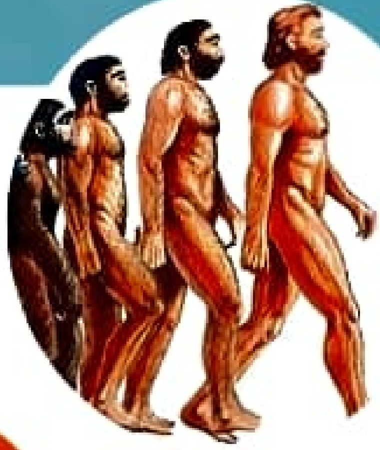
UNIT - II

6

CHAPTER

Evolution



"Each has his own tree of ancestors, but at the top of all sits probably arboreal"

Chapter Outline

Learning Objectives

- *Understands the evolution of life on earth.*
- *Gains knowledge on theories of evolution.*
- *Interprets evidences (anatomical, embryological and geological) of evolution.*
- *Learns the principles of biological evolution.*
- *Understands the importance of gene frequencies in a population.*
- *Studies the geological time scale.*

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The term evolution is used to describe heritable changes in one or more characteristics of a population of species from one generation to the other. The present state of mankind on earth is the outcome of three kinds of evolution - chemical, organic and social or cultural evolution.

Radiometric dating of meteorites yields an estimated age for the solar system and for earth as around 4.5 – 4.6 billion years. The new born earth remained inhospitable for at least few hundred millions years. At first it was too hot. This is because the collisions of the planetesimals that coalesced to form earth released much heat to melt the entire planet. Eventually outer surface of the earth cooled and solidified to form a crust. Water vapour released from the planet's interior cooled and condensed to form oceans. Hence origin of life can be reconstructed using indirect evidences. Consequently, biologists have turned to gather disparate bits of information and filling them together like pieces of jig saw puzzle. Many theories have been proposed to explain the origin of life. Few have been discussed in this chapter.

6.1 Origin of life – Evolution of life forms

Theory of special creation states that life was created by a supernatural power, respectfully referred to as "God". According to Hinduism, Lord Brahma created the Earth. Christianity, Islam and most religions believe that God created the universe, the plants and the animals.

According to **the theory of spontaneous generation** or Abiogenesis, living organisms originated from non-living materials and occurred through stepwise chemical and molecular evolution over millions of years. Thomas Huxley coined the term abiogenesis.

Big bang theory explains the origin of universe as a singular huge explosion in physical terms. The primitive earth had no proper atmosphere, but consisted of ammonia, methane, hydrogen and water vapour. The temperature of the earth was extremely high. UV rays from the sun split up water molecules into hydrogen and oxygen. Gradually the temperature cooled and the water vapour condensed to form rain. Rain water filled all the depressions to form water bodies. Ammonia and methane in the atmosphere combined with oxygen to form carbon-dioxide and other gases.

Coacervates (large colloidal particles that precipitate out in aqueous medium) are the first pre-cells which gradually transformed into living cells.

According to the **theory of biogenesis** life arose from pre-existing life. The term biogenesis also refers to the biochemical process of production of living organisms This term was coined by Henry Bastian.

According to the **theory of chemical evolution** primitive organisms in the primordial environment of the earth evolved spontaneously from inorganic substances and physical forces such, as lightning, UV radiations, volcanic activities, etc..., Oparin (1924) suggested that the organic compounds could have undergone a series of reactions leading to more complex molecules. He proposed that the molecules formed colloidal aggregates or 'coacervates' in an aqueous environment. The coacervates were able to absorb and assimilate organic compounds from the environment. Haldane (1929) proposed that the primordial sea served as a vast chemical laboratory powered by solar energy. The atmosphere was oxygen free and the combination of CO_2, NH_3 and UV radiations gave rise to organic compounds. The sea became a 'hot' dilute soup containing large populations of organic monomers and polymers. They envisaged that groups of monomers and polymers acquired lipid membranes and further developed into the first living cell. Haldane coined the term prebiotic soup and this became the powerful symbol of the Oparin-Haldane view on the origin of life (1924-1929).

Oparin and Haldane independently suggested that if the primitive atmosphere was reducing and if there was appropriate supply of energy such as lightning or UV light then a wide range of organic compounds can be synthesized.

6.2 Geological time scale

The duration of the earth's history has been divided into **eras** that include the **Paleozoic, Mesozoic,** and **Cenozoic.** Recent eras are further divided into **periods,** which are split into **epochs.** The geological time scale with the duration of the eras and periods with the dominant forms of life is shown in **Table 6.1.**

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The Paleozoic era is characterized by abundance of fossils of marine invertebrates. Towards the later half, other vertebrates (marine and terrestrial) except birds and mammals appeared. The six periods of Paleozoic era in order from oldest to the youngest are Cambrian (Age of invertebrates), Ordovician (fresh water fishes, Ostracoderms, various types of Molluscs), Silurian (origin of fishes), Devonian (Age of fishes, many types of fishes such as lung fishes, lobe finned fishes and ray finned fishes), Mississippian (earliest amphibians, Echinoderms), Pennsylvanian (earliest reptiles), Permian (mammal like reptiles).

Mesozoic era (dominance of reptiles) called the **Golden age of reptiles**, is divided into three periods namely, Triassic (origin of egg laying mammals),

Table 6.1 Geological Time Scale

ERA	YEARS IN MILLION	PERIOD	EPOCH	FAUNA	FLORA
Cenozoic	1	Quaternary	Recent (Holocene)	Age of Mammals	Angiosperms Monocotyledons
	6		Pleistocene	Age of Human beings	Age of Angiosperms - Dicotyledons
	10	Tertiary	Pliocene	Human evolution	
	15		Miocene	Mammals and birds	
	20		Oligocene		
	100		Eocene		
			Paleocene		
Mesozoic	125	Cretaceous		(Golden age of Reptiles) Rise of Dinesurs	Sphenopsides, Ginkgos, Gnetales, (Dicotyledons)
	150	Jurassic			Herbaceous lycopods, Ferns, Conifers, Cycads
	180	Triassic			
Paleozoic	205	Permian		Mammal like reptiles	Arborescent lycopods
	230	Carboniferous	Pennsylvanian	Earliest reptiles	Seed ferns and Bryophytes
	255		Mississippian	Earliest Amphibians and abundant Echinoderms	
	315	Devonian		Age of fishes	Progymnosperms
	350	Silurian		Earliest fishes and land invertebrates	Zosterophyllum
	430	Ordovician		Dominance of invertebrates	Appearance of first land plants
	510	Cambrian		Fossil invertebrates	Origin of algae
Precambrian	3000	Upper		Multicellular organisms	
		Middle		Appearance of eukaryotes	
		Lower			Planktons prokaryotes

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Jurassic (Dinosaurs were dominant on the earth, fossil bird – ***Archaeopteryx***) and Cretaceous (extinction of toothed birds and dinosaurs, emergence of modern birds).

Cenozoic era (Age of mammals) is subdivided into two periods namely Tertiary and Quaternary. Tertiary period is characterized by abundant mammalian fauna. This period is subdivided into five epochs namely, Paleocene (placental mammals, Eocene (Monotremes except duck billed *Platypus* and *Echidna*, hoofed mammals and carnivores), Oligocene (higher placental mammals appeared), Miocene (origin of first man like apes) and Pliocene (origin of man from man like apes).Quaternary period witnessed decline of mammals and beginning of human social life.

The age of fossils can be determined using two methods namely, relative dating and absolute dating. **Relative dating** is used to determine a fossil by comparing it to similar rocks and fossils of known age. **Absolute dating** is used to determine the precise age of a fossil by using radiometric dating to measure the decay of isotopes.

6.3 Biological evolution

Formation of protobionts

Abiotically produced molecules can spontaneously self assemble into droplets that enclose a watery solution and maintain a chemical environment different from their surroundings. Scientists call these spheres as 'protobionts'. Liposomes are lipids in a solution that can self assemble into a lipid bilayer. Some of the proteins inside the liposomes acquired the properties of enzymes resulting in fast multiplication of molecules.

The coacervates with nucleoprotein and nutrients had a limiting surface membrane that had the characters of a virus or free living genes. Sub sequently number of genes united to form 'proto viruses' somewhat similar to present day viruses. Two major cell types that appeared during this time were significant. One form of the earliest cell contained clumps of nucleoproteins embedded in the cell substance. Such cells were similar to the Monera. They are considered as ancestral to the modern bacteria and blue green algae. The other form of earliest cells contained nucleoprotein clumps that condensed into a central mass surrounded by a thin membrane. This membrane separated nucleoproteins from the cell substances. Such cells were referred to as Protista. When the natural sources of food in the ocean declined in course of time the ancestors of Monera and Protista had to evolve different methods for food procurement. These may be summarized as parasitism, saprophytism, predator or animalism and chemosynthesis or photosynthesis. When the number of photosynthetic organisms increased there was an increase in the free O_2 in the sea and atmosphere.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$
$$4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$$

The atmospheric oxygen combined with methane and ammonia to form CO_2 and free nitrogen. The presence of the free O_2 brought about the evolution of aerobic respiration which could yield large amounts of energy by oxidation of food stuffs. Thus Prokaryotes and Eukaryotes evolved.

Experimental approach to the origin of life

Urey and Miller (1953), paved way for understanding the possible synthesis of organic compounds that led to the appearance of living organisms is depicted in the **Fig. 6.1.** In their experiment, a mixture of gases was allowed to circulate over electric discharge from an tungsten electrode. A small flask was kept boiling and the steam emanating from it was made to mix with the mixture of gases (ammonia, methane and hydrogen) in the large chamber that was connected to the boiling water. The steam condensed to form water

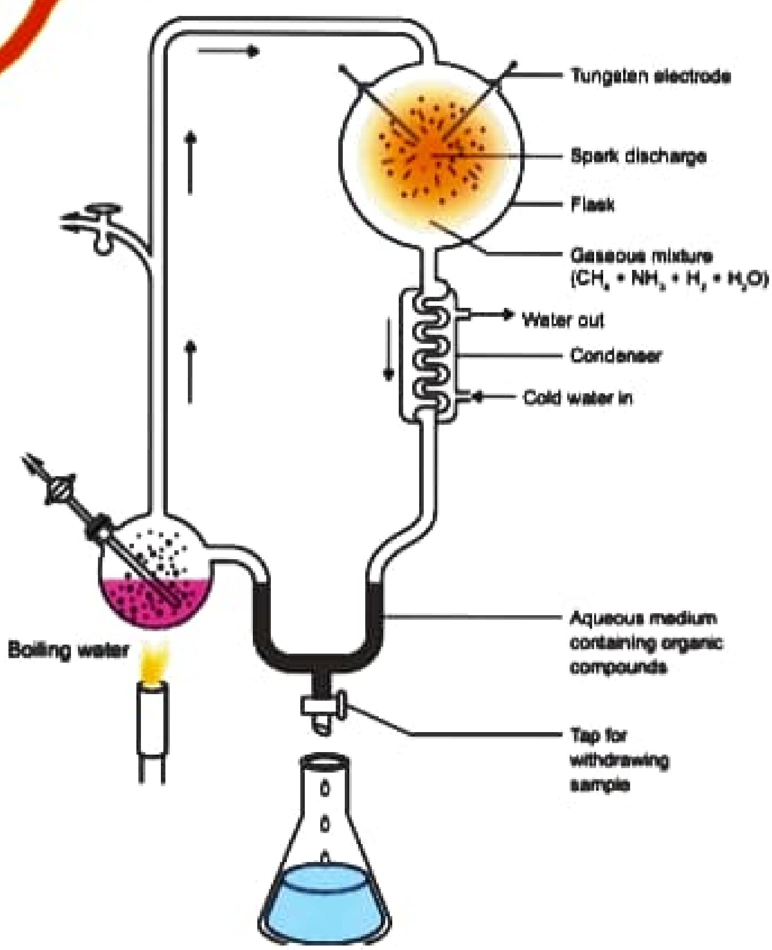

Fig. 6.1 Diagrammatic representation of Urey-Miller's experiment

which ran down the 'U' tube. Experiment was conducted continuously for a week and the liquid was analysed. Glycine, alanine, beta alanine and aspartic acid were identified. Thus Miller's experiments had an insight as to the possibility of abiogenetic synthesis of large amount of variety of organic compounds in nature from a mixture of sample gases in which the only source of carbon was methane. Later in similar experiments, formation of all types of amino acids, and nitrogen bases were noticed.

6.4 Evidences for biological evolution

6.4.1 Paleontological evidences

Paleontology is the study of prehistoric life through fossils. Fossils are described as the true witnesses of evolution or documents of various geological strata of evolution. Fossilization is the process by which plant and animal remains are preserved in sedimentary rocks. They fall under three main categories.

i) Actual remains – The original hard parts such as bones, teeth or shells are preserved as such in the earth's atmosphere. This is the most common method of fossilization. When marine animals die, their hard parts such as bones, shells etc., are covered with sediments and are protected from further deterioration. They get preserved as such as they are preserved in vast ocean; the salinity in them prevents decay. The sediments became hardened to form definite layers or strata. For example, Woolly Mammoth that lived 22 thousand years ago were preserved in the frozen coast of Siberia as such. Several human beings and animals living in the ancient city of Pompeii were preserved intact by volcanic ash which gushed out from Mount Vesuvius.

ii) Petrifaction – When animals die the original portion of their body may be replaced molecule for molecule by minerals and the original substance being lost through disintegration. This method of fossilization is called petrifaction. The principle minerals involved in this type fossilization are iron pyrites, silica, calcium carbonate and bicarbonates of calcium and magnesium.

iii) Natural moulds and casts – Even after disintegration, the body of an animal might leave indelible impression on the soft mud which later becomes hardened into stones. Such impressions are called moulds. The cavities of the moulds may get filled up

theory of recapitulation" which states that the life history of an individual (ontogeny) briefly repeats or recapitulates the evolutionary history of the race (phylogeny). In other words **"Ontogeny recapitulates Phylogeny"**. The embryonic stages of a higher animal resemble the adult stage of its ancestors. Appearance of pharyngeal gill slits, yolk sac and the appearance of tail in human embryos are some of the examples **(Fig. 6.4)**. The biogenetic law is not universal and it is now thought that animals do not recapitulate the adult stage of any ancestors. The human embryo recapitulates the embryonic history and not the adult history of the organisms.

The comparative study of the embryo of different animals shows structural similarities among themselves. The embryos of fish, salamander, tortoise, chick and human start life as a single cell, the zygote, and undergo cleavage to produce the blastula, change to gastrula and are triploblastic. This indicates that all the above said animals have evolved from a common ancestor.

Molecular evidences

Molecular evolution is the process of change in the sequence composition of molecules such as DNA, RNA and proteins across generations. It uses principles of evolutionary biology and population genetics to explain patterns in the changes of molecules.

One of the most useful advancement in the development of molecular biology is proteins and other molecules that control life processes are conserved among species. A slight change that occurs over time in these conserved molecules (DNA, RNA and protein) are often called molecular clocks. Molecules that have been used to study evolution are cytochrome c (respiratory pathway) and rRNA (protein synthesis).

6.5 Theories of biological evolution

6.5.1 Lamarck's theory

Jean Baptiste de Lamarck, was the first to postulate the theory of evolution in his famous book '**Philosophie Zoologique**' in the year **1809**. The two principles of Lamarckian theory are:

i. The theory of use and disuse - Organs that are used often will increase in size and those that are not used will degenerate. Neck in giraffe is an example of use and absence of limbs in snakes is an example for disuse theory.

ii. The theory of inheritance of acquired characters - Characters that are developed during the life time of an organism are called acquired characters and these are then inherited.

The main objection to Lamarckism

Lamarck's "Theory of Acquired characters" was disproved by **August Weismann** who conducted experiments on mice for twenty generations by cutting their tails and breeding them. All mice born were with tail. Weismann proved his germplasm theory that change in the somatoplasm will not be transferred to the next generation but changes in the germplasm will be inherited.

Neo-Lamarckism

The followers of Lamarck (Neo-Lamarckists) like **Cope, Osborn, Packard** and **Spencer** tried to explain Lamarck's theory on a more scientific basis. They considered that adaptations are universal. Organisms acquire new structures due to their adaptations to the changed environmental conditions. They argued that external conditions stimulate the somatic cells to produce certain 'secretions' which reach the sex cells through the blood and bring about variations in the offspring.

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6.5.2 Darwin's theory of Natural Selection

Charles Darwin explained the theory of evolution in his book **'The Origin of Species by Natural Selection'**. During his journey around the Earth, he made extensive observations of plants and animals. He noted a huge variety and remarkable similarities among organisms and their adaptive features to cope up to their environment. He proved that fittest organisms can survive and leave more progenies than the unfit ones through natural selection.

Darwin's theory was based on several facts, observations and influences. They are:

1. **Over production (or) prodigality of production**

All living organisms increase their population in larger number. For example, Salmon fish produces about 28 million eggs during breeding season and if all of them hatch, the seas would be filled with salmon in few generations. Elephant, the slowest breeder that can produce six young ones in its life time can produce 6 million descendants at the end of 750 years in the absence of any check.

2. **Struggle for existence**

Organisms struggle for food, space and mate. As these become a limiting factor, competition exists among the members of the population. Darwin denoted struggle for existence in three ways –

Intra specific struggle between the same species for food, space and mate.

Inter specific struggle with different species for food and space.

Struggle with the environment to cope with the climatic variations, flood, earthquakes, drought, etc.,

3. **Universal occurrence of variations**

No two individuals are alike. There are variations even in identical twins. Even the children born of the same parents differ in colour, height, behavior, etc., The useful variations found in an organism help them to overcome struggle and such variations are passed on to the next generation.

4. **Origin of species by Natural Selection**

According to Darwin, nature is the most powerful selective force. He compared origin of species by natural selection to a small isolated group. Darwin believed that the struggle for existence resulted in the survival of the fittest. Such organisms become better adapted to the changed environment.

Objections to Darwinism

Some objections raised against Darwinism were –

- Darwin failed to explain the mechanism of variation.
- Darwinism explains the survival of the fittest but not the arrival of the fittest.
- He focused on small fluctuating variations that are mostly non-heritable.
- He did not distinguish between somatic and germinal variations.
- He could not explain the occurrence of vestigial organs, over specialization of some organs like large tusks in extinct mammoths, oversized antlers in the extinct Irish deer, etc.,

Neo Darwinism

Neo Darwinism is the interpretation of Darwinian evolution through Natural Selection as it has been modified since it was proposed. New facts and discoveries about evolution have led to modifications of Darwinism and is supported by **Wallace, Heinrich, Haeckel, Weismann** and **Mendel**. This theory emphasizes the change in the frequency of genes in population arises due to mutation, variation, isolation and Natural selection.

6.5.3 Mutation theory

Hugo de Vries put forth the Mutation theory. Mutations are sudden random changes that occur in an organism that is not heritable. De Vries carried out his experiments in the Evening Primrose plant (*Oenothera lamarckiana*) and observed variations in them due to mutation.

According to de Vries, sudden and large variations were responsible for the origin of new species whereas Lamarck and Darwin believed in gradual accumulation of all variations as the causative factors in the origin of new species.

Hugo de Vries believed that Mutations are random and directionless, but Darwinian variations are small and directional.

Hugo de Vries believed that speciation are due to Mutation and called saltation (single step large Mutation).

Salient features of Mutation Theory

- Mutations or discontinuous variation are transmitted to other generations.
- In naturally breeding populations, mutations occur from time to time.
- There are no intermediate forms, as they are fully fledged.
- They are strictly subjected to natural selection.

6.5.4 Modern synthetic theory

Sewell Wright, Fisher, Mayer, Huxley, Dobzhansky, Simpson and Haeckel explained Natural Selection in the light of Post-Darwinian discoveries. According to this theory gene mutations, chromosomal mutations, genetic recombinations, natural selection and reproductive isolation are the five basic factors involved in the process of organic evolution.

i. **Gene mutation** refers to the changes in the structure of the gene. It is also called gene/point mutation. It alters the phenotype of an organism and produces variations in their offspring.

ii. **Chromosomal mutation** refers to the changes in the structure of chromosomes due to deletion, addition, duplication, inversion or translocation. This too alters the phenotype of an organism and produces variations in their offspring.

iii. **Genetic recombination** is due to crossing over of genes during meiosis. This brings about genetic variations in the individuals of the same species and leads to heritable variations.

iv. **Natural selection** does not produce any genetic variations but once such variations occur it favours some genetic changes while rejecting others (driving force of evolution).

v. **Reproductive isolation** helps in preventing interbreeding between related organisms.

6.5.5 Evolution by anthropogenic sources

Natural Selection (Industrial melanism)

Natural selection can be explained clearly through industrial melanism. Industrial melanism is a classical case of Natural selection exhibited by the peppered moth, *Biston betularia*. These were available in two colours, white and black. Before industrialization peppered moth both white and black coloured were common in England. Pre-industrialization witnessed white coloured background of the wall of the buildings hence the white coloured moths escaped from their predators. Post industrialization, the tree trunks became dark due to smoke and soot let out from the industries. The black moths camouflaged on the dark bark of the trees and the white moths were easily identified by their predators. Hence the dark coloured moth population was selected and their number increased when compared to the white moths. Nature offered positive selection pressure to the black coloured moths. The above proof shows that in a population, organisms that can adapt will survive and produce more progenies resulting in increase in population through natural selection.

Artificial selection is a byproduct of human exploitation of forests, oceans and fisheries or the use of pesticides, herbicides or drugs. For hundreds of years humans have selected various types of dogs, all of which are variants of the single species of dog. If human beings can produce new varieties in short period, then **"nature"** with its vast resources and long duration can easily produce new species by selection.

6.5.6 Adaptive Radiation

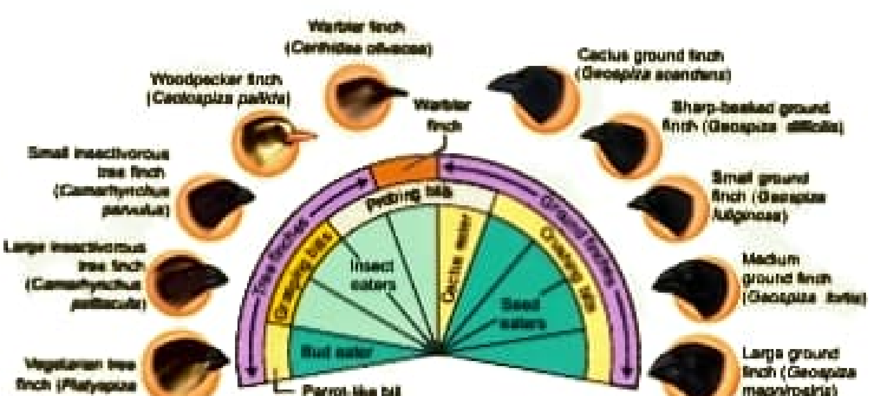
The evolutionary process which produces new species diverged from a single ancestral form becomes adapted to newly invaded habitats is called adaptive radiation. Adaptive radiations are best exemplified in closely related groups that have evolved in relatively short time. Darwin's finches and Australian marsupials are best examples for adaptive radiation. When more than one adaptive radiation occurs in an isolated geographical area, having the same structural and functional similarity is referred to as convergent evolution.

Darwin's finches

Their common ancestor arrived on the Galapagos about 2 million years ago. During that time, Darwin's finches have evolved into 14 recognized species differing in body size, beak shape and feeding behavior. Changes in the size and form of the beak have enabled different species to utilize different food resources such as insects, seeds, nectar from cactus flowers and blood from iguanas, all driven by Natural selection. **Fig. 6.5** represents some of the finches observed by Darwin. Genetic variation in the ALX1 gene in the DNA of Darwin finches is associated with variation in the beak shape. Mild mutation in the ALX1 gene leads to phenotypic change in the shape of the beak of the Darwin finches.

Marsupials in Australia and placental mammals in North America are two subclasses of mammals they have adapted in similar way to a particular food resource, locomotory skill or climate. They were separated from the common ancestor more than 100 million year ago and each lineage continued to evolve independently. Despite temporal and geographical separation, marsupials in Australia and placental mammals in North America have produced varieties of species living in similar habitats with similar ways of life. Their overall resemblance in shape, locomotory mode, feeding and foraging are superimposed upon different modes of reproduction. This feature reflects their distinctive evolutionary relationships.

Over 200 species of marsupials live in Australia along with many fewer species of placental mammals. The marsupials have undergone adaptive radiation to occupy the diverse habitats in Australia, just as the placental mammals have radiated across North America.



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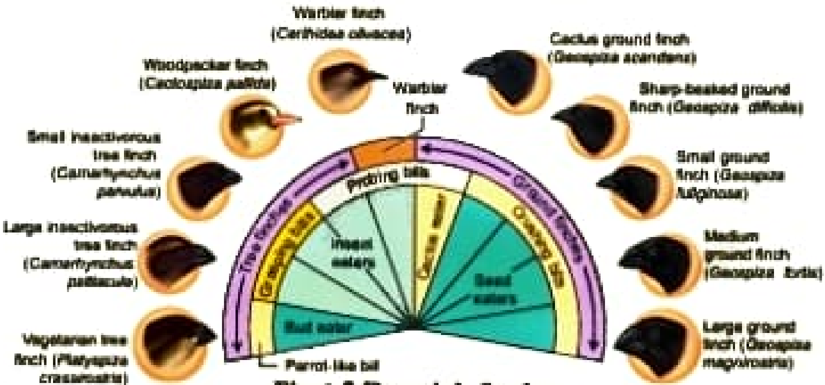

Fig 6.5 Darwin's finches

6.6.4 Mutation

Although mutation is the original source of all genetic variation, mutation rate for most organisms is low. Hence new mutations on an allele frequencies from one generation to the next is usually not large.

6.7 Hardy - Weinberg Principle

In nature, populations are usually evolving such as the grass in an open meadow, wolves in a forest and bacteria in a person's body are all natural populations. All of these populations are likely to be evolving some of their genes. Evolution does not mean that the population is moving towards perfection rather the population is changing its genetic makeup over generations. For example in a wolf population, there may be a shift in the frequency of a gene variant for black fur than grey fur. Sometimes, this type of change is due to natural selection or due to migration or due to random events.

First we will see the set of conditions required for a population not to evolve. Hardy of UK and Weinberg of Germany stated that the allele frequencies in a population are stable and are constant from generation to generation in the absence of gene flow, genetic drift, mutation, recombination and natural selection. If a population is in a state of Hardy Weinberg equilibrium, the frequencies of alleles and genotypes or sets of alleles in that population will remain same over generations. Evolution is a change in the allele frequencies in a population over time. Hence population in Hardy Weinberg is not evolving.

Suppose we have a large population of beetles, (infinitely large) and appear in two colours dark grey (black) and light grey, and their colour is determined by 'A' gene. 'AA' and 'Aa' beetles are dark grey and 'aa' beetles are light grey. In a population let's say that 'A' allele has frequency (p) of 0.3 and 'a' allele has a frequency (q) of 0.7. Then $p+q=1$.

If a population is in Hardy Weinberg equilibrium, the genotype frequency can be estimated by Hardy Weinberg equation. $(p + q)^2 = p^2 + 2pq + q^2$

p^2 = frequency of AA

$2pq$ = frequency of Aa

q^2 = frequency of aa

$p = 0.3, q = 0.7$ then,

$p^2 = (0.3)^2 = 0.09 = 9\ \%$ AA

$2pq = 2(0.3)\ (0.7) = 0.42 = 42\ \%$ Aa

$q^2 = (0.7)^2\ 0.49 = 49\ \%$ aa

Hence the beetle population appears to be in Hardy- Weinberg equilibrium. When the beetles in Hardy- Weinberg equilibrium reproduce, the allele and genotype frequency in the next generation would be: Let's assume that the frequency of 'A' and 'a' allele in the pool of gametes that make the next generation would be the same, then there would be no variation in the progeny. The genotype frequencies of the parent appears in the next generation. (i.e. 9% AA, 42% Aa and 49% aa).

If we assume that the beetles mate randomly (selection of male gamete and female gamete in the pool of gametes), the probability of getting the offspring genotype depends on the genotype of the combining parental gametes.

Hardy Weinberg's assumptions include

No mutation - No new alleles are generated by mutation nor the genes get duplicated or deleted.

Random mating – Every organism gets a chance to mate and the mating is random with each other with no preferences for a particular genotype.

No gene flow - Neither individuals nor their gametes enter (immigration) or exit (emigration) the population.

Very large population size - The population should be infinite in size.

No natural selection- All alleles are fit to survive and reproduce.

If any one of these assumptions were not met, the population will not be in Hardy-Weinberg equilibrium. Only if the allele frequencies changes from one generation to the other, evolution will take place.

6.8 Origin and Evolution of Man

Mammals evolved in the early Jurassic period, about 210 million years ago (mya). Hominid evolution occurred in Asia and Africa. Hominids

Australian ape man. He was about 1.5 meters tall with bipedal locomotion, omnivorous, semi erect, and lived in caves. Low forehead, brow ridges over the eyes, protruding face, lack of chin, low brain capacity of about 350 – 450 cc, human like dentition, lumbar curve in the vertebral column were his distinguishing features.

Homo habilis lived about 2 mya. Their brain capacity was between 650 – 800cc, and was probably vegetarian. They had bipedal locomotion and used tools made of chipped stones.