HEREDITY AND EVOLUTION

Reproduction give rise to new individuals which are similar to parents but not identical. Sexual reproduction leads to VARIATION (i.e. difference in characters or traits among the individuals of a species). Some amount of variations can also be produced in asexual reproduction (due to small inaccuracies in DNA copying) but it is very small. For example, in a field of sugarcane, all plants almost look alike or there is a very small variations among the individual plants. But in animals (including human beings) which reproduce by the process of sexual reproduction, a large number of variations are produced. It is due to these variations that no two human beings look alike (except identical twins). In this chapter, our main focus will be on -.

(i) How these variations are created and inherited to next generation.

(ii) Long term consequences of accumulation of variations.

ACCUMULATION OF VARIATIONS DURING REPRODUCTION - The variations produced in organisms during successive generations get accumulated in the organisms. The significance of variation shows up only if it continues to be inherited by the offspring for several generations. For example, a bacterium produces two bacteria by asexual reproduction, Suppose if one of the offspring bacterium has a variation due to which it can tolerate a little higher temperature (or more heat). than the other one. Now this variation of little more heat resistance will go on accumulating in the offsprings of successive generations of this bacterium. And this will ultimately give rise to a variant of bacteria which will be highly heat resistant and able to survive even at very high temperature.

The great advantage of variation to a species is that it increases the chance of its survival in a changing environment e.g. the accumulation of heat resistant variation in some bacteria will ensure its survival even when the temperature in its environment rises too much due to heat wave or some other reason. On the other hand, the bacteria which did not have this variation to withstand heat would not survive under these circumtances and die. Thus selection of variants by environmental factors forms the basis of evolutionary process.

HEREDITY - The transmission of characters from the parents to their offspring is called heredity.

- Some of the Important terms which are required to understand the transmission of characters from parents to their offspring or progeny are described below-.

(i) CHARACTERS – It is distinct, well defined morphological or physiological feature of the individual e.g. height.

(ii) TRAIT – It is a distinguishable expression of a character e.g. tall or dwarfness.

(iii) CHROMOSOMES – are thread like structures present in the nucleus of cell. It is formed of DNA which carries the genes.

(iv) GENES – A gene is a unit of DNA on a chromosome which governs the synthesis of a protein that controls a specific characteristics (or trait) of an organism. Genes are considered as unit of heredity which transfer traits from parents to their offspring during reproduction. Genes work in pairs and genes controlling the same characteristics are given the same letters. For example, the gene for tallness is represented by the letter T, whereas the gene for dwarfness is represented by the letter t. The letters T and t actually represent two forms of the same gene which controls the length of the plant. Thus there are two types of genes — (a) dominant gene
(b) recessive gene.

(a) dominant gene – The gene which decides the appearance of an organism even in the presence of an alternative gene is known as dominant gene.

(b) recessive gene – The gene which decides the appearance of an organism only in the presence of identical gene is called recessive gene.

– The dominant gene is represented by a capital letter and the corresponding recessive gene is represented by the corresponding small letters. For example in pea plant, the dominant gene for tallness is 'T' and the recessive gene for dwarfness is 't'.

(v) GENOTYPE – is the description of genes present in an organism. e.g. the genotype for tallness can be TT or Tt whereas that of dway plant is tt.

(vi) PHENOTYPE – the character that is visible in an organism is called its phenotype. For example, being "tall" or "dwarf" are phenotypes of a plant because these traits can be seen by us or these are visible to us.

(vii) F_1 – GENERATION – When two parents cross (or breed) to produce progeny (or offspring), then their progeny is called first filial generation or F_1 generation.

(viii) F_2 – GENERATION – When the first generation progeny cross among themselves to produce second progeny, then this progeny is called second filial generation or F_2 generation.

(ix) HOMOZYGOUS – It is an individual having identical alleles of a gene. eg TT or tt.

characteristic of an organism. (one is dominant and other is recessive gene). Each parent possesses a pair of genes for each characteristic on a pair of chromosome. However each parent passes only one of the two genes of the pair for each characteristic to its progeny through gamets. Thus, the male gamete and female gamete carry one gene for each characteristic from the gene pairs of parents.

When a male gamete fuses with a female gamete during fertilization, they form a zygote with a full set of genes (or chromosomes). The zygote grows and develop to form a new organism having characteristics from both the parents which it has inherited through genes. The two genes responsible for a particular characteristic are always present on the corresponding positions of the pair of chromosome. Though the progeny inherits two genes for each trait from its parent but the trait shown by the progeny depends on which inherited gene is dominant of the two.

Thus in this way progeny restores the normal number of chromosomes ensuring the stability of DNA of the species.

HOW DO THESE TRAITS GET EXPRESSED — Factors are Genes or segments of DNA that control the expression of traits. They operate through controlling the synthesis of proteins or enzymes formed from them. A dominant factor takes part in the synthesis of a fully functional protein or enzyme so that it produces its morphological or physiological effect. A recessive factor is unable to produce the fully effective protein or enzyme. The latter is incomplete, defective or little efficient. As a result it is unable to express its effect in the presence of dominant factor. Its effect becomes apparent only when the recessive allele occur in a pair.

For example, plant height is controlled by hormones. Tallness or dwarfness would depend upon the amount of growth promoting hormone. The latter will be influenced by the efficiency of the process for making it. A protein that is important for this process is synthesized by the factor for tallness more efficiently than the factor for dwarfness. As a result plants having the T factor grow taller while the ones having tt remain dwarf.

SEX DETERMINATION — Establishment of male and female individuals through differential development of their sex organs is called sex determination.

Different species use very different strategies for this. Some rely entirely on environmental cues. e.g. in some animals, the temperature at which short plants with wrinkled seeds), two new combinations were also there i.e. tall plants with wrinkled seeds and short plants with round seeds.

TTRR × ttrr
Tall plants with round seeds — short plants with wrinkled seeds.

↓ ↓

TR tr — Gametes

TtRr — F₁-generation

Tall plants with round seeds.

	TR	Tr	tR	tr
TR	TTRR Tall & round	TTRr Tall & round	TtRR Tall & round	TtRr Tall & round
Tr	TTRr Tall & round	TTrr Tall & wrinkled	TtRr Tall & round	Ttrr Tall & wrinkled
tR	TtRR Tall & round	TtRr Tall & round	ttRR small & round	ttRr small & round
tr	TtRr Tall & round	Ttrr Tall & wrinkled	ttRr short & round	ttrr short & wrinkled

Gametes. F_2 - generation

Tall plants with round seeds : 9
Tall plants with wrinkled seeds : 3
Short plants with round seeds : 3
Short plants with wrinkled seeds : 1.

On the basis of above results, another law is given by Mendel i.e. Law of independent assortment.

LAW OF INDEPENDENT ASSORTMENT- According to this law, when there are two pairs of contrasting characters, then the distribution of each pair to the gametes is independent of the distribution of the other pair of characters or each pair of characters may combine with either of the other pair.

HOW ARE CHARACTERISTICS TRANSMITTED TO PROGENY -.

Genes are responsible for the characteristic feature (or traits) of an organism. These traits are transmitted from parents to their progeny through genes present on their chromosomes during the process of sexual reproduction.

Genes work in pairs. There is a pair of genes for each

(X) HETEROZYGOUS / HYBRID – An individual having both the contrasting allele of a character is called hybrid or heterozygous individual e.g. Tt.

(XI) MONOHYBRID CROSS – in which only one pair of contrasting character is taken into consideration.

(XII) DIHYBRID CROSS – in which two pairs of contrasting characters are taken into consideration at a time.

GREGOR JOHANN MEDEL is known as FATHER OF GENETICS as he was the first scientist to make a systematic study of patterns of inheritance which involved the transfer of characteristics from parents to progeny. Mendel selected pea plant for his experiments due to following reasons –

(i) Easy availability of detectable contrasting traits of several characters and pure varieties of pea.
(ii) Flower structure normally allows self fertilization but cross fertilization can also be carried out easily.
(iii) Annual nature of the plant.
(iv) Formation of a large number of seeds by each plant.
(v) Requirement of little care except at the time of cross-breeding.

Mendel selected seven visible characters each with two contrasting traits are shown in the following table –

S. NO.	Character	Dominant trait	Recessive trait
1.	seed shape	Round	Wrinkled
2.	Seed colour	Yellow	Green.
3.	Flower colour	Violet	White
4.	Pod shape	Full	Constricted.
5.	Pod colour	Green	Yellow.
6.	flower position	Axial	Terminal.
7.	Stem height	Tall	Dwarf.

MONOHYBRID INHERITANCE – In order to trace the inheritance of a single pair of characteristics among the pea plants, Mendel first crossed pure-bred tall pea plants with pure-bred dwarf pea plants. He found that only tall pea plants were produced in first generation or F_1 generation. No dwarf or medium height pea plants were obtained in F_1 generation. This meant that only one of the parental trait was seen and not the mixture of two. Mendel then crossed the tall pea plants of F_1 generation and found that both tall and dwarf plants were obtained in F_2 generation. Out of these 3/4 pea plants were tall and 1/4 were dwarf.

This indicates that both the tallness and shortness traits were inherited in F_1 plants but only the tallness trait was expressed as it was a dominant trait. Thus two copies of the trait are inherited in each sexually reproducing organism. These two may be identical or different. He also noted that all the pea plants produced from the hybrid in F_2 generation were either tall or dwarf. There were no plants with intermediate height (or medium height). This shows that the traits are inherited independently. This is because if the traits of tallness and dwarfness had blended (or mixed up) then medium sized pea plants would have been produced.

TT (Tall plants) × tt (Short plants)

↓

Tt — Tall plants (F_1 – generation)

Tt × Tt ($F_1 \times F_1$)

Tall plants   Tall plants

T t   T t

TT   Tt   Tt   tt (F_2 – generation)

Tall   Tall   Tall   Short

Phenotypic ratio :- 3 : 1

Genotypic ratio :- 1 : 2 : 1

On the basis of above results Mendel formulated two laws – law of dominance and law of segregation.

(i) LAW OF DOMINANCE – Out of a pair of contrasting characters brought together in an offspring, one always dominates over other. The one that is expressed is dominant and the one that remains masked is recessive.

(ii) LAW OF SEGREGATION – From a pair of contrasting character (or alleles) only one is present in a single gamete, and one character is dominant and other is recessive in F_1 and in F_2 these characters are segregated in the ratio of three to one.

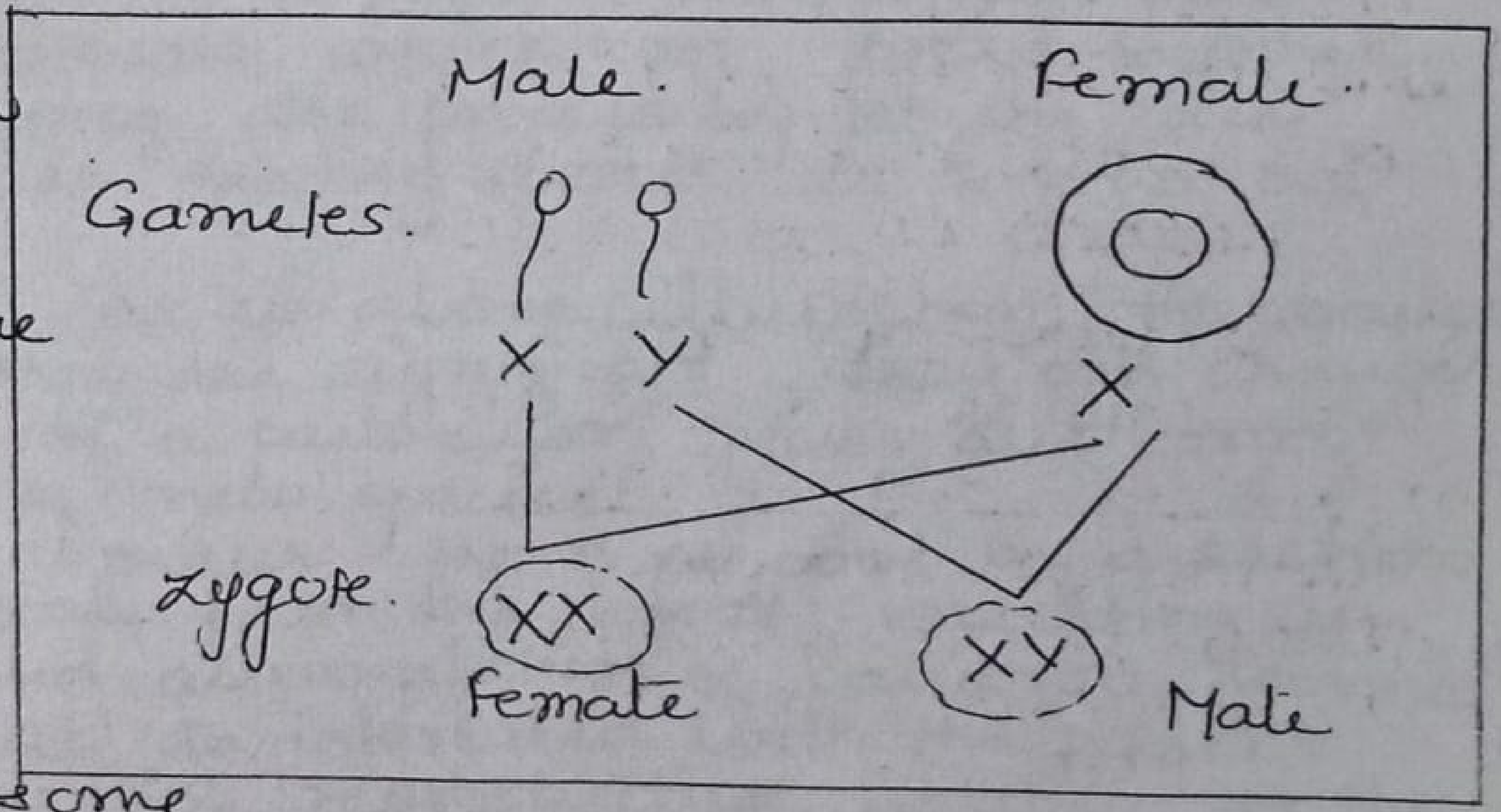
DIHYBRID INHERITANCE – To study the inheritance of two pairs of contrasting traits, Mendel crossed tall plants with round seeds and short plants with wrinkled seeds. In F_1 generation all the plants were found to be tall having round seeds. Tallness and round seeds are thus dominant trait. But when F_1 progeny are used to generate F_2 progeny by self pollination, it was found that in addition to existing combinations (i.e. tall plant with round seeds and fertilized eggs are kept determines whether the animal developing in the egg is male or female. In other animals such as snails, individual can change sex indicating that sex is not genetically determined.

In human beings and a number of other animals, the sex of an individual is genetically determined. They have two types of chromosomes —

(i) Autosomes — which control normal function of the body.
(ii) Allosomes or sex chromosomes — which determine sex of an individual.

Human beings have 23 pairs of chromosomes — 22 pair of autosomes and a single pair of sex chromosome. Female has a perfect pair of sex chromosomes, both called X. while male has a mismatched pair in which one is normal sized X chromosome while the other one is short called Y chromosome.

All the eggs produced by female contain X chromosomes while 50% of sperms contain X chromosome and 50% will have Y chromosome. The sex of child is determined at the time of fertilization depending upon which type of sperm fuses with ovum. If sperm containing X-chromosome fuses with ovum, then the offspring will have XX chromosome and will be a female. On the other hand, if sperm having Y-chromosome fuses with the ovum having X-chromosome, the offspring will have XY chromosome and will be male.



ACQUIRED AND INHERITED TRAITS —

Acquired traits are those variations which are not inherited but develop in response to some environmental change. Their influence is restricted to somatic cells, therefore non inheritable (i.e. cannot be passed on to the DNA of the germ cells). e.g. weight of the beetles in above illustration.

Another example is of an experiment done on mice by Weismann. He removed the tails of mice for 21 generations but could not find any change in tail size in 22nd generation. This is because removal of tail cannot change the genes of germ cells of mice.

Inherited traits are those characteristics which are passed from parents to their offspring generation after generation. because in this changes have occurred in genes (DNA) present in the germ cells.

On the basis of above results, Darwin proposed its THEORY OF NATURAL SELECTION which states that organic evolution occurs through natural selection and accumulation of inheritable variations which provides structural and functional superiority to some individuals over others in their survival and reproduction.

SPECIATION —

SPECIES is a population of organisms consisting of similar individuals which can breed together and produce fertile offspring. The process by which new species develop from the existing species is known as SPECIATION.

In microevolution (as in above illustration), the changes are small even though they are significant. They can change the common characteristic of a particular species but cannot result in the formation of new species.

For speciation to occur the gene pool of a section of population should separate from the rest, resulting in stoppage of gene flow and accumulation of variation, some of which do not allow it to interbreed with the parent population. Development of reproductive isolation is the basis of the formation of new species.

The major factors responsible for formation of new species are —

(i) Geographical isolation — A physical barrier like valley, mountain, water body etc. develops between two populations of a species. Each separated population accumulates its own variations in structure, physiology and behaviour so that the members of separated populations are unable to interbreed even if bought together. They form new species. It is a major factor in sexually reproducing animals but not in self pollinating plant species or in asexually reproducing organisms.

(ii) Genetic drift

(iii) variation caused in individual due to natural selection.

Consider a large population of beetles spread over a mountain range. The individual beetle feed mostly on a few nearby bushes throughout their life time. Thus subpopulation of

EVOLUTION — There is an inbuilt tendency to variation during reproduction both because of error in DNA copying and as a result of sexual reproduction. EVOLUTION refers to a gradual change brought by variation from one generation to another since the beginning of the life. It brings a change in genetic composition of a population.

AN ILLUSTRATION — Consider a group of 12 red beetles which reproduces sexually and live in the bushes with green leaves. Sexual reproduction produces inheritable variations. The beetles are preyed upon by crow. The population of beetles can meet the following fates —.

I[st] situation — A colour variation is produced during reproduction so that there is one beetle that is green in colour instead of red. This beetle can pass the colour on to its progeny so that all the progeny beetles are green in colour. These green beetles cannot be seen by crows so they are not eaten. As a result with the passage of time there will be more number of green beetles than red beetles.

In this case the variation become common because it gave a survival advantage or it was naturally selected. The natural selection is exerted by crows. The more crows there are, the more red bettles would be eaten and more the proportion of green beetles in the population would be.

Thus NATURAL SELECTION is directing evolution in beetle population. It results in adaptations in the beetle population to fit their environment better.

II[nd] situation — Again a colour variation arise during reproduction which results in blue coloured beetles. This beetle can also pass the colour on to its progeny so that all its progeny beetles are blue. Crow can see blue coloured beetles in the green leaves of bushes as well as they can see the red ones and therefore can eat them. Initially there will be more number of red beetles than blue beetles. But at this point an elephant comes by and stamps on the bushes where the beetles live. This kills most of the beetles. But by chance, the few beetles which have survived are mostly blue. These blue beetles will now slowly increase their number.

In this case, the colour change gave no survival advantage. It is simply a matter of accidentall survival of beetles of one colour that change the common characteristic of the resultant population. This random change in gene frequency occurring by chance irrespective of its being harmful or beneficial is called GENETIC DRIFT. i.e. diversity without any adaptations. This generally occurs in small populations.

III[rd] situation — In this, as the beetle population begins to expand the bushes start suffering from a plant disease. The amount of leaf material is reduced and as a result, the average weight of the adult beetles decreases due to scarcity of food. Their number also decreases. After few years, when the plant disease is eliminated, the average weight of beetles once again increase due to availability of food. Thus the beetle population have come back to its normal size and weight. This change is not inherited over generation.

beetles are formed. The process of reproduction will occur mostly within these subpopulations. or rarely between two different subpopulations. So gene flow between two sub-population will be in very less amount. If however, between two such subpopulations, a large river comes into existence the two subpopulations will be isolated. The level of gene flow will further decrease between the two subpopulations. Over generations, the process of natural selection and genetic drift further isolate two subpopulation of beetles. Now members of these two subgroups will be incapable of interbreeding even after they meet each other. It results in reproductive isolation and formation of a new species.

There can be a number of ways by which interbreeding between two beetles of two subgroups stops. The change in DNA structure or number of chromosomes will make the gametes incompatible and prevent fertilization. The morphology of reproductive organs change which prevents compatibility and fertilization. The difference in the behaviour of male and female will also prevent mating. The organisms may habe developed different breeding periods. Effectively new species of beetles will generated.

EVOLUTION AND CLASSIFICATION — Classification is the arrangement of organisms into groups and subgroups on the basis of similarities and dissimilarities and placing them in heierarchy that brings out their relations. Similarities and dissimilarities are determined by the characteristics present in the organism. It shows how closely organisms are related with respect to evolution. It is based on the assumption that each organism has descended from its ancestral type with some modification.

Characteristics are physical, physiological and behaviouristic features of organisms. They are of two types — basic and derived. Basic characteristics are parts of basic body design which are present in all members of a large group of organisms. They also decide the fundamental differences among different groups of organisms. Derived characteristics develop due to evolutionary changes in basic characteristics. They determine subgroup of organisms. Further evolutionary changes in derived characteristics produce new features that give rise to smaller subgroups. Presence of similar characteristics in a group indicates a common ancestory.

Some basic characteristics will be shared by most organisms. The cell is the basic unit of life in all organisms. The next level of classification will be shared by most but not by all organisms. i.e. whether the cell has a nucleus or not. Bacterial cells do not have a nucleus while the cells of most other organisms do. The organisms with nucleus may be unicellular or multicellular. The basis of classifying multicellular ~~animals~~ organisms is whether they are capable of doing photosynthesis or not. Among the multicellular organisms that can not do photosynthesis, whether the skeleton is inside the body or around the body will mark another fundamental design difference.

The more common characteristics two species have, the more closely they are related. The more closely two species are related, the more recent will be their common ancester. For example, a brother and a sister are closely related as they have common ancestor in the form of their parents. While a girl and her first cousin are also related but less than a girl and her brother. This is because two cousins have a recent common ancestor as their grandparents (in second generation before them). Thus classification of species is in fact a relation of their evolutionary relationship. By arranging subgroups into group and groups into supergroups, we can arrange the organisms in evolutionary lineages. All lineages will ultimately have a common ancestor from which all the organisms have evolved.

- <u>TRACING EVOLUTIONARY RELATIONSHIPS</u> — Common characteristics used in identifying common ancestry does not mean they are morphologically and functionally similar. They should have a similar basic pattern of structure though they may have different appearances and different functions due to evolution. They are called <u>homologous organs</u>. Apparently similar structures with similar function may have nothing in common but still they show evolution because of development of functionally similar structures from basically different structures. They are called <u>analogous organs</u>.

<u>HOMOLOGOUS ORGANS</u> — are those organs which have a similar basic pattern i.e. similar internal structure and similar origin but may have become different externally. They may appear quite different and may perform different functions e.g. forelimbs of bird, lizard, frog and human. The basic structure of the limbs is similar though it has been modified to perform different functions in vertebrates. Thus, the presence of homologous organs show that all these evolve from a common ancester.

<u>ANALOGOUS ORGANS</u> — are organs which have a different origin and basic plan but perform similar function. Modification of different structures to perform a similar function in unrelated organisms supports evolution.
For example the wings of birds and bats are analogous organs. They perform the same function of flight and have nearly same appearance but structurally they are quite different. The wings of bats are skin fold stretched mainly between elongated fingers while the wings of birds are a feathery covering all along the arm.
Thus the fore limbs of a bird and a bat are homologous but their wings are analogous.

- <u>FOSSILS</u> — are the remains or impressions of dead animals and plants that lived in remote past. Normally when organisms die, their dead bodies decompose and get lost. However, some part of the body may be in an environment that does not let it decompose completely. For example, if an insect gets entrapped in hot mud, it will not decompose quickly. The mud will enventually harden and retain the impressions of body parts of the insect and thus preserved as fossils. Evolution can be worked out by the study of not only living species but also of fossils.

Various kinds of fossils have been found from sedimentary rocks. These include —

(i) treetrunk.

(ii) Invertebrates — Ammonite (Molluscs)
Trilobite (Arthropode).

(iii) Fish (Knightia)

(iv) Dinosaur skull (Rajasaurus).

- The age of the fossil can be determined by two methods -

<u>1st method</u> — is relative i.e. Fossils closer to the surface of the earth are more recent than the fossil present in the deeper layer.

<u>2nd method</u> — is radioactive dating i.e. by finding the ratio of different isotopes of the same element in the fossil material.

<u>EVOLUTION BY STAGES</u> — Evolution is a gradual process. The evolution in an organism from simple to complex form has taken place in stages. Few examples are —

— the most primitive eyes developed in flatworms e.g. planaria. These are eye spots which are photosensitive and help the animals to be aware of environment. Such photosensitive spots also occur in anelids. In insects, both simple and compound eyes evolved. Perfect eyes developed in molluscs. They have all the components of vertebral eye. but their origin is different.

Thus, eyes have evolved through different pathways and different intermediate stages in different groups (showing separate evolutionary origin). The initial stages are useful to the animals in making them aware of the surroundings.

— Also a change that is useful for one property to start with can become useful later for quite a different function. e.g. feathers in dinosaurs are to provide them insulation in cold weather as they don't fly. Later on birds adapted them to flight. This shows that birds are very closely related to reptiles.

— Another example is of wild cabbage plant. The plant has been under cultivation for more than 2000 years as a food plant. <u>Artificial selection</u> carried out at different times have given rise to following vegetables

<u>Cabbage</u> — closer leaves provided more value to the food plant.

<u>Kale</u> — Selection of larger leaves for enhancing food value of the plant ⇒ give rise to leafy vegetable.

Kohlrabi - swollen stem part is selected.
Broccoli - plants with green immature flowers has been selected.
Cauliflower - cluster of sterile flowers is selected.

All these varieties look so different from their ancestor wild cabbage that if people had not seen it being done with their own eyes, they would never have believed that vegetables having such different structures can be evolved from the same ancestral vegetable plant.

Another way of tracing evolutionary relationship is by comparing nucleotide sequences of DNA molecules of different ~~micro~~organisms (i.e. MOLECULAR PHYLOGENY). Organisms having more differences in their DNAs are more distantly related than organisms having few differences in their DNAs. By comparative study of DNAs of the ancestral form it can be determined when a genetic change made two organisms to diverge from each other or which is close to the ancestral form of an organism.

EVOLUTION SHOULD NOT BE EQUATED WITH PROGRESS

- Evolution should not be equated with progress nor elimination of older less efficient species and formation of a more efficient new species. Continuation of old species depends upon the environment. The new species may or may not be better. Formation of new species depends upon the genetic drift and natural selection that leads to the formation of new population or species which is unable to show interbreeding with the original species.
- Evolution does not proceed continuously in a particular direction. The family tree is not similar to a ladder. No species sits at the top. Instead the tree has several branches, with some branches terminating in present day living species.
- Chimpanzee is related to but less evolved than human. Human beings are not evolved from chimpanzee. Rather both human and chimpanzee have evolved from a common ancestor that lived long time ago. It was neither similar to chimpanzee nor to human beings. The ancestor did not give rise to modern day chimpanzee and human in one step. Instead, the descendants of the common ancester evolved in various directions, giving rise to various forms. One of them formed human, another chimpanzee while some others produced other apes. Therefore, there is no such thing as ladder of progress but these are branches from the family tree of species.

- Again, it is not as if the body designs of older organisms were inefficient. This is because, many of the older and simpler form of organisms still survive on earth. For example, one of the simplest and primitive life forms called "bacteria" still inhabitat some of the most unfavourable habitats such as hot springs, deep-sea thermal vents and ice in Antarctica. Most other organisms cannot survive in such harsh environment.

HUMAN EVOLUTION — Human evolution has been studied by using various tools of evolutionary relationships like excavating (digging earth), studying fossils and determining DNA sequences. There is a great diversity of human forms and features across the planet. The most common one is colour of skin. Irrespective of where we have lived for the past few thousand years, we all come from Africa. And we all human are a single species called Homosapiens. About hundred thousand years ago, some of our ancesters left Africa while others stayed back. Those who left Africa slowly spread across the whole earth. They went forwards and backwards with groups sometimes separating from each other, sometimes coming back to mix with each other, even moving in and out of Africa. Like all other species on the planet, they had come into being as an accident of evolution and were trying to live their lives the best they could.