EVOLUTION

This is a gradual developmental process by which a new species is formed from the pre-existing one over a period of time. Therefore evolution is a continuous change from simple to complex organisms.
Individuals do not evolve/change. A population is the smallest group that evolves.
But how then did the first primitive organisms arise and from where? To answer the question, many biologists have tried to put up theories to explain the origin of life.

Theories of origin of life

They are uncertain and include;

i) Special creation theory
ii) Spontaneous theory
iii) Cosmozoan theory
iv) Steady state theory
v) Biochemical theory

1. Special creation theory:
Suggests that life was created by a super natural being with super natural powers called God at a particular time in the past and this has been greatly supported by religion and civilization.
One of the proponents of this theory archbishop Ussher in 1650AD added figures of ages of all the people in the biblical generations from Adam to Jesus and concluded that God had created the earth in October 4004BC.
The theory has only one criticism; special creation occurred only once therefore cannot be observed yet all scientific knowledge must be experimentally proven.

2. Steady state theory:
Suggests that the earth had no origin, has always been able to support life, has changed remarkably little if at all and all species had no origin. It asserts that earth has always existed, species too never originated, they have always existed and in history of species, the only alternatives are numbers to vary or it to become extinct. Critics of the theory say that it does not believe in paleontologists.

3. Spontaneous generation theory:
Suggested that life arose from nonliving matter on numerous occasions and it was prominent and prevalent in ancient Chinese.
Aristotle believed that life arose spontaneously and assumed that certain particles of matter that contained an active principle would produce a living organism when conditions are suitable.
From his observations, Aristotle concluded that such are facts, everything comes into being not only from mating but also from decay of the earth. In plants, some developed from seeds while others by spontaneous generation by natural forces.
Basing on this principle, Van Helment described an experiment which gave rise to mice in three weeks. The raw materials were a dirty shirt, human sweat, wheat grain and dark cupboard. The active principle in the experiment was sweat and in 3 weeks, mice were seen in the cupboard thus concluded that mice arose spontaneously from sweat, dirty shirt and wheat grains in the dark cupboard.

Criticisms:

- He omitted a control experiment in which each variable was systematically eliminated therefore, not scientific.
- Francesco Redi in 1685 observed that the little maggots on decaying fish were actually larvae and by a series of experiments, he produced evidence to support the idea that life can only arise from pre-existing life.
- Louis Pasteur showed that bacteria were ubiquitous and living matter would easily become contaminated if it was not adequately sterilized. He assumed that each generation of organisms develop from the previous generation and not spontaneously.

4. Cosmozoan theory (pans Permian theory):
This extends the origin of life to an **extra-terrestrial** source elsewhere in the universe. Life could have arose from somewhere else and arrived on to the earth by some means.
According to this theory, life is distributed throughout the universe in form of spores that can germinate in the right environments.

Repeated sighting of **UFOs and aliens** provide evidence for this theory. In addition, research on comets and meteorites has revealed presence of many organic compounds like hydrocyanic acid which might have acted as seeds.

5. Biochemical theory (biogenesis)

This theory states that the origin of the earth is due to the result of slow and gradual process of chemical evolution that occurred probably about 3.8m years ago. This theory was proposed by Alexander Oparin in 1923. According to this theory;

i) Spontaneous generation of life under the present day environmental conditions is not possible.
ii) They believe that the state of early earth was different from that of the present earth in that;
   - Early earth atmosphere was a reducing one yet present atmosphere is an oxidizing one.
   - Early earth was too hot while present earth is cool
   - Main source of energy in early earth was solar radiation and lightening
iii) As the earth cooled, carbon and less volatile metals condensed and formed the earth's core whose surface was barren and rugged due to volcanic activity and continuous earths movements but contraction on cooling folded and fractured the surface.
iv) It is believed that lighter gases like hydrogen, helium, nitrogen oxygen and argon would have escaped because the gravitational field of the partially condensed planet would not contain them but however, simple compounds containing them like water, ammonia, carbon dioxide and methane would have been retained and until the earth had cooled to 700^oC, all the water existed in vapour form.
v) Through a series of chemical reactions, simple organic molecules would have been formed due to presence of a reducing atmosphere as recent experiments in the laboratory show and from a collection of such chemical substances through progressive chemical reactions, the first life arose.

In 1923, Alexander Oparin suggested that these organic compounds for example hydrocarbons, formed in the water, from simple compounds and energy was supplied by strong solar radiation which surrounded the earth before formation of the ozone layer which now blocks much of it out of the earth.

He argued that considering the multitude of simple molecules that were present in oceans, the surface area of the earth, the energy that was available and the time scale, oceans would have gradually accumulated organic molecules to produce a primordial soup in which life could have arisen.

Evidence:

Basing on the above, in 1953, Stanley Miller performed experiments that proposed conditions on the early earth and they successfully synthesized many substances after a few days including, amino acids, proteins and nucleotides.

Similar experiments by Miller and other scientists were able to produce amino acids, some proteins, nucleotides, ATP, ADP, and other molecules which are characteristics of living things. The simple molecules are believed to have reacted with themselves to form larger molecules like RNA and proteins.

The complex organic molecules could have become the building blocks of the first living organism which were just in single cell form (prokaryotes) and their habitat was water. Many chemical reactions continued taking place with modifications and development of new features in already existing prokaryotes until complex organisms (multicellular) arose which also underwent modification, adaptations and advancements to form the present complex multicellular terrestrial organisms like man.

MECHANISM OF EVOLUTION

Lamarck and Darwin have tried to explain evolution to reveal the difference in the existing life forms.

LAMARCK'S THEORY OF EVOLUTION

It's also known as the use and dis use theory. The theory was based on two conditions that is; use and dis use of structures and the inheritance of acquired characteristics.

According to Lamarck, in the life of an organism, a change in environment would bring about a change in structures of the organism in order to allow efficient functioning. Structures which are often used become bigger and structures which are not used would become reduced. Therefore, throughout life, changes on the organism could accumulate and those characteristics would be passed onto the next generation. After many generations with continued accumulation of changes, the overall structure of the organism would be different from that of the earlier organism and thus since different organisms lived in different environments, the changes accumulated would be different depending on the different environmental conditions. For example, according to Lamarck, the present day long necked giraffes obtained their long necks from their short necked ancestors through the same process. As the short necked giraffes stretched to reach leaves on tall trees, it created a small elongation of the neck and that was passed on to the next generation and with further stretching of the neck to feed on tall trees, the neck became longer in the proceeding generations.

Therefore, Lamarck's theory states that the characteristics organisms acquire during their life time are transmitted to the off spring.

Criticism/short comings of Lamarckism

Acquired characters are brought about by the environment and development but not the genes and therefore cannot be inherited.

The use and disuse of somatic cells does not influence the reproductive cells therefore cannot play a role in inheritance and evolution.

The formation of gametes have nothing to do with what it does and in females, gametes are formed before birth in ovaries,

Lamarck however had his contribution towards evolution:

- ❖ He recognized the effect of the environment in evolution i.e. creating needs for which adaptations are made.
- ❖ He recognized that the inheritance of characters from one generation to another was important in evolution.

DARWIN'S THEORY OF EVOLUTION (evolution through natural selection)

Charles Darwin visited Galapagos Archipelago islands and studied the finches which inhabited each of the island.

While they all had a general resemblances to those of the main land to the equator. They however differed in certain aspects e.g. the shape of the beaks.

He urged that the finches of Galapagos resemble with those of the main land in South America because they descended from a common ancestor. They differed from one another e.g. shape of beaks because each is adapted to its own mode of life and in some instances restricted to its own particular island.

He noted that a few finches had crossed from the main land to those volcanic islands shortly after formation. They encountered a range of different foods and each type of finch developed a beak which was adopted to suit its diet.

All along his voyage, Darwin was trying to find out the mechanism by which changes occurred. Independent of Darwin, Alfred Wallace had drawn his own conclusions on the mechanism of evolution. Wallace sent Darwin a copy of his theory and Darwin realized that they were the same as his. As a result, they joined to present their findings to the scientific society. A year later, Darwin published his book on the origin of species by means of natural selection and the preservation of the favored races in the struggle for existence.

The essential features of Darwin's theory included:

1. ***Over production of offsprings.*** He believed that all organisms produced a large number of offsprings which would lead to an increase in the size of the population.
2. ***Constancy of numbers.*** Despite the tendency of organisms to increase in number due to over production of species, most populations maintained relatively constant numbers. The majority of offsprings die before they are able to reproduce.
3. **Struggle for existence**. He concluded on the basis of the above two that members of the species were constantly competing with each other with effort to survive. In this struggle for existence only few would live for long enough to breed.
4. ***Variation among offsprings***. They sexually produced offsprings of any species to show individual variation that no two offsprings are identical.
5. ***Survival for the fittest by natural selection.*** Among the variety of offsprings, some are better adapted to withstand the prevailing conditions than others. I.e. some will be able to survive in the struggle for existence. Such types are more likely to survive long enough to breed.
6. ***Like produce like.*** Those that survived to breed are likely to produce offsprings similar to themselves. The advantageous characteristics which gave them a win in the struggle for existence are likely to be passed on in the next generation.
7. ***Formation of new species.*** Individuals lacking favourable characteristics are less likely to survive long enough to breed and over many generations, their numbers decline. The individuals with favourable characteristics breed with consequent increase in their number. The inheritance of one small variation may not by itself produce new species however, the development of a number of variations in a particular direction over many generations gradually leads to variation of a new species.

Limitations of Darwin's theory (N/S)

- Darwin made no attempt to describe how life originated on earth. He only explains how new species arise from pre-existing one
- The theory 'struggle for existence' was popularized by the coiling of unfortunate terms such as 'survival of the fittest' and 'elimination of the unfit'.
- A misconception that human beings descended from apes which was perceived as offensive by both religious and secular communities.
- Contradiction with the Genesis six-day creation and that of a progressive origin for species.
- The theory fails to account for the extinction of dinosaurs and the giant ferns

Exclusive:

Bishop Samuel Wilberforce Vs prof Thomas H Huxley; if he traced his decency from a monkey through his grandies - bishop. "I would rather have a monkey for an ancestor than being connected with man who uses expensive gifts to obscure the truth."- Prof.

Darwin's law of natural selection

It states that in a highly reproducing population, there is variation among individuals and some characters are inherited such that those possessing them survive to reproduction stage, while those ones which are not favoured by their environment die before they reproduce i.e. favoured characters are selected for while the unfavoured ones are selected against.

How Darwin explained the development of the long necked giraffes

Initially both short and long necked giraffe varieties existed. Due to exhaustion of food at the ground level, the short ones could not reach the tree branches and hence starved and died of hanger. The long necked giraffes survived and produced the long necked giraffes.

Modern theory of evolution (Theory of organic evolution)

With the contemporary evidence from research in genetics and molecular biology, the theory of evolution as stared by Darwin and Wallace was modified into what currently is known as **Neo-Darwinism.** This is the theory of organic evolution by n/s of genetically acquired characteristics.

This should not be confused with chemical evolution which describes the process of formation of organic molecules from simple inorganic molecules which gave rise to the first life forms in the primitive earth. Organic evolution focuses on the gradual modification of organisms from the first primitive forms of the time to the current forms.

For Neo-Darwinism theory to be accepted, it is necessary to:

i) Establish the fact that evolution has taken place in the past (past evolution)
ii) Demonstrate a mechanism which result in evolution (natural selection of genes)
iii) Observe evolution happening today (evolution in action).

Evidence for evolution comes from many sources based on geology e.g. fossils and stratigraphy. It is found in the experimental and observable data of the natural selection of characteristics that are inherited such as the selection of shell colour in the snail and the mechanism of inheritance demonstrated by Mendelian genetics as in Mendel's work on peas.

N.B: Neo-Darwinism may be defined as ***the theory of organic evolution by natural selection of inherited characteristics.***

The debate these days is not so much about whether evolution takes place but about how it takes place by natural selection of randomly generated mutation.

NATURAL SELECTION

This is the process by which organisms that are better adapted to their environment survive to breed while those less adapted fail to do so and die in the process. The better adapted ones are likely to pass their characteristics to the succeeding generations. Therefore selection determines the spread of any allele within a gene pool.

How natural selection occurs

During periods of population increase, some resources become limiting and competition sets in for such resources.

This creates a struggle for existence in which individuals that are physically, physiologically or behaviorally better adapted to the environment (have ***a selective advantage)*** and are selected for by the environment. These reproduce and pass their traits to the next generations, and their numbers increase over time. Those that are less adapted are

said to have a ***selective disadvantage*** and are selected against, fail to reproduce or survive and their numbers decline significantly. Gradual accumulation of the favorable traits in one direction over a long period of time may result into the two groups evolving into different species.
Selection acts by weeding out those individuals, whose characteristics confer a selective disadvantage (unfit) in favor of the fit individuals.
S.q Explain how n/s can lead to speciation

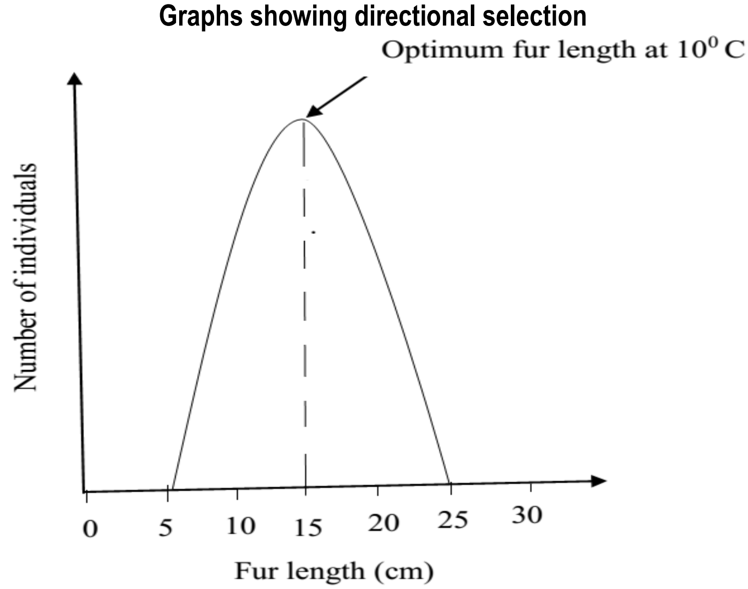
Types of natural selection

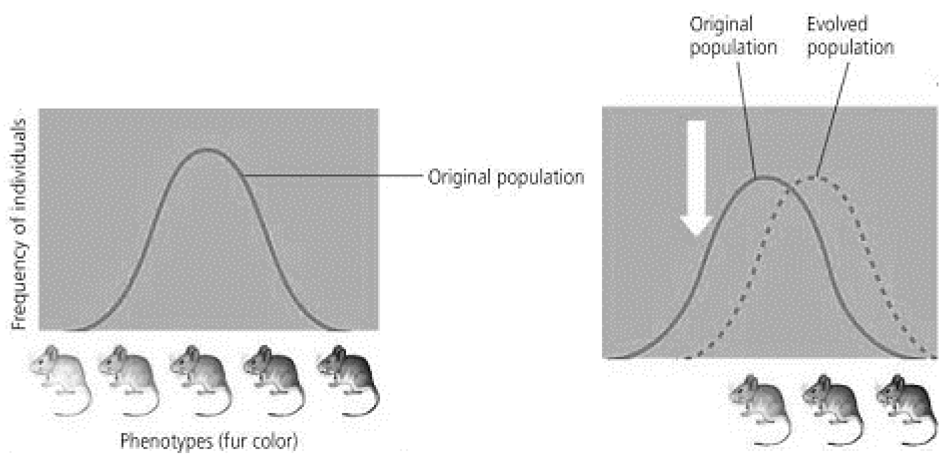
They are directional selection, stabilizing selection and disruptive selection.

Directional selection

When environmental changes favours a new phenotype, then the individuals of this phenotype are likely to become numerous in the population at the expense of those not favoured hence the mean shifts to a new one and the composition of the population changes accordingly. This is known as directional selection (progressive selection).
When environmental conditions change, there is a selection pressure on the species causing it to adapt to new conditions.
Within the population, there is a range of individuals in respect to a particular character. The continuous variation among individuals forms a normal distribution curve with a mean representing the optimum for existing conditions. When these conditions change, there is a selection pressure on the species causing them to adapt to new conditions. As the conditions change, also the optimum necessary conditions for survival will change. In this case, only a few individuals will possess the new optimum requirements and by selection, they will dominate the environment.
This means that the mean for this particular character will have shifted e.g. the different fur lengths suits different temperature conditions.
Directional selection favours change in allele frequencies and may lead to evolutionally change and forms the basis for the artificial selection of plants and animals and day to day observations of natural selection. Probably when food was in short supply, only the tallest giraffes could reach enough food for survival and only these reproduced to pass their traits, hence gradual development of long necks.
Industrial melanism, resistance to anti-biotics and selective breeding are examples of the operation of directional selection.

Graphs showing directional selection





Stabilizing selection

When natural selection favours individuals near the mean, and in distribution it selects against individuals at the extremes, it brings about constancy in the population and does not favour evolution. It ensures that most individuals surviving are then adapted to the environmental conditions.

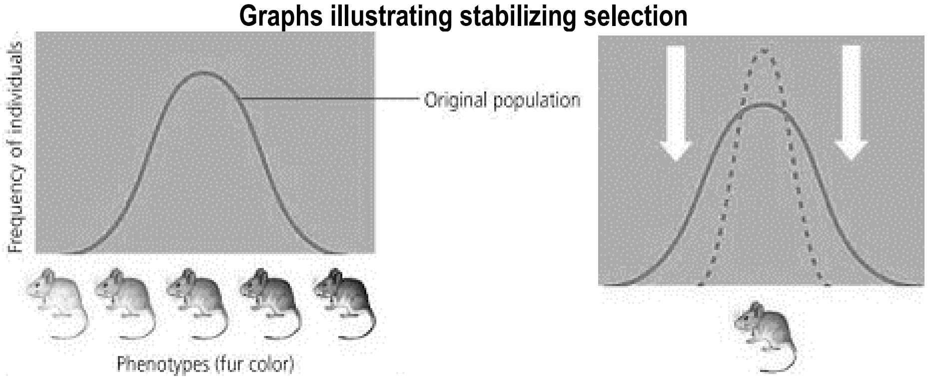
Stabilizing selection occurs in all population and eliminates extremes hence reducing variation in the population, thus no opportunity for evolutionary checkup. E.g. in the earlier example, it was seen that at 10^{0}C there was an optimum fur length of 15cm. Individuals within a population however had a range of fur length ranging from 5cm to 25cm under normal climatic circumstances, the average temperature varies from 1 year to the next.

In a warm year with an average temperature of 15^{0}C, the individuals with short fur may be at an advantage as they lose heat more quickly. In such years, the numbers reduce because individuals with short fur die and reduce in number. The periodic fluctuation in environmental temperature therefore help to maintain individuals with relatively long and short fur and tries to eliminate those with longest and shortest fur thus reducing variation.

Its average environmental temperature was 10^{0}C every year and there were no fluctuations without the warmer years to give them an advantage in competition with others in the population, the individuals with short hair would decline in number.

Like ways, the absence of colder years would reduce the number of long haired individuals. The mean fur length would remain at 15cm but the distribution curve would show a much narrow range of length.

Graphs illustrating stabilizing selection



When the environmental temperature constantly remains the same (10^{0}C), individuals with the longest and shortest fur are eliminated from the population over a number of generations. The inheritance of sickle cell anemia confirms to this type of natural selection since the individuals at the extreme die of their sickle cell disease or malaria while the majority of heterozygous survive.

Disruptive selection

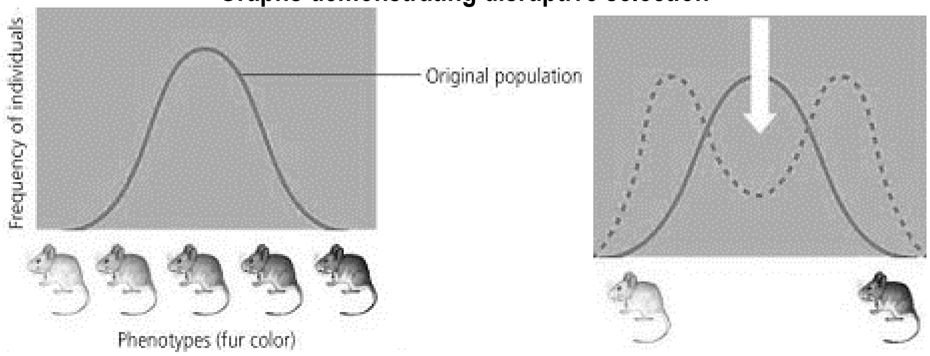
When natural selection favours the phenotype towards the extremes and selects against those near the mean, it is the reverse of stabilizing selection and may lead to splitting of a single gene pool into two hence two different species may arise (speciation) hence it is one of the agents of quick speciation.

Speciation is the process of forming new species of organisms. Disruptive selection is less common but important in evolutionary change. It can occur when an environmental factor takes a number of disruptive forms e.g. suppose the environmental temperature alternated between 5^{0}C in winter and 15^{0}C in summer with no intermediate temperature occurring. These conditions would favour the development of two distinctive phenotypes within the population: one with a fur length of 20cm at an environmental temperature of 5^{0}C while the other of 10cm optimum length at 15^{0}C.

It's possible that the group with 20 cm fur length would aestivate or migrate in summer to avoid the problem of over-heating. The other group might hibernate or migrate in winter to avoid the problem of heat loss. In this way, reproduction between the two groups may be interrupted and the flow of genes between them prevented. Each population might then become a separate species.

During the evolution of the Galapagos finches, birds with short beaks had an exclusive use of nuts for food while those with long slender beaks had an almost exclusive use of insects. Members with intermediate beaks were probably out competed

Graphs demonstrating disruptive selection



NB: Disruptive selection may result into a population expressing two distinct phenotypes; this is referred to as polymorphism

Polymorphism refers to the existence of two or more distinct forms of the same species in the same population. Such phenotypes are referred to as **morphs**

The best example is the existence of two forms of peppered moths, the melanic and the normal forms and the existence of different forms of land snail *Cepaea nemoralis.*

There are two types of polymorphism; balanced/stable and transient polymorphism

Balanced polymorphism: this occurs when different forms co-exist in the same population in a stable environment. The best example is the existence of two sexes in plants and animals, ABO blood groups in man, red-green colour blindness and the existence of workers, drones and queen bees. In such cases, the genotypic frequencies of the various forms exhibit equilibrium because they have a selective advantage of equal intensity. Whilst the genotypic frequencies may vary within the population, they tend to remain constant from generation to generation.

Transient polymorphism: this arises when different forms or morphs exist in a population undergoing a strong selection pressure, the frequency of the morphs being dependent on the intensity of the selection pressure. It usually applies in situations where one form is gradually being replaced by another for example in the melanic and non-melanic forms of peppered moths

NATURAL SELECTION IN ACTION

This refers to the day to day observations of natural selection or examples of natural selection.

Examples include the following.

- ✓ Insects resistance to insecticides, like flies and mosquitoes to Dichlorodiphenyltrichloroethane (DDT)
- ✓ Pests resistance to pesticides
- ✓ Heavy metal tolerance in grass and other plants
- ✓ Antibiotic resistance by pathogens e.g. bacteria to penicillin and methycilin
- ✓ Resistance to antimalarial drugs

How does the resistance arise?

Resistance usually occurs due to continuous exposure of organisms to such chemicals which induce random mutations. This causes synthesis of an oxido-reductase enzyme which either reduces or oxidizes the chemical into a harmless substance making them resistant.

In such populations, the chemical acts a directional selection pressure that tends to eliminate the non-resistant forms in favour of the resistant ones. The latter have a selective advantage hence a higher reproductive potential, reproduce more rapidly and their numbers increase as resistance is passed to next generations. The non-resistant forms are eliminated and sooner than later, the whole population becomes resistant to the chemical

In the same way; soils near mines are usually devoid of vegetation. This is because such soils contain high concentrations of heavy metals like mercury, lead, zinc and copper which are highly toxic to plant growth. However a few plants like the horsetails are found scattered in such soils which have developed tolerance to such metals. In such plants, mutations occur rendering them ability to trap these metals into their cell walls, confine them in vacuoles or excrete them. Tolerance is passed to next generations enabling the plants to flourish in polluted areas as their nontolerant competitors are killed by heavy metals, while in unpolluted areas they have a competitive disadvantage, less competitive and rarely survive

Bacterial populations can easily become resistant because of the same following reasons:

- ✓ They have a haploid DNA such that in case of a mutation, the resistant allele is instantly expressed phenotypically due to absence of the non-resistant copy
- ✓ They reproduce rapidly by binary fission hence the number of resistant individuals' increases so rapidly that soon the whole population becomes resistant.
- ✓ Ability of individual bacteria to exchange resistant alleles. This is called **plasmid exchange** leading to a rapid spread of resistance in a population

NB: The most important example of n/s in action is illustrated by industrial melanism

Industrial melanism

Industrial melanism is the process that led to the appearance of higher frequencies of melanic forms of peppered moths than non-melanic forms as a result of air pollution that followed the industrial revolution

Peppered moths (*Bistonbetularia)* are known to occur in two phenotypic forms (polymorphic) namely; *Bistonbetularia typica* and *Bistonbetularia carbonaria***.** The former are speckled white in colour and are the normal non melanic forms while the latter are melanic mutants and appear darker (almost black). This phenotype is thought to have arisen due to a spontaneous mutation

The peppered moths are known to fly at night and during day they are resting on tree trunks and walls of buildings. They depend on cryptic colouration to camouflage with their backgrounds in effort to prevent predation by birds.

Explanation

Originally (before the industrial revolution) due to low pollution levels, the tree barks had a pale appearance due to lichen growth. The light forms could unlike the dark forms camouflage beautifully as their body colour emerged properly with their back grounds, that predators could not easily spot them. These had a selective advantage which rendered them a higher reproductive potential and their numbers increased much more than those of the dark forms which could not emerge well with a pale background. Predators could easily spot them for food which kept their numbers very low. Following the industrial revolution, the air pollution resulted into killing of the lichens and backgrounds were further darkened by smoke. In such conditions, the dark forms could more easily camouflage than the light forms and could not easily be spotted by predators. These therefore had a higher selective advantage under a directional selection pressure provided by selective predation, which eliminated the light forms in favor of the dark forms. Over time, the relative numbers of the dark forms increased gradually while those of the light forms decreased; this is referred to as **industrial melanism.**

It is also a good illustration of transient polymorphism. The two forms can still interbreed successfully and are therefore of the same species.

Question: Explain the term industrial melanism in a peppered moth?

It is a process that led to evolution of melanic form of moths which took place during industrial evolution or development through natural selection in a way that mutant forms never appeared before the light background thus eaten by the birds. Industrial evolution led to a dark/black back ground thus the black moths which were favoured were not eaten. Therefore black moth became dominant and many.

ARTIFICIAL SELECTION

Man has been cultivating plants and keeping animals for about 10,000 years. Over this time, he tried breeding them selectively. There are two basic methods of selective breeding i.e. inbreeding and outbreeding.

Inbreeding

When by chance a variety of plants and animals arose which possessed some useful characters, it was bred with its close relatives in hope of retaining the characters for future generations.

The problem with inbreeding is that it increases the danger of the harmful recessive gene exposing itself because there is a greater risk of a double recessive individual appearing.

Outbreeding

This is done to improve the existing varieties where two individuals of the same species each having the beneficial feature are combined during outbreeding to produce a better feature. Outbreeding frequency produce stronger individuals with a better chance of survival.

Extreme examples of outbreeding occur when individuals of different species are mated. It's only in rare cases where it succeeds. Where it succeeds, the resulting offsprings are normally sterile. A cross between a horse and a donkey produces a mule which is stronger than either parents thus showing hybrid vigor.

The improvement of human race by the selective or elimination of specific characters is called ***eugenics*** but its success is minimal.

The disadvantage with outbreeding is that it makes consistent qualities harder to achieve but the advantage remains that it results in healthier and stronger offsprings (hybrid).

EVIDENCES OF EVOLUTION

These include;

1. Paleontology
2. classification
3. Geographical distribution
4. Comparative anatomy
5. Comparative embryology
6. Comparative bio chemistry

1. PALEONTOLOGY

This is the study of fossils. A fossil is any form of preserved remains thought to have been derived from a living organism and it includes the entire organism, hard skeletal structures, mould and casts, petrification, impressions, imprints, and fecal pellets.

The fossil evidence doesn't prove that evolution occurred but it shows the progressive increase in complexity of organisms because in old fossil bearing rocks there are a few types of simple structured fossilized organisms while in younger rocks, there is a great variety of complex structured fossilized organisms.

Throughout the fossil record, many species will appear at early stratigraphic level but disappear at the later level. This shows the period of origin and extinction of that species and in evidence, these organisms might have appeared increased in complexity or have become extinct due to changes in geographical regions and climatic conductor. For example, plants appeared before animals and insects appeared before insect pollinated flowers.

The best example for the study of fossil was the horse which underwent various gradual but progressive modifications in feeding and locomotion structures, from the ancient hyacottherium to the recent advanced equus horse.

Weakness of paleontology

The records are less significant if the fossil record is not continuous that is to say it has missing links in the fossil record such that ancient organisms can't be linked to the present ones.

Explanation for gaps or incompetence's of fossil record

Paleontologists have the following explanations to account for missing links in the fossil record;

- Some dead organisms decompose readily and leave no fossils.
- Some dead organisms might be eaten by scavengers.
- Some organisms are soft bodied therefore not fossilized easily.
- During favourable conditions for fossilization, only a small fraction of living organisms might die.
- Only a fraction of fossils have been discovered.

2. CLASSIFICATION

Before Darwin put forward his theory of evolution, some organisms had led some scientists to propose a system of classification between organisms. This forms a neutral series of phyla, classes, orders, families, genera and species. This was possible because organisms were related by descent.

3. COMPARATIVE EMBRYOLOGY

Adaptive embryology refers to the study of embryonic stages of organisms. Embryological studies on vertebrates reveal striking structural similarities among embryos of all vertebrate groups especially in early fetal stages of cleavage and gastrulation as well as in early embryonic stages. This has been summarized as the recapitulation principle which states that **"Ontogeny recapitulates phylogeny"***(Haeckel)***.** This literally means that all vertebrates during their embryonic development repeat the evolutionally trends of their proposed ancestors and indicates a common ancestry for all vertebrates.

However the recapitulation principle does not apply universally as no organism shows all the stages of its proposed ancestor

At comparable stages of vertebrates, their embryos possess the following features

- ✓ External branchial grooves (gill pouches) in the pharyngeal region. These in fish form the gill slits involved in gaseous exchange while in other vertebrates form the Eustachian tube and the auditory canal involved in hearing
- ✓ Segmental myotomes. These are the muscle blocks that are evident in the tail-like structure that is completely retained in certain species only.
- ✓ A single circulatory system which includes a two-chambered heart. This is fully retained in the fishes only

4. COMPARATIVE ANATOMY (comparing structures)

The detailed study of unrelated organisms reveal many structures which are similar. These similarities indicate such individuals have a common ancestor.

The pentadactyl limb is common to all vertebrates except fish, but during evolution, it has become modified for a number of functions.

In birds, it forms the wings for flight, in primates it forms the hands for grasping whereas in whales it is modified for swimming.

Homologous structures are structures from the common ancestral origin that serve different functions e.g. the pentadactyl limb composed of five digits like in the horse for running, monkeys for grasping, human beings for handling and bats for flying. This type of evolution is called ***divergent evolution*** which is the type of evolution where by organisms with common ancestors have developed structures that perform different functions because of change in the environment they live in. **Divergent evolution** therefore refers to the gradual development of dissimilar structures among phylogenetically related organisms due to adaptive radiation of organisms to different modes of life. E.g. the Darwin's finches

Co-evolution is the joint change of two or more species in close interaction **Predators** and their **prey** sometimes co evolve; parasites and their hosts; plant-eating animals and the plants upon which they feed also coevolve.

Another example of coevolution is between **plants and the animals that pollinate them**.

When structures are further compared, it is observed that some of them differ but serve the same functions. Such structures are known as ***analogous structures.***

Thus ***analogous structures are structures from different ancestral origin but serve the same functions***. Such evolution is called convergent evolution which is a type of evolution where by different organs with different ancestral origins perform the same function. This is because of the similar environments they live in e.g. wings of birds and wings of insects.

5. COMPARATIVE BIOCHEMISTRY

In the same way, the similar structures like pentadactyl limb indicates a common ancestral origin. Simple chemicals such as water, glucose, proteins, lipids, nucleic acid, etc. are common to organisms. Cytochromes, haemoglobin and ribosomal RNA are also used in the search for evolutionary affinities (closeness).

The theory of biochemical homology among organisms emerges from biochemical studies like serological tests, x-ray analysis and protein sequence analysis. The ubiquitous occurrence of similar biochemical molecules and metabolic process in a wide range of organisms suggests a common ancestry. The slight differences like amino acid sequence in proteins and differences in DNA base sequence reflect changes due to adaptive radiation

Examples of biochemical homology include

- ✓ Proteins like cytochromes, haemoglobin, myoglobin and nucleic acids occur in almost all living organisms
- ✓ The occurrence of similar hormones like prolactin, adrenaline and thyroxin among all vertebrates

Comparative serology has been often used to establish the level of biochemical affinity (closeness) among organisms. When foreign protein molecules present in the serum are injected into the blood stream of an animal, they act as antigens that stimulate its immune system to synthesize anti bodies against them. If after some time the same sample of serum is added, antibody/antigen interaction occurs resulting into a precipitate which settles and can be measured. If for the second time, serum samples from a variety of animals are added to the sensitized blood stream, the degree of precipitation reveals the level of biochemical similarity between these animals to the first one. The higher the level of precipitation is the closer the animal is related to the first animal.

6. GEOGRAPHICAL DISTRIBUTION

Plants and animals species are not evenly distributed throughout the world. Some zones have their own characteristic fauna and flora.

It is expected that where identical conditions occur in different parts of the world, the same organisms will be found, but this is not the case. E.g. elephants are found in Africa and India together with South Africa, but the habits are different.

Britain and New Zealand have similar flora and fauna but having different organisms proves that evolution took place.

This discontinuous distribution of species can be explained as follows:

i) A species originates in a particular area.
ii) Individuals continuously disperse to avoid over-crowding.
iii) As they encounter new environments as a result of dispersal, they adapt to meet the new conditions which is termed as adaptive radiation.
iv) Climatic topographical and other changes create barriers between the new varieties and their ancestors.
v) This genetic isolation leads to separate gene production and new species.

It is thought that in this way, individual species become restricted to specific areas. These barriers are formed by continental drift. It is thought that continents of the earth were formed from a single mass that broke up at the South Pole.

This land mass broke up into sections which floated on the earths' molten mantle and drifted apart. Land bridges remain between individual sections and members of the species would freely interbreed.

Where these bridges were submerged by changes in sea level, groups became genetically isolated and new species arose.

By the time land bridges were reformed due to the fall of sea level, interbreeding between the original groups was impossible, hence the discontinuity of distribution of organisms which used to be of the same species.

POPULATION GENETICS

Population genetics is the branch of biology that deals &provides the mathematical structure for the study of micro evolutionary process.

Microevolution refers to the change in one gene pool or the allele frequencies that occur within a population over time. Mainly due to mutations, genetic drift, gene flow, selection (natural and artificial), gene flow for example industrial melanism, microevolution of resistance to antibiotics, pesticides etc.

Macroevolution refers to speciation or evolutionary changes at a level higher than the species level, resulting into formation of a higher taxonomic group such as class or genus.

Some biologists believe that macroevolution results from a build-up of small changes due to microevolution. One common **misconception** about evolution is that individual organisms evolve. It is true that natural selection *acts* on phenotypic x-tics of individuals to determine the fate of genotype.

Each organism's combination of traits affects its survival and reproductive success compared to other individuals; it's only those individuals that can reproduce successfully before death that contribute to the future species. But the evolutionary impact of natural selection is only apparent in the changes in a *population* of organisms over time, for this reason; **though individual organisms are acted upon by natural selection, its populations that evolve but not individuals. The population is the smallest unit of evolution.**

TERMS USED:

A population is a group of organisms of the same species living together in a given habitat at a given time.

A species refers to a group of organisms with similar features which can interbreed successfully to produce fertile offsprings.

Gene pool; Refers to the total variety of genes and alleles present in a sexually reproducing population. A population whose gene pool shows consistent change from generation to generation is said to be undergoing evolutionary change.

NB: A static gene pool is one where genetic variation is inadequate to bring about evolutionary change.

Allele frequency

Allele frequency refers to the total number of copies of a given allele expressed as a percentage of the total number of alleles for that gene in a population.

For example in human beings, production of body pigments is determined by a dominant allele while the recessive allele results into no pigment production (albinism). The frequencies of the dominant and recessive alleles are 99% and 01% respectively. Since the total percentage is 100%; 99 + 01 = 100. However, frequencies in population genetics are usually represented as decimals rather than percentages or fractions,

$\rightarrow$ 0.99 + 0.01 = 1.00.

Mathematically; if we let **p** and **q** to represent the dominant and recessive allele frequencies respectively,

Then **p + q = 1.. (I)**

From equation (i) above; if the allele frequency of either allele is known, the allele frequency of the other can be determined. E.g. If the allele frequency of the recessive allele is 25%,

Then q = 0.25. Using p + q = 1, p = 0.75.

Genotype frequency

Genotype frequency refers to the total number of individuals carrying a particular genotype expressed as a percentage of the total population.

In most populations, it's only possible to estimate the frequency of two alleles in a homozygous recessive state as this is the only genotype which can be directly observed phenotypically. E.g. 1 person in 10000 is albino. Albinism is known to be a recessive character, for the person to be an albino, they must be possessing two copies of the defective allele (homozygous recessive). The mathematical relationship between the frequencies of alleles and genotypes in populations was developed by Hardy and Weinberg. The relationship is therefore known as the '***Hardy-Weinberg principle***'.

Hardy-Weinberg's principle

It states that ***"The allele and genotype frequency of a large sexually reproducing population remains constant from generation to generation provided that disruptive factors like mutation and selection do not act"***

The gene pool of such a population remains static and the population is said to be in Hardy-Weinberg equilibrium, it cannot undergo evolutionary change.

For this principle to hold, the following factors must be fulfilled:

i) Provided the population is sufficiently large that no genetic drift occurs.
ii) Mating should be random such that no sex selection occurs.
iii) All genotypes should be equally fertile such that there is no selection or genetic load.
iv) No mutations should occur as these tend to increase genetic diversity.
v) Provided generations do not overlap.
vi) There should be no emigration or immigration i.e. there is no gene flow between populations.
vii) Natural selection should not act, as this would favour some genotypes over others.

NB: In prevalence of the above factors, the frequencies of all alleles and genotypes will remain constant over generations. In case all or at least one of the above factors is reversed, the frequencies are prone to change and the stability of the population is upset. This initiates evolutionary change.

Hardy-Weinberg equation is a mathematical relationship between the frequencies of alleles and genotypes in a population. This can be used to calculate genetic changes in populations.

Considering a population with a certain gene occurring in two allelic forms, one homozygous for a dominant allele **A** and the other for a recessive allele **a**; all the F1 off springs will be heterozygous (**Aa**).

If the frequency (probability) of ***A* = *p*** while that of ***a* = *q*.** The results from a cross between two F1 organisms would be as follows:

F1 phenotypes	Heterozygous	*X*	Heterozygous
F1 genotypes	Aa		Aa
Gametes	A a		A a

Random fertilization	AA	2Aa	aa
	(p^2)	(2qp)	(q^2)

Therefore:
p^2 = homozygous dominant
2pq = heterozygous
q^2 = homozygous recessive
Genotype frequency (sum of the 3 genotypes) = 1
$p^2 + 2pq + q^2 = 1$
In mathematical terms p+q=1 is the mathematical equation for probability and $p^2 + 2pq + q^2 = 1$ is the binomial expansion of that equation i.e. $(p+q)^2$.
That is allele frequency is p+q=1 and genotype frequency is $p^2 + 2pq + q^2 = 1$

Examples

1. One person in 10000 is albino, i.e. the albino genotype frequency is 1 in 10000. Since albino is recessive;
   $q^2 = \frac{1}{10\,000} = 0.0001$
   $q^2 = 0.0001$
   $q = \sqrt{0.0001} = 0.01$
   Therefore the frequency of the albino allele is 0.01 or 1%
   Since p+q = 1
   p = 1 - q
   p = 1 – 0.01 = 0.99
   Therefore the frequency of the dominant allele in the population is 0.99 or 99%
   Since p = 0.99
   $p^2 = 0.99^2 = 0.9801$
   Therefore the frequency of the homozygous dominant genotype is 0.9801 or 98%
   2pq = 2x0.99x0.01
   = 0.0198
   The frequency of heterozygous genotype is 0.0198 or 2%
2. In a population of 200 plants 128 are homozygous tall, 64 are heterozygous tall and 8 are dwarf.
   i) Using suitable symbols, state the genotype of all the plants
   ii) Calculate the allele frequency of t and T
   iii) Calculate the genotype frequency
3. In a Caucasian population, the frequency of individuals affected by cystic fibrosis is approximately 1 in 2500. This is a recessive disorder and affected individuals are homozygotes. If q represents allele frequency of the disease, find the frequency of the carrier genotype.
4. In a human population the gene responsible for tongue rolling is dominant over the gene for non-tongue rollers. The population of tongue roller is 84% and non-tongue roller is 16%. Find the percentage of individuals, who are,
   i) Homozygous for tongue rolling
   ii) Heterozygous for tongue rolling

Factors responsible for changes in allele frequencies of the population

The 4 major sources of genetic variation within a gene pool are;
- Crossing over during meiosis
- Independent segregation during meiosis
- Random fertilization
- Mutation

Others are explained below:
Natural selection:
This tends to favour alleles and genotypes that produce environmentally adapted phenotypes, leading to increase in their frequencies while those that are less adapted to the environment are eliminated hence their frequencies decline.

Gene flow:
It refers to the movement/continual interchange of alleles from one population to another as a result of interbreeding among the members of the two populations. This results into introduction of new alleles hence from other populations leading to change in the allele frequencies of the population. However, gene flow is said to be conservative to evolutionary change in the long run. It tends to ensure uniform distribution of alleles in all populations which reduces genetic variation and increases uniformity among organisms as all populations share a common gene pool, this limits the action of n/s. For this reason, interrupting gene flow is a prerequisite to evolutionary change and speciation.

Mutations:
Mutations are random occurrences which change the genetic constitution of organisms. They greatly increase genetic diversity, where advantageous mutations are favoured by natural selection and disadvantageous ones are phased out.

Non-Random Mating:
This occurs when there is sexual selection (a mechanism on non-random mating). It occurs when the presence of one or more inherited characteristics increases the likelihood of successful fertilization. In such cases, only organisms having certain characteristics will have high chances of reproducing hence passing on their traits to next generations, while those without such features will have reduced reproductive potentials. Only some alleles will be passed to next generation leading to change in their frequencies
Examples include eye colour in drosophila (females prefer red-eyed males), colour patterns in insects and birds, petal size and colour in flowers etc.

Genetic drift:
This refers to the change in the gene frequencies within a population as a result of chance rather than by n/s
Although chance events occur in populations of all sizes, they alter allele frequencies substantially only in small populations.
A phenomenon associated with genetic drift is the ***founder effect.*** A small population may become isolated from a large population and it may not be truly representative of the original population in terms of allele and genotype frequencies. Some alleles may be absent while others may be disproportionally represented. Continuous breeding within the pioneer population will produce a gene pool with allele frequencies different from that of the original parent population; this is known as the founder effect **(**as it occurs in the founder population).
In the same way, a sudden change in the environment, (such as a fire or flood) may drastically reduce the size of a population, just by chance, certain alleles may be overrepresented among the survivors, others may be underrepresented, and some may be absent altogether. Ongoing genetic drift is likely to bring about changes in the allele frequencies of the population and may result into a gene pool that is different from the original population. This is referred to as the ***bottleneck effect*,** (named so because the population passed through a restricted path
Random genetic drift may lead to the following;
- ✓ Total loss of some alleles from the population, due to death of the few individuals carrying such alleles
- ✓ Total extinction of the population
- ✓ The population becoming much better adapted to the environment
- ✓ Wide divergence of the population from the parent population, and all these occur just by chance rather than n/s.

NOTE: whereas genetic drift may lead to a reduction in variation within a population it can increase variation within the species as a whole. Small isolated populations may develop characteristics unusual of the main population which may have a selective advantage if the environment changes. In this way genetic drift can contribute to the process of speciation.

Genetic load:
This is the existence within the population of disadvantageous alleles in heterozygous genotypes.
Very many disadvantageous alleles are able to exist in populations in heterozygous forms as in this form they are rarely expressed phenotypically for possible elimination by environmental selection, for example albinism, colour blindness, sickle-cell anemia, etc.
The maintenance of fairly high frequencies of a recessive allele which may be potentially hazardous in a homozygous recessive state is referred to as the **heterozygous advantage**.

The most obvious example is illustrated by the sickle-cell trait.

Sickle-cell trait is a condition when an individual has one copy of the normal allele for hemoglobin production and a recessive allele for abnormal hemoglobin. Such heterozygotes/carriers have both normal and sickle-shaped red blood cells and this is referred to as sickle-cell trait.

Sickle-cell carriers have consistently shown a high resistance to malaria much more than both the normal and the sick. This therefore confers a selective advantage to the heterozygotes leading to consistently high frequencies of the sickle cell allele especially in such areas as the tropics where malaria is prevalent.

Explanation The carriers have both normal and sickle-shaped red blood cells, the former contain very low levels of oxygen due to abnormal hemoglobin while the latter contain high oxygen levels. This makes it difficult for the plasmodia parasites to survive in the low oxygen environments in sickle cells and to adapt to constantly changing oxygen contents. Some of them die while others are effectively eliminated by the body defense system before establishment of the disease leading to resistance.

SPECIATION

This is the process by which new species may arise from pre-existing species.

Intraspecific speciation is when a single species gives rise to new species. If this occurs when the whole population is occupying the same geographical area, its referred to as **sympatric** speciation whilst **allopatric speciation** occurs when the populations are occupying geographical isolated habitats In some cases, commonly in flowering plants, two species may give rise to a new species; this is known as ***interspecific hybridization.***

Allopatric speciation

This is the type of intraspecific speciation which occurs as a result of spatial separation of a population into two subpopulations, usually due to geographical barriers like mountain ranges, seas, rivers or differences in habitat preferences. This prevents interbreeding among the individuals of the two subpopulations leading to reproductive isolation and interrupts gene flow. Due to continuous n/s, mutations and random genetic drift result into changes in the allele and genotype frequencies of the two populations, making their gene pools to diverge more from that of the original population. Prolonged separation results into the populations becoming genetically isolated such that the individuals can no longer interbreed successfully, the two are now different species and speciation is said to have occurred. E.g. the Galapagos finches

Sympatric speciation

This is the type of sympatric speciation that occurs when all members of the population are occupying the same geographical area. It usually occurs following a short term period of allopatric/geographical isolation which results into accumulation of reproductively isolating traits among the individuals. This interrupts gene flow leading to genetic isolation of the two groups coexisting in the same area. The overall result is independent change in the allele and genotype frequencies of the two subpopulations due to n/s; leading to formation of races and subspecies. If genetic isolation persists over a long period of time, these may gradually evolve into different species, this is referred to as sympatric speciation.

Interspecific hybridization:

This is a form of sympatric speciation which occurs when a new species is produced by the crossing of individuals from two unrelated species. It is common in plant breeding and most hybrids are infertile but can reproduce asexually, though allopolyploidy may result into production of fertile off springs due to non-disjunction.

ISOLATING MECHANISMS

An isolating mechanism is a means of producing and maintaining reproductive isolation within a population. They are often called ***reproductive isolation mechanisms***

Reproductive isolation refers to the existence of biological factors (barriers) that impede members of the same or different species from interbreeding successfully

Within a population of one species, there are *groups of individuals which breed with one another. Each of these breeding sub units is called a* ***deme***. Although individuals within a deme breed amongst each other, most of the time it is still possible for them to breed with other individuals from other demes. Therefore it remains a single gene pool but if demes become separated in any way, the flow of genes between them may cease.

Each deme may then develop a long a separate line. The two demes may become so different that even if reunited, they will be incapable of successful breeding with each other. They would thus become separate species each with its gene pools.

Geographical isolation:
Any physical barrier which prevents two groups of the same species from mating must prevent them from interbreeding. Such barriers include mountains, deserts, rivers, oceans, etc.
The environmental conditions on either side of the barrier frequently differ. This leads to a group on either side adapting to suit its own environments. The process is known as adaptive radiation.
Ecological isolation:
Occur when two species inhabit similar regions but have different habitat preferences within that same area. Such species can meet only very rarely if at all.
Behavioral mechanism:
This occurs where animals exhibit courtship patterns. Mating only results if the courtship behavior displayed by one sex is accepted or interpreted by another. (Colour and marking on members of the opposite sex) E.g. Darwin's finches.
Seasonal isolation:
Occurs when two species mate or flower at different times of the year. Eg *Pinus radiata*in February and *Pinus attenuata*in April
The timing of courtship behaviour and gamete production is also important in that if the breeding season of the two demes does not coincide, they can't breed. On the other hand, different flowering times of plants mainly at cross pollination is impossible.
Physiological/reproductive isolation:
This is where two groups of individuals cannot breed due to a number of reasons connected to their physiological nature.
i) The genetalia of the groups may be incompatible (***mechanical isolation).*** It may be physiologically impossible for the penis of the male to enter a female's vagina.
ii) The gametes may be prevented from meeting e.g. in animals, the sperms may not survive in the female reproductive parts or in plants, the pollen tube may fail to grow.
iii) Fusion of gametes may not take place despite the sperm reaching the ovum or the pollen tube entering the micropyle thus in this case, the gametes are incompatible so do not fuse. (***gametic isolation***)
iv) Development of the embryo may not occur despite fertilization taking place, further development may not occur or fetal abnormalities may arise during early growth. (***hybrid isolation)***
v) The hybrid may be sterile (hybrid sterility). E.g. a mule. (***hybrid isolation)***

Isolating mechanisms are classified as **prezygotic** mechanisms (Which are barriers that may lead to formation of hybrids) or **post zygotic** mechanisms (barriers that prevent hybrids from reproducing)
Post zygotic mechanism (barriers that occur after fertilization)
- ✓ ***Hybrid inviability***; this is when the produced hybrids are unable to survive to reproductive maturity. The genes of different parent species may interact in ways that impair the hybrid's development or survival in its environment. Sometimes development of embryo may not occur after fertilization
- ✓ ***Hybrid sterility***: This is when hybrids are viable but fail to produce functional gametes and are therefore infertile. This is because the chromosomes of the two parent species differ in number or structure, that they cannot allow for complete pairing of chromosomes during meiosis e.g. the mule (2n =63) results from a horse 2n=60 and donkey (2n=66)
- ✓ ***Hybrid breakdown***: The F1 hybrids are fertile but the F2 hybrids and their back crosses are infertile E.g. hybrid formed between *sp* of cotton.

"***The deep emotional conviction of the presence of a superior reasoning power, which is revealed in the incomprehensible universe, forms my idea of God" Albert Einstein.***