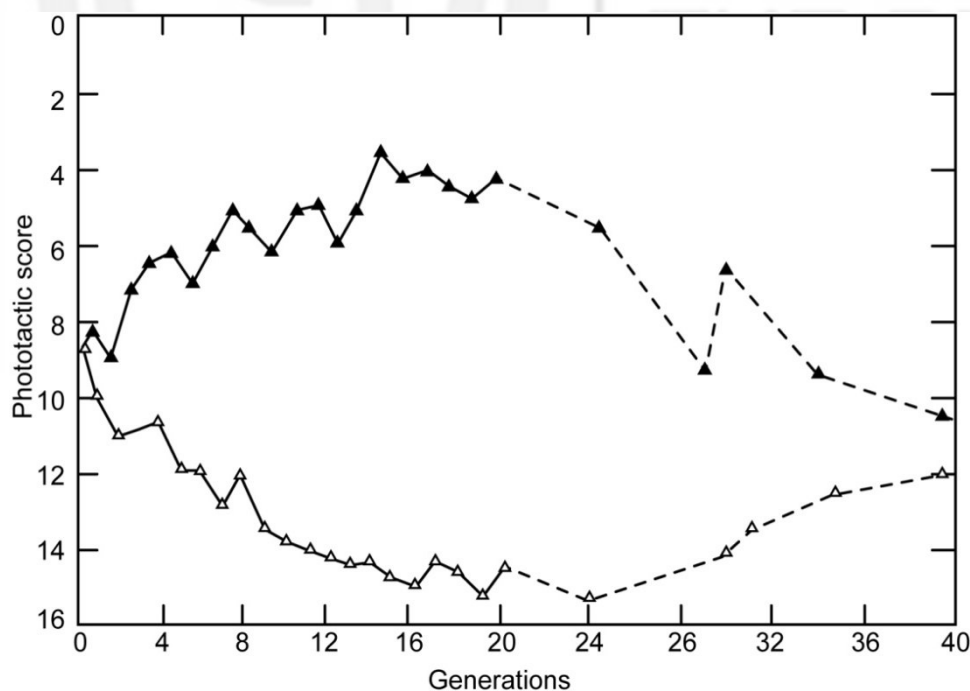


Fig. 13.4: Artificial selection for positive and negative phototaxis followed by normalizing natural selection in laboratory population of *Drosophila pseudoobscura*. Artificial selection for 20 generations is successful for both negative (light triangle) and positive (dark triangles) phototaxis. When the artificial selection is stopped after generation 20, natural selection favours a mean value once again.

The above two examples 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.

13.5.2 Action of Natural Selection in Changing Environments (Directional Selection)

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. 13.5b). This in turn shifts the mean of the trait to a new favoured extreme (13.5c). 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.

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 the 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 directional selection eliminates those insects from the population which are more or 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.

Industrial Melanism

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.

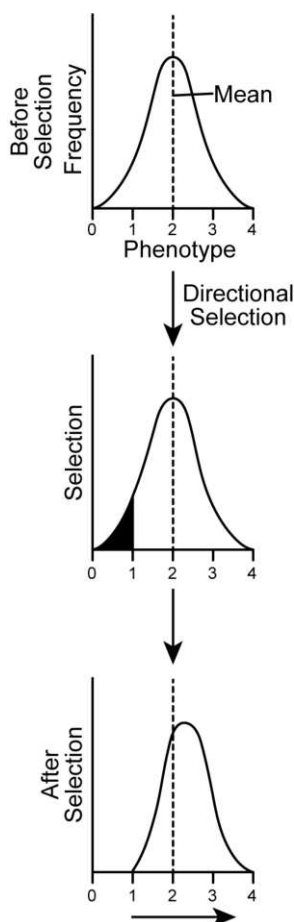


Fig. 13.5: Directional selection. a) Distribution of the population prior to selection. b) Due to change in the environment, Selection weeds out individuals from the two ends of the curve unequally (shaded areas indicates the individuals on whom selection acts). c) The mean value of the trait is shifted to a new favoured extreme.

The peppered moths *Biston betularia* occur in two forms, the melanic and non-melanic. As shown in Fig. 13.6 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 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. 13.6). 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 preyed 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 13.2) 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.

"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).

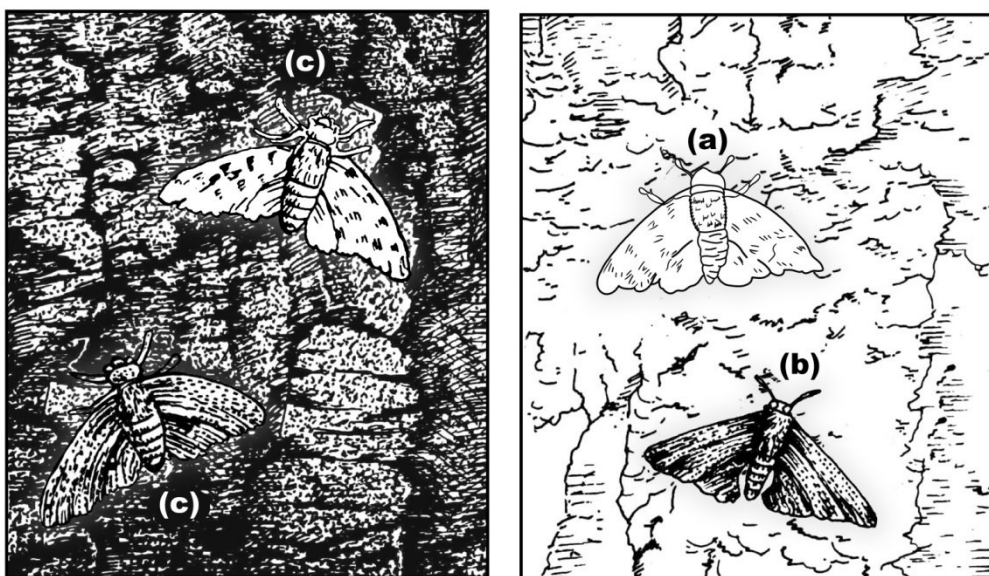


Fig. 13.6: Industrial melanism in *B. betularia*: a) non-melanic on lichen covered tree; b) melanics on lichen covered tree; c) both melanics and non-melanics on soot-covered tree.

Table 13.2: The results of the marking and recapturing experiments, of *B. betularia* in two different localities (Based on Ford 1964).

	Typical Form		Carboniria
Unpolluted Woodland	Released	496	473
	Recaptured	62 (12.5%)	30 (6.3%)
Soot-polluted Woodland	Released	137	447
	Recaptured	34 (16%)	154 (34%)

“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 196 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)

Biology Education
(Macmillan India) 7
(4), 248-250.

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.

SAQ 3

Fill in the blanks:

- Natural selection always aims at those alleles which are ill-adapted to environment.
- Biston betularia* occurs in two forms, the and the
- After the commencement of, melanic forms in numbers and non-melanic forms were becoming
- Industrial melanism is a case in which the favoured a specific character namely
- is one type of natural selection operating when the organism have to adapt themselves to a changing environment.
- favours an allele already well adapted to the environment by eliminating marked changes from it.

13.5.3 Action of Natural Selection of Heterogeneous Environments (Disruptive Selection)

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 13.7, the different sub-environments come to be occupied by different genotypes and such an occupation would be as complete and efficient as possible.

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 fertilization could occur between resistant and non-resistant varieties, genetic differentiation is maintained because of the inability of non-resistant seedlings to grow in contaminated 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.

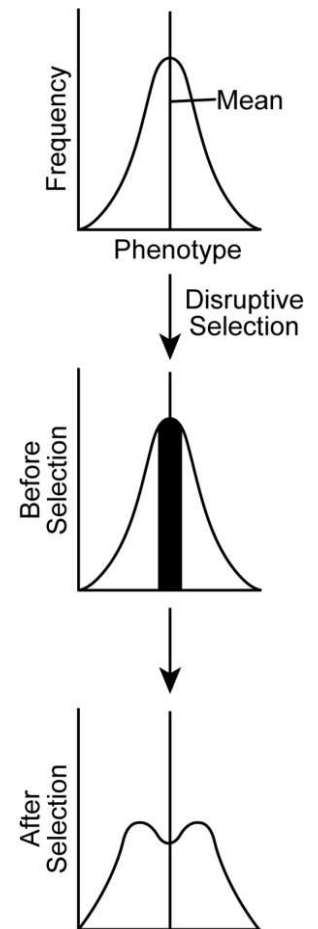


Fig. 13.7: Disruptive selection

- Distribution of the population prior to selection.**
- Selection acts against intermediate phenotypes and favours both extremes, (shaded area indicates the action of selection on individuals with intermediate traits).**
- Two distinct neighbouring populations each with its own mean is produced.**

SAQ 4

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.

13.6 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 *Eupkctus 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 an adaptive advantage on the males.

While discussing sexual selection, one question that is often raised is, will an extreme specialisation of any character lead to the extinction of the species? In **Anderson's** 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 among them having extreme development of the tail. We mentioned earlier that conspicuous 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 possibly result in the extinction of the species. R.A. Fisher termed this kind of selection process as runaway selection.

SAQ 5

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.
- 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.
- iii) Extreme specialization of character may reduce the fitness of the individual to a given environment and might possibly result in the extinction of a species.

13.7 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 any way contribute to the reproductive success of the species, the chances are it may be eliminated from the population. Certain critics of Darwin pointed out that the common altruistic behaviour of individuals provided evidence contrary to the theory of natural selection. Whether it is so or not, will be discussed in the following subsections.

13.7.1 Kin Selection

Before we proceed to discuss kin selection we should define the term altruism. It refers to the behaviour pattern of an individual in the population for the benefit of 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 of the flock or a honey bee stinging an intruder in order to defend its hive, are couple 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 bee usually dies. It should be obvious to you that the death of these individuals would result in the elimination of concerned genes for such behaviour. Critics of Darwin argue that although altruism as a behaviour pattern is an adaptation, the fact that altruists are victims of such behaviour refutes the concept that natural selection would 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 explain altruistic behaviour. The term kin selection could be equated to natural selection when we are considering the kin or relatives of an individual. For instance a mother expending energy suckling or caring for her children, only ensures the reproductive success of her own genes through her progeny. Kin selection essentially favours such altruistic behaviour when the risk taken or energy spent by an individual is more than compensated by the benefits accrued by the relatives.

Let us look at kin selection from another point of view. A parent has more than two 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 variety 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.

13.7.2 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 6

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, ...

13.8 SUMMARY

Let us summarise what you have learnt in the Unit:

- 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 combinations 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. Various terms 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.

- The example of industrial melanism provides an excellent insight into the operation of natural selection under natural conditions during our own life time.
- The theory of sexual selection states that competition among males for mates had led to an evolution of characters that are attractive to the female counterparts.
- And that 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 does not contradict the theory of natural selection. Contrarily the kin and group selection theory form the genetic basis of Sociobiology.

13.9 TERMINAL QUESTIONS

1. How do you justify the statement that natural selection is synonymous with differential reproduction?
2. If the heritable variability does not exist in populations, could there have been an evolutionary process?
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?
4. What is 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).
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 A₁ variant has optimal activity on the starch of beech tree leaves and the A₂ 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 or genotypes with willow digesting enzyme was higher in collections made at the “willow side”. How do you interpret the above situation?
6. Industrial melanism is an excellent model to demonstrate the natural selection in action. Analyse the above statement critically.
7. What do you understand by sexual selection. Illustrate your answer with a suitable example.
8. How would you answer the criticism against Darwinism that common altruistic behaviour of individuals provided evidence contrary to the theory of natural selection?

13.10 ANSWERS

Self Assessments Questions

1. i) False, ii) True, iii) False, iv) False, v) True, vi) True.
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
3. a) iii; b) iv; c) v; d) i; e) ii.
4. a) Elimination
b) Melanics, Non-melanics
c) Industrial revolution, increased, rarer
d) Selection, protective coloration
e) Directional selection
f) Stabilising selection
5. a) False, b) True, c) True.
6. a) Altruism, b) Natural Selection, c) Group Selection.

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 heterozygotes HbA/HbS at high frequencies. The two homozygotes are not favoured for the following reasons. The HbS/HbS genotype causes the sickle cell disease and the persons homozygous for HbS die early because of the **lysis** of erythrocytes. (Refer section 13.3.2), HbA/HbA homozygotes are susceptible to falciparum malaria. In heterozygotes 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.
- 6) 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.
- 7) 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. Anderson's study on widow birds is another example to show that female's choice of certain characters confers an adaptive advantage on males.

- 8) 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. In other words genes considered to be adaptive or favourable ones are eliminated, although natural selection is supposed to promote such favorable 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.

SUGGESTED READINGS

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ONLINE TOOLS AND WEB RESOURCES

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- <https://www.coursera.org/learn/genetics-evolution>
- <https://swayam.gov.in/courses/4062-environmental-biology-genetics-and-evolution>.

