Chapter 35

EVOLUTION --- History of Life

The term **evolution** means development of life with time. It comes from Latin word *evolvere*, meaning to unroll. It refers to opening of record by unrolling a scroll, i.e., origin from earlier life. It is defined as ***the development of differentiated organisms from pre-existing less differentiated organisms over the course of time.***

Evolution means that living things change. A species may slowly change into a new species or even into two or more new species. It means that the plants and animals that are present on the earth now are not the first plants and animals. It also means that many plants and animals that once flourished are no longer alive, since if one species evolve into other species, the orginal species no longer exists. The knowledge about these extinct species is provided by their remains preserved in the rocks called **fossils**.

Theory of evolution has a special place in the study of history of life. It is most inclusive theory of all the theories in biology. It helps us to understand the unity as well as the diversity of plants and animals. Once life appeared on earth, it slowly evolved into many kinds of plants and animals. But evolution has not made the organisms completely different. Biochemical similarities such as association of ATP with the energy reactions in all the cells; nearly identical modes of inheritance, for instance DNA nearly always carries the instructions for inheritance; and similar patterns of development among organisms is due to their common origin. Evolution provides us a unifying picture of life. Life has a common pattern because all life is interrelated through evolutionary descent. This is evident from classification which has its scientific basis in evolutionary interrelationship.

Evolution is also taken as field of inquiry in which scientists try to discover how this process of change occurs. They try to find answers to questions such as what are the raw materials for evolution; what forces and factors control the direction in which species may evolve; what is the rate of evolution and what factors control it?; what is the past history of plants and animals living today?; and what plants and animals lived in past but are no longer alive?

Evolution may be:

i. Macroevolution

The kind of evolution during which new forms of life evolved replacing the old ones is called **macroevolution**. Macroevolution is evolutionary change on grand scale resulting in new kinds of organisms penetrating new habitats.

ii. Microevolution

It refers to change within populations. Darwin did not focussed at the way in which new species are formed from old ones, but rather the way that changes occur within species. According to him, individuals in a population possessing certain variations produce more surviving offspring than the others. These variations have genetic basis and provide advantage to the individuals. Natural selection act and new populations evolve. This progressive change in gene frequencies is called **microevolution**.

DEVELOPMENT OF THEORY OF EVOLUTION

Evolution is a scientific theory now. In its present form it began in 1859 as a **hypothesis of Charles Darwin** (1809-1882) after publication of his **On the Origin of Species**. However, people long before Darwin noticed basic structural and functional similarities among organisms and proposed various hypotheses to explain diversity among living organisms.

Ancient Beliefs and Hypothesis of Special Creation

Ancient Chinese believed that life originated from a single source through a gradual unfolding and branching. Some of the **early Greek thinkers** talked about the gradual evolution of life. But **Aristotle** believed that species were fixed and did not change. According to him the living things can be arranged in order of increasing complexity and there are no spaces to be filled by new forms of life. **William Paley** (1802), in his book **Natural Theology**, argued that if one comes across a watch, from its intricate structure one could conclude that there was a watchmaker. Thus, the great complexity of living things was sufficient evidence of work of a Creator. His hypothesis was known as **special creation**.

Theory of Uniformitarianism

James Hutton (1726-97), founder of geology, suggested that earth developed from rocks gradually by erosion. His hypothesis was called **gradualism** and it became the basis of **theory of uniformitarianism** developed by **Chalres Lyell** (1797-1875), another geologist. Lyell described evidence for believing that mountains, valleys, deserts, rivers, lakes and coastlines have come about through the actions of existing forces and natural conditions througout the ages. Such changes had occurred slowly changing the face of the earth. Thus, the age of the earth is quite old. His theory of uniformitarianism led Darwin to imagine that if earth is quite old and so changed, did it had the kinds of life we now have? If not so, the life also changed gradually.

Hutton also observed fossils in the beds in sedimentary rocks. Later the age of earth was estimated to be about 4500 millions (4.5 billion) years and life as having originated 3500 millions (3.5 billion) years ago.

Hypothesis of Catastrophism

Gerorges Cuvier (1769-1832) attempted to explain the role of fossils in creation. He showed relationship between living organisms with the help of fossils. From his studies, he concluded that there were vast number of extinct species, and many new forms of life had appeared. According to him this is due to repeated mass extinction of life due to periodic catastrophes. The affected areas were repopulted by species from elsewhere on earth. His hypothesis was termed **catastrophism**.

Use and Disuse of Organs — Vestigeal Structures

Georges-Louis Buffon (1707-88) realised that the idea that the species were fixed and unchanging was wrong. He believed that if structures were not used for long (disuse) they degenerate. It may result in change of organisms. Such structures were named **vestigeal**, for example pelvic, limb girdle and limb bones of the *snake* are reduced as compared to other living reptiles that they have lost their original function. He considered *ape* as degenerate human. He also suggested that species that resemble each other have a common ancestor.

Organic Evolution

Erasmus Darwin (1731-1802), grandfather of Charles Darwin, believed in **organic evolution**, i.e., evolution of living world. He believed in evolution by variation and improvement of species by their own inherent activities. He also believed that characteristics acquired by the parent may be transferred to the offspring (inheritance of acquired characters). Therefore, he is considered as an outright evolutionist. Charles Darwin read his grandfather's work and was impressed very much.

Theory of Evolution by Natural Selection

Charles Darwin, a doctor by profession but gave up his career after witnessing surgical operations conducted on children. Later, he joined church but abandoned it as well. He joined as resident naturalist on an expedition to the southern hemisphere on **HMS Beagle** and travelled for five years. During his voyage he accumulated geological and fossil evidence that supported the idea that life changes with time. He also studied the flora and fauna of mainland South America and of some surrounding islands, including the **Galapagos islands**. For example, he found evidence about the development of a variety of forms among *finches* (a kind of birds) from a single ancestral group, due to adaptation to feeding on different kinds of food.

After returning home he continued his study and experiments. He also studied the effect of light on plant growth that later led to discovery of plant hormones, climbing and insectivorous plants, earthworms, soils, orchids, insects and plants of various habitats, aspects of geology, and emotion in humans and animals. He started developing a theory, he called **transmutation**. He discussed his theory with his close friends and made a first draft of his theory in 1842.

Darwin read **R. Malthus**'s ***"An Essay on the Principle of Population"***, in which he emphasized that there is a contest among the members of a population for food (**struggle for survival**), and one who is fittest survives (**survival of the fittest**). Darwin found that a similar struggle exists among all living things. He suggested that all species show **variations** with time. Some variations are of advantage in struggle for existence. Organisms with favourable variations are most likely to breed and to pass on their favourable characteristics. In this way new species arise from existing ones, becaue the nature selects the fittest --- **evolution by natural selection**.

Darwin recieved a hypothesis similar to his own from **Alfred Russel Wallace** (1823-1913), also a naturalist who travelled widely in South America, Malaya and Eastern Indian archipelago, through a private letter. That stimulated him to publish his work. The theory was presented in a joint paper read to a Linnean society meeting in 1858, but did not acknowledge much.

Darwin was aware of defects in his theory and lack of evidence for it. For instance, Darwin recognised variations as a raw material for natural selection, but blending theory of inheritance was prevalent at time which tend to reduce variations. Also there was no evidence for natural selection in action and Darwin relied upon variations in the breeds of domestic animals such as *pigeons*. By careful artificial selection, he demonstrated the natural selection process. Darwin continued his work and went on to develop his ideas in his book **On the Origin of Species by Natural Selection**, published in 1859.

Darwin's ideas were well received by many scientists and by a large segment of general public. There was much opposition, however. His theory was defended by **Joseph Hooker** and

Thomas Henry Huxley (1825-1895). Darwin's theory is considered as a unique contribution to the debate about evolution as its states:

a. the evidence for evolution very clearly,

b. reviewed objections and answered those,

c. proposes a mechanism for evolution he called **natural selection**, and

d. convinces most of the scientists that species have evolved from earlier forms of life.

Lamarck's Theory of Evolution — LAMARCKISM

There have been other hypotheses to explain how evolution occurs, but none has been as useful as Darwin's. One of the most interesting and important was porposed by the French naturalist **Jean B. Lamarck** in 1809. His hypothesis was based on two conditions:

a. the use and disuse of parts, and

b. the inheritance of acquired characteristics.

According to Lamarck changes in the environment may lead to changed patterns of behaviour which can necessitate new or increased use or disuse of certain organs or structures. Extensive use would lead to increased size and/or efficiency while disuse would lead to degeneracy and atrophy. These traits acquired during the lifetime of the individual were believed to be heritable and thus transmitted to the offspring. His theory of evolution is known as **Lamarckism**.

Long Neck and Legs of *Girrafe* --- An Example of Lamarckian Evolution

According to Lamarck, the long necks and legs of modern *giraffe* were the result of evolution due to use and disuse. According to him, ancestral *giraffe* probably had short necks and legs. They started feeding on leaves instead of grass to satisfy their need for food. The necks were subjected to frequent stretching to enable the girrafes to reach the leaves of the trees present at higher levels. As a result slight longer necks and legs produced in each generation. This change passed on to the next generation. Continuous stretching and its inheritance for generations resulted in modern *giraffes*.

Other Examples

The webbed feet of aquatic birds and shape of flat fish could be explained similarly. In ***aquatic birds*** the constant spreading of the toe bones and the skin between them in order to swim to find food and escape predators gave rise to their webbed feet. Similarly according to Lamarckism flat body in ***flat fish*** resulted because the fish use to lie on thier sides in shallow water.

Lamarck's theory of evolution is simple, clear, attractive but wrong. Lamarck himself and others were unable to collect evidence in favour of the thoery. However, Lamarck's emphasis on the role of environment in producing variations in individuals was correct. For example, body building exercise will increase the size of muscles, but this acquired change is non-genetic and cannot be inherited.

Weismann's Theory of Continuity of Germ-Plasm

Later, **Weismann** proposed **theory of continuity of germ-plasm**. He postualted that somatic or body acquired characteristics resulting in variations did not affect the germ or gamete cells (in other words DNA, the genetic material) which are responsible for transmission of genetic characteristics.

Neo-Darwinism

The theory of evolution proposed by Darwin and Wallace has been extended and elaborated in the light of evidence from genetics (Mendel and post-Mendilian work), molecular biology, palaeontology, and ecology and is known as **neo-Darwinism** (*neo* = new).

According to this theory, genetic variations originate as a result of chromosome mutation, gene mutation, random assortment of parental chromosomes, and recombinations produced as a result of crossing over. These genetic differences established in an organism are called **phenotypic variations**. Some of these variations may be better adapted than others in a particular environment. Then, when natural selection operates, there is a change in the proportion of genetic variation in a population of the species. This may lead to the formation of new varieties and species.

Neo-Darwinism may be defined as **"the theory of organic evolution by the natural selection of genetically determined characteristics".**

Population Genetics and Evolution

An important development in the understanding of theory of evolution was the birth of **population genetics**, and the realisation that continuous variation may be genetically controlled. Population genetics made it possible to analyze changes in the genetic composition of populations to demonstrate the forces responsible for evolutionary change.

DARWIN'S THEORY OF NATURAL SELECTION

Natural selection is the mechanism by which new species arise from pre-existing species. This hypothesis is based on the following observations.

i. Overproduction

Individuals within a population have a great reproductive potential, i.e, they tend to produce a large number of offspring. The capacity for reproduction is basic to all living organisms because it ensures continuation of species.

The organisms reproduce in a geometrical ratio. For example, *elephant* which is considered as the slowest breeder, begins to breed at the age of thirty, and continue to do so at the age of ninety, producing six youngs during this period. Darwin calculated that a single pair of ***elephants*** would produce 19 million descendants in 750 years. Similarly ***cod fish*** lays seven million eggs, and if all eggs developed into fish, the seas would soon become filled with *cod fish* alone. The rate of reproduction is more rapid in invertebrates, for example, an ***oyster*** lays 90 million eggs in a season. If the progeny of a single *oyster* survived and multiplied at this rate for five generations, the heap of shells produced would be eight times the size of the earth. Similarly a ***Paramecium*** divides three times a day. It has been calculated that if all the offspring of a single *Paramecium* survived and multiplied at this rate for five years, the mass of protoplasm produced would be almost equal to ten thousand times the volume of the earth.

Malthus highlighted the reproductive potential of humans and observed that human potentials are able to increase expotentially (arithmatically).

ii. Struggle for Existence

Increase in population size lead to continuous competition between individuals for food, space and light. It results in **struggle for existence**. The competition may be between members of the same species known as **intraspecific competition**, or between the members of different species called **interspecific competition**. The intraspecific competition is more intense because the members compete for same resources.

It has been observed that all population sizes are checked by various environmental factors, such as food availability, space and light. The populations tend to increase in size until the environment supports, otherwise there is no increase and an equilibrium is reached. Also certain organisms fail to survive (die at early age) or reproduce (are sterile). Hence population sizes generally remain approximately constant over a period of time related to the length of the organism's life cycle.

iii. Variations

All individuals in a population exhibit variations in form, size, coloration, physiology and habits; and a struggle for existence has been clearly established, therefore some individuals possessing particular variations will be more suited to survive and reproduce.

Adaptation: The key factor in determining survival is adaptation to the environment.

iv. Natural Selection *or* Survival of the Fittest

The individuals with variations that help them to adapt better in an environment will survive. **Herbert Spencer** termed it as **survival of the fittest**. Thus, any variation that gives one organism an advantage over another organism will act as **selective advantage** in the struggle for existence. Favourable variations are inherited to next generation. Unfavourable variations are selected out. According to **Darwin**, nature selects the fittest or an organism with selective advantage. Thus, natural selection ensures the survival of better adapted species.

v. Origin of New Species

The better adapted species live to maturity and transmit favourable variations to their offspring. The selective process continues generation after generation, and during the course of time these variations accumulate to such extent that species is modified into a new one.

CAUSES OF VARIABILITY

VARIATION

The term variation refers to differences in characteristics shown by organisms belonging to the same species. If we look around it is easy to see that organisms within the same species vary from one another. The variation may be:

i. **Genetic variations**

ii. **Environmental variations**

i. Genetic Variations

Some of the variations between individuals is caused by **genes**. Most genes have different forms called **alleles**. In sexually reproducing organisms these alleles are reshuffled each time a new organism is produced. This reshuffling occurs during meiosis as a result of **crossing over** and **independent assortment**. The **random fusion of gametes** from two parents also produces new combinations of alleles in the offspring. Another source of genetic variation is **mutation**. Crossing over, independent assortment and random fusion produce new combinations of alleles while mutations produce completely new alleles. Genetic variations are inheritable, therefore when organisms reproduce they pass on some of their genes to their offspring. Genetic variation affect DNA of the organisms.

ii. Environmental Variations

Some of the variations among individuals are not caused by their genes. For example, two persons with naturally fair skin may have very different skin colours, because one is exposed to sunlight more than the other. Similarly two persons possessing genes for tallness would grow tall but may have different heights, because they ate very different diets when they were young. Plants also exhibit such variations. They may differ in size and colour of leaves because one may be growing in shade and nutrient deficient soil and other in light and nutrient rich soil. Such differences that arise during an organism's lifetime are called **environmental variations**. These variations do not affect DNA of organisms, therefore are not inherited.

Both genetic and environmental variation are important for plant and animal breeders and also in understanding the process of natural selection. However, only characteristics with a relatively high genetic influence are really important in natural selection, or can be improved by selective breeding.

Continuous and Discontinuous Variation

A study of phenotypic differences in any large population shows that two types of variation occur:

a. Discontinuous variation

b. Continuous variation

Studies of variation in a character involve measuring the expression of that characteristic in a large number of organisms within the population, such as height in humans. The results reveal **frequency distribution** of the variations of that characteristics within the population. These results can be plotted as a histogram or a graph.

a. Discontinuous Variations

There are certain characteristic within a population which exhibit a limited form of variation. Variation in this case produce individuals showing clear-cut differences with no intermediate forms. For example, a person belongs to one of the four blood groups in the ABO blood system, A, B, AB or O. There are no inbetweens and only a few clearly defined groups of individuals. Such variations are called **discontinuous variations**.

The characteristics showing discontinuous variation are usually controlled by two major genes which may have two or more allelic forms. These variation are unaffected by environment.

b. Continuous Variations

In most caharacteristics the variations are not clear-cut. These characteristics show a complete gradation from one extreme to the other without any break. For example, human skin or eye colour cannot be categorised into clearly defined colours. Continuous variations may be caused by genes or by the environment, or both. The human eye colour is caused by the combined effect of many genes (polygenes). Individually each of these genes has little effect on the colour of the eye, but their combined effect is significant. Therefore, there are different sorts of eye colours. On the other hand, variations in skin colour (also a case of polygenic inheritance) are caused partly by genes and partly by environment. Variation in leaf length in *Oxford ragwort plant* is caused by environment entirely, beacuse all cells in the plant were produced by mitosis from a single zygote and so contain exactly the same genes.

SOURCES OF VARIATION

Genetic variations do not occur in asexually reproducing organisms as replication of DNA is perfect. Any apparent variation in these organisms may be due to influence of the environment. However, there is ample opportunity for genetic variation to arise in sexually reproducing organisms. The main causes of variations are:

i. Gene recombination

ii. Mutation

I. GENE RECOMBINATION

Gene recombination originate as a result of crossing over during meiosis, random migration of chromosomes at the time of cell division and random fusion of male and female gametes during fertilisation.

i. Crossing Over

Reciprocal crossing over of genes between chromatids of homologous chromosomes may occur during prophase I of meiosis. This produces new linkage groups and so provides a major source of genetic recombination of alleles.

ii. Orientation of Chromosomes during Cell Division

The orientation of the chromatids of homologous chromosomes (bivalents) on the equatorial spindle during metaphase I of meiosis determines the direction in which pairs of chromatids move during anaphase I. This orientation of chromatids is random. During metaphase II the orientation of pairs of chromatids is random once more and determines which chromosomes migrate to opposite poles of the cell during anaphase II. These random orientation and the subsequent independent assortment (segregation) of the chromosomes gives rise to a large number of different chromosome combinations in the gametes.

iii. Random Fusion of Male and Female Gametes during Fertilisation

The fusion of male and female gametes containing complementary sets of haploid chromosomes to produce a diploid zygote nucleus is completely random. Thus, any male gamete is potentially capable of fusing with any female gamete, resulting in genetic variation.

These sources of genetic variation account for genetic reshuffling which is basis of continuous variation. The environment acts on the range of phenotypes produced and those best adapted to it survive and flourish. This leads to change in allele and genotype frequencies.

II. MUTATION

The gene reshuffling do not generate major changes in genotypes which are necessary to give rise to new species. These changes are produced by mutations.

A* mutation *is a change in the amount or the structure of the DNA of an organism. This produces a change in the genotype which may be inherited by cells derived by mitosis or meiosis from the mutant cell. A mutation may result in the change in appearance of a characteristic in a population. Mutations occurring in gamete cells are inherited, whereas those occurring in somatic cells can only be inherited by daughter cells produced by mitosis. These are called **somatic mutations.**

***A change in the amount or arrangement of DNA is known as* chromosomal mutation** or **chromosomal aberration**; whereas ***a change in the structure of the DNA at a single locus is called* point mutation** or **gene mutation**. The term mutation is usually used to describe gene mutation.

The concept of mutation as the cause of the sudden appearance of a new characteristic was first proposed by the Dutch botanist **Hugo de Vries** in 1901, following his work on *Oenothera lamarckiana* (evening primrose). Nine years later **T. H. Morgan** began a series of investigations into mutations in *Drosophila* and recognised over 500 mutations.

Causes of Mutation — Mutagens

There are certain physical and chemical agents which cause an heritable change in a gene and thus produce its allele. These are called **mutagens**. There are three main categories of mutagens. These are:

i. Ionizing Radiations

These are high energy radiations like alpha-, beta-, gamma and cosmic rays. They are called ionizing because they penetrate the tissues deeply causing ionization of the molecules encountered. As they penetrate the cells, electrons are forced to flow out of the molecules, thus stable molecules and atoms are transformed into free radicals and reactive ions. These radiations affect the genetic material altering the purines and pyrimidines in the DNA and resulting in point mutation.

ii. Non-ionizing Radiation

These include ultraviolet rays. These cannot ionize the target tissue. The ultraviolet light affect pyrimidines mainly to cause a change in DNA.

iii. Chemical Mutagens

Certain chemicals such as nitrous acid, hydroxylamine, dimethyl sulfonate, methyl ethyl sulfonate, acridine, etc act as mutagens. In addition a variety of other chemical substances including mustard gas, caffeine, formaldehyde, colchicine, certain components of tobacco and an increasing number of drugs, food preservatives and pesticides, also cause mutations.

Mutation Frequency

Mutations occur randomly and spontaneously, therefore any gene can undergo mutation at any time. The rates at which mutations occur also vary from species to species. The factors that alter mutation frequency include temperature, aging and malnutrition. The work of **H. J. Miller** (1920) showed that frequency of mutations can be increased by X-rays. Since then it has been shown the rate of mutation can be increased by the effect of different mutagens described above. In *Drosophila*, definite genes called **mutator genes** are present that increase the mutation frequency.

Chromosome Mutations

Chromosomal mutation may be the result of changes in the number or structure of chromosomes.

Changes in Number of Chromosomes

Changes in number may affect several genes and have a more profound effect on the phenotype than gene mutations. These changes usually result from errors (**non-disjunction**) occurring during meiosis. However, they can also occur during mitosis. These changes may involve *the loss or gain of single chromosome, a condition called* **aneuploidy** (2n-1 or 2n+1), or *the increase in entire sets of chromosomes, a condition called* **euploidy** (**polyploidy** -- 3n, 4n, 5n and so on).

Zygotes containing less than the diploid number of chromosomes (**aneuploids**) usually fail to develop, but those with polysomic chromosomes may develop. In most cases where aneuploidy occurs in animals, it produces severe abnormalities. One of the commonest chromosomal mutation in humans is **Down's syndrome**. Polyploidy is more in plants than in animals. Approximately half the known plant species are polyploids. Polypoloidy is often associated with advantageous features such as increased size, hardiness and resistance to disease. This is called **hybrid vigour**. Most of our domestic plants are polyploids producing large fruits, storage organs, flowers or leaves.

Changes in Structure of Chromosomes

Structural changes in chromosomes result from:

i. Deletions and Duplications

During these changes the number of gene loci on chromosomes is changed, and this have profound effect on phenotypes.

ii. Inversions and Translocations

These changes result in change in allele sequence of parental linkage groups and produces recombinants, but no gene loci are lost. These also produce profound phenotypic effects. (for more details consult chapter 30)

Point Mutations

A change in the nucleotide sequence of DNA molecule in a particular region of the chromosome is called a **point mutation**. Such a change in the base sequence of the gene is

transmitted to mRNA during transcription and may result in a change in the amino acid sequence of the polypeptide chain produced from it during translation at the ribosomes.

Since point mutations are changes in the DNA, we can expect them to occur in any kind of cell, somatic (**somatic mutations**) as well as the germ cells (**gene mutations**).

Somatic Mutations

Somatic mutations tend to remain undetected because dominant allele is present at that locus on homologous chromosome. They affect the organism in which these occur and are lost on the death of that organism. However, somatic mutations in some plants have given rise to **plant varieties of commercial value**, such as the *navel orange* (oranges without seeds). In each case, a mutation arose in a single somatic cell. By repeated mitotic divisions, cells derived from original mutant cell produced a branch composed of identical cells, each with the original mutant gene. Since such fruits are often sterile, therefore can be propagated asexually by cuttings or grafts. Similarly **variegated flowers** with segments of different colours, e.g., in certain varieties of *roses*, are examples of somatic mutation. Also, in some cases these mutations may produce cells with increased rate of growth and division. These cells may give rise to a tumour which may be malignant, i.e., live parasitically on healthy cells, and cause **cancer**.

Gene Mutations

Gene mutations occurring during gamete formation are transmitted to all the cells of the offspring and from one generation to the next, therefore may be significant for the future of the species. Most minor gene mutations are recessive, therefore pass unnoticed in the phenotype. However, there are cases where a change in single base have a profound effect on the phenotype, for example **sickle cell anemia** in humans, where mutation affects only single base in one of genes involved in the production of haemoglobin.

Kinds of Gene Mutations

Gene mutation may be:

a. Spontaneous Mutation

The mutation which arises for no apparent reason and cause a genetic alteration is called **spontaneous mutation**. A spontaneous mutation is random and natural. It may occur at any site on a chromosome. It is found that majority of them produces just a slight effect and are harmful.

The frequency of spontaneous mutations is 1-10 per million gametes, but it should not be underestimated, as any higher organism contains thousands of gene loci. Because there are so many genes present, the chance that some one of them will undergo a change becomes quite significant. Studies on the total mutation rate in *Drosophila* indicate that in one generation there is the probability that 5% of the gametes will contain a mutation which arose in that generation time. Overall mutation frequency per generation in humans is calculated to be 5% also.

b. Induced Mutation

A mutation that is produced artificially during experimentation by using mutagens such as X-rays, ultra violet rays, etc. is called **induced mutation**.

c. Lethal and Deterimental Mutation

A mutation may be **lethal** whose effect is drastic enough to eliminate the individual before reproductive age; or **deterimental** that may not kill the individual possessing it, but the gene is adversely affecting him in some way and is decreasing his probability of survival.

e. Back Mutation

Once a gene has mutated to an allelic form, this mutant gene will continue to duplicate itslef until it is eliminated altogether. However, at times the mutant gene may mutate back to the original or wild form of the gene. This is called **back mutation** or **reverse mutation**. The frequency of back mutations is rarer than the forward mutation, the change from wild to mutant.

Effect of Mutations

Evolutionary progress depends on the ability of gene to change. However, a very high or uncontrolled amount of gene mutation would prove fatal to a species because most mutations are harmful. The effects of chromosome and gene mutations are very variable. In many cases the mutations are lethal and prevent development of the organism, for example in humans about 20% pregnancies end in natural abortion before 12 weeks and of these about 50% exhibit a chromosome abnormality. But some forms of chromosome mutation may bring certain gene sequences together, and that combined effect may produce a beneficial characteristic. Another significance of bringing certain genes closer together is that they are less likely to be separated by crossing over and this is an advantage with beneficial genes.

Gene mutation may lead to several alleles occupying a specific locus. This increases both the heterozygosity and size of the gene pool of the population and leads to an increase in variation within the population. Gene reshuffling as a result of crossing-over, independent assortment, random fertilisation and mutations, may increase the amount of continuous variaiton but the evolutionary implications of this are often short-lived since the changes produced may be rapidly diluted. Certain gene mutations on the other hand, increase discontinuous variation and this has more profound effect on changes in the population. Most gene mutations are recessive to the normal allele which has come to form genetic equilibrium with the rest of the genotype and the environment as a result of successfully withstanding selection over many generations. Being recessive the mutant alleles may remain in the population for many generations until they come together in the homozygous condition and are expressed phenotypically. Occasionally a dominant mutant allele may arise in which case it will appear immediately in the phenotype.

NEO-DARWINISM or SYNTHETIC THEORY OF EVOLUTION

A* population *is a group of organisms of the same species usually found in a clearly defined geographical area. Darwin was concerned with how natural selection worked at the level of the individual organism in bringing about evolutionary change. However, after the rediscovery of Mendel's work the importance of genotype became significant in the study of variation, inheritance and evolutionary change. The study of population genetics became the basis of modern views of evolutionary theory called **neo-Darwinism** or the **synthetic theory of evolution**.

The theory can be explained as followings:

Genetic Composition of Populations

Individual organisms are born, mature, and eventually die. Along the way, an individual may change, but it does not evolve. Rather, it is a **species**, a group of interbreeding organisms that evolve. The members of a species form groups, or populations, that occupy a particular region. Some species consist of a just a single population living in one area such as a small lake or an island. Other species are made up of more than one population, each in a different locality. For evolution to take place a change must occur in the genes that are present in the members of a population. These changes are passed on to the next generation during reproduction and are spread throughout the population by interbreeding.

Genetic Variation

The genes can occur in different forms or **alleles**. Most alleles are either dominant or recessive, and an individual can have either two identical alleles or two different alleles at any particular gene locus. Not all individuals that can make up a population have the same alleles, therefore there is **genetic variation** in the population. For example in humans there is difference in pigmentation, facial characteristics, and blood types among different individuals and ethnic populations.

Gene Pool

The total variety of genes and alleles present in a sexually reproducing population is called **gene pool**. In any given population the composition of the gene pool may be constantly changing from generation to generation as new combinations of genes produce unique genotypes and individuals with genetic variations are produced. The environmental selection pressure determines which genes pass onto the next generation.

A population whose genes show consistant change from generation to generation is undergoing evolutionary change. A static gene pool represent a condition where genetic variation between the members of species is inadequate to bring about evolutionary change.

Allele Frequency

The relative occurrence of an allele in the gene pool is expressed as an **allele frequency**. The number of organisms in a population carrying a particular allele determines the allele frequency. For example, in humans the frequency of the dominant allele for production of pigment in the skin, hair and eyes is 99% or 0.99. The recessive allele which is responsible for the lack of pigment, a condition known as **albinism**, has a frequency of 1% or 0.01. Since the total population represents 100% or 1 it can be seen that:

dominant allele frequency + recessive allele frequency = 1

0.99 0.01 = 1

If dominant allele for normal pigmentaion is represented by **N** and recessive allele for the albino condition by **n**. The **N** = 0.99 and **n** = 0.01. Mathematical symbols of probability, **p** and **q** are used to express frequency of dominant and recessive alleles of the population. Therefore,

$$p + q = 1$$

where **p** = dominant allele frequency, and **q** = recessive allele frequency.

In the case of pigmentation in humans, p = 0.99 and q = 0.01

since $p + q = 1$

$0.99 + .01 = 1$

The value of above equaion lies in the fact that if the frequency of either allele is known, the frequency of the other may be determined. For example, if the frequency of the recess allele is 25% then q = 25% or 0.25.

Since $p + q = 1$

$p + 0.25 = 1$

$p = 1 - 0.25$

$p = 0.75$

That is, the frequency of the dominant allele is 0.75 or 75%.

Hardy-Weinberg Law

Evolution occurs when the composition of the gene pool changes. Therefore, a basic component of the evolutionary process is the change of allele frequencies over time. What causes allele frequencies to change? In 1908, the British mathematician **G. H. Hardy** and German biologist **W. Weinberg** independently discovered that under certain ideal conditions, allele frequencies will remain constant from generation to generation in sexually reproducing populations. They developed a mathematical relationship betwen the frequencies of alleles and entotypes in populations. The relationship is now known as the **Hardy-Weinberg Law**. It states that:

> ***"the frequency of dominant and recessive alleles in a population will remain constant from generation to generation provided certain conditions exist"***

Genetic Equilibrium

Populations that are not changing, i.e., they have the same allele frequencies from one generation to the next, are said to be at **Hardy-Weinberg equilibrium** or **genetic equilibrium**.

Five ideal conditions must exist if a population is to remain at genetic equilibrium. These are:

i. There must be an absence of mutation so that no new alleles appear in the population.

ii. Individuals cannot migrate in or out of the population so that no new alleles enter, or existing alleles leave the population.

iii. The population must be very large so that it is not affected by random changes in allele frequency.

iv. All individuals in the population must have an equal chance of survival, i.e., there are no genetic traits that give individuals a survival advantage.

v. Mating must combine genotypes at random, i.e., no preference is shown in the selection of a mate.

Causes of Change in Gene Frequencies

Based on these five conditions, we can identify the factors that disrupt genetic equilibrium and cause changes in the frequency of alleles in a population's gene pool. These are: ***i.* mutation; *ii.* gene flow; *iii.* genetic drift; *iv.* natural selection;** and ***v.* nonrandom mating**.

i. Mutation --- The Source of New Alleles

A mutation is a random change in the DNA of an organism. Only those mutations that occur in germ cells contribute to evolutionary changes. Mutations add new alleles to gene pool resulting in variations on which other evolutionary forces operate. Some mutations are beneficial, some are detrimental (harmful), and others are neutral and have no apparent effect on the survival or reproductive capacity of an organism. Many harmful mutations are immediately removed from the gene pool because they disrupt the structure and function of a protein whose activity is required for life to continue. Whether a mutation is beneficial, deterimental or neutral often depends on the environment in which the organism is living at the time. If the environment changes, the effects of the mutation on survival and reproduction can also change. For example, a mutation that causes an enzyme to function optimaly at a higher temperature will be beneficial if the environmental temperature rises and will be detrimental if the temperature falls.

ii. Gene Flow --- Exchange of Alleles between Populations

***The transfer of alleles between populations through interbreeding is called* gene flow.** It is common for animals or their larvae to migrate over large distances, and for the seeds and pollen of plants to be dispersed by the wind or carried by birds to distant locations. Consequently, individuals from one population of a species are moved to another population, creating the opportunity for the transfer of alleles from one population's gene pool to another. Immigrants into a population may add new alleles to the population's genes pool, or they may change frequencies of alleles that are already present. Emigrants out of a population may completely remove alleles, or they may reduce the frequencies of alleles in the remaining pool.

The amount of gene flow between populations varies and depend upon a number of factors such as:

a. number of migrating individuals;

b. the ease of movement;

c. the harshness of the environment to be traversed, and

d. the amount of interbreeding that actually takes place when migrants come in contact with a new population.

Gene flow is one of the factors responsible for the widespread resistance among *insects* to pesticides. Resistant individuals from one population emigrate into new populations, spreading resistance-conferring alleles into new geographic areas. The importance of gene flow can also be illustrated in humans by the fact that 70% of the alleles for **cystic fibrosis** in the United States population are probably derived from a single northern European ancestor.

iii. Genetic Drift -- Random Changes in the Gene Pool

Genetic drift *is change in allele frequency that results simply by chance*. This refers to the fact that variation in allele frequency can occur by chance rather than by natural selection. It may be an important mechanism in evolutionary change in small or isolated populations.

In small populations, the fequencies of particular alleles may be changed drastically by chance alone. The individual alleles of a given gene are all represented in few individuals, and some of them even be lost from the population if those individuals fail to reproduce. ***Since these changes in allele frequency appear to occur randomly, as if the frequencies were drifting, it is known as*** **genetic drift**. A series of small populations that are isolated from one another may come to differ strongly as a result of genetic drift. In this connection, it is interesting to realise that humans have lived in small groups for much of the course of their evolution; genetic drift consequently, may have been a particularly important factor in the evolution of our species.

Founder Effect

Sometimes one or a few individuals are dispersed and become founders of a new, isolated population at some distance from their place of origin. When this occurs, the alleles that they carry are of special significance. Even if these alleles are rare in the source population, in their new area they will be significant fraction of the whole population's genetic endowment. This effect by which rare alleles and combinations of alleles may be enchanced in the new populations is called the **founder effect**. It is a particularly important factor in the evolution of organisms on distant oceanic islands, such as Hawaiian Islands and the Galapagos Islands visited by Darwin. Most of the kinds of organisms that occur in such areas have probably been derived from one or a few initial **founders**.

The particular genetic constitution of the founding individuals played key roles in the evolution of Hawaiian plants and animals. **Tarweeds** is a group of more than 100 western North American species of the sunflower family, *Asteraceae*. *Adenothamnus validus* is a primitive tarweed. In the Hawaiian Island, a group of unusual species of *tarweeds* have evolved from ancestors similar to *Adenothamnus*, which reached Hawaii by chance dispersal over long distances.

iv. Natural Selection --- The Driving Force behind Adaptation

After his voyage on the *Beagle*, Charles Darwin became convinced that organisms evolve over time. Later he concieved a mechanism that could actually cause a change. This mechanism was **natural selection**. Artificial selection helped Darwin to concieve the mechanism. It demonstrated that continued selection was powerful enough to bring about large scale changes within a species. Darwin concluded that natural selection could produce similar changes in natural environment. According to his theory of natural selection, not all individuals survive and reproduce equally well in a given environemnt. Therefore, some individuals contribute more offspring to the next generation than do others. As generations passs, those individuals with adaptive characteristics will become more common, and those with deterimental characteristics will be eliminated. In other words the environment plays the role of the breeder in natural selection. Off all the forces that influence evolution, only natural selection generates populations whose members are better adapted to their environment.

v. Nonrandom Mating

When individuals choose mates on the basis of their phenotypes, **nonrandom mating** occurs. Nonrandom mating can be caused by a number of factors. If frequently occurs when there is a preference for a particular type of mate or when the population becomes so small that there is no choice except to mate with a close relative.

Sexual Selection

Not all characteristics favoured by natural selection improve an individual's chances of survival; rather some increase its chance of reproducing. The spectacular tail feathers of a *peacock* and spreading antlers of male *deer* appear as if they could actually impede tha animal's pursuit of food and escape from predators. Since these characteristics improve the chances of attracting females and reproducing, however they will be strongly selected for. This form of natural selection is called **sexual selection**.

Sexual selection often lead to sexual **dimorphism**, i.e., visible differences between the male and female of the same species. Sexual selection is common among the animals because a female's reproductive success is limited by number of eggs she can produce in her lifetime, and a male's reproductive success is limited by number of females he can inseminate. Therefore, it is to the female's advantage to choose the most fit male as her mate, and it is to the male's advantage to attract as many females as possible. This lead to natural selection of certain male characteristics, either through male competition with one another or through female choice. On the other hand, males may compete for directly by fighting, or they may compete for territory, the possession of which attracts the females. Consequently, in these species, males develop characteristics that enable the animal to fight or intimidate other males, like the antlers of a *deer* or the huge body size of the male *elephant seal*. On the other h and, females choose a mate, so natural selection favours those characteristics such as the bright-coloured plumage of male birds in *peacocks*.

SELECTION

It is well known that individual members of a population are not identical, but show phenotypic variation. Selection is a process by which certain organisms of a population survive and reproduce whereas others fail to do so. The organisms that survive are better adapted to the environment, and possess characteristics that give them a competitive advantage. Selection help perpetuation of those organisms that are able to ensure survival of the species, and depends upon presence of phenotypic variation within the population.

When a population increases in size, certain environmental factors such as food availability in animals and light in case of plants become limiting. This results in competition for resources between members of population. The organisms possessing characterisitics which provide them competitive advantage will be able to get food or light, survive and reproduce Those organisms that lack these characteristics may die before reproducing. The environmental limiting factors and population size operate together to produce a **selection pressure**.

Therefore, selection is the process determining which alleles are passed on to the next generation; and selection pressure is a means of increasing the spread of an allele within the gene pool. The changes in allele frequency can lead to evolutionary change. Major changes in genoytpe arise from the spread of mutant alleles through the gene pool.

The extent and timing of selection depend upon the nature of the mutant allele and the degree of effect it has upon the phenotypic trait. If the allele is dominant, it will appear in the phenotype and be selected for or against. If the allele is recessive, as is the case with most mutants, it will not be selected until it appears in the homozygous state. Because the chances of this occurring are slight, therefore the allele may be lost from the gene pool before appearing in the homozygous condition. A recessive allele may persist in a given environment until changes in the environment occur and it may express as a dominant one in these changed environment. These effects would probably appear first in the heterozygote and selection would favour its spread throughout the popultion , as in the case of sickle cell anemia.

A recessive mutant allele may spread rapidly through a population if it occupies a position (locus) to a functionally important dominant allele which is strongly selected for. In this linked condition the chances of the mutant allele combining with another mutant allele to produce the homozygous condition are increased.

The influences of a given mutant allele can vary. The mutations affecting alleles controlling important functions are likely to be lethal and removed from the population immediately. Evolutionary change is generally brought about by the gradual appearance of many mutant alleles which exert small progressive changes in phenotypic characteristics.

Types of Selection

There are three types of slection processes occurring in natural and artificial populations. These are: *i*. **stabilising selection**; *ii*. **directional selection**; and *iii*. **disruptive selection**.

i. Stabilising Selection

This operates when phenotypic features coincide with optimal environmetal conditions and competition is not severe. It occurs in all populations and tend to eliminte extremes from population.

Many species of plants produce flowers at a particular time of the year triggered by changes in the day length. Individuals which flower earlier or later than the average are often far apart and may fail to attract pollinating insects. *Bees*, for example collect nectar selectively from flowers which are abundant. Therefore, individuals which flower at other times are less likely to be pollinated and will leave fewer offspring in the next generation. Stabilising selection ensures that the majority of individuals of a particular species will continue to flower at approximately same time.

Human infant mortality provides another example of stabilizing selection. The optimum body mass at birth is 3.6 kg. Babies which are heavier than this, as well as those which are lighter, show an increased mortality. Thus, babies of average size are selected for, and babies at either extreme are not slected, although improvements in medical treatment make survival much more likely.

Stabilising selection pressure do not promote evolutinary changes but tend to maintain phenotypic stability within the population from generation to generation.

ii. Directional Selection

This form of selection operates in response to gradual changes in environmental conditions. It operates on the range of phenotypes within the population and exerts selection pressure which moves the mean phenotype towards one phenotypic extreme. Once the mean phenotype coincides with the new optimum environmental conditions stabilisation selection will take over. This results in a change in phenotype in one particular direction. Most predator-prey relationships are likely to have evolved in this way. The *cheetah* which is faster is more likely to be successful in killing prey, while the *antelope* which is faster more likely to evade capture. Selection will always act in the direction of increased speed.

This kind of selection brings about evolutionary change by producing a selection pressure which favours the increase in frequency of new alleles within the population. Directinal selection forms the basis of artificial selection where the selective breeding of phenotypes showing desirable traits increases the frequency of those phenotypes within the population.

iii. Disruptive Selection

This is rarest form of selection but can be very important in bringing about evolutionary change. It leads to emergence of two distinct phenotypes. Fluctuating conditions in an environment, for example season and climate may favour the presence of more than one phenotype within a population. Selection pressure acting from within the population as a result of increased competition may push the phenotypes away from the population mean towards the extremes of the population. This can split the population into two sub-populations. If gene flow between the sub-populations is prevented, each population may give rise to a new species.

Pacific salmon (a fish) breed only once in its lifetime. The spawning males can be of two types. Most males are large and aggressive and fight vigorously amongst themselves for a position close to a female. However, in many populations, a proportion of much smaller males, called "**jacks**", ascend the river and because of their small size, sneak between the rocks of the river bed until they are close to a spawning female. When female relases her eggs, these males release sperms and may be successful in fertilizing upto to 40% of the offspring. Males of an intermediate size could not compete effectively with either of the exisitng types.

In some cases this form of selection can give rise to the appearance of different phenotypes within a population, a phenomenon known as **polymorphism**.

Intensity of Selection Pressure

The intensity of selection pressure within a population varies at different times and in different places and may be produced by changes in external or internal factors. The external factors include increase in numbers of predators or pathogens or competition from other species for food and breeding space in the case of animals; and light, water and mineral slats in the case of plants. Changes in climatic conditions or the state of habitat in which organisms live may exert new selection pressures. Internal factors such as rapid increase in the size of population can result in increased competition for environmental resources. As the population size increases, so do the numbers of parasites and predators. Pathogens are more easily transmittted from organism to organism as the host population rises and diseases spread very rapidly. All of these factors may not only affect the intensity of the selection pressure but also the direction of the pressure New phenotypes and genotypes are selected and poorly adapted organisms are eliminated from the population.

One result of increased selection pressure is that it may cause organisms to become specialised to certain modes of life or narrower environmental conditions. This may be a disadvantage for the future of that species. Increased uniformity and dependency by a species increases the likelihood of that species becoming extinct should environmental conditions change. The fossil record contains many extinct organisms that were bizarre and overspecialised.

A reduction in the intensity of selection pressure usually has the opposite effects to those described above. It may be produced by an absence of predators, pathogens, parasites and competing species or an increase in optimum environmental conditions. These cnditions are usually found when an organism is introduced into a new environment. It is condition such as these which are believed to have favoured the idversity of finch species found on the Galapagos island.

ARTIFICIAL SELECTION

A process very similar to natural selection used to produce animals and plants which can be used by humans for their own purpose is called **artificial selection**. In artificial selection humans exert a directional selection pressure which lead to changes in the allele and genotype frequencies within the population. This is an evolutionary mechanism which give rise to new breeds, strains, varieties, races and sub-species. Humans used this process long before anything was understood about genes, alleles, natural selection or evolution. Darwin used evidence from artificial selection to account for the mechanism that brings changes in species in natural populations.

The basis of artificial selection is the isolation of natural populations and the selective breeding of organisms.

Selective Breeding

Individuals showing one or more of the desired features than the other organisms are chosen for breeding. Some of the alleles controlling these features pass on to their next generation. Again the best individuals from this generation are chosen for breeding. Over many generations, alleles controlling desired characteristics increase in frequency, while those controlling undesired characteristics by the breeder will decrease in frequency, or lost entirely. This is called **selective breeding**.

The aims and objectives of selective breeding include:

a. increasing yeild and nutritive value of crop plants;

b. increasing the growth rate, meat production, milk yield and egg production of livestock;

c. improving the performance of various animals such as race horses and domestic *pigeons*;

d. producing new combinations of colours and scents in garden flowers;

e. produing particular characteristics in breeds, for example, *dogs*, *cats* and *birds*;

f. producing pest-resistant and disease-resistant varieties of plants and animals;

g. producing plants and animals that are tolerant of environmental changes in, for example, temperature or water supply.

Both evolution and selective breeding result from changes in allele frequencies with time. The selection pressure in evolution is natural selection, while the selection pressure in selective breeding is the artificial selection that results from the breeder's choice of parents.

Types of Selective Breeding

Selective breeding may be: *i.* inbreeding and *ii.* outbreeding.

i. Inbreeding

Artificial selection often involves breeding closely related organisms together, for example between offspring produced by the same parents. This is called **inbreeding**. Plants such as *wheat*, *pea* and *tomatoes*, that normally self pollinate are **natural inbreeders**; while the plants that cross pollinate are called **natural outbreeders**, for example *maize*, *apple* and *sunflower*. In animals inbreeding is common in the breeding of show animals such as *cats* and *dogs*. Inbreeding is used by livestock breeders to produce *cattle*, *pigs*, *poultry* and *sheep* with high yields of milk, meat, eggs and wool respectively.

Prolonged inbreeding result in a reduction in size and yield, and loss of vigour and fertility. This is called **inbreeding depression**.

ii. Outbreeding

Outbreeding is particularly useful in plant breeding, but is also used in commercial production of meat, eggs and wool. It involves crossing members of different varieties or strains, and in certain plants between closely related species. The offspring is called **hybrids** (F_1 hybrids) and they show advantages such as increasd fruit size and number, increased resistance to disease and earlier maturity. The phenomenon is called **hybrid vigour** or **heterosis**. Hybridisation in *maize* has increased grain yield by 250% over the parental plants. Double-cross hybridisation, i.e., crosses between hybrids from two inbred strains, exhibit more vigour and economical.

Increased vigour results from increased heterozygosity which arises from gene mixing. Each homozygous parent may possess some of the dominant alleles for vigorous growth, whereas the heterozygote will carry all the dominant alleles.

Selective hybridisation results in **polyploidy** which can lead to the production of new species.

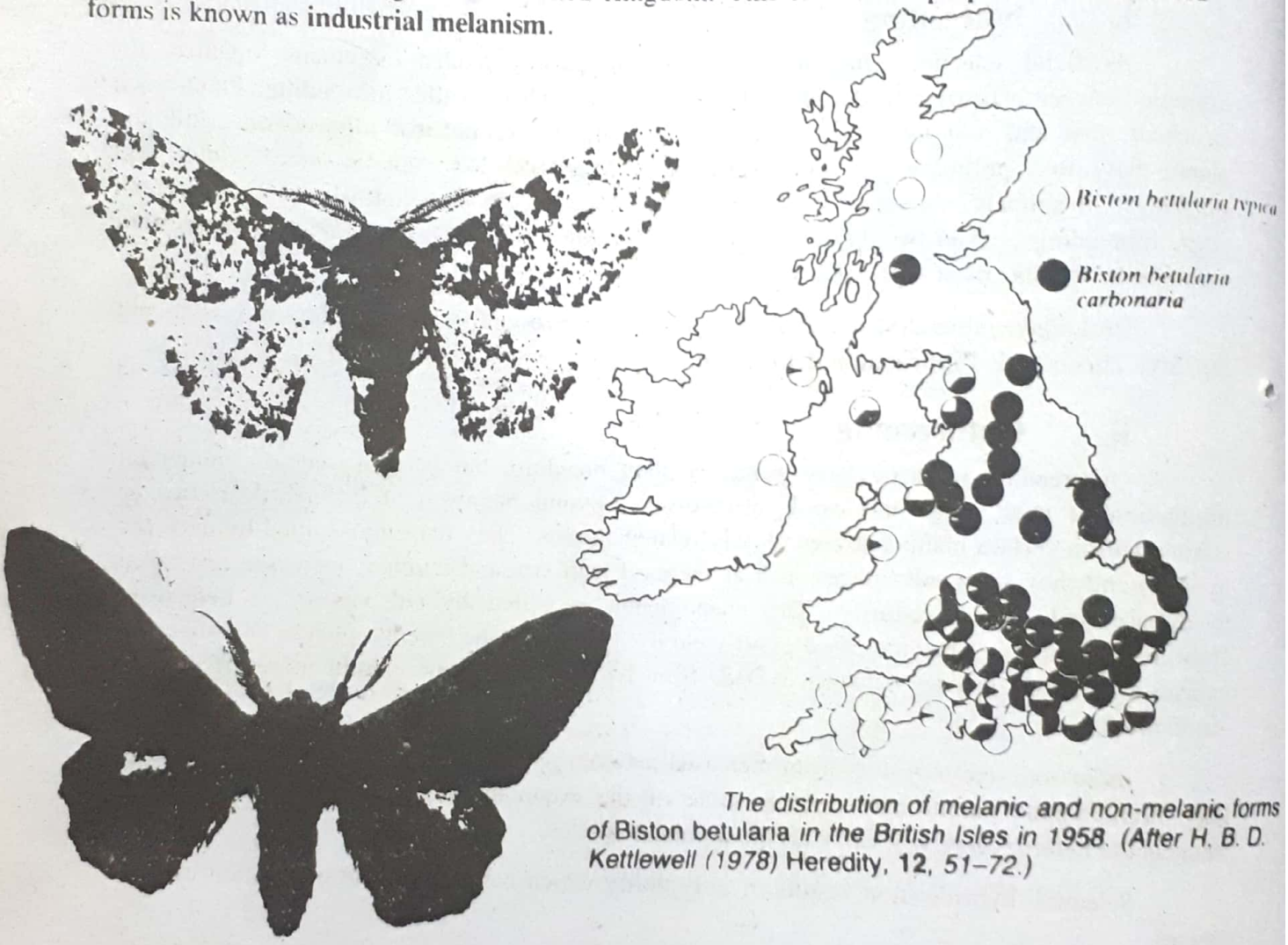
NATURAL SELECTION

The hypothesis of natural selection postulated by Darwin was based upon historical background. According to Darwin the time span involved in the evolutionary change in a population was such that it cannot be observed directly, therefore only the evidences can support it. However, recent advancements in the fields of industry, medicine and technology has caused so much directional and disruptive pressures that it has resulted in dramatic changes. These changes in phenotype and genotype of populations can be observed very easily within days.

A few examples are discussed below:

Industrial Melanism

Since industrial revolution in the early part of the nineteenth century, air pollution of gases such as **sulphur dioxide** from burning coal and solid matter mainly **soot** (coal black) was distributed over the industrial towns and cities and surrounding country side in United Kingdom. It resulted in killing of *lichens* and *mosses* growing on brick-work and tree trunks. Upto 1848 all the reported form of **peppered moth** (*Biston betularia*) present in these areas was creamy-white with black dots and darkly shaded areas. In 1848 a black form of moth was recorded in Manchester, and by 1895, 98% of the peppered moth population in Manchester was black. Within the last 100 years darkened forms of about 80 species of moths have appeared in varying frequencies throughout the United Kingdom. This rise in the proportion of darkened forms is known as **industrial melanism**.



The distribution of melanic and non-melanic forms of Biston betularia *in the British Isles in 1958. (After H. B. D. Kettlewell (1978)* Heredity, **12**, *51–72.)*

The black **melanic** form arose as a result of random mutation, but its phenotypic appearance had a strong selective advantage in the industrial areas. The moths fly by night and during the day they rest on the trunks of trees. The birds feed on these moths. The normal **non-melanic** form (creamy white in colour) of moth is extremely well camouflaged as its colouration merges with that of the *lichens* growing on the trunks. But due to rapid industrialisation the *lichens* were killed because of sulphur dioxide pollution and bark of trees was exposed and turned black due to soot deposits. It was observed that population of melanic form increased in polluted areas than non-melanic form because they were better camouflaged in changed environmets.

The colouration in *peppered moth* is controlled by a single gene with two alleles. The dark colouration is due to presence of a dominant melanic allele C. Therefore, the moths with CC or Cc alleles are melanic and moths of genotype cc are non-melanic.

Industrial melanism is a classical example of evolutionary change due to directional selection pressure produced by the atmospheric pollution.

Polymorphism

The organisms that exist in two forms in significant numbers are examples of **polymorphism**. It is defined as ***the existence of two or more forms of the same species***. It can be applied to biochemical, morphological and behaviourial characteristics.

There are two forms of polymorphism:

a. Transient polymorphism

In this case one form is gradually replaced by another. The frequency of the phenotypic appearance of each form is determined by the intensity of selection pressure, such as the melanic and non-melanic forms of the *peppered moth*. It applies in situations where one form is gradually replaced by another.

b. Balanced polymorphism

In this case both forms coexist within a population in equilibrium. For example, the existance of male and female sexes in animals and plants. The genotypic frequencies of various forms exhibit equilibrium since each form has equal selective advantage. A, B, AB and O blood groups in humans are examples of balanced polymorphism. The genotypic frequencies within different populations may vary but they remain constant from generation to generation wihin the population. This is because none of them have a selective advantage over the others.

Lead Tolerance

A. D. Bradshaw and others have studied the *grasses* that grow on small areas of land around the lead mines (mine tailings) in Wales. The soil in these areas is rich in lead, copper and other unusual materials that are toxic to plant growth, therefore, the land is almost bare. The few kinds of plants growing there include **bent grass**, *Agrostis tenuis*. Bradshaw compared the growth patterns of *Agrostis* plants taken from nearly pastures and areas where lead is not abundant in the soil with those of the plants from the mine tailings. He grew plants taken from the two different kinds of soils side by side in samples of both soil types.

In normal pasture soil, the plants from the mine area were smaller and grew more slowly than the ordinary pasteur plants, but they did survive. In the altered environment of lead-rich mine soil, the plants that Bradshaw had collected from the mine area grew well. In complete contrast, the pasture plants were, with a few exceptions, unable to grow in the mine soil, most of them dying within a few months. The exceptions, howere, were significant: in one sample of 60 plants from a pasture, 3 showed some ability to grow in the lead-rich soil. Such plants were undoubtedly the kind from which those that could grow in the mine soil had been selected originally. In this way, a race of *bent grass* that was able to grow well in lead-rich mine soil evolved, the altered environment selecting in favour of individuals tolerant of high levels of lead.

Because plants able to grow on lead-rich soil are found in association with mines less than a century old, the populations of *Agrostis tenuis* clearly are able to evolve, i.e., change their genotypic frequencies, quickly when the environment demands it. Similarly rapid changes have now been studied for other populations of organisms.

Antibioitc Resistance in *Bacteria*

Many diseases are caused by bacteria. Before 1940, when **penicillin** was discovered, bacteria were a major cause of death. Wounds, for example, often became infected by bacteria which could spread into the blood system and cause death by blood poisoning. Penicillin is an **antibiotic**, a chemical which kills bacteria inside the body but does no harm to a person's own cells.

The use of antibiotics has introduced new selection pressures within bacterial populations. Like all organisms, bacteria vary from one another. Some individuals in a population, for example, may carry a gene which confers resistance to an antibiotic such as penicillin. These resistance genes are often present on a plasmid rather than on the main DNA molecule in the cell. If a person takes penicillin, then any such individual bacterium has a considerable selective advantage over the others. The non-resistant individuals will be killed, but the resistant bacterium will survive. It can then reproduce rapidly, producing a whole population of bacteria that also contain the gene which makes them resistant to penicillin.

This has happened many times. Penicillin acts by inhibiting the synthesis of some parts of the bacterial cell wall. Some bacteria have genes with code for an enzyme called *beta-lactamase* which can break down penicillin and other antibiotics with a similar chemical structure. Other resistance genes may work by affecting the structure of proteins in the bacterium's membrane, stopping it from taking up the antibiotic at all, or by pumping it out after it has been taken up.

The pharmaceutical industry has a tremendous problem in trying to produce new antibiotics faster than bacteria evolve resistance to them. Most antibiotics have been developed from chemicals which are naturally synthesized by fungi which live in soil; the fungi use them to prevent too many bacteria living and feeding close to them, as the bacteria might compete with the fungi for food. Now this source seem to have been almost exhausted and researchers are looking elsewhere. Frog skins might prove to be a fruitful hunting ground, as might microorganisms living in unusual environments. However, in the end bacteria are always likely to develop resistance to whatever antibiotics are used, and it will be a constant struggle to keep ahead of them.

EVIDENCE FOR EVOLUTION

According to theory of evolution, organisms living today have arisen from earlier types of organisms by a process of genetic change that has occurred over a period of several billion years. The fact that all organisms have arisen from a common ancestor explains why they have the same mechanisms for the storage and utilization of genetic information, many of the same types of cellular organelles, and similar types of enzymes and metabolic pathways. At the same time the evolution also explains how a single species can give rise to numerous other species, leading to great biological diversity. The evidence supporting the evolution have come from fields such as paleontology, comparative anatomy, embryology, biochemistry, molecular

biology and biogeography. While the biologists may argue over the mechanisms of evolution, they agree that all life descended with modification from a single common ancestor.

EVIDENCE FROM PALAEONTOLOGY

Palaeontology is study of fossils. **Fossils** are remains of life from the past. Fossils are created when organisms become buried in sediment, the calcium in bone and other hard tissue is mineralized, and the sediment is eventually converted into rock. They may include entire organism, hard skeletal structures, moulds and casts, petrifications, impressions, imprints and fossilized faecal pellets.

The most direct evidence of evolution is provided by the fossil record, although it alone is inadequate to support an evolutionary theory, but it supports a that there is progressive increase in complexity of organisms and denies that species do not change. By dating the rocks by measuring the degree of decay of certain radioisotopes present in the rock, we can get an idea how old the fossils are. When these fossils are arranged according to their age, from oldest to youngest, they often provide evidence of progressive evolutionary change in the direction of greater complexity. For example, it has been observed that bony bumps on the nose of *hoofed mammals* changed progressively into large blunt horns. Similarly in the evolution of *horses*, the number of toes on the front foot is gradually reduced from four to one.

Archaeopteryx --- An example of Fossil Evidence

It is one of the best known fossils discovered in 1861 in a limestone quarry in Bavaria, Germany. The skeleton suggested that animal had been a bipedal dinosaur, imprints of wings with feathers suggested that it is a bird, therefore it was named *Archaeopteryx lithographica* (*archaeo* = old + *pteryx* = wings). It was determined that it lived 150 millions years ago in the forests of central Europe. It differs from modern birds in having teeth, a long tail containing over 20 vertebrae, free-floating ribs, and wings containing movable fingers with claws. All these characteristics resemble small, carnivorous *reptiles* called **theropods**. Therefore, *Archaeopteryx* provides evidence of an evolutionary pathway leading from reptiles to birds.

Fossil Plants

The earliest known fossil plants ar about 410 million years old. Within the next 100 million years, plants became abundant and diverse, eventually forming extensive forests. During **carboniferous period** (360 to 286 millions years ago), these forests formed many of the great coal deposits that we are consuming now. In these coal deposits, we have a relatively complete record of the *horsetails*, *ferns* and *primitive seed plants* that had made ancient forests. The **Permain period** was cool and dry and provided ecological stress and a chance for evolution. The conifers, a group of seed plants represented today by *pines*, *spruces*, *firs*, and similar *trees* and *shrubs*, originated during that period. Seed-bearing plants with feather-like leaves, similar to living *cycads* were abundant in the **Mesozoic era**. The oldest fossils of flowering plants or *angiosperms* are from the early **Cretaceous period** about 127 million years ago. They become dominant and diverse on land about 100 million years ago. The insects are considered to be evolved alongwith flowering plants (**coevolution**), because as the flowering plants became more diverse so as the insects. The feeding habits of insects were closely linked with the characteristics of flowering plants. All the other dominant groups of land organisms including mammals, birds and fungi are thought to have evolved their characteristics largely in relation to those of the flowering plants.

Pollen Analysis

A large number of pollen grains and spores (microfossils) are found preserved in peat and in lake sediments. They have an extremely long geological life, especially if they become rapidly submerged below the water table. The outer part of the wall of a pollen grain, the exine, effectively resists decay. The general shape of grains and spores and sclupturing of their outer surfaces are used by palaeobotanists to identify them, sometimes to species or genus and sometimes to family. Studies of pollens found in sediments can throw light on the kind of vegetation that prevailed in the area in the past. The oldest known spore is from Silurian period, more than 450 million years old; and oldest pollen fossil was formed in Carboniferous period, about 350 million years ago.

EVIDENCE FROM COMPARATIVE ANATOMY

Comparing the structures of the parts of the bodies of different organisms is probably the most commonly used evidence of evolution. In order to gather comparative evidence for evolution, biologists study external characteristics, examine bones and teeth, dissect organ systems, study sections of tissue under the light microscope, and examine finer details of cells and tissues under the electron microscope.

Homologous Structures

Comparative anatomy reveals that certain structural features are basically similar. For example, the **basic structure of all flowers** consists of sepals, petals, stamens, stigma, style and ovary; yet the size, colour, number of parts and specific structures are different in different species. Similarly structural pattern of limb in all tetrapods, from *amphibians* to *mammals*, is similar. It is called **pentadactyl limb**. This basic pattern has been modified in several ways in different organisms.

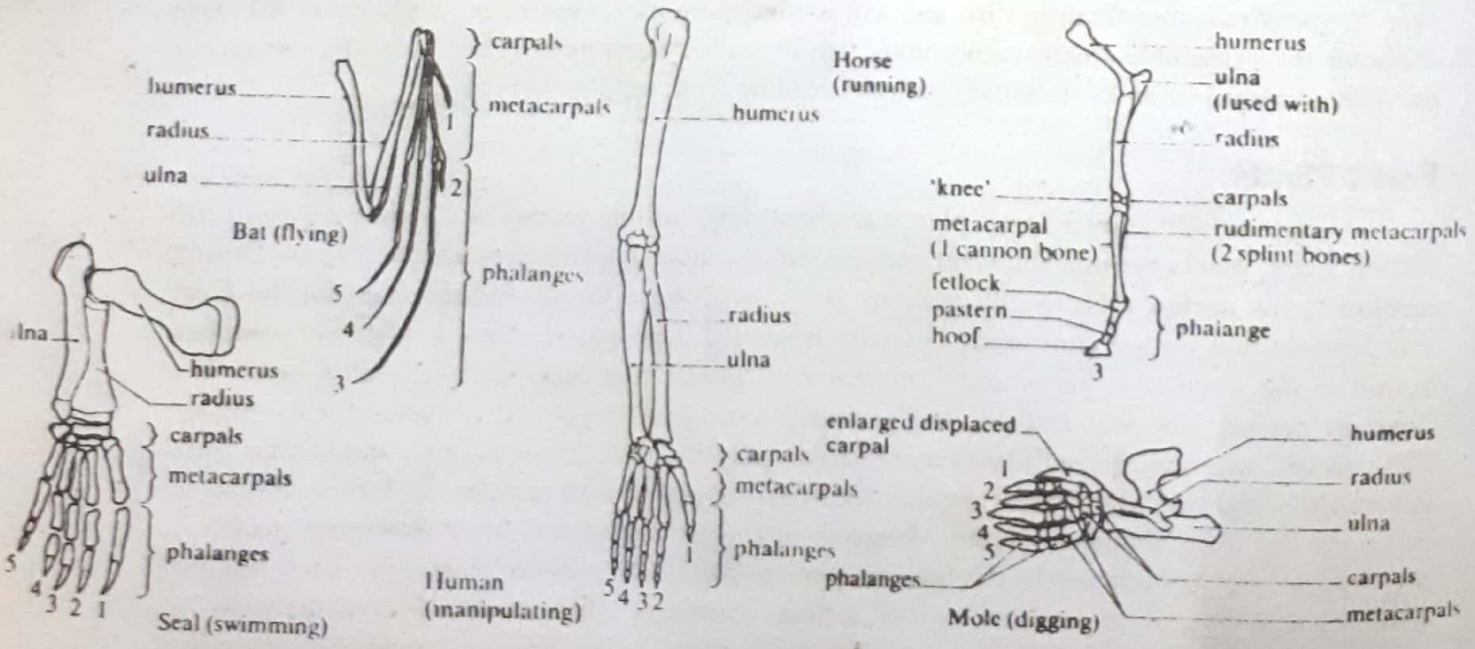


Fig. 35.1: Adaptations of the pentadactyl limbs as shown by mammals — Homologous Structures.

For example, **bones in forelimbs of** *horse* are modified into legs used for running, in *whale* into flippers used for swimming, in humans into arms for manipulating, and in bat into wings meant for flying. These are modification of a primitive skeletal pattern that was present in early terrestrial vertebrate ancestor. ***Organs having a similar basic pattern but modified into different forms to perform characteristics functions are called*** **homologous structures.**

Other homologous structures are: **ear osicles**; **halteres**, the hind pair wings of most insects modified into rods, which help to maintain balance in flight; and **pericarp**, the ovary wall modified in a variety of ways to help dispersal of seed, etc.

Vestigeal Structures

Certain homologous structures in some species have no apparent function and are described as vestigeal organs. For example, the underdeveloped pelvis and leg bones in *snakes*, the diminished toe bones in *horses* and the appendix and coccyx in *humans*. The non-functional **pelvis and leg bones** in *snakes* are thought to be homologous with the hip bones and hindlimbs of vertebrates. The **appendix** is shortened caecum which contains cellulose-digesting enzyme in herbivores and **coccyx** represents the tail possessed by our ancestors. ***Presence of vestigeal organs is a strong evidence for evolution. If species had been created as they are today, there would be no explanation for such structures.***

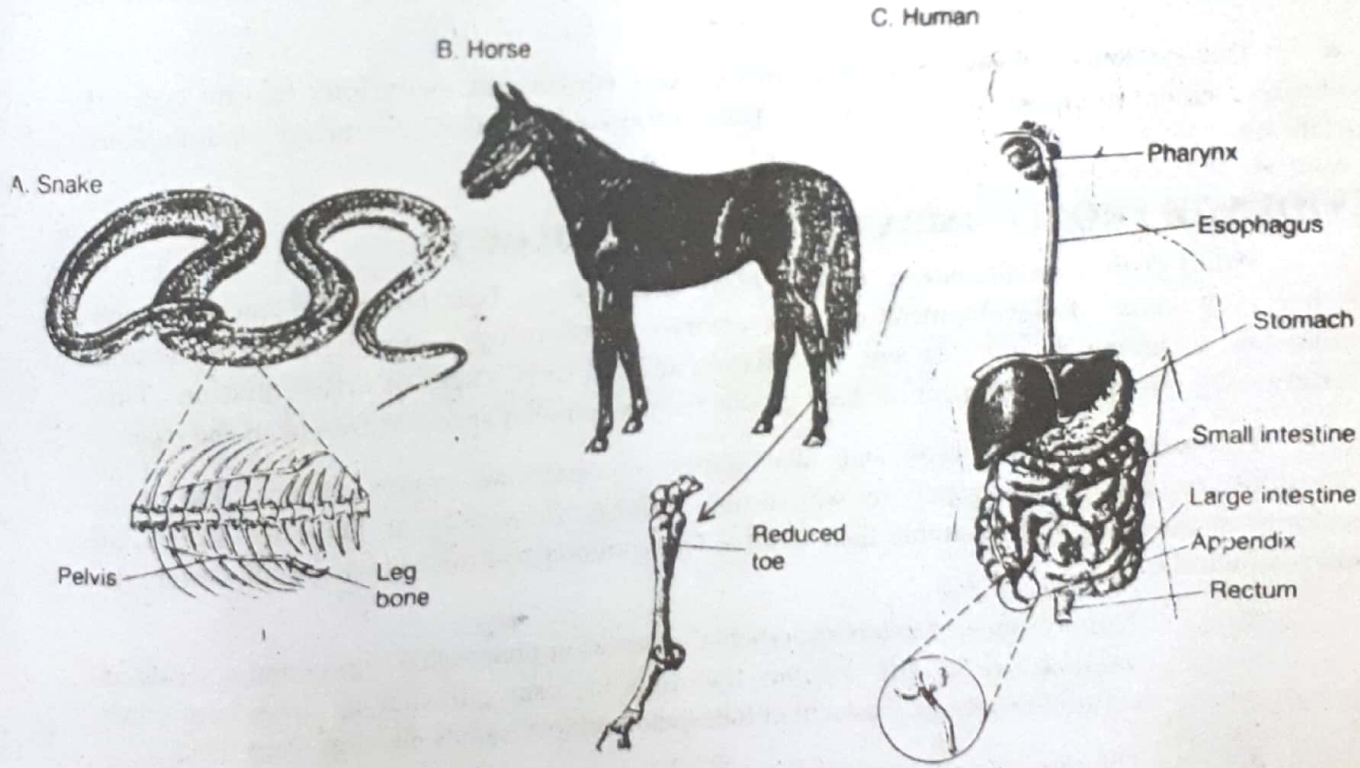


Fig. 35.2: Vestigeal organs.

Adaptive Radiation

When a group of organisms share a homologous structure which is differentiated to perform a variety of different functions, it illustrates a principle known as **adaptive radiation.** All organisms belonging to a particular class share a number of diagnostic characteristics. The variations between different species within the class enable them to adapt to different habitats. For example, the **mouthparts of** *insects* consist of the same basic structures: a labrum (upper lip), a pair of mandibles, a hypopharynx (floor of the mouth), a pair of maxillae and a labium

(fused second pair of mandibles, lower lip). Insects are able to feed upon a variety of food materials because some of these strucutures are enlarged and modified, whereas the others reduced and lost. This produces a variety of feeding structures. This adaptive ability have enabled the insects to occupy of wide range of ecological niches.

Analogous Structures

Similar structures, physiological processes or modes of life in organisms that differ in their structural pattern but show adaptations to perform the same functions are described as **analogous structures**. For example, eyes of *vertebrates* and *cephalopods*, the wings of insects and bats, the jointed legs of insects and vertebrates, the presence of thorns on plant stems and spines on animals, and the existence of vertebrate neurotransmitters such as acetylcholine.

Analogous structures only bear superficial similarities. For example, the wings of *insects* are supported by toughened veins composed of cuticle, whereas both *bats* and *birds* have hollow bones for support. The embryological development of the *cephalopod* and *vertebrate* eyes is different. The former produces an erect retina with photoreceptors facing the incoming light, whereas the latter has an inverted retina with photoreceptors separated from incoming light by their connecting neurons. Thus, the vertebrate eye has a blind spot which is absent in *cephalopods*.

The existence of analogous structures suggest **convergent evolution**. In this type of evolution, the environments act through the agency of natural selection, favouring advantageous variations.

EVIDENCE FROM COMPARATIVE EMBRYOLOGY

Adult *fishes*, *salamanders*, *turtles*, *birds* and *humans*, bear no resemblances to one another, yet study of development of their embryos (embryology) show striking structural similarities occurring during cleavage, gastrulation and the early stages of differentiation. This strongly suggests the development of these groups from a common ancestor present in the past.

Examination of embryos and fetal stages of vertebrate groups reveals that it is impossible to identify the group to which they belong. It is only at the later stages of development they begin to resemble their adults. The common features shown by all vertebrate embryos include:

a. The presence of external branchial grooves in pharyngeal region and a series of internal paired gill pouches that join to form gill slits in *fishes*. In other vertebrate groups Eustachian tubes and auditory canals develop from these.

b. The presence of segmental myotomes in the tail-like structure which is retained in certain species only.

c. There is a single circulation which includes a two chambered heart showing no separation into right and left halves. This kind of heart is retained by fishes only.

This suggest that all vertebrate groups had a common ancestor. The organisms have retained the developmental mechanisms of their ancestors. Later part of development is modified because of adaptations to different environmental conditions and modes of life. It has been observed that the organisms having common adult homologous structures exhibit longer similar embryological developmental phases.

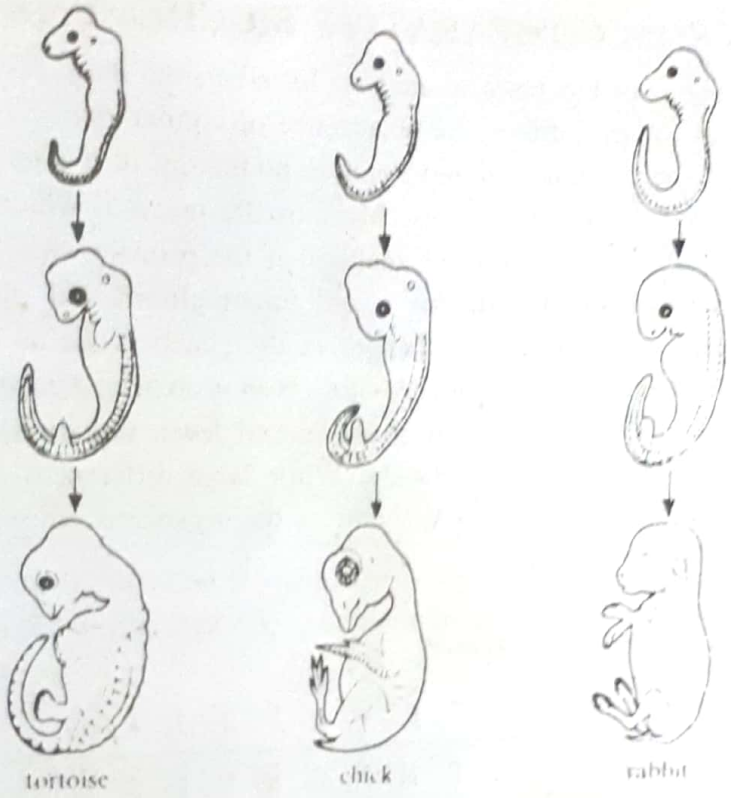


Fig. 35.3: Stages in embryological development as shown by examples from three vertebrate classes.

A classical example of embryological evidence is **presence of nipples in males** proposed by **Stephen J. Gould** recently. Male and female *mammals* of a species pass through identical stages of embryo development. The male and female development diverge at the time of secretion of sex hormones. Nipples are present in males before the time of sexual differentiation. Later sexual maturation leads to changes in the female breast and nipples. The male nipples remain as the vestige of an embryonic structure.

The evidence of progressive development on the basis of embryology can be seen in plants as well, but the examples are less. The **gametophytes** of primitive *mosses* and *ferns* are represented by **protonema** produced by germination of the spores has a similar structure, physiology and pattern of growth to filamentous *green algae*, from which they thought to be evolved.

Alternation of generation in plant life cycles and homologous variations in it are considered to be due to adaptations to various environmental conditions. For example, *gymnosperms* are regarded as a group inbetween land plants and plants which still requires water for fertilisation. In *Cycas*, the male gametophyte resemble pollen grains of *angiosperms* in that it is distributed by wind. As it develops, pollen tube is formed, but instead of carrying gametes it act as haustorium for absorption of food. The gametes are flagellated and swim to ovule to fertilise the egg present there. The *Cycas* therefore represents intermediate group of plants. It suggests that *gymnosperms* are adapted to a different environment and are phylogenetic intermediate forms between non-vascular plants and angiosperms. Many of these intermediate forms are extinct and are represented by fossils.

EVIDENCE FROM COMPARATIVE BIOCHEMISTRY

As techniques of biochemical analysis have become more precise, this field of research provided evidences for evolution. The occurrence of similar molecules in a complete range of organisms suggest the existence of biochemical homology in a similar way to the anatomical homology shown by organs and tissues. Most of the research which has been carried out on comparative biochemistry has involved analysis of the primary structure of widely distributed protein molecules, such as **cytochrome *c*** and **haemoglobin** and most recently **nucleic acid molecules** particularly **rRNA**. Slight changes in the genetic code as a result of gene mutation produce variations in the overall strutcture of a given protein or nucleic acid. It can be assumed that fewer differences in the molecular structure and fewer mutations result in greater affinity between organisms containing the molecule. While large differences in the molecular structure represent large differences in the DNA, therefore the organisms are separated and exhibit fewer anatomical homologies.

Species	*Amino acid sequence*																										
	70										80									90							
	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5
Human	D	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	V	G	I	K	K
Rhesus monkey	D	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	V	G	I	K	K
Horse	E	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Pig, bovine, sheep	E	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Dog	E	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Grey whale	E	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Rabbit	D	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Kangaroo	D	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Chicken, turkey	D	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Penguin	D	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Pekin duck	D	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Snapping turtle	E	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Bullfrog	D	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Tuna	D	T	L	M	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Screwworm fly	D	T	L	F	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Silkworm moth	D	T	L	F	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	I	K	K
Wheat	N	T	L	Y	D	Y	L	L	N	P	K	K	Y	I	P	G	T	K	M	I	F	A	G	L	K	K
Fungus (*Neurospora*)	N	T	L	F	E	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	V	F	A	G	L	K	K
Fungus (*baker's yeast*)	N	N	M	S	E	Y	L	T	N	P	K	K	Y	I	P	G	T	K	M	V	F	P	G	L	K	K
Fungus (*Candida*)	P	T	M	S	D	Y	L	E	N	P	K	K	Y	I	P	G	T	K	M	A	F	G	G	L	K	K
Bacterium	A	N	L	A	A	Y	V	K	N	P	K	A	F	V	L	E	S	K	M	T	F	K	–	L	T	K

Key to amino acids

A alanine	F phenylalanine	K lysine	P proline	T threonine
C cysteine	G glycine	L leucine	Q glutamine	V valine
D aspartic acid	H histidine	M methionine	R arginine	W tryptophan
E glutamic acid	I isoleucine	N asparagine	S serine	Y tyrosine

Table. 35.a: Cytochrome *c* amino acid sequences for 21 species.

Cytochrome *c*

Cytochromes are respiratory proteins situated in the mitochondria and are responsible for transfer of electrons along the respiratory pathway. Cytochrom *c* is one such protein from the pathway. It is a conjugated protein composed of an iron-containing prosthetic group

surrounded by polypeptide chain containing between 104 and 112 amino acids, depending upon species. The primry structure of this protein has been worked out for 21 different organisms including *bacteria*, *fungi*, *wheat*, *silkworms*, *tuna*, *penguin*, *kangaroo* and *primates*. It has been observed that in 20 out of 21, amino acids in position 78-88 were identical. The amino acid sequence for cytochrome *c* of *humans* and *chimpenzee* is identical and differ from the *rhesus monkey* by only one amino acid. The computer study based on amino acid sequences of cytochrome *c* have produced plant and animal **phylogenetic trees** which show close agreement with phylogenetic trees based on anatomical homologies.

Similar results have been obtained from the study of the globin proteins, **haemoglobin** and **myoglobin** involved in oxygen transport and storage.

Another example of biochemical homology is the presence of similar hormones in vertebrates where they carry out different functions. For example, a hormone similar to mammalian **prolactin** occurs in all vertebrates groups where it is produced by pituitary gland. In all these groups it is involved in osmoregulation and reproduction.

EVIDENCE FROM COMPARATIVE MOLECULAR BIOLOGY

Until recently, biologists had to rely solely on phenotypic differences among organisms to assess evolutionary relatedness. With advances in DNA technology, evolutionists can now focus directly on differences in genotypes, the source of biological variations.

The entire technology used in the formation of recombinant DNA is based on the universality of the genetic code. DNAs from diverse sources such as humans, viruses and bacteria can be spliced together to form a single, continuous DNA molecule. This recombinant DNA can then be introduced into a host cell, usually either bacterial or mammalian cell. Once in the host cell, the human DNA will direct the formation of a human protein that is indistinguishable from the same protein produced by human cell.

The DNA recombinant technique has been used by evolutionary biologists. Mutations can lead to changes in the nucleotide sequence of DNA. These changes can serve as the raw material for biological evolution. Since mutations in DNA occur continuously over time, the longer the amount of time that passes since two organisms diverged from a common ancestor, the greater the differences in their DNA sequences. Molecular data has been used to determine that humans are more closely related to chimpenzee than gorillas. The molecular data have alos been used to resolve evolutionary controversies.

What is a Bat? --- The Use of Molecular Data in Studying Evolution

There are two major groups of bats:

a. The ***microchiroptera***, which incldues bats commonly seen at night. This group includes more number of bats and members feed upon *insects*, *frogs*, etc.

b. The ***megachiroptera***, also called flying foxes because of their fox-like faces. These feed upon food and live in tropics.

Bats are highly specialised for flight, and many of the features reveal that their closest relatives have been modified almost beyond recognition because of natural selection. This resulted in debate among biologists over the evolution of bats. One group of scientists

determined that the skeletal evidence pointed to a close relationship between *microchiroptera* and *megachiroptera* and that both groups are distantly related to primates. Other scientists claimed that evidence derived from studying nervous system indicated that *megachiroptera* and *primates* were closest relatives. There seemed to be no data to solve the debate until late 1991, at which time molecular biologists determined the sequence of the DNA that codes for ribosomal-RNA of all the three groups, *microchiroptera*, *megachiroptera* and the *primates*. The molecular evidence showed that the *microchiroptera* and *flying foxes* were indeed closest relatives.

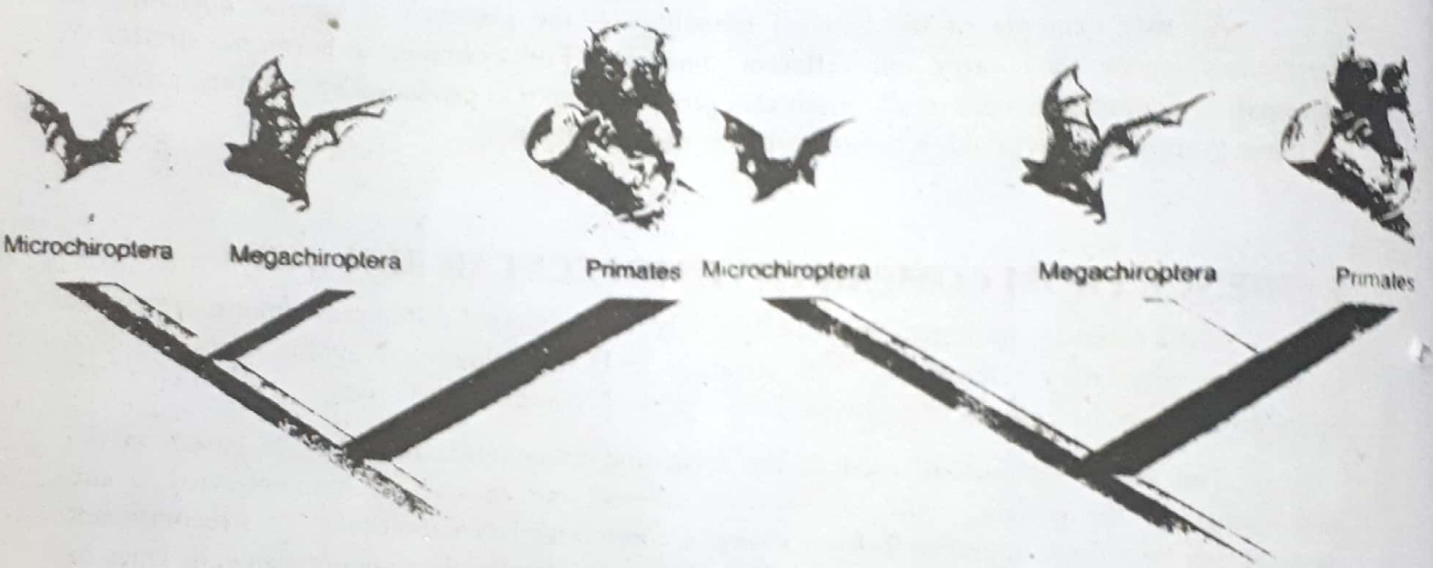


Fig. 34.4: Evolution of Bat.

EVIDENCE FROM BIOGEOGRAPHY

Biogeography ***is study of geographical distribution of organisms***. Darwin's theory of natural selection is based upon observations he made on the Galapagos islands. Darwin found that species found on oceanic islands were not found anywhere else in the world. In fact, many were found on a particular island in the chain and varied from one island to the next. Darwin observed that different species of *finches* living on different islands possessed different anatomic features. Their beaks were modified for obtaining different types of foods, but birds were similar in their overall anatomy, both to one another and to species found on the mainland. Darwin concluded that individuals from the mainland species had migrated to the islands, where, given the absence of competition from other birds, they had evolved into a variety of different species adapted to different local conditions and food sources. A common origin also explained why the plants and animals of the Galapagos were generally so similar to those species living on mainland, even though two region had totally different climates and terrain.

These types of biogeographical observations are not restricted to Galapagos. Plants and animals living in nearly areas typically are similar, regardless of differences in climate and terrain, because they are closely related. In fact, island and mainland species are often placed in the same genus. In contrast, plants and animals living in similar environments on different continents tend to be quite different.

EVIDENCE FROM SYSTEMATICS

The branch of biology dealing with naming of organisms and their arrangement into groups and sub-groups is **systematics**. The system of naming and classification was proposed by Linnaeus before the time of Darwin, but has implications for the origin of species and and evolutionary theory.

Evolution implies that species have common ancestors and that living things originated at some remote time in the past. The structural similarities among organisms suggest the existence of evolutionary process. The evolutionary history of related groups of organisms is known as **phylogeny**. In classifying living organisms an attempt is made to base on evolutionary relationships. This system of classsification is called **natural** or **phylogenetic classification**. The similarities and differences between oragnisms may be explained as the result of progressive adaptation by organisms within each taxonomic group to particular environmental conditions over a period of time.

Within different schemes of classification, some of the groups show similar levels of structural complexity. The members of such groups are derived from more than one ancestral forms and are said to have a **polyphyletic origin**. For example, it seems that the members of *Protozoa* are polyphyletic, their only common feature being that they consist of a single cell. Similarly *Arthropoda* incldues very diverse sub-groups such as the *insects*, *spiders*, *crustaceans*, *millipedes* and *centipedes*. On the other hand, all organisms belonging to angiosperms produce seeds inside an ovary. Also all of these show double fertilisation in the embryo sac. These features suggest that they have a common evolutionary history or **monophyletic origin**. The classification in these is based on homologous structures.

The ability to classify a significant proportion of of living organisms within a phylogenetic scheme is evidence for evolution.