General Knowledge Today

General Science-5: Evolution and Genetics Basics

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Evolution

Scientific Hypotheses about Origin of Life

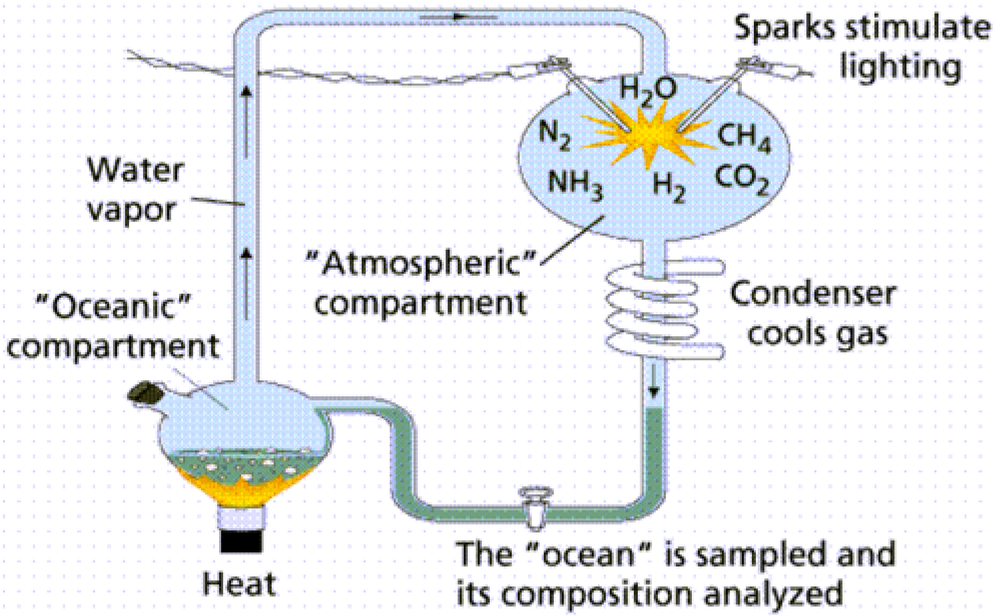
Earth is believed to be some 4500 million years old. Life on earth is believed to have originated after around 1 billion years of Earth's birth i.e. 3500 million years ago. Various theories, mostly mythological tried to explain the origin of life on earth. Currently, this scientific problem remains unsolved.

However, there is a general agreement among scientists that all life has evolved from common descent from a single primitive life form. Further, it is also believed that some kind of Chemical evolution happened before biological evolution.

However, which came first –*metabolism or genetics*? – This question also remains unsolved. There are two main hypotheses in this context viz. *RNA World Hypothesis* and *Protein World Hypothesis.* The *RNA world hypothesis*, which came in 1980s, says that genetics came first. The primitive life had only RNA as genetic material and structural molecules, and later it turned into DNA and proteins. The logic behind this theory is that RNA predates DNA and it can work both as catalyst as well as enzyme. The *Protein World Hypothesis* says that first proteins evolved which worked as enzymes and metabolism. It formed amino acids and then all other things followed.

Both of the above hypotheses are based upon the primitive atmosphere of Earth. Currently, Earth's atmosphere is composed mainly of molecular nitrogen and oxygen. Presence of molecular oxygen in the primitive atmosphere was extremely rare. Oxygen became abundant with emergence of the Photosynthetic organisms. Further, the water cycle was also much faster that what it is today due to extremely high temperature, characterized by harsh storms and intense electrical charge. Moreover, it is believed that there was no ozone layer protection from ultraviolet rays from Sun.

In summary, electricity, radiation and heat were the main available of sources of energy. In 1953, **Stanley Miller** arranged something of this kind of environment in his laboratory. He heated a mixture of methane, ammonia, hydrogen and circulating water that, when heated, was transformed into vapour.



Miller made this mixture subject to a continuous bombardment of electrical discharge. After a few days, he obtained a liquid residual within which he discovered organic molecules. Among these organic molecules were amino acids glycine and alanine, which are most abundant components of the proteins. This experiment was reproduced by other researchers who were able to make possible formation of organic molecules such as lipids, carbohydrates and nucleotides!

This theory put full stop on all mythological theories regarding origin of life and brought forward the natural organic synthesis concept for the origin of life on earth.

Origin of Photosynthesis and Aerobic Life

Another related and unsolved question in context with the origin of life is -who came first – *autotrophic or heterotrophic organisms?* The heterotrophic hypothesis has got little more weight here. This theory claims that first living organisms were *fermenting heterotrophs*. They released CO_2 via fermentation and then the atmosphere became rich in this gas. Through mutation and natural selection, organisms capable of using CO_2 and light to synthesize organic material appeared. These would have been the first photosynthetic organisms. These were called *fermenting autotrophs* because oxygen was not in abundance in the atmosphere. When Molecular oxygen became available, some organisms developed aerobic respiration, a highly efficient method to produce energy.

Further, it is believed that the prokaryotes appeared before Eukaryotes. Life first originated in water because protection from UV radiation was not available on land in primitive earth. Life on land was possible only when there was enough oxygen in atmosphere and ozone layer was formed to filter the

UV rays from sun.

Theory of Evolution

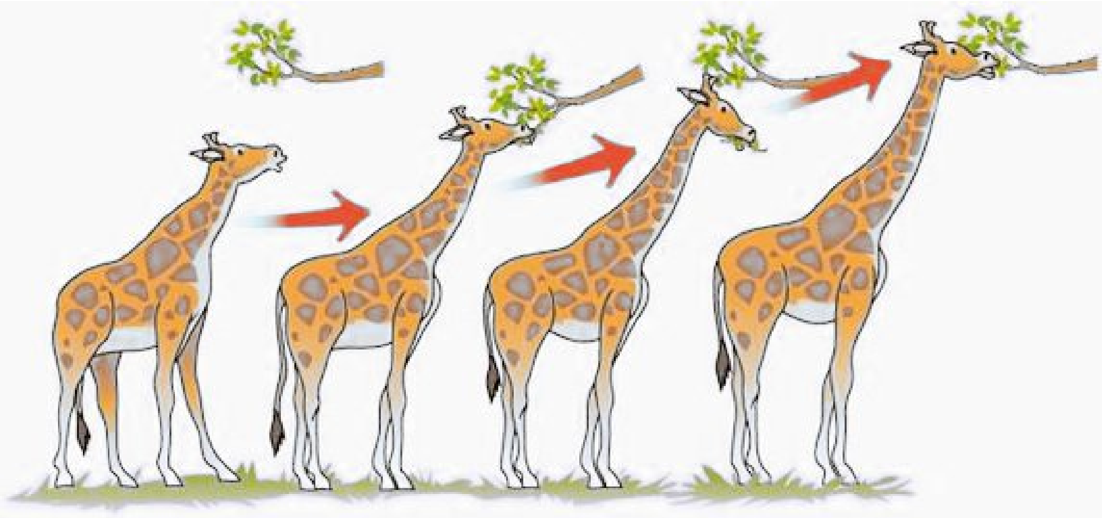
The theory of evolution tries to solve the question – *how different living organisms on earth appeared?* This question also has numerous mythological answers. One theory is *fixism*, which proposed that there is no evolution at all, and all species on earth were identical to species in last and no change has taken place into them. The religious version of fixism is *creationism*, which has its own different forms. The basic idea behind creationism is that God created all the organisms.

However, science is in favour of evolution of species. There are many evidences in favour of evolution. *First,* there is paleontological evidence which shows gradual change in fossils from different periods. *Second,* evidence is of the comparative anatomy, such as the existence of residual organs or other structures with same origin and function (For example, Darwin theorized that the appendix in humans and other primates was the evolutionary remains of a larger structure, called a cecum, which was used by now- extinct ancestors for digesting food) that reveal relationships among species. *Third evidence is of* comparative embryology. There are similarities between structures and developmental processes among embryos of related species. *Fourth* evidence is of molecular biology, which shows the existence of a large percentage of similar nucleotide sequences in the DNA of species with common ancestors.

Evolutionary theories

The two main evolutionary theories were *Lamarckism* and *Darwinism*. Prior to that we need to understand what were *law of use and disuse* and *law of transmission of acquired characteristics.*

The *law of use and disuse* says that the characteristics of a body vary depending on whether it is used more or less. This rule is valid for features such as muscle mass and the size of the bones, for example. The *law of the transmission of acquired characteristics* believed that the parents could transmit characteristics acquired by the use and disuse to their offspring. In 19th century, French Naturalist **Lamarck** proposed a theory by combining these two laws. Lamarckism says that individuals do not only pass on the things they received from their parents, but also some things they experienced during their lifetime. To support his theory, he gave an example of Giraffes, which have long necks. He argued that Giraffe must have evolved from ancestors with much shorter necks. Since the adults needed to stretch their neck to reach leaves from high branches; their children inherited longer necks.



This theory was albeit doomed to be rejected; was important because it was proposed at a time when fixism and creationism dominated. In fact, Lamarck must be hailed for his bravery to introduce an evolutionary theory based on natural law in those times.

Darwinism

Charles Darwin is considered the father of the theory of evolution. When he was about 23 years old, he had embarked on a ship called *Beagle* as volunteer scientist for a five year expedition to the South American coast and the Pacific. During the voyage, the most famous part of which was the stop in the Galapagos Islands, Darwin collected data that he used to write his masterpiece *The Origin of Species in 1859.* In this work, the principles of the common ancestry of all living organisms and natural selection as the force that drives the diversity of species were described.

Natural selection

The original name of Darwin's work was "*Origin of Species by Means of Natural Selection*". The core idea behind natural selection is that species which are *less adapted to environment* are eliminated.

Natural selection is when the organisms with favourable traits are more likely to reproduce. In doing so, they pass on these traits to the next generation and over the time; this process would allow organisms to adapt to their environment. This is because the frequency of genes for favourable traits increases in the population.

Darwin noted that within on particular species, there are individuals with different characteristics. Such differences could lead to different survival and reproduction chances for each individual. Therefore, he discovered the importance of the effect of the environment on organisms and the preservation of those with characteristics more advantageous for survival and who are more able to generate offspring. This is how he described the basis of the principle of natural selection.

Natural selection explains why living organisms change over time to have the anatomy, the functions and behaviour that they have. It works like this:

1. All living things have such fertility that their population size could increase rapidly forever.
2. Actually, the size of populations does not increase to this extent. Mostly, numbers remain about the same.
3. Food and other resources are limited. So, there is competition for food and resources.
4. No two individuals are alike. Therefore, they do not have the same chance to live and reproduce.
5. Much of this variation is inherited. The parents pass the traits to the children through their genes.
6. *The next generation comes from those that survive and reproduce*. The elimination is caused by the relative fit between the individuals and the environment they live in. After many generations, the population has more helpful genetic differences, and fewer harmful ones.

In summary, the Natural selection is really a continuous *process of elimination*.

Industrial revolution in England – An example of natural selection

One of the classic examples of natural selection is the moths of industrial zones of England at the end of the 19th century and the beginning of the 20th century. As the industrial revolution advanced, the bark of the trees that moths landed on became darker due to the soot released from factories. The population of light moths decreased and was substituted by a population of dark moths, since the mimicry of the dark moths in the new environment protected them from predators, meaning that they had an adaptive advantage in that new environment. Light moths in turn suffered the negative effect of natural selection because they had become more visible to predators, and were almost eliminated. In the open forest far from factories, however, it was experimentally verified that light moths maintained their adaptive advantage and the dark moths continued to be more easily found by predators.

Comparison of Lamarckism vs. Darwinism

Both Lamarckism and Darwinism are evolutionary theories opposed to fixism and, both admit the existence of processes that caused changes in the characteristics of living organisms in the past.

However, these two theories have different explanations for those changes. Lamarckism combines the law of use and disuse with the law of the transmission of acquired characteristics to explain the changes. Darwinism defends the effect of natural selection.

Neo-Darwinism

The modern Darwinist theory that incorporates knowledge from genetics and molecular biology is called neo-Darwinism. It is also known as *synthetic theory of evolution*. It argues that the variation of inherited characteristics is created by *alterations in the genetic material of individuals*, and *more precisely by modifications or recombination of DNA molecules*. Small changes in genetic material accumulate and new phonotypical characteristics emerge. The carriers of these characteristics are then subject to natural selection.

Modern science has established that the genetic variability occurs from various thins such as recombination of chromosomes during sexual reproduction; DNA mutation in germ cells and gametes etc. Such variability creates individuals which are carriers of some new features compared to their ancestors. These individuals are submitted to environmental pressure and can be more or less well-adapted concerning survival or reproduction. Those better adapted transmit their genetic heritage to a *larger number of descendants*, thus increasing the frequency of their genes in the population. Those less well-adapted tend to transmit their genes to a smaller number of descendants, thus decreasing the frequency of their genes in the population or even becoming extinct.

Neo-Darwinism and Antibiotic Resistance

The appearance of multi drug resistant strains of pathogenic parasites such as bacteria or superbugs can be explained by the synthetic theory of evolution. As in any environment, TB bacteria in hospitals undergo changes in their genetic material. *In the hospital environment, however, they undergo continuous exposure to antibiotics.* Many of them die from the effect of the antibiotics but *carriers of mutations that provide resistance to those antibiotics proliferate freely.* These resistant microorganisms, when subject to other antibiotics, once again undergo natural selection and those which became resistant to these other drugs are preserved and proliferate. This is how MDR, XDR kinds of TB and NDM-1 *(New Delhi metallo-beta-lactamase* 1) types of super bugs develop. The use (and overuse) of antibiotics is a factor that promotes natural selection and the emergence of multi-resistant bacteria.

Reproductive isolation

Reproductive isolation refers to various mechanisms by which different species cannot cross-breed among themselves; or even if they cross-breed would produce infertile offspring. This is an important phenomena because it defines the concept of a species. These mechanisms are as follows:

Spatial Isolation

If two populations are either at a great distance from each other or inhabit different parts of same area, it is called spatial isolation.

Geographical Isolation

If there is a physical barrier between two species such as water bodies, mountains, deserts etc. then it would prevent interbreeding between them and the process of natural selection would occur independently on both the sides. A common example of Geographical isolation is Darwin's finches on Galapagos Islands.

Ecological or Habitat Isolation
In this case, the populations are not separated by great distances but occupy different habitats within the same area. Brown bears and polar bears are a good example of habitat isolation.

Temporal Isolation
Temporal isolation is when two species are ready to mate at different times. For example, one species active during day and another at night; or one species mates in different season than other.

Behavioral Isolation
In some species, there are certain courtship displays and rituals needed for mating. These include courtship calls, songs, dances or other such rituals.

Mechanical Isolation
When mating is physically impossible because of incompatible genitalia, it is called mechanical isolation. Such isolation is common in insects whereby the genitalia work like locks and keys.

Gametic Isolation
When gametes (sperms and eggs) are unable to fuse and fertilize, then it is called gametic isolation.

Apart from the above, there is some Post-Mating mechanism also which prevent hybrid formation even if all premating mechanisms given above fail. These are as follows:

Gametic mortality

In this case, the sperms fail to fertilize the egg due to various reasons such as adverse climate (in case of external fertilization) or sperm death in female genital tract (in case of internal fertilization)

Zygotic mortality
Zygotic mortality is when egg and sperm have met and fused, but the zygote dies without further development.

Hybrid inviability
This is a post-zygotic barrier in which Hybrid does not mature into a healthy and fit adult. The relatively low health of these hybrids in comparison to pure-breed individuals would prevent gene flow between species.

Hybrid sterility
In this case, the hybrids are sterile. Sterility is mainly because of incompatibility of the Chromosomes. Mules and Hinnies are examples of this kind of barrier.

Hybrid breakdown
Hybrid breakdown is when the hybrids are fertile but their progeny abnormal or sterile. The interspecific hybrids of cotton (Gossypium) are common example of Hybrid breakdown.

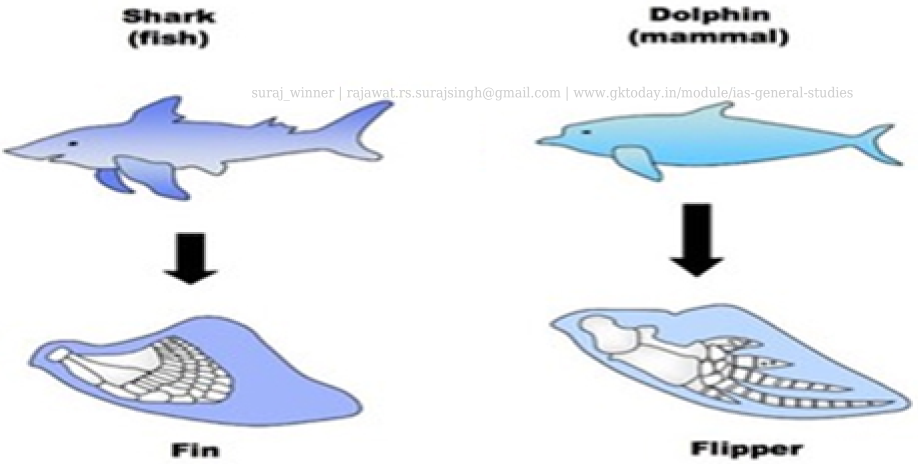
Speciation
Speciation refers to the process by which different species emerge from a common ancestor. Speciation generally begins when populations of the same species become geographically isolated, for example when they are separated by some physical barrier that disallows cross-breeding between individuals from one population and individuals of another population. The basic theory in

speciation is that the groups which are kept in geographical isolation for a long time, tend to accumulate different phenotypical (appearance) characteristics from each other by means of genetic variability (i.e. mutations and recombination) and natural selection. Speciation is considered to have occurred when they reach at a point where cross breeding between these two groups becomes impossible.

Adaptive Convergence and Adaptive Radiation

Adaptive Convergence

Adaptive convergence refers to a phenomenon in which living organisms that face similar environmental pressures or problems might incorporate similar solutions (structures in their bodies) during evolution. Such similar structures are called analogous to each other. A common example of this is fins and hydrodynamic body of Shark (Fish) and Dolphin (Mammal), Taxonomically and phylogenetically, they are distant animals but they have similar organs and shape because they need to adapt to similar environments.

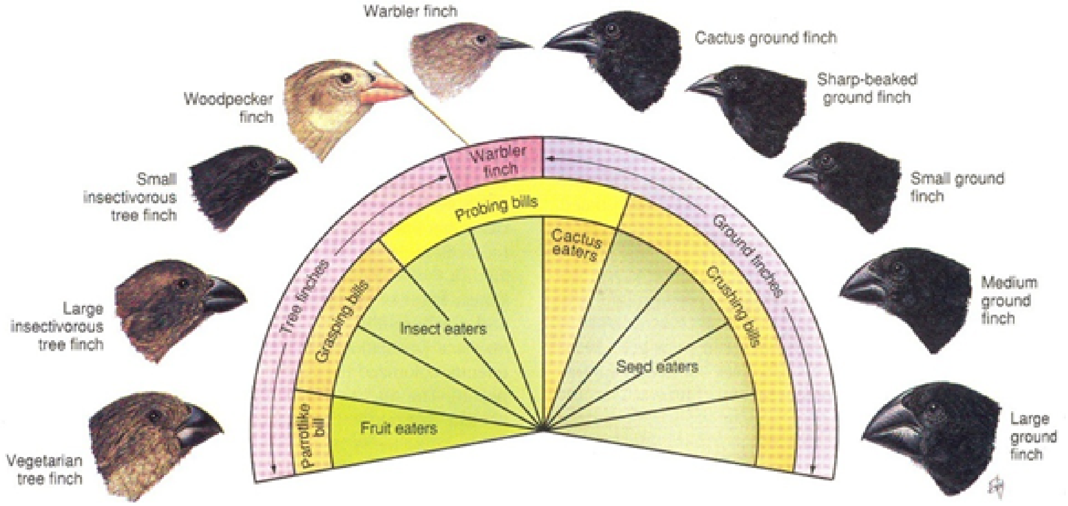


Adaptive Radiation

Adaptive radiation is when a single ancestral form diversifies into several or many different types because they spread to various regions or environments. It is also known as Divergent Evolution.

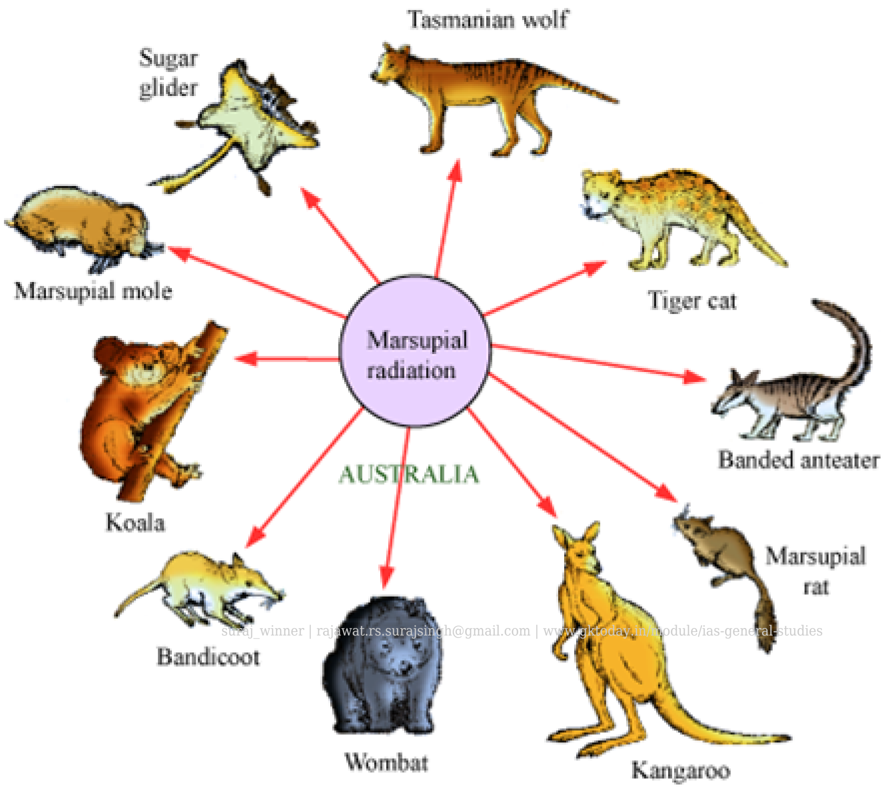
Adaptive Radiation in Darwin's Finches

The classic example of Adaptive Radiation is the finches of Galapagos Islands, also called Darwin's Finches. During his five weeks there, Darwin noticed that Finches differed from one island to another. When he returned to England, his speculation on evolution deepened after experts informed him that these were separate species, not just varieties, and famously that other differing Galápagos birds were all species of finches. All the 15 finches observed by Darwin are thought to have been radiated from a common seed eating ancestor. They occupy different ecological niches as well as habitats.



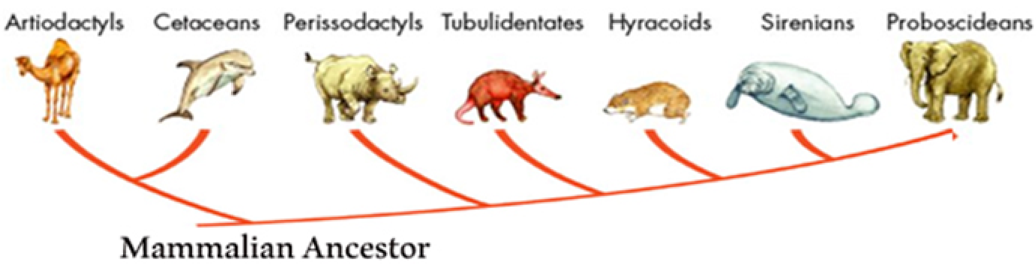
Adaptive radiations in Marsupials

There are lots of species that have evolved from Marsupials via adaptive radiation. This is also called Marsupial Radiation.



Adaptive radiations in mammals:

Around 65 Million years ago at the end of the Cretaceous period, only few lineages of the Eutherians were present. It is believed due to a vacuum created by the disappearance of dinosaurs, there was a rapid evolution of new mammalian types during the Eocene and Oligocene periods due to moving into different habitats and ecological niches. This is how different kinds of mammals originated from common ancestor.



The above theory also proposes that the primitive common ancestor might be a insect eater like a common shrew.

Analogous and Homologous Organs

Organs of different species are said to be analogous when they have the same biological function. For example, wings of bats and the wings of insects.

Organs of different species are called homologous when they have the same biological origin, or when they are the products of the differentiation of the same characteristic of a common ancestor. The forelimbs of various vertebrates such as humans, dogs, birds and whales are examples of homologous organs. Each of them has a different function, they have similar bone structure; and have that originated from the same embryonic tissue. This is considered as an evidence for descent from a common ancestor.

Genetics

Genetics is the branch of science that deals with mechanism of inheritance.

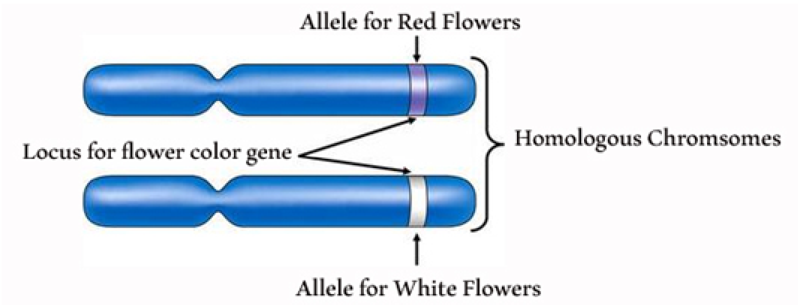
Gene and Chromosome

A gene is a *portion of a DNA* molecule that codifies a specific protein. A gene is made of several triplets of DNA nucleotides with their respective nitrogen-containing bases, such as AAG or CGT. A chromosome is a DNA molecule that may contain several different genes as well as portions of DNA that are not genes. A gene locus (locus means place) is the location of a gene in a chromosome; or rather, the position of the gene in a DNA molecule.

Alleles and Genes

Most of the genes exist in more than one form; and when expressed, they result in different characteristics. These different forms of genes are termed alleles. This implies that an allele is *one of the at least two alternative forms of genes*.

Alleles are similar in type but their genetic instructions produce visible different organisms. This visible difference is called **Phenotype.** For example, a single gene may be a controller of flower color in a plant. Its two alleles may be such that one produces red flowers while other produces white flowers.



As shown in the above graphics, alleles are located at corresponding locations on the Chromosomes, which constitute a chromosomal pair. All diploid organisms (animals and plants) have two alleles at a given location on a pair of chromosome. On the other hand, the gametes (for example sperms or eggs) contain only one allele of a particular gene. After fertilization, when the diploid condition is restored, one allele of the two may dominant or recessive resulting in the phenotypes.

We can understand this by human example. I have 23 pairs of chromosomes. Each pair has two homologous chromosomes (one from my mother and one my father). Both of these contain information related to production of same proteins (except sex chromosomes, which are heterologous). Whether I look more like my father or my mother – is an example of a phenotype.

We note here that naturally one allele comes from father and another from mother, it is not obligatory always. In clones, both alleles would come from a single parent.

Further, there may be three or more copies of the chromosome rather than the expected two copies in some cases called Polysomy. In this case, additional alleges would be found in organism. For example, three alleles would be found in trisomy whole four in tetrasomy.

Phenotype and Genotype

A phenotype is observable characteristic, while a genotype nucleotide sequences contained in the chromosomes. Thus, a phenotype is biological manifestation of genotype. If a gene of a diploid species has two different alleles, such as A and a; then there may be three possible genotypes viz. Aa, AA, and Aa. These three genotypes manifest in three different kinds of phenotypes. Aa and AA are called Homozygous while Aa is called heterozygous.

The alleles may be dominant and recessive. In this example, if the allele A is dominant over the allele a, the phenotype A will be manifest; whether it's AA, or Aa. a will manifest only if genotype is aa.

A recessive allele can remain hidden because it may be present in the genotype but is not expressed in the phenotype. When this allele is transmitted to the offspring and forms a homozygous genotype with another recessive allele from another chromosomal lineage, the phenotypical characteristics that appear reveal its existence.

Mendel's Laws

Gregor Mendel (1822–84) is known as the "father of modern genetics". Ironically, his work was discovered and recognized only 16 years after his death. He was an Austrian *Friar* {Friars are members of some secular religious orders who practice the principles of monastic life and devote themselves to the service of humanity}. He carried out experiments and studies on heredity on pea plants and postulated the Mendel's laws.

Selection of Pea plant for experiments

Mendel used pea plants in his experiments for two main reasons. First, the Pea plants reproduce sexually; and second that these plants are self-pollinating (the male and female organs are enclosed in the same flower). This ensured true breeding of the plants. Mendel used self-fertilization in peas over several generations for the purpose of obtaining individuals with the desired characteristics and to ensure that parent pea plants were pure or homozygous.

Once such pure lines were obtained he cross bred them and obtained their hybrid offspring. He again crossbred the hybrids and called them F1 or First Filial generation. When again the offspring crossed, he called them F2 or second Filial generation. The results he obtained were postulated as Mendel's two laws of heredity. These are as follows:

- First Law is also known as *Law of segregation or also law of purity of gametes.* It says that a trait of an individual is always determined by *two factors*, one inherited from the father and the other from the mother. When gametes are produced, these two factors separate and a gamete only receive one or the other.
- Second law is called *Law of Independent Assortment. This law says that a*lleles of different genes separate independently of one another when gametes are formed. So Mendel thought that different traits are inherited independently of one another. We now know this is only true if the genes are not on the same chromosome, in which case they are not linked to each other.

Ironically, Mendel was ahead of times in his research. His work was only identified later and understood properly when study of cells developed and scientists knew about the nucleus, chromosomes, genes, mitosis, meiosis etc. properly.

Non-Mendelian Inheritance

What Mendel called as "Factors" was later identified as Genes. It was later understood that the phenotype is determined by the genotype and dominant alleles. However, it was also observed later that there are many types of inheritance that don't exactly follow the Mendelian pattern. These included Polysomy (multiple alleles), gene interactions; gene linkages etc.

Other concepts

Incomplete Dominance

Incomplete dominance is when heterozygous individual presents an intermediate phenotype between the two types of homozygous ones. Example of incomplete dominance is Sickle Cell Anaemia. In Sickle Cell Anaemia, the heterozygous individual produces some sick red blood cells and some normal red blood cells.

Codominance

In codominance, heterozygous individual has a phenotype totally different from the homozygous one, and not an intermediate form. Example of Codominance is MN blood group system.

Pleiotropy

Pleiotropy is when a single gene manifests in several different phonotypical traits.

Lethal Genes

Lethal genes are genes with at least one allele that, when present in the genotype of an individual, cause death. There are recessive lethal alleles and dominant lethal alleles.

Multiple Alleles

Multiple alleles is when same gene has more than two different alleles (in normal Mendelian inheritance, the gene only has two alleles). In multiple alleles, relative dominance among the alleles may exist. Common example of Multiple alleles is ABO blood group system, in which there are three alleles (A, B or O, or IA, IB and i). IA is dominant over i, which is recessive in relation to the other IB allele. IA and IB lack dominance between themselves.

Complementary Genes

In complementary genes, a phenotypic trait is manifested by two or more genes.