Chapter 4

Evolution

Chapter Contents

Introduction

Our earth is full of **animate** (living) and **inanimate** (non-living) matter. This matter undergoes changes from time to time, like living organisms take birth, grow old and ultimately die off. This is the life history of a particular organism. But if we study the history of complete flora (plant life) and fauna (animal life) on planet earth, we will come to know that these all have undergone a lot of changes over millions of years. All the life forms like plants, animals or microorganisms that we see around comprise the **biodiversity** on earth. These all life forms have a long history of changes and the study of history of life forms on earth is called **Evolutionary Biology**. To understand the changes in the flora and fauna that have occurred over million of years on earth, we must have an understanding of the context of origin of life, *i.e.*, evolution of earth, of stars and indeed of the universe itself.

In this chapter, we will deal with the various aspects of evolutionary biology like origin and evolution of life forms, the evidences of evolution, mechanism of evolution with special emphasis on the origin and evolution of man.

Meaning of Evolution

Evolutionary biology is that branch of biology which talks about the word 'evolution'. Now what exactly is evolution?

- **Evolution** means the act of unfolding or unrolling and in simple terms, evolution is an orderly '**change**' from one form to another.
- But before we learn about how an organism evolved, we must have an understanding of how that organism originated. Therefore, before learning 'evolution of life', we must learn 'Origin of Life'.

ORIGIN OF LIFE

Life is an inherent capacity that an organism possesses to maintain and reproduce itself. The origin or beginning of life is a unique event in the history of universe. Let us first aquaint ourselves with the origin of universe.

Universe

The universe is a very vast and expanded region of space. It is possibly infinite in volume. Billions of galaxies are present in it which are clustered together to form this huge universe. The galaxies are themselves very massive and contain many stars, planets and rocky bodies bound together with the gravitational forces and the clouds of gas and dust.

The universe is such a vast entity that when we compare the size of earth with the size of universe, it appears like a small spot or a speck.

The distances between these heavenly bodies present in the space, *i.e.*, stars, planets, galaxies, etc., are known as **stellar distances**. The stellar distances are measured in **light years**.

Did You Know?

A light year is the **distance** that light travels in vacuum in one year. Like metre or kilometre, it is also a unit of length but used only when the distances to be measured are in millions or billions of kilometres.

Any object will only be seen when the light emitted by it reaches our eyes. Now if an object is present very near to us or in our immediate surroundings, then it will be seen instantly and in the present time because the light rays emitted by this object will take less time to reach our eyes. These light rays take less time because they have to travel less distance.

But if an object is far away from us; say billions (10^9) or trillions (10^{14}) of kilometres away, then the light emitted by it will take millions of years to reach our eyes. **This is the reason when we look at stars on a clear night sky, it is said we are in a way, looking back in time or we can say when we see stars we apparently are peeping into the past.**

Origin of Universe

Big Bang Theory :

- Origin of universe was the most important phenomenon in the origin of life. The **Big Bang Theory** attempts to explain the origin of universe. This theory proposes that the universe is very old and its origin took place almost 20 billion (20×10^9) years ago. It states that a **single huge explosion** (*i.e.*, Big Bang) took place in the space which was so powerful that it is unimaginable in physical terms. Due to this explosion, the universe expanded in volume and the temperature of the space came down. Slowly Hydrogen and Helium gases formed, which condensed due to the gravitational forces present in the surroundings. This all resulted in the formation of billions of galaxies about which we have already discussed.
- In the solar system of milky way galaxy earth was supposed to have been formed about **4.5 billion years** back.
- The gaseous envelope or **atmosphere** was not present on the early earth. Due to volcanic eruptions, the molten mass was released which slowly covered the surface of earth. From this molten mass, various gases released into the surroundings like **methane (CH_4)**, **ammonia (NH_3)**, **carbon dioxide (CO_2),** water vapour etc. The ultraviolet (UV) radiations present in the sunlight acted upon water and broke up water into hydrogen and oxygen and lighter H_2 escaped. Oxygen readily combined with other gases like NH_3 and CH_4 to form again H_2O, CO_2 and other gases. Therefore, **free oxygen** (like today's environment) was **not present** on the **early earth**. Therefore, the **early atmosphere** was **reducing** unlike today's oxidising atmosphere. It was only present in the form of compounds like H_2O, CO_2, etc. Oxygen also participated in the formation of ozone (O_3) molecules due to action of UV rays on it. These O_3 molecules clustered together to form the **ozone layer** which acts as a **shield** to save our present atmosphere from harmful UV rays.
- The water vapour condensed to form water drops which fell as **rain** and slowly filled the depressions present on the surface of earth which is supposed to be the **origin of large oceans** seen today.
- But during all these changes, life took approx. 500 million (500×10^6) years to appear or we can say that the **life appeared** 500 million years after the formation of earth or almost 4 billion (4×10^9) years back from now (as earth formed 4.5 billion years ago).

Did You Know?

1. Our galaxy is named as milky way galaxy.
2. Galaxy is also known as Aakash ganga.
3. 1 Billion = 1000 millions.

Example 1 : *Life cannot originate from inorganic materials at present because of*

(1) High degree of environmental pollution

(2) Very high atmospheric temperature

(3) A very high amount of oxygen in the atmosphere

(4) Absence of raw materials

Solution : A very high amount of oxygen in the atmosphere.

This is because oxygen is a strong oxidising gas which oxidises the inorganic materials present in our atmosphere and thus prevents chemical origin of life.

Try Yourself

1. The early atmosphere was
   (1) Oxidising (2) Reducing
   (3) Non-reactive (4) Non-reducing
2. Which of the following was most likely absent in free form in the primordial atmosphere at the time of origin of life?
   (1) Ammonia (2) Methane
   (3) Oxygen (4) Hydrogen

Theories on the Origin of Life :

1. **Theory of special creation** states that the life was created by supernatural power in the form which has not undergone any change. It was given by **Father Suarez**. God created life in six days **from** materia prima and man was created by Him on the sixth day. According to this theory, earth is about 4000 years old.
2. **Theory of catastrophism** was given by **Cuvier**, according to which after a gap of certain period (called age), the world undergoes a catastrophe (sudden calamity) which kills almost all the living organisms and then God creates a new generation or new life from inorganic matter.
3. **Theory of biogenesis** (*i.e.* life from life, *omnis vivum ex. vivo*) was proved by **Redi, Spallanzani** and **Pasteur** independently. They disproved (refuted) theory of spontaneous generation (**abiogenesis**). Francesco Redi (1668) proved that flies could not arise from putrefying meat without their eggs. Spallanzani (1767) demonstrated that putrefaction of meat is due to microbes in the air and it can be prevented by boiling and sealing the meat in air tight containers. **Pasteur gave a definite proof of life arising from pre-existing life using microbes and sterilization methods.** He performed **"swan neck flask"** experiment.
4. **Cosmozoic Theory (Did Life Come from Outer Space) :** Some scientists believe that the life came on the earth from other stars or planets. They were the early Greek thinkers (Richter Helmholtz) who said that the living organisms exist throughout the universe. Like we have our own earth, many other planets also have their own living organisms and the life was transferred from one planet to other in the form of some small units of life called **spores** or **seeds** or **sperms**. The transfer of spores was termed Panspermia (Suggested by Arrhenius 1908). **Panspermia** states that life is present througout the universe (pan-complete). Transfer of life from one planet to another is called cosmozoic theory. Panspermia is still a favourite idea for some astronomers, but this theory has no scientific proof.

5. **Theory of Spontaneous Generation :** The supporters of this theory stated that the life did not come from outerspace. Rather there was a natural 'spontaneous' generation of the **living** organisms **from non-living** matter present on the earth.
   - For example, they believed that the **decayed** and **rotting** material like mud, straw, etc. had the capacity to give rise to organisms like frogs, flies, etc.
   - However this concept was **experimentally disproved** by many scientists. One of them was **Louis Pasteur**. Louis Pasteur by careful experimentation demonstrated that life comes only from pre-existing life. He showed that in pre-sterilised flasks, life did not come from killed yeast while in another flask open to air, new living organisms arose from killed yeast.

Knowledge Cloud

Experiment : Pasteur took two flasks which were sterilised by him to make them **free** from the microbes. He made a **thick soup** of yeast and water (called broth) in both the flasks. Then he boiled the broth and now the yeast was called '**killed yeast**'.

He kept one flask open to air and curved the neck of other one so that the yeast present in the second flask was not in direct contact with the air. He showed that in the flask, which was **open to air**, new living organisms **arose** while **no life appeared** in the flask which was **not open to air**. He showed that in pre-sterilised flasks, life did not come from killed yeast in the flask with the curved neck, while in another flask open to air, new organisms arose from 'killed yeast'. The purpose of experiment was not to show that new organisms arose from the 'killed yeast' but to explain that it was actually the 'air' in which living organisms were present that entered the flask when it was kept open to air. On the other hand, curved neck trapped the microbes from entering inside the another flask thereby preventing their growth inside the flask. Hence, it was proved that life cannot arise from the non-living objects (here killed yeast) and could only arise from pre-existing living organisms.

Louis Pasteur

The theory of spontaneous generation was dismissed once for all on this basis. But still, there was no explanation as how the first life form came on the earth.

6. **Theory of Chemical Evolution or Oparin-Haldane Hypothesis :** Oparin of Russia and Haldane of England proposed that the first form of life could have come from pre-existing non-living organism molecules (*e.g.* RNA, protein etc). and that formation of life was preceded by chemical evolution *i.e.*, formation of diverse organic molecules from inorganic constituents

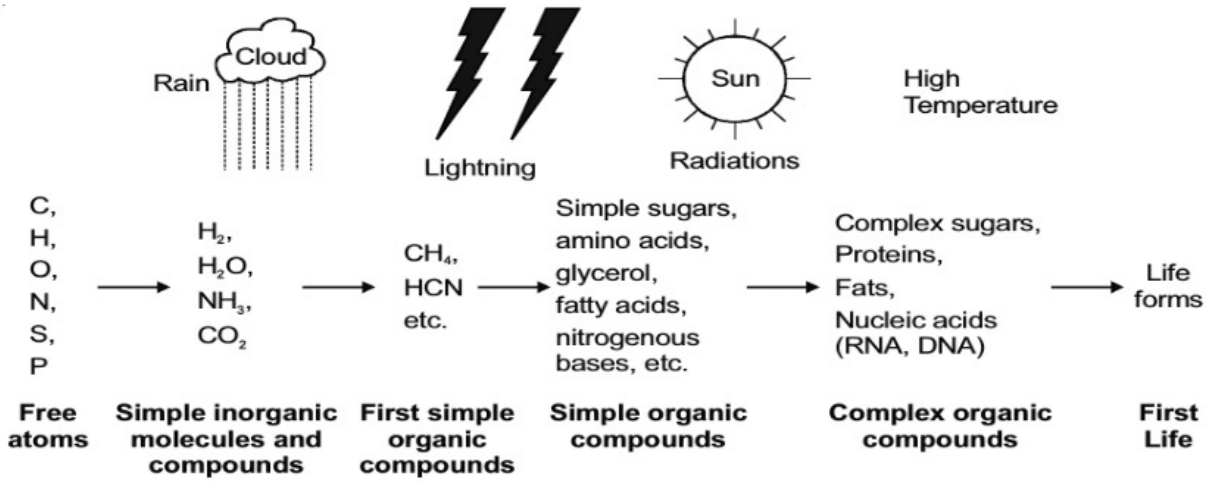


Fig.: Process of chemical origin of life (as proposed by Oparin and Haldane)

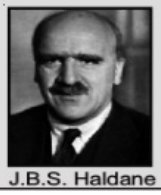
The formation of diverse organic molecules from inorganic constituents was termed **chemical evolution**.

Knowledge Cloud

A.I. Oparin (1894–1980) was a Soviet (Russian) biochemist, notable for his contributions to the theory of origin of life and for his book *The origin of life*.


A. I. Oparin

J.B.S. Haldane (1892–1964) was born in Oxford, England but chose to leave in and move to India and become an Indian citizen. He was a geneticist (a biologist who studies genetics) and evolutionary biologist (who studies evolutionary biology).


J.B.S. Haldane

*Now the question arises. What was the stimulus that initiated the above discussed chemical reactions on the earth? Oparin and Haldane proposed that the **energy** and **stimulus** were provided to these reactions (i.e., chemical reactions) by the **conditions** present on the early earth like*

(1) High temperature

(2) Volcanic eruptions (storms)

(3) Reducing atmosphere containing CH_4, NH_3, etc.

Early atmosphere was reducing unlike present oxidising atmosphere because it had no free oxygen.

Experimental Evidence for Chemical Evolution :

Based on the hypothesis proposed by Oparin and Haldane, S.L. Miller provided an experimental evidence of the chemical evolution in 1953 in a laboratory set-up. S.L. Miller, an American Scientist, created the similar conditions as described by Oparin and Haldane on a laboratory scale. Miller sealed in a spark chamber a mixture of **water (H_2O), methane (CH_4), ammonia (NH_3)** and **hydrogen gas (H_2).** He made arrangement for insertion of two electrodes to provide electrical energy (simulation of lightning) to the spark chamber. CH_4, NH_3, H_2 were in 2 : 1 : 2 ratio and water vapour at **800°C**. Electric sparks of **75,000 volt** was provided to the mixture. The spark chamber was connected to another flask with arrangement for boiling water (provision for evaporation). The other end of the spark chamber was connected to a trap by a tube that passed through a condenser (an arrangement for condensation and collection of aqueous solution, equivalent to rain and Haldane's soup). The trap, in turn, was connected with the flask for boiling water (arrangement for circulation). **The control apparatus contained every arrangement except that it was devoid of energy source. After eighteen days**, significant amount of the simple organic compounds (monomers), such as amino acids and peptide chains began to appear in the aqueous sample of the experimental set. Amino acids found were **alanine**, **glycine** and **aspartic** acid. Therefore, the obvious inference was that abiotic synthesis of organic monomers occurred in the simulated experimental condition. By analogy, such synthesis could have occurred in the primitive atmospheric condition. Later on many scientists repeated Miller's experiment using slightly different starting materials and UV radiation or other energy sources. All of them could successfully synthesise amino acid and related compounds. With hydrogen cyanide (HCN), even adenine and other nitrogen bases were produced.

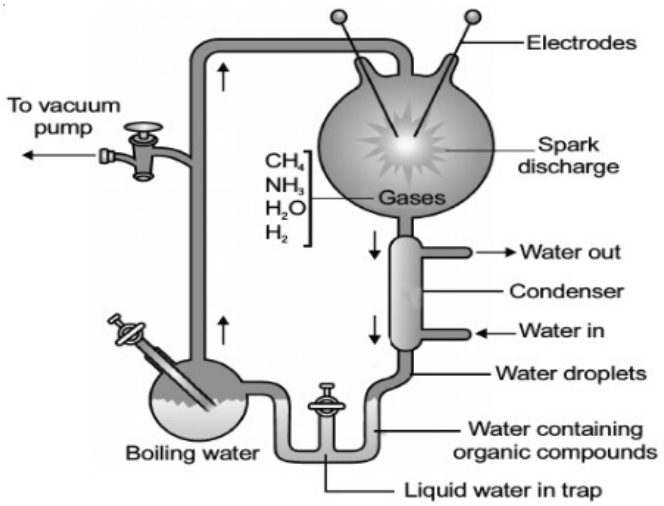


Fig.: Diagrammatic representation of Miller's experiment

- Several other scientists also conducted **similar experiments** by slightly changing the starting materials and sources of energy like UV radiations and became successful in generating **sugars** like ribose, hexose, **nitrogen bases** like adenine, guanine, **pigments** and **fats**.

  The meteorites strike the earth and their components fall on it. When the composition of meteorites was analysed, they were found to contain the similar compounds as produced in the above experiments. It indicates that similar chemical reactions were taking place somewhere else also in the space.

- With **experimental demonstration** and **evidence of meteorites**, the concept of chemical evolution, *i.e.*, origin of complex organic molecules from simple inorganic molecules was more or less accepted but the 2nd part of the conjectured story, *i.e.*, origin of life forms from these organic compounds was still not proved.

Abiotic synthesis of biomolecules is studied under following headings :

1. **Chemogeny :** Synthesis of organic molecules by chemical reactions.
2. **Biogeny :** Formation of self replicating biomolecules in broth (primordial hot soup or warm little pond).
3. **Cognogeny :** Evolution of various forms of life or **diversification of existing groups**.

Enclosing the Prebiotic Systems

The experiments of Miller and other scientists demonstrate that prebiotic molecules could have been formed under the conditions which most likely existed on early Earth. Still, the formation of prebiotic soup of small molecules does not necessarily lead to the origin of life. For origin of life, atleast three conditions needed to have been fulfilled:

1. There must have been a supply of self-replicators *i.e.*, self-producing molecules.
2. Copying of these replicators must have been subject to error via mutation.
3. The system of replicators must have required a perpetual supply of free energy and partial isolation from the general environment.

The high temperature prevailing in early Earth would have easily fulfilled the second condition, that is, the requirement of mutation. The thermal motion would have continually altered the prebiotic molecules.

The third condition, partial isolation, has been attained within aggregates of artificially produced prebiotic molecules. These aggregates called **protobionts** can separate combinations of molecules from the surroundings; maintain an internal environment but are unable to reproduce. Two important protobionts are **coacervates** and

microspheres. Oparin (1924) observed that if a mixture of a large protein and a polysaccharide is shaken, coacervates form. Their interiors, which are primarily protein and polysaccharide, with some water, become separated from the surrounding aqueous solution. The later has much lower concentration of proteins and polysaccharide. **Oparin's** coacervates also exhibits a simple form of metabolism. **As these coacervates do not have lipid outer membranes and cannot reproduce, they fail to fulfil the requirement as a candidate of probable precursors of life**.

Microspheres were formed when mixtures of artificially produced organic compounds were mixed with cool water. If the mixture contains lipids, the surface of the microspheres consists of a lipid bilayer, reminiscent to the lipid bilayer of cell membranes. Sydney Fox (1950) obtained **protenoid microspheres**.

There is considerable discussion among biologists as to how the first cells may have evolved. The discovery made in the 1980's that RNA can act like enzyme to assemble new RNA molecules on an RNA template raised the interesting possibility that **Coacervates may not have been the first step in the evolution of life**. **Perhaps the first macromolecules were RNA molecules**, and the initial steps on the evolutionary line were ones leading to more complex and stable RNA molecules. Later, the stability might have been improved by surrounding the RNA within a coacervate. Still other scientists reject the notion of 'RNA world', entirely, pointing out that some RNA components are too complex to have been present on the primitive earth.

Origin of Heterotrophs

The first living organisms originated among organic molecules and in oxygen free atmosphere (reducing atmosphere). They presumbly obtained energy by the fermentation of some of these organic molecules. They were **anaerobic,** capable of respiration in the absence of oxygen. They required readymade organic material as food and thus they were **heterotrophs.**

Origin of Autotrophs : When the supply of exisiting organic molecules was exhausted, some of the heterotrophs might have evolved into **autotrophs.** These organisms were capable of producing their own organic molecules by chemosynthesis or photosynthesis.

(a) Development of Chemosynthesis : The organisms performing chemosynthesis are called **chemoautotrophs.** They were anaerobic. Chemoautotrophs developed the ability to synthesise organic molecules from inorganic raw materials. Such a mode of nutrition is present even now in some bacteria, *e.g.,* sulphur bacteria, iron bacteria, nitrifying bacteria.

(b) Development of Photosynthesis : The photosynthetic organisms, the photoautotrophs, developed the pigment **chlorophyll** by combination of simple chemicals. They prepared organic food by using solar energy captured with the help of chlorophyll. They lacked the biochemical pathways to produce oxygen. They were still anaerobic and utilized hydrogen from sources other than water. At later stage, oxygen releasing photosynthetic organisms developed. These were similar to the existing blue green algae **(cyanobacteria).** They used water to get hydrogen and released oxygen. Addition of O_2 to the atmosphere started oxidising the methane and ammonia, which began to disappear.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

$$4NH_3 + 3O_2 \longrightarrow 2N_2 + 6H_2O$$

Life was present on Earth about 3.9 billion years ago. However, the oldest microfossils discovered so far are that of photosynthetic cyanobacteria that appeared 3.3 to 3.5 billion years ago.

Formation of Ozone Layer : As oxygen accumulated in the atmosphere, the ultraviolet light changed some of oxygen into ozone.

$$2O_2 + O_2 \longrightarrow 2O_3$$

The ozone formed a layer in the atmosphere, blocking the ultraviolet light and leaving the visible light as the main source of energy.

Formation of Eukaryotic Cells (True nuclear cells) : Aerobic respiration evolved sufficient oxygen in the primitive atmosphere. The prokaryotes gradually modified to adapt themselves according to new conditions. They developed a true nucleus and other specialized cell organelles. Thus *free-living eukaryotic cell-like organisms originated in the ancient ocean, presumably about 1.5 billion years ago.* Primitive eukaryotes led to the evolution of protista, plantae, fungi and animalia.

Summary of main steps in the origin of life according to Modern theory of Origin of Life :

1.	Free Atoms ↓	H (Hydrogen), C(Carbon), N(Nitrogen), O(Oxygen), etc
2.	Formation of inorganic molecules ↓	H_2, H_2O, NH_3, CO_2
3.	Formation of Simple organic molecules ↓	CH_4, HCN, simple sugars, Fatty acids, Glycerol, Aminoacids, Nitrogenous bases (purine and pyrimidines)
4.	Formation of Complex organic compounds ↓	Polysaccharides, Fats, Proteins, Nucleotides, Nucleic acids
5.	Formation of Eobionts ↓	Coacervates and Microspheres are protobionts
6.	Prokaryotes ↓	Without organised nucleus
7.	Eukaryotes	With well organised nucleus

Knowledge Cloud

Stanley Lloyd Miller (1930 – 2007) was an American chemist and biologist who is known for his studies into the origin of life.

Stanley Miller

Example 2 : *Which of the following scientists conducted an experiment on 'killed yeast' to disprove the theory of spontaneous generation?*

(1) Louis Pasteur

(2) S.L.Miller

(3) A.I.Oparin

(4) J.B.S.Haldane

Solution : Louis Pasteur conducted the experiment on 'killed yeast' and gave an experimental proof to disprove the theory of spontaneous generation.

Example 3 : *What were the conditions present on the early earth that provided energy for the chemical origin of life?*

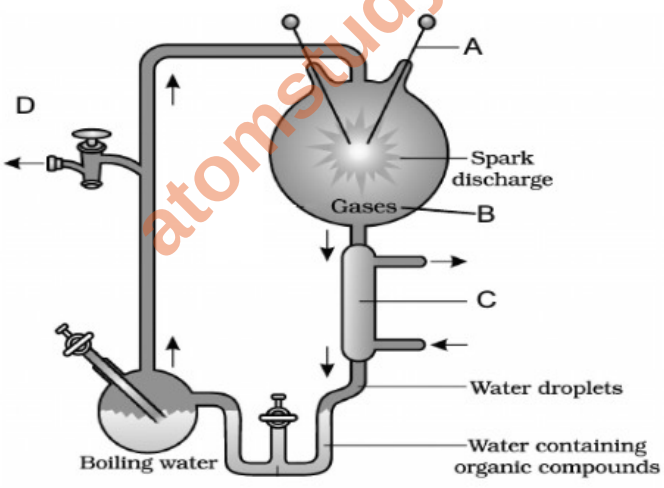
Solution : The conditions were (1) High temperature (2) Reducing atmosphere with no free oxygen (3) Volcanic eruptions.

Try Yourself

3. All of the following theories were given for the origin of life, **except**
   (1) The Big Bang theory (2) Theory of Panspermia
   (3) Theory of Spontaneous generation (4) Theory of Chemical evolution
4. Life originated in
   (1) Air (2) Water
   (3) Sun (4) Soil
5. Which of the following was used as an energy source by Miller in his experiment?
   (1) UV radiations (2) Oxygen
   (3) Condenser (4) Electric discharge
6. First cellular form of life originated on earth about
   (1) 3 billion years ago (2) 2 million years ago
   (3) 2 billion years ago (4) 3 million years ago

EXERCISE

1. Following is the diagrammatic representation of Miller's experiment. What is **correct** labelling? Choose the correct option.



Diagrammatic Representation of Miller's Experiment

	A	B	C	D
(1)	Electrodes	$CH_4 + NH_3 + H_2 + H_2O$	Condenser	Vacuum pump
(2)	Electrodes	$NH_3 + H_2O + CH_4$	Hot water	Trap
(3)	Electrodes	$NH_3 + CH_4$	Steam	Trap
(4)	Electrodes	$NH_3 + CO_2 + H_2 + H_2O$	Hot water	Vacuum

2. Which of the following is **not** true about coacervates?
   (1) They are protein aggregates
   (2) They do not have lipid membrane and cannot reproduce
   (3) The work on coacervates was done by Oparin
   (4) They are protobionts with polysaccharides, proteins and water

3. Extra-terrestrial origin of life was proposed by theory of
   (1) Catastrophism (2) Spontaneous generation
   (3) Special creation (4) Panspermia

4. Which of the following is **incorrect** about protobionts in abiogenic origin of life?
   (1) They were partially isolated from the surroundings
   (2) They could maintain an internal environment
   (3) They were able to reproduce
   (4) They could separate combination of molecules from the surroundings

5. Miller's experiment provided evidence for the theory of
   (1) Special creation (2) Abiogenesis
   (3) Biogenesis (4) Chemical evolution

6. Select the **wrong** pair :
   (1) Haldane : Hot dilute soup
   (2) Oparin : Coacervate
   (3) Fox : Microspheres
   (4) Spallanzani : Abiogenesis

7. The first cellular form of life did **not** possibly originate till about
   (1) 3 billion years ago (2) 2000 million years ago
   (3) 4.5 billion years ago (4) 50,000 years ago

8. The theory of special creation has three connotations. Which of the following is **not** true?
   (1) The diversity was always the same since creation and will be the same in future also
   (2) Earth is about 4000 years old
   (3) Species are immutable
   (4) There has been gradual evolution of life forms

9. The earliest cells were
   (1) Chemoautotrophs (2) Chemoheterotrophs
   (3) Eukaryotes (4) Photoautotrophs

10. Who said that "Life arises from pre-existing life"?
   (1) Aristotle (2) Louis Pasteur
   (3) Oparin (4) Darwin

EVOLUTION OF LIFE FORMS – A THEORY

Based on the observation made during sea voyage by Charles Darwin in sail ship H.M.S. Beagle around the world. He was appointed as a naturalist for this voyage to study the vast flora and fauna of the different continents and islands. He said that every living organism, whether animal or plant, has its own '**characteristics**'. Now what do we understand by characteristics? **These are the details of appearance or behaviour**. For example, we have four limbs and bearing four limbs is one of our characteristics (that is why we are called tetrapods). While moving from one place to another during his voyage, Darwin observed that even different looking and differently behaving organisms **share some similarities** among themselves.

These similarities may either be in the body structure or in the behaviour. He also observed that living organisms share similarities not only among themselves but also with those organisms which became extinct from earth.

Based on his observations, Darwin concluded that all the existing life forms share similarities to varying degrees and also may share **common ancestors**. More are the similarities, more closely they are related and more closely they are related, more recently they shared common ancestors. Hence, we can say that if two organisms share common ancestor in the recent history, it would be present in the same epoch, period or era. And if they share common ancestor in distant history, it would be present in the different epoch, period or era; depending upon how distantly they share it. Hence, we can conclude from it that the **geological history of the earth closely correlates with the biological history of earth**. There had been extinctions of different life forms in the years gone by just as new forms of life arose at different periods of history of earth. There has been gradual evolution of life form.

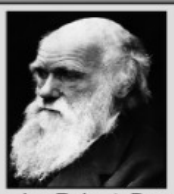
Concept of Natural Selection

Darwin not only talked about the similarities but also about the **differences** or **variations** among the organisms. He said that every population has its own characteristic features that differ from the characteristics of other populations.

Nature poses the same challenges to all living organisms in the form of harsh climate, food scarcity, natural disasters like flood, droughts, etc. The characteristics that enable some organisms to survive better than others in the same environment, are said to be **selected by nature**. Some used the word '**fitness**' for this capability to survive better. But, Darwin only referred to the '**reproductive fitness**' which means those organisms who are better fit in their environment produce more number of offsprings than others or we can say their **reproduction rate** is higher than the others. These, therefore, will survive more and hence are selected by nature. Darwin used the phrase '**natural selection**' for this and said that it is the natural selection which is responsible for the evolution. There was one more naturalist called **Alfred Wallace**, who worked in the **Malay Archepelago**. Like Darwin, he also talked about the fitness of organisms. He also came to the similar conclusions that those organisms which can adapt better in their environment, are selected by the nature.

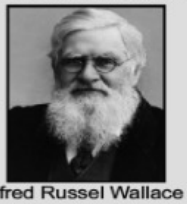
Knowledge Cloud

Charles Robert Darwin (1809–1882) was an English naturalist who published his work on the evolution in his book '*on the Origin of Species*' (in 1859). He set out on sea voyage when he was only 22 years old. The five year voyage took him to South America and the islands off its coast.



Charles Robert Darwin

Alfred Russel Wallace (1823–1913) was also a British naturalist and geographer. He is best known for independently proposing a theory of **evolution due to natural selection** that probably prompted Charles Darwin to publish his own theory.



Alfred Russel Wallace

Did You Know?

Malay Archepelago : Archepelago means the chain or cluster of islands. Malay here comes from the Malay race (or brown race) of humans.

Malay Archepelago is the Archepelago between mainland Southeastern Asia and Australia.

Example 4 : *Who proposed the concept of common ancestor?*

Solution : Charles Darwin.

Example 5 : *On what basis the concept of common ancestor was given?*

Solution : On the basis of similarities in the characteristics of organisms.

Try Yourself

7. At what level of grouping of organisms does evolution occur?
8. If two organisms are more closely related then which of the following is a possibility?
   (1) They will share common ancestor in the future
   (2) They share a common ancestor in the distant history
   (3) They share a common ancestor in the recent history
   (4) They will not at all share any common ancestor
9. According to Darwin, what is the driving force of evolution?
10. What was the term given by Darwin for the differences in characteristics?
    (1) Natural selection (2) Fitness
    (3) Evolution (4) Variation

WHAT ARE THE EVIDENCES FOR EVOLUTION?

Many important evidences are present in our nature which show that evolution has indeed taken place on earth. These evidences clearly demonstrate that the various new life forms have evolved since the creation of earth. Some of the evidences are discussed below :

(I) Fossils (Palaentological Evidences)

With the course of evolution, many species got extinct from the earth forever. But how do we know that these extinct species ever existed on the earth? We know this by studying the **fossils**.

When an organism dies, its body decomposes and hence lost in the environment. But when any body part or complete body gets preserved in the rocks or any other form, it becomes a fossil.

Hence, fossils are the preserved remains of hard parts of the organisms (plants, animals etc.) like bones, teeth, shells, wood, etc. in the rocks.

As the time passed, new rocks formed on the previously formed rocks and hence a kind of sedimentation took place. The earth's crust shows rocks or sediments of different ages and it was interpreted that the organisms who died earlier, fossils are formed deeper layers and those who died later the fossils are formed upper layers.

Therefore, by studying the fossils in the different sedimentary layers of earth's crust, we can estimate the geological period in which they existed. The study also showed that life-forms varied over time and certain life forms are restricted to certain particular geological time-spans. Hence, new forms of life have arisen at different times in the history of earth. All this is called **paleontological evidence**.

(i) Number and Nature of Fossils in Early Rocks : The rocks of early era *(e.g.,* Proterozoic) contain less number of fossils then the rocks of later era and only fossils of simple marine invertebrates are in these rocks. It is due to the fact that the life first originated in sea as a simple form. So fossils were not in plenty in the beginning as they were in later stage.

(ii) Distribution of Fossils in the Successive Strata : The distribution of fossils indicates that early fossils present in the bottom rocks are simple, however the recent fossils found in the upper layers of the rocks are more complex. It shows that fossil forms become more and more complex as we proceed from earliest to the recent rocks. The rocks of the **proterozoic era** contain few fossils. The **palaeozoic era** contains abundant fossils of invertebrates, fishes and amphibians. The rocks of the **mesozoic era** have the fossils of great reptiles **(dinosaurs)** and primitive birds and mammals. *Brontosaurus* was herbivore dinosaur, 25 metres long. 4.5 metres high and 45 metric tonnes in weight. *Tyrannosaurus* was the largest of the flesh-eating dinosaurs, 5.4 metres tall and 13 metres long. In the **coenozoic era**, the fossils of various mammals are abundant.

(iii) Disparity between the Past and Present Forms of Life : On the basis of fossil study it has been shown that the early organisms were very different from their modern forms, viz., the early man lived in the caves without any social life and spent their life like beasts, but man progressed and the modern man has become civilized, and leads a vigorous social life. Thus, the organisms have been changing since their appearance, which supports that evolution has been taking place.

(iv) Missing Links (Transitional Forms) : The fossil organisms which show characters of two different groups are called missing links.

Example : *Archaeopteryx* *(Archae* - primitive, old, *pteryx*-wing). It was found in the rocks of the Cretaceous period. *Archaeopteryx lithographica* was discovered in 1861 by Andreas Wagner from the lithographic quarry at Solenhofen, Bavaria, in Germany. This fossil is placed in the British Museum, London. It displays the characters of both the reptiles and birds.

Reptilian characters of *Archaeopteryx* :

(a) The body axis is more or less lizard-like
(b) A long tail is present.
(c) The bones are not pneumatic.
(d) The jaws are provided with similar teeth.
(e) Presence of a weak sternum.
(f) Presence of free caudal vertebrae as found in lizards.
(g) The hand bears typical reptilian plan and each finger terminates in a claw.

Avian characters of *Archaeopteryx* :

(a) Presence of feathers on the body.
(b) The two jaws are modified into a beak.
(c) The fore limbs are modified into wings.
(d) The hind-limbs are built on the typical avian plan.
(e) An intimate fusion of the skull bones as seen in the birds.

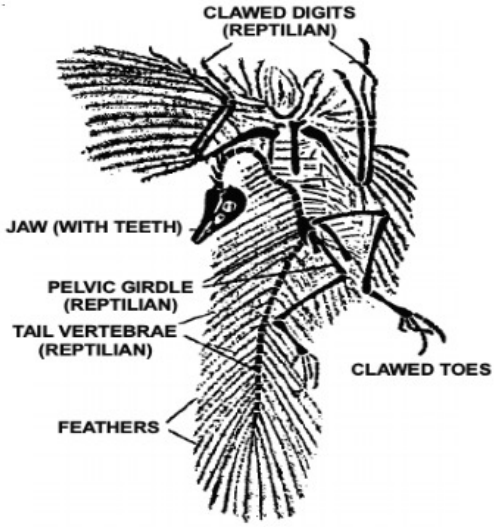


Fig. Fossil of *Archaeopteryx*

By careful analysis of the distribution of fossils in different strata of rocks, the time in history when different species were formed or became extinct can be inferred.

Time Line of Evolution : When scientists first began to study and date fossils, they had to find some way to organise the different time periods from which the fossils came. They divided the earth's past into large blocks of time called **eras**. Eras are further sub-divided into smaller blocks of time called **periods**, and some periods, in turn, are sub-divided into **epochs**. The major geological eras, with their approximate dates in millions of years as given in the table. "The geological time scale."

Table-I : THE GEOLOGICAL TIME SCALE

ERA	PERIOD	EPOCH	AGE (MILLION OF YEARS)	SOME IMPORTANT EVENTS IN THE HISTORY OF LIFE
Cenozoic (Age of mammals)	Quaternary	Recent holocene	0.01	Historic time
		Pleistocene	1.8	Ice ages; **humans appear**
	Tertiary	Pliocene	5	**Apelike ancestors of humans appear**
		Miocene (Golden age of mammals)	23	Continued radiation of mammals and angiosperms
		Oligocene	34	Origin of most modern mammalian orders, including apes
		Eocene	57	Angiosperm dominance increases; further increase in mammalian diversity
		Palaeocene	65	Major radiation of mammals, birds, and pollinating insects
Mesozoic (Age of reptiles)	Cretaceous		144	Flowering plants **(angiosperms)** appear; dinosaurs and many groups of organisms become extinct. First modern birds appeared.
	Jurassic		208	Gymnosperms continue as dominant plants; dinosaurs dominant; first birds
	Triassic		245	Gymnosperms dominate landscape; first dinosaurs and mammals
Paleozoic	Permian		285	Radiation of reptiles, **origin of mammal-like reptiles and most** modern orders of insects; extinction of many marine invertebrates
	Carboniferous		360	Extensive forests of vascular plants; first seed plants; origin of reptiles; amphibians dominant. **Age of amphibians**
	Devonian		408	Diversification of bony fishes; first amphibians dominant. **Age of fishes**.
	Silurian		438	Diversity of jawless vertebrates; colonization of land by plants and arthropods; origin of vascular plants
	Ordovician		505	First vertebrates (jawless fishes); marine algae abundant. **Age of invertebrates**
	Cambrian		544	Origin of most invertebrate phyla; diverse algae
Precambrian or Proterozoic			700	Origin of first animals
			1500	Oldest eukaryotic fossils
			2500	Oxygen begins accumulating in atmosphere
			3500	Oldest definite fossils known (prokaryotes)
			4600	Approximate origin of Earth

Knowledge Cloud

Types of Fossils

Only a minute fraction of the organisms living at any one time are preserved as fossils, most of them in **Sedimentary rocks.**

Fossils are formed when parts of dead organisms decay with the passage of time and get replaced, molecule for molecule, by inorganic material like iron pyrites, silica and calcium carbonate. This mineral replacement is called **PETRIFICATION**. Hard parts like bones, shells, teeth or trunks of trees are preserved more readily than soft parts. Rarely, however, soft tissues also get petrified. Thin sections of fossils when observed under the microscope, reveal the original structure.

A fossil is formed only under certain conditions. The dead organism should not get washed away or completely decomposed by bacteria. Instead, if it is buried near a river or a sea, it may become covered by sand or silt. If petrifaction then sets in, it is turned into a fossil.

Fossils are also formed by processes other than petrifaction. For example, an organism may get buried intact in preservatives like snow, oil, tar, volcanic ash or amber (a resinous secretion from fossil pine trees).

Sometimes what is left behind as a fossil is just an impression of the organism. Such an impression is formed when material surrounding the buried organism hardens followed by decay and subsequent removal of the organic matter. An exact replica of the original structure is left behind. **Such impressions are called moulds**. A common type of plant fossil is where the internal structure is lost, leaving a thin carbon film which gives the outline of the original plant. This kind of fossil formation is called **compression.**

Coprolite : Excreta preserved as fossil.

Pseudofossils : occassionaly rocks present structures resembling plant remains. They are normally products of minerals in rock crevices. Mineral substances crystallise and develop into patterns resembling the outlines of the plant.

Fossil Parks : Our country has rich deposits of fossil plants spanning a gap of 3500 million years. Twenty million years old fossil forests have been discovered and studied by the **Birbal Sahni Institute of Palaeobotany, Lucknow.** These forests need to be systematically studied and conserved for scientific understanding and enlightenment. Some of the excellent localities that can be raised to the status of national fossil parks are:

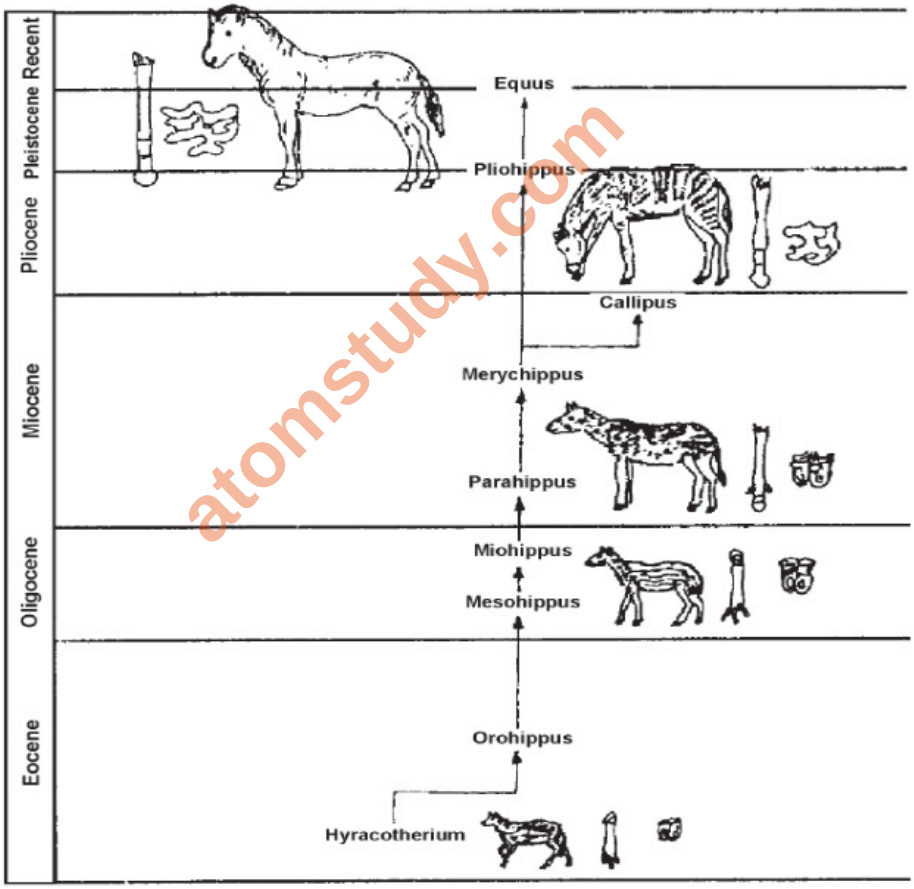
1. Fifty million years old fossil forests preserved in the sediments between the streaming lava flow that poured out into the Deccan country at Mandla district, Madhya Pradesh.
2. One hundred million years old fossil forest located in Rajmahal Hills, Bihar.
3. Two hundred and sixty million years old coal-forming forests in Orissa.

Microfossils and Fossil Fuel Exploration : Palaeobiological study helps in understanding and locating coal and hydrocarbon sources. **Palynofossils** – tiny microscopic spores, pollen and other vegetal remains of the past – assist us in interpreting ancient environmental conditions favourable for organic matter accumulation and its conversion to fossil fuels by transformation and subsequent thermal alteration. By quantitative analysis of microfossils, it is possible to determine the approximate location and configuration of near shore marine deposits, which are in turn responsible for formation and accumulation of hydrocarbons. The main source of hydrocarbons are phytoplankton, marine and terrestrial algae as well as lipid-rich plant remains. Thus, the study of fossil plants offers an effective tool in stratigraphical geology and can be exploited in tapping organic fuel resources.

Evolution of Modern Horse : Eohippus (=Hyracotherium). The evolution of modern horse began in the **Eocene epoch**. The first fossil named *Eohippus*, '**dawn horse**', was in North America. This horse was about the size of a fox or terrier dog (a type of small dog for unearthing foxes), only 40 cm high at the shoulders. It had short head and neck. The fore limbs were with four complete fingers (2, 3, 4 and 5) and one **splint** of first finger and the hind limbs with three functional toes (2, 3 and 4) and one splint of fifth toe. Splints are non-functional reduced fingers and toes of horse. Teeth were with incomplete cement. Molar teeth **had no serrations**. **Low-crowned molar teeth were adapted to browse soft lush vegetation**.

Mesohippus : *Mesohippus*, **the intermediate horse**, evolved from *Hyracotherium* about three crore years ago during **Oligocene epoch**. It was of the size of modern sheep, about 60 cm high at the shoulders. Fore feet had three fingers and one splint of fifth finger and hind feet possessed three toes, but the middle one was longer than others and supported most of the body weight. Molar teeth had some serrations.

Merychippus : *Merychippus*, the **ruminating horse**, arose from *Mesohippus* in **Miocene epoch** about two crore years ago. It was of the size of small pony, about 100 cm high at the shoulders. It had a longer neck. Its fore and hind limbs had three fingers and three toes, the middle finger and toe being longer than others and supported entire body weight. There was no splint. Teeth were longer with cement. Molar teeth had well developed serrations.



Evolution of Horses

Pliohippus : *Pliohippus*, the **Pliocene horse**, evolved from *Merychippus* in **Pliocene epoch** about one crore years ago. It was the size of modern pony, about 120 cm high at the shoulders. Its each fore and hind limbs had one complete finger and one complete toe and two splints hidden beneath the skin. *Pliohippus is, therefore, referred to be the first one toed horse*. The molar teeth were long with well developed cement and serrations. Teeth were adapted for eating grass.

Equus : This is the **modern horse** which arose from *Pliohippus* in **Pleistocene epoch** about nine to ten lakh years ago in North America and later spread throughout the world except Australia. It is about 150 cm high at the shoulders. It has a long head and a long neck. Each fore and hind limb of the modern horse has one finger and one toe and two splints. The crowns of molar teeth are elongated with enameled ridges and are highly suitable for grinding.

During evolution of horse, there was :

(i) General increase (with occasional decrease) in size,

(ii) Progressive loss of toes,

(iii) Lengthening of toes that was retained,

(iv) Lengthening of limbs in general,

(v) Enlargement of brain, especially cerebral hemispheres,

(vi) Increase in height,

(vii) Increase in the complexity of molar teeth and an enlargement of the last three premolars until they came to resemble molars.

Knowledge Cloud

Connecting Links : The organisms which possess the characters of two different groups. Examples

1. ***Proterospongia* :** A link between Protozoa and Porifera.
2. ***Neopilina* :** A connecting link between Annelida and Mollusca.
3. ***Peripatus* :** A connecting link between Annelida and Arthropoda.
4. Lungs fishes, *e.g.*, ***Protopterus***, ***Lepidosiren***, ***Neoceratodus*** are considered the connecting links between the fishes and amphibians.
5. Egg laying mammals; example duck billed *Platypus* (***Ornithorhynchus***) and **spiny ant eater** (***Echidna***) are considered connecting links between reptiles and mammals.

Try Yourself

11. What is phylogeny?
12. What do you understand by the principle of superposition?
13. What evidence supports the hypothesis that whales evolved from land dwelling mammals?
14. The statement given below is true/false. If false, why?

    "The match between many flowers and their pollinators is an example of artificial selection"
15. Large leg muscles built up in an individual, is an example of acquired or inherited characteristic.

Dinosaurs got extinct from earth and their skeletons are being found from different areas of earth. Even some present day organisms resemble the extinct dinosaurs in structure which indicates that these modern organisms have evolved from dinosaurs. It will be more clear from the following figure.

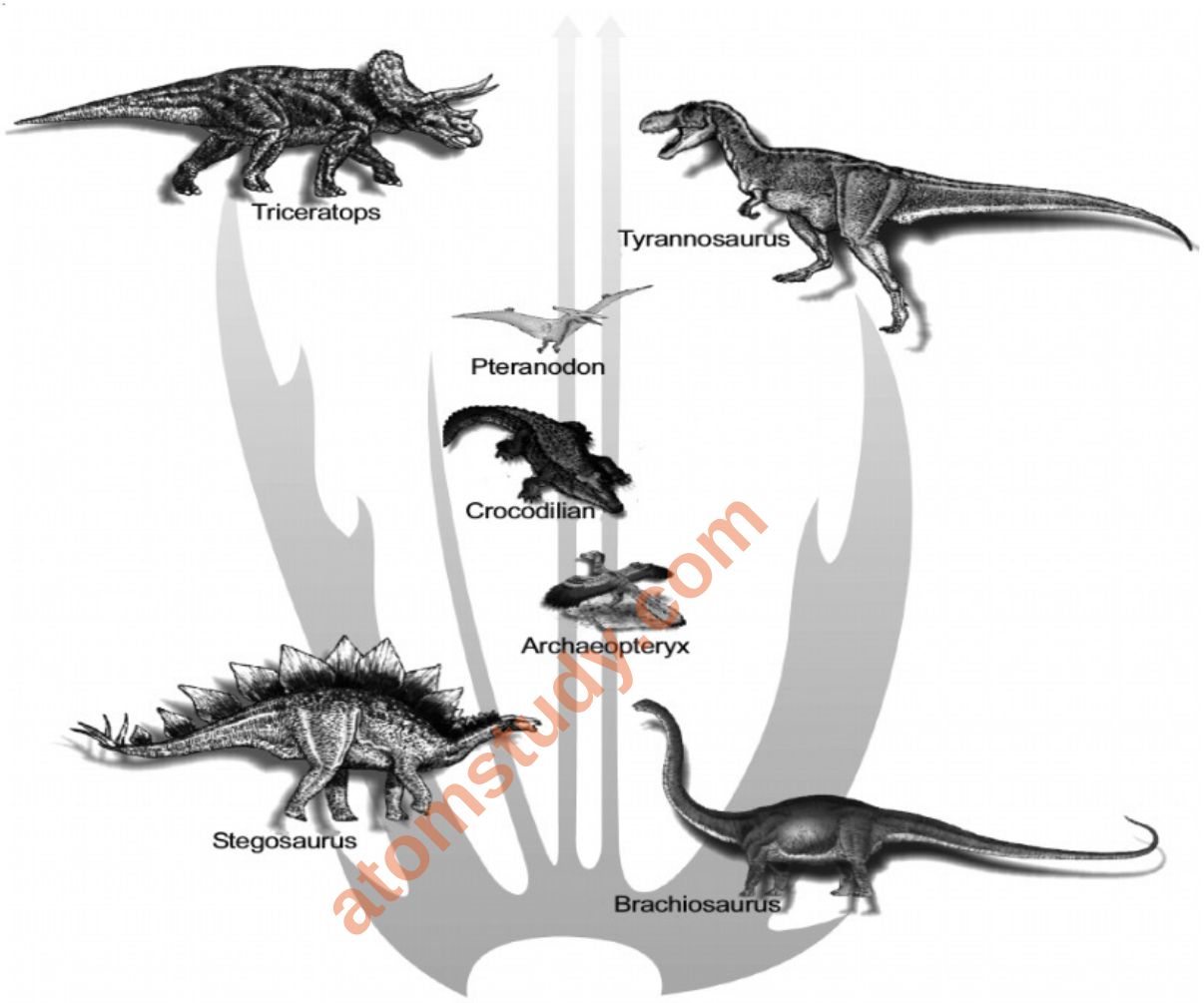


Fig. : A family tree of dinosaurs and their living modern day counterpart organisms like crocodiles and birds

The given figure shows :

(a) Dinosaurs (*Stegosaurus*, *Triceratops*, *Tyrannosaurus* and *Brachiosaurus*);

(b) *Pteranodon*,

(c) Crocodile and

(d) *Archaeopteryx*.

Only *Archaeopteryx* belongs to class aves, rest others in the figure belong to class reptilia.

The given figure, tries to explain that the dinosaurs (all extinct), *Pteranodon* (extinct), Crocodilians (crocodiles, alligators and gavialis; all living) and *Archaeopteryx* (extinct) all have evolved from same common ancestor.

Knowledge Cloud

Methods of finding the ages of fossils [Time Dating of Fossils]

There are two ways of finding the age of fossils :

(i) Relative dating

(ii) Radioactive dating

Relative dating : In this method, we dig the earth and start finding the fossils and it is reasonable to suppose that the fossils we find **closer** to the surface of earth are **more recent** than the fossils we find in the **deeper layers**. Hence, by this method, we can guess and compare the ages of fossils but cannot precisely find it. More precise method is radioactive dating.

Radioactive dating : All organic matter on the earth is made up of various elements, each having its own atomic number. Additionally, elements may exist in different isotopes. For example, ^{12}C and ^{14}C are the isotopes of carbon element. Now ^{14}C is a **radioactive isotope (hence unstable)** and ^{12}C is a **stable isotope**. And we know that **naturally occurring unstable radioactive isotopes** decay over the course of time at a steady rate and produce nonradioactive isotopes of other elements. This steady rate is known as the **half life** of that radioactive isotope, usually given in the units of years. Taking into consideration this half life of radioactive isotope, we can calculate the ratio of observed abundance of that radioactive isotope and its decay product in the fossil or rock we are studying. This is the **principle** of radioactive dating.

Commonly employed methods use the following isotopes :

	Radioactive Isotope		**Non-radioactive Isotope (of other element)**
(1)	Potassium^{40}	$\longrightarrow$	Argon^{40}
(2)	Carbon^{14}	$\longrightarrow$	Nitrogen^{14}
(3)	Uranium^{238}	$\longrightarrow$	Lead^{207}

Half life of carbon-14 is approx. 5730 years which means in every 5730 years, half of the C^{14} will decay back to N^{14}. C^{14} can be used to determine the age of fossils upto 70,000 years old. Half life of potassium^{40} is 1.3 billion years or $\mathbf{1.3 \times 10^9}$ years so this method is applicable to the old rocks.

EXERCISE

11. Which of the following is **incorrect** sequence?
    (1) Palaeozoic - Mesozoic - Coenozoic
    (2) Triassic - Jurassic - Cretaceous
    (3) Silurian - Devonian - Carboniferous
    (4) Devonian - Permian - Carboniferous

12. The cretaceous period during which the flowering plants appeared, occurred approximately
    (1) 220 million years ago (2) 140 million years ago
    (3) 280 million years ago (4) 345 million years ago

13. The fossil remains of *Archaeopteryx* is a connecting link between

(1) Fishes and amphibians

(2) Reptiles and birds

(3) Reptiles and mammals

(4) Amphibians and reptiles

14. Mass extinction at the end of Mesozoic era was probably caused by

(1) Continental drift

(2) Massive glaciation

(3) Collision of earth with large meteorite

(4) Both (1) and (3)

15. Charles Robert Darwin published his work on the evolution in his book

(1) Origin of life (2) On the origin of species

(3) Genetics and origin of species (4) Natural selection

16. Which of the following is a missing link?

(1) *Balanoglossus*

(2) *Ornithorhyncus*

(3) *Archaeopteryx*

(4) More than one option is correct

17. Age of invertebrates is

(1) Cambrian period (2) Ordovician period

(3) Silurian period (4) Carboniferous period

18. Which of the following character of *Archaeopteryx* is similar to reptiles?

(1) Presence of feathers on body

(2) Presence of long tail

(3) Intimate fusion of skull bones

(4) Jaws are modified into beaks

19. Which of the following is referred to be the first one toed horse?

(1) *Eqqus* (2) *Eohippus*

(3) *Merychippus* (4) *Pliohippus*

20. The dinosaurs which had three horns on head and collared neck

(1) *Tyrannosaurus* (2) *Triceratops*

(3) *Stegosaurus* (4) *Brachiosaurus*

(II) Comparison of Anatomy and Morphology of Organisms (Morphological and Anatomical Evidences)

Morphology refers to the external structure of an organism and anatomy refers to the internal structure and functional organisation.

A diverse range of living organisms is present on the earth. These living organisms are categorised into different groups (kingdoms, species, class or phyla) on the basis of their **common characteristics**. Hence, study of characteristics is important to categorise or classify them but on the other hand, these characteristics can also be used as **evidence** for the evolution. By comparing the morphology and anatomy, we can find the similarities as well as differences between the present living and remote extinct organisms. We have already learnt that if two organisms show similarities in structure or function, then they are supposed to be evolved from common ancestors and with this concept, we can trace the **evolutionary relationships** among organisms. For this, let us study the homologous and analogous structures.

(1) Homologous Structures : The structures in different organisms which have **similarity** in their **anatomy** or basic plan but serve **different functions** are known as homologous structures. This similarity in their anatomy is due to the phenomenon of common ancestry. Let us elaborate this with the help of following examples.

(i) The pattern or arrangement of bones of forelimbs in whales, bat, cheetah and human. We know that all of these mentioned organisms are the different species of the same class Mammalia.

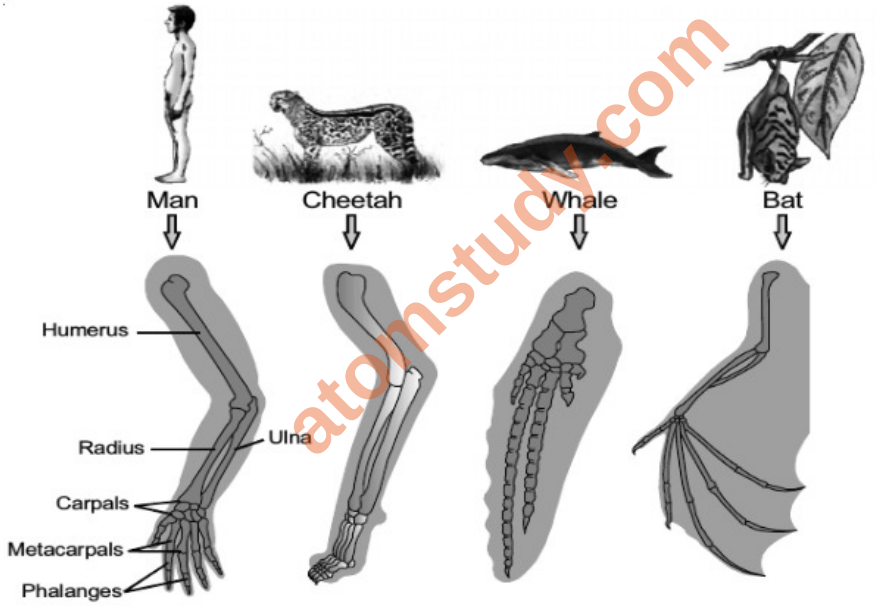


Fig.: Example of homologous organs in Animals

A close look at the anatomy of their forelimbs reveals similar (but not same) anatomical structures, *i.e.*, all of them have humerus, radius, ulna, carpals, metacarpals and phalanges in their forelimbs. But if we think of the functions of forelimbs in these animals, all of them show clear dissimilarities.

	Man	Cheetah	Whale	Bat
Functions of forelimbs	Holding the objects	Running	Swimming	Flying

We can see that in these animals, same structure (here forelimbs) developed along different directions due to **adaptations** to different needs. This is called **divergent evolution** because originwise common structure diverged towards different directions to perform different functions according to the need of the organism. Hence, **homologous structures are the result of divergent evolution**.

(ii) Vertebrate hearts and brains: The hearts in various vertebrates (fishes, amphibians, reptiles, birds and mammals) show similarity in the basic plan but they have **varied degree of specialization** according to the habitat in which they live, energy requirements and scale of evolution.

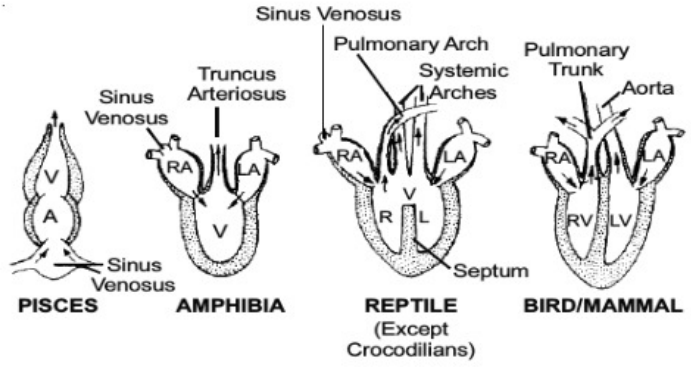


Fig.: Hearts of different vertebrates. Note the progressive complexity.
A = Auricle, V = Ventricle, R = Right, L = Left

Likewise brains of these vertebrates show similarity in the basic structure but progressive complexity has developed from fishes to mammals according to the need of the organism.

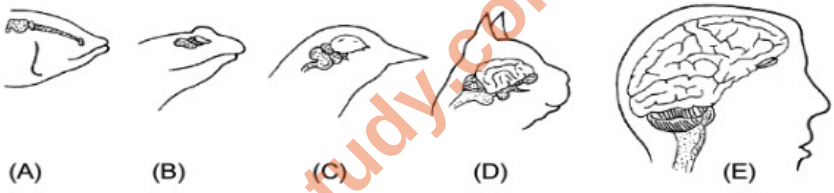


Fig.: Homologous structure : Vertebrate brain
(A) Fish, (B) Frog, (C) Bird, (D) Cat and (E) Human being

(iii) Homologous structure can also be traced in the **plants**. One of the examples in plants is of thorn of ***Bougainvillea*** and tendril of ***Cucurbita***.

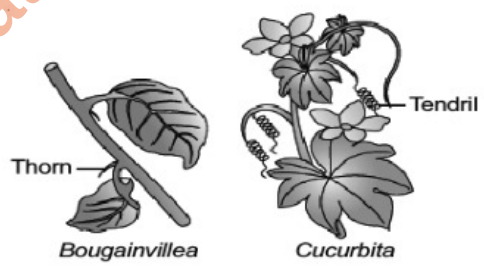


Fig.: Example of homologous organs in Plants

In these plants, thorns and tendrils both are axillary in position and are the modifications of axillary buds. But they perform different functions as thorns are for protection of the plant and tendrils help the plant in climbing.

(iv) Example of **biochemical or molecular homology :** Just now we discussed the structural similarities among diverse (different) organisms, now we will move on to more depth, *i.e.*, at the molecular level. For example, the proteins found in the blood of man and ape are similar, suggesting their ancestral relationship. Similarly we can trace the similar genes in different or unrelated organisms which points towards the common ancestry (origin).

(2) **Analogous Structures :** The structures in different organisms which are **not similar anatomically** though they **perform similar functions** are called as analogous organs. Morphologically they may or may not be similar which means that analogous structures may or may not look alike externally. The property of bearing analogous structures is called analogy. The analogous structures do not exhibit common origin. Unlike homology which indicates common ancestry, the analogy does not indicate common ancestry.

Following are some of the common examples of analogous structures :

(i) **The wings of butterfly and of birds**. Butterflies are the invertebrates whereas birds are vertebrates. The wings in both of them perform the common function of flying but the internal designs and components of these two types of wings are very different from one another. The wings look alike externally because they have a common use of flying.

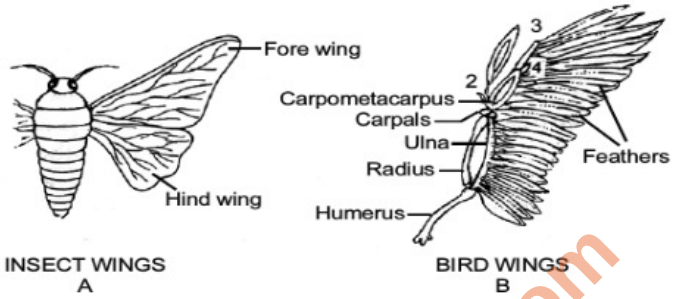


Fig.: The wings of an insect are analogous to wings of bird

Now how analogous structures are related to the evolution?

Here in this example, the anatomically different structures evolved towards the same direction (*i.e.*, towards same function) due to **adaptations** to similar needs or **similar habitats**. This is called the **convergent evolution** because anatomically dissimilar and originwise different structures converged towards the common function. **Hence, analogous structures are the result of convergent evolution**.

(ii) **Eye of the octopus and of mammals :** Eye of octopus and of mammals have different internal structures (as they differ in the retinal position) but they serve the common function of vision.

(iii) **Flippers of Penguins and Dolphins :** Penguin (a bird) and Dolphin (a mammal), both have flippers which serve the common function of swimming although have different internal structures and origin.

(iv) **Sweet potato and potato :** Sweet potato is a modified underground root and potato is a modified underground stem, therefore, originwise both are entirely different. But they serve the similar function and are meant for the storage of food, hence, are also the example of analogous structures.

(3) **Vestigial organs :** They are believed to be **remnants** of organs which were complete and functional in their ancestors. The study of vestigial organs offer an evolutionary explanation of such rudimentary vestiges by stating that adaptations to new environment of the organism have made these structures redundant. Such structures are called vestigial organs. The rudiment of the reptilian jaw apparatus, the rudiment of the hind limbs of python and Greenland whales are some of the examples of vestigial organs. In humans, many vestigial structures indicate a relationship to other mammals, including the primates. For instance, muscles of the external ear and scalp are rudimentary and often non-functional. But these are common to many mammals where they are functional. The reduced tailbones and nictitating membrane of the eye, the appendix of the caecum, rudimentary body hair and wisdom teeth – all are examples of vestigial organs.

The appendix of man is thought to be a remnant of the large caecum - the storage organ for cellulose digestion in herbivorous mammals. Similarly, the non-functional vestiges of the pelvic girdle in python and porpoise show, for instance, that the snake and the porpoise originally evolved from four footed ancestors.

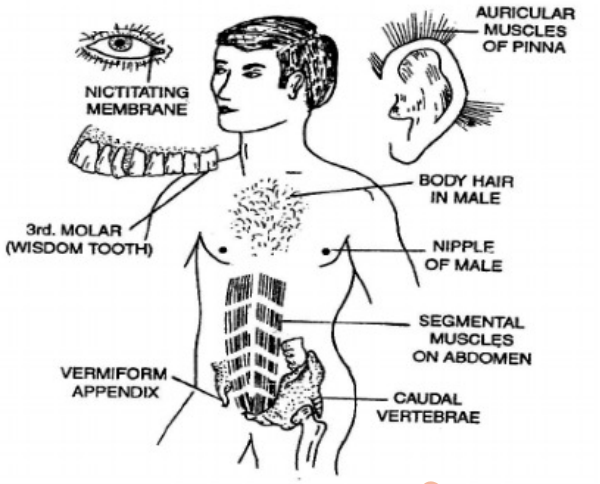


Fig. : Some vestigial organs in human Body

Vestigial Organs in Plants : One or more staminodes (vestigial stamens) occur in the flowers of several plants belonging to Labiatae, Scrophulariaceae, Casesalpinioideae, Cucurbitacae. etc. Non-functional pistils called pistilloides occur in the male flowers of cucurbitaceae. In the ray florets of Sunflower, the stamens are absent while the pistil is rudimentary with small functionless stigma and ovule-less ovary. Leaves are reduced to scales in *Cuscuta, Orobanche, Asparagus, Ruscus* and a number of other plants.

(4) Connecting Links : The organisms which possess the characters of two different groups are called **connecting links**. Following are some important examples of connecting links.

Examples:

(a) ***Euglena*** is a chlorophyll-containing green protozoan that forms connecting link between the animals and plants.

(b) ***Proterospongia*** is a colonial protozoan. It consists of flagellated and collared individuals that resemble choanocytes (collar cells) of sponges. Thus, it is a link between Protozoa and Porifera.

(c) ***Neopilina*** **:** It is a connecting link between Annelida and Mollusca. It resembles molluscs as it possesses a shell, a mantle and a large muscular foot. Its annelid characters are presence of segmentally arranged gills, nephridia and muscles and a trochophore-like larval stage.

(d) ***Peripatus*** **:** An arthropod, is a connecting link between annelida and arthropoda. Its arthropod characters include haemocoel, tracheae as respiratory organs and tubular heart with ostia. The annelid characters exhibited are the worm-like body, structure of the eyes, unjointed legs, presence of segmental nephridia, soft cuticle and continuous muscle layers in the body wall.

(e) ***Balanoglossus*** **:** It is a hemichordate (nonchordate) and is a connecting link between nonchordates and chordates.

(f) **The lung fishes :** *e.g.. Protopterus* (African lung fish), *Lepiidosiren* (South American lung fish) and *Neoceratodus* (Australian lung fish) may be considered the connecting links between the fishes and amphibians. The lung fishes have all the characters of a typical fish, but they are capable of respiring through lungs and possess a three chambered heart.

(g) ***Latimeria*** (Coelacanth fish) is considered a connecting link between fish and amphibians.

(h) **Chimaera :** It is a connecting link between cartilaginous fishes and bony fishes.

(i) **Egg-laying mammals** (*e.g., Ornithorhychus,* Duck-billed platypus and *Tachyglossus* or *Echidna* or Spiny ant eater) bear hair and mammary glands, but also possess some of the reptilian characters such as laying of eggs, presence of cloaca and some skeletal similarities. Thus they are connecting link between reptiles and mammals.

(5) **Atavism :** It is the reappearance of certain ancestral characters which had either disappeared or were reduced. There are present some examples of atavism in human beings, *viz.*. the power of moving pinna in some persons, greatly developed canine teeth, exceptionally long dense hairs, short tail in some babies and presence of additional mammae in some individuals. Atavism is also observed in plants. In *Citrus* leaf the lamina is separated from wing petiole by means of joint or constriction. Sometimes the winged part of the petiole is enlarged to produce two lateral leaflets making the leaf trifoliolate. It shows that Citrus leaf was once trifoliolate compound but during evolution two leaflets have degenerated.

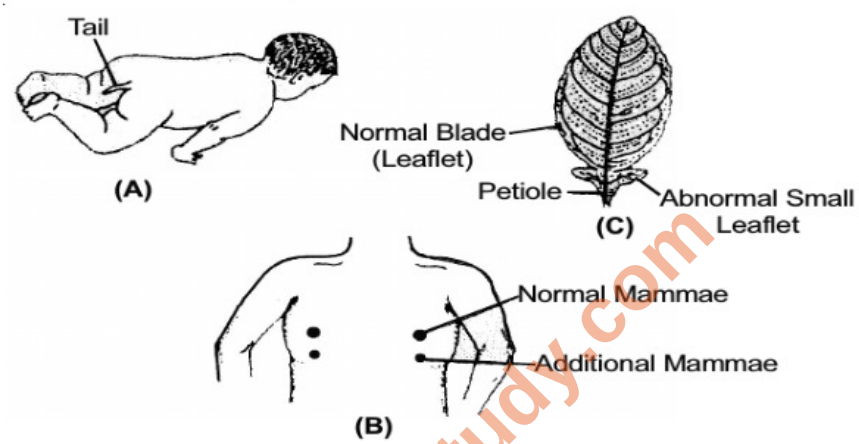


Fig. : Atavism. **(A)** A baby with tail, **(B)** Additional mammae, **(C)** A *Citrus* leaf with two extra leaflets.

(III) Embryological evidences :

These evidences are based on the comparative study of the embryos of various animals :

1. **Similarity in Early Development :** In all the multicellular animals the fertilized egg **(zygote)** undergoes segmentation **(cleavage)** to produce a solid structure, the **morula.** The morula develops into a single layered hollow **blastula.** The latter changes into either two or three layered **gastrula.** The animals having two layered gastrula are said to be **diploblastic.** *e.g.,* coelenterates. The animals in which three layered gastrula is found are known as **triploblastic,** such as frog, lizard, etc. Diploblastic gastrula consists of ectoderm and endoderm. These two or three layers of gastrula are termed as **primary germ layers,** which give rise to the entire animal. Such a similar early development establishes a close relationship among all multicellular animals.
2. **Resemblance among Vertebrate Embryos :** If a comparative study of embroys of the same age of vertebrates, such as a fish, a salamander, a tortoise, a chick and a man is made, it is observed that they resemble one another closely. They have more or less the same form and structures like gill clefts, tail, etc. Although the embroys of all vertebrates resemble with one another but the embroys of closely related groups resemble more closely than the embryos of the distant groups. This is another evidence establishing close relationship among these divergent vertebrates.
3. **Resemblances among Invertebrate Larvae :** Annelids and molluscs possess a similar type of larva called trochophore. Echinoderms and hemichordates also have similar larvae. Larval resemblance points to a common ancestry.

4. **Progressive Metamorphosis :** Ammocoete larva of Lamprey resembles the adult form of Amphioxus or *Branchiostoma* in most of the details which are possible only if we presume that Lamprey has evolved from *Branchiostoma* like animals.

5. **Retrogressive Metamorphosis :** Animals like *Sacculina* and tunicates (*e.g.*. Herdmania) are degenerates and do not show any resemblance to other groups of animals. However, the study of their embryology has helped as to find their true systematic position on account of the characters present in their embryos. *Sacculina* is a parasite on crabs. Limbs, mouth, alimentary canal and special sense organs are absent. The parasite has a stalked ovoid sac which sends outgrowths into the host for absorbing nourishment. The taxonomic position of *Sacculina* was found out through the study of its larva which resembles the nauplius larva of crustaceans. Similarly, the tunicate *Herdmania* has a simple purse-like body which shows no trace to chordate connection. However, its larva possesses all the important chordate characteristics which proves that *Herdmania* is a chordate.

6. **Temporary Embryonic Structures :** Embryos often possess structures which do not occur in the adults. For example, bird embryo has tooth buds and gill clefts which are not found in the adult animal. Presence of tooth buds has no relevance to the embryo as food is obtained from yolk through special blood vessels. The adult which feeds on hard grains and seed needs the teeth but is devoid of them. The presence of tooth buds in the embryos can be explained only on the assumption that

   (i) Birds have developed from toothed ancestors

   (ii) Birds have lost teeth during evolution

   (iii) The bird embryo possesses some ancestral characters due to the persistance of some genes that express their effect during developmental stages.

   Whale is an aquatic mammal. It does not possess body hair. Its foetus or embryo possesses hair which are shed before birth. Hair are useless to the embryo because it is well protected inside the mother's body.

   Early tadpole of frog possesses gills and tail, during metamorphosis these structures disappear.

7. **Development of Vertebrate Organs :** Development of many vertebrate organs (*e.g.,* heart, brain, kidney) indicate the possible path of evolution as well as the common ancestry of vertebrates. For example, during its development the heart of a mammal or bird is initially two-chambered (as in fishes), then three-chambered (as in amphibians and some reptiles) and ultimately four-chambered. It clearly shows that birds and mammals have originated from fishes through amphibians and reptiles.

   In all vertebrates, the brain arises as an anterior enlargement of the neural tube., Soon it develops two grooves and gets divided into three parts-fore brain, mid brain and hind brain. Each of these parts develops further to attain the adult state.

   Vertebrates have three types of kidneys : Pronephric, mesonephric and metanephric. Pronephric kidney occurs in hag fishes. Mesonephric kidney is found in other fishes and amphibians while metanephric kidney is present in reptiles, birds and mammals.

8. **Biogenetic law :** Embryological support for evolution was also proposed by Ernst Haeckel based upon the observation of certain features during embryonic stage common to all vertebrates that are absent in adult. For example, the embryos of all vertebrates including human develop a row of vestigial gill slits behind the head, but it is a functional organ only in fish and not found in any other adult vertebrate.

   We can say, that the sequence of embryonic development in different vertebrates show striking similarities. Gill clefts and notochord appear in the embryonic development of all vertebrates from fishes to mammals. The notochord is replaced by vertebral column in all adult vertebrates. Similarly, gills are replaced by lungs in adult amphibians and mammals. Such similarities in embryonic development once again reinforce the idea of evolution from common ancestors. Occasionally, embryonic features such as the tail and gill slits persists in adults.

   According to Ernst Haeckel, ontogeny (development of embryo) is recapitulation of phylogeny (the ancestral sequence). This view is summarised by his **Biogenetic Law : Ontogeny recapitulates phylogeny.**

   Developmental evidence for evolution is also available from plants. It is generally believed that mosses and ferns are more evolved than algae. Protonema of mosses resembles certain green algae. This provides a clue to their evolutionary relationship. Both bryophytes and pteridophytes have ciliated sperms and require

water for fertilisation. Gymnosperms do not need water for fertilisation. But *Cycads* and *Gingko*, the primitive gymnosperms, have ciliated sperms like the pteridophytes. This suggests that gymnosperms have descended from pteridophyte-like ancestors. The occurrence of ancestral traits in embryo is called **Palaeogenesis.**

Fig. : Similarity in the embryo of different vertebrates

(IV) Biogeographical Evidences

The study of patterns of distribution of animals and plants in different parts of the earth is called **Biogeography**.

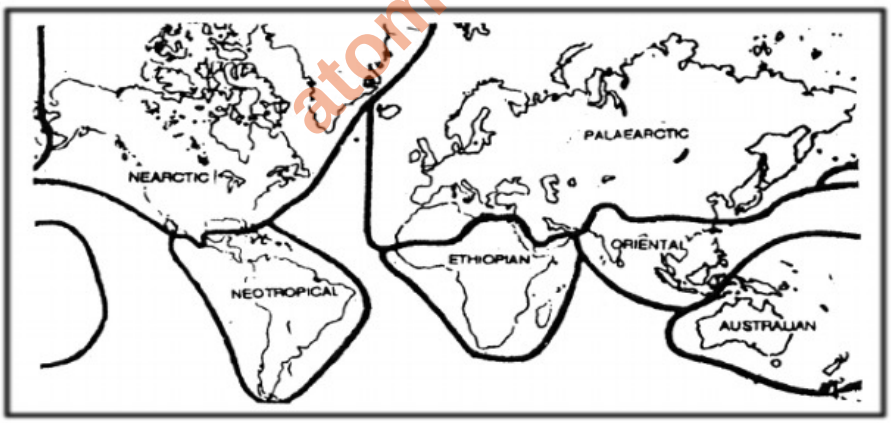


Fig. : Different biogeographic realms (regions) of the world.

Alfred Russel Wallace (1823 - 1913) divided the whole world into six major biogeographical regions or realms.

1. **Palaearctic** : Europe and Asia north of the tropics, north-western corner of Africa, including the Atlas Mountains.
2. **Nearctic** : North America exclusive of the tropics, Alaska, Canada, United States and Mexico.
3. **Neotropical** : Central America including low lands of Mexico, islands of the Caribbean and all of South America.

4. **Ethiopian** : Africa (with exception of the Atlas Mountains), Madagascar and adjacent islands.
5. **Oriental** : Tropical part of Asia (including India) south of the Himalaya Mountains and eastward through Sumatra, Java, Borneo and the Philippines.
6. **Australian** : Australia, Tasmania, New Guinea and all islands of the Indonesian archipelago that lie east of Borneo, beginning with Celebes.

Biogeographic map of the world is that in which the six major biogeographic realms are present. Geologists believe that millions of years ago, all the continents we demarcate today, were in the form of a single land mass. On account of geological changes, especially movements of crustal plates below the surface of the earth, huge land masses broke off and drifted apart from one another. As these land masses (continents) moved away, the seas separated them and acted as barriers to the free movement of organisms among the continents. Because of variable environmental conditions prevailing on the different continents, over centuries, plants and animals evolved independently in each biogeographical region.

Oriental realm is separated from Palaearctic realm by Himalayan mountains. Ethiopian relam and Australian relam are separated by sea.

Oriental realm and Australian realm are separated by **Wallace's line.** Palaearctic realm and Nearctic realm together form **Holoarctic region.**

(1) Discontinuous Distribution of Closely Related Species : Sometimes closely similar species exit at widely separated places without any representative in intervening territory. This is called **discontinuous distribution.** Two specific examples of discontinuous distribution are given below.

(a) Alligators : They occur only in southeastern United States and extern China. The North American continent was connected with east Asia in early coenozoic. The alligators were distributed over the entire region. But due to certain barriers, the alligators of two regions were separated for long time and developed some mutations. Therefore, these alligators are somewhat different but they are related species of the same genus.

(b) Lung Fishes : During early stages of continental drift, South America, Africa, Antarctica and Australia were interconnected. Later on they were separated. Antarctica was shifted to a far away place. Now the lung fishes are only found in South America, Africa and Australia.

(c) Camels : They occur in Asia, while their nearest allies Llmas are found in South America.

(d) Elephants : They are found in Africa and India and not in places with identical climate in Brazil.

(e) Magnolias, Tulips and Sassafras : These plants now grow naturally in the eastern USA and in China only. The reason is the same as for the alligators.

(2) Restricted Distribution : The parts separated from the main land have unique fauna and flora. For example, Australia has

(a) Egg-laying mammals

(b) Pouched mammals : That occur only in Australia. This restricted distribution may be explained in the following way. Australia separated from the main land of Asia during mesozoic era, before placental mammals evolved. Placental mammals, being more adapted, eliminated the egg laying and most of the pouched mammals in other parts of the world. The egg laying and pouched mammals of Australia survived as placental mammals could not reach there due to lack of land route.

(c) Deserts of America possess cacti while those of Africa have euphorbias.

(d) Double coconut is restricted to Seychles island.

The birds in Galapagos Islands show differences in bills and feeding habits. The bills of several of these species resemble those of different, distinct families of birds on the mainland. All these birds are thought to have evolved from a single common ancestor.

EXERCISE

21. Which of the following animals show adaptive radiation based on locomotion?
(1) Scorpion, elephant, human (2) Cheetah, kangaroo, mole
(3) Praying mantis, seal, python (4) Cockroach, squirrel, toad

22. Which of the following is **not** an example of homologous organ?
(1) Vertebrate hearts or brains
(2) Thorns of *Bougainvillea* and tendrils of *Cucurbita*
(3) Leg of cheetah, and flipper of whale
(4) Eye of octopus and of mammals

23. Darwin's finches are example of
(1) Biogeographical evidence (2) Paleontological evidence
(3) Embryological evidence (4) Analogous organs

24. What are the anatomical structures called that share a common ancestry?
(1) Analogous structures (2) Homologous structures
(3) Evolutionary structures (4) Vestigial structures

25. Tendrils in different plants are example of
(1) Analogous organs (2) Divergent evolution
(3) Homologous organs (4) Both (1) & (2)

26. Which of the following structures are vestigial in *Python* but not in human?
(1) Nictitating membrane (2) Ear pinna
(3) Hind limbs (4) All of these

27. Which of the following is not a connecting link?
(1) *Neopilina* (2) *Peripatus*
(3) *Latimeria* (4) *Limulus*

28. Which of the following realms are separated by Himalayan mountains?
(1) Oriental and Australian realm
(2) Oriental and Ethiopian realm
(3) Oriental and Palearctic realm
(4) Oriental and Nearctic realm

29. Choose the example of discontinuous distribution
(1) Lung fishes (2) Egg laying mammals
(3) Pouched mammals (4) All of these

30. Biogenetic law was proposed by
(1) Mayer (2) Ernst Haeckel
(3) Darwin (4) Alfred Wallace

Artificial Selection (As Evidence of Evolution)

Artificial selection, as the name depicts, is the selective breeding of plants or animals for desired traits. It is done artificially by employing various breeding methods and that is why it is called artificial selection. Following are the examples of artificial selection.

(1) Generation of different breeds of dogs, cows, sheep.

(2) Generation of different vegetables like Broccoli, Kale, Cauliflower, etc. from wild mustard.

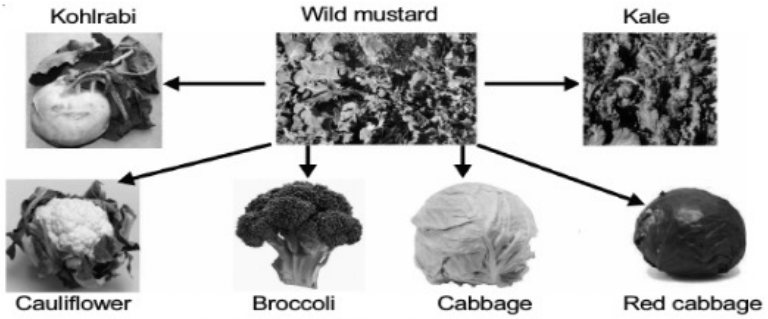


Fig.: Evolution of wild mustard

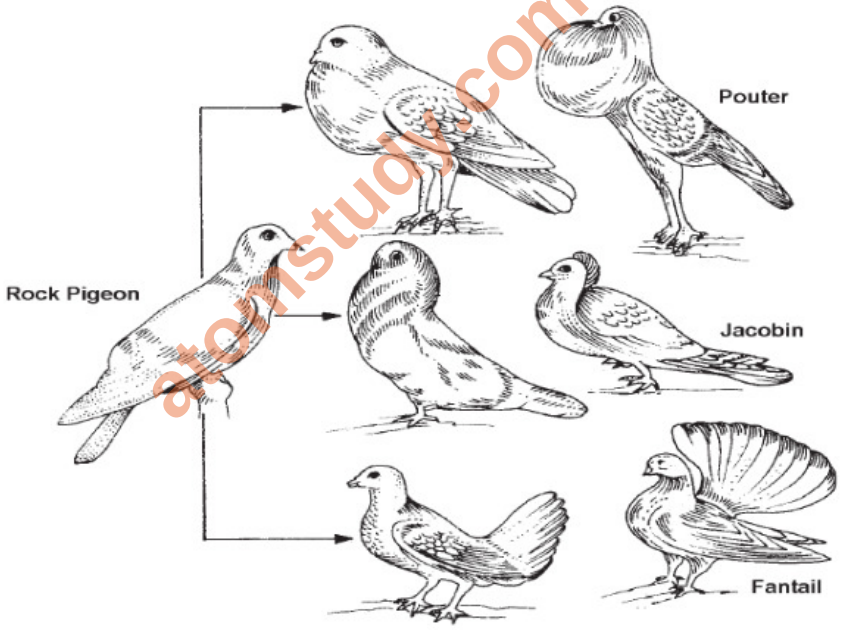


Fig. : Variation among breeds of domestic pigeons.
Ancestry of different breeds can be traced to wild rock pigeon. (Artificial Selection)

Man domesticated wild animals and plants and then selectively bred them for the traits or group of traits desired by him in various fields. Like in **agriculture**, he bred cows, buffaloes, etc. to increase yield and quality of milk; in **horticulture** (science of plant cultivation), he bred various crops to improve yield, nutritional value and disease resistance crops. For **sports**, he bred better breeds of fowls, bulls and horses for cock-fighting, bull race, and horse race respectively. And for the **security** purposes, he bred good and powerful breeds of horses, camels and dogs, etc.

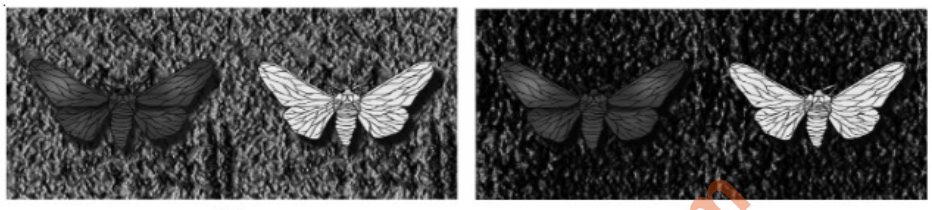
It is argued that if within hundred of years man could create new breeds then could not nature have done the same over millions of years.

Natural Selection (As Evidence of Evolution)

Darwin and Wallace talked about the natural selection, *i.e.*, the selection done by nature. An interesting example of natural selection comes from the **Industrial Melanism**.

(1) Industrial Melanism: Before emergence of **industrialisation** (*i.e.*, in 1850s) in England, white-winged moths were more in number than the dark-winged or melanised moths. But after industrialisation, *i.e.*, in 1920, the condition was reversed. It was seen that in the post-industrialisation period, the number of dark-winged moths increased much more than white-winged moths in the same area of England. What could be the reason for this phenomenon?

This could be explained as follows : The moths rest on tree trunks. Before industrialisation, no air pollution was there. The tree trunks were lighter in colour as no deposition of smoke and soot took place on the tree trunks. And also there was a thick growth of almost **white-coloured lichen** on the tree trunks. Under this condition it is difficult for a predator (bird) to spot or find the white-winged moths against the light background of tree trunks but easy to spot the dark-winged moths. Hence, the birds killed and ate dark-winged moths resulting in the decrease in the number of dark-winged moths.



(a) (b)

Fig.: Figure showing white-winged moth and dark-winged moth (melanised) on a tree trunk
(a) In unpolluted area **(b)** In polluted area

But **after industrialisation** set in, the pollution increased and the tree trunks became darker in colour – first, due to smoke and soot deposition and secondly due to absence of lichens on the tree trunks (as they do not grow in polluted area). Smoke has SO_2 that eradicated the lichens so the dark brown colours of the bark was exposed. As a result, the white-winged moths could not camouflage themselves, *i.e.*, hide in the background and therefore, were predated by the birds. This resulted in the decrease in the number of white-winged moths.

- ❖ This explanation was further supported by the fact that in the rural areas, the count of melanic (dark-winged) moths was low and of white-winged was more as industrialisation did not occur in these areas.
- ❖ Hence, this all explains that in a mixed population having different variants (types) of moths, those that can better adapt will survive and will produce more offsprings or we can say that they will be naturally selected. Natural selection brings evolution. But remember no variant is completely wiped out.

(2) Antibiotics or drugs resistance: We continuously use drugs and antibiotics against microbes. With course of time, some microbes developed 'resistance' against these drugs by bringing changes or modifications in their structures. Those which became resistant, survived and hence selected by the nature. Hence, developing 'drug resistance' by microbes is also an example of natural selection. Moreover this kind of natural selection took place in a small period of time, *i.e.*, months or years and not centuries.

(3) Herbicide resistance (developed in wild varieties) : Similarly herbicide and pesticide resistance developed in the weeds and pests respectively after prolonged use of herbicides and pesticides. This is also an example of natural selection which supports the process of evolution.

All above mentioned examples (industrial melanism, drug resistance etc.) are due to the involvement and actions of man and that is why these are called the examples of **evolution by anthropogenic action**.

All above mentioned evidences also suggest that evolution is a **stochastic process** which is **based on many** probabilities. It is based on **chance events** in the nature and **chance mutations** in the organisms. And we can see in the example of moths, the survival of moths was dependent on the pollution created by man and if industrialisation would not have occurred, any other probability would have been there which would have determined the survival of moths. Hence, many probabilities are there for every phenomenon occurring in the nature and evolution cannot be seen as a directed process in the light of **determinism**.

Example 6 : *Fossilization can occur when*

(1) Animals are buried and preserved by natural processes

(2) Animals are destroyed by the scavengers

(3) Animals are eaten up by predators

(4) Animals are destroyed by environmental conditions

Solution : Animals are buried and preserved by natural processes. This is because if they are eaten or destroyed, they will be no more present in any form on earth and hence cannot be fossilized.

Example 7 : *Why artificial selection can be taken as an evidence of evolution?*

Solution : Because if man can breed a number of organisms according to his needs and desires then why could not the nature do so over a period of millions of years. Hence, evolution can be illustrated by artificial selection.

Try Yourself

16. Fossils are dated by
    (1) Amount of calcium residue in them
    (2) Their sodium content
    (3) Their number in an area
    (4) Amount of radioactive carbon isotope in them
17. Analogous structures are
    (1) Similar in origin
    (2) Similar in function
    (3) Non-functional
    (4) Similar in anatomy
18. In the post-industrialisation period in England
    (1) Melanised moths were more in number than white-winged moths
    (2) White-winged moths were more in number than melanised moths
    (3) Both had an equal number
    (4) Both became extinct
19. The divergent evolution can be seen in
    (1) Analogous structures
    (2) Artificial breeding
    (3) Drug resistance
    (4) Homologous structures

WHAT IS ADAPTIVE RADIATION?

The process of evolution of different species in a given geographical area starting from a point and literally radiating to other areas of geography (habitats) is called **adaptive radiation**.

Or

When because of the competition for food and living space, a single ancestral species evolves into different species/forms which occupy different habitats(areas), it is called the **adaptive radiation**.

Adaptive radiation is exemplified by the following examples :

1. Darwin's Finches

Darwin studied the flora and fauna of **Galapagos islands**, a chain of islands at the west coast of **South America**. There he found an amazing range of creatures existing. He found that there were many varieties of **small black birds** in these islands which differed mainly in the **shape of beaks** and **feeding habits**. These varieties of small black birds were later called **Darwin's Finches**.

After analysing them, he realised that all of these varieties evolved on the same island itself and were not from separate areas. He conjectured that these varieties evolved from the **original seed-eating** ancestor bird which was present in the South America. Some of them flew to these islands and according to the needs of different environments, they developed different shapes of beaks and feeding habits. Some became insect eating, some fruit eating, some cactus eating, etc.

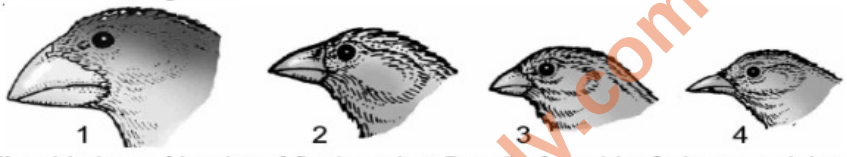


Fig.: Variety of beaks of finches that Darwin found in Galapagos Island

2. Australian Marsupials

The wide range of Australian marsupials also support the phenomenon of adaptive radiation. We can see in the figure that a number of marsupials, each different from the other, like Koala, Kangaroo, Wombat, etc. originated from an ancestral marsupial, but all within the same island Australia. We can see all these varieties differ from each other in morphology and other features and these differences are due to the adaptations to different environment.

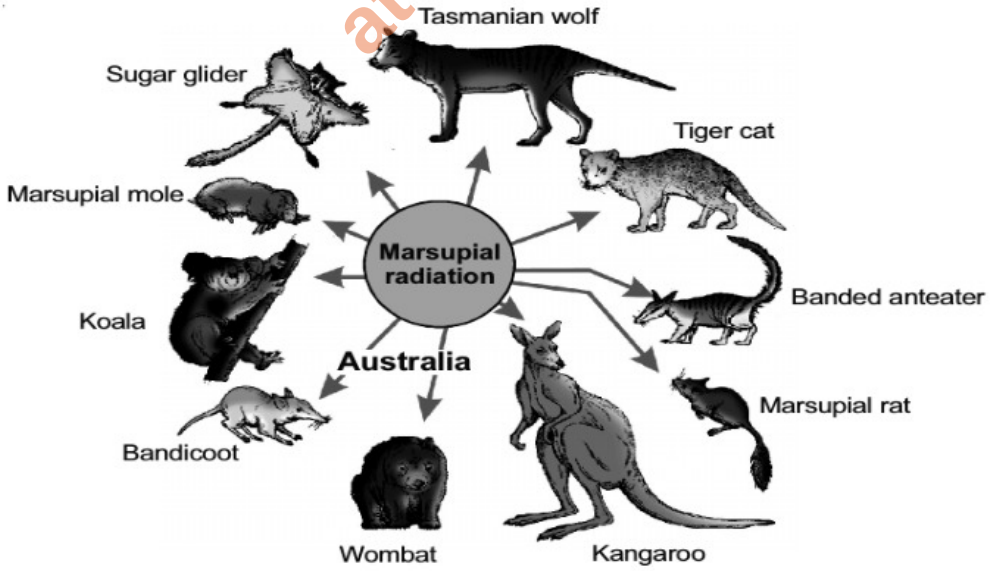


Fig.: Adaptive Radiation of marsupials of Australia

3. Placental Mammals

Not only marsupial mammals, but placental mammals also underwent the adaptive radiation and developed into different varieties.

Convergent Evolution : It was seen that many placental mammals resembled the marsupial mammals not only in structure but also in leading the similar ways of life. These similarities in these two different types of mammals (marsupials and placentals) are due to living in the **similar ecological niches**. Hence, two different types of organisms **converged** towards similarity which depicts that convergent evolution has taken place. Or it can be said that convergent evolution resulted in the origin of similar looking members in both the groups, *e.g.*, Placental wolf and Tasmanian wolf-marsupial.

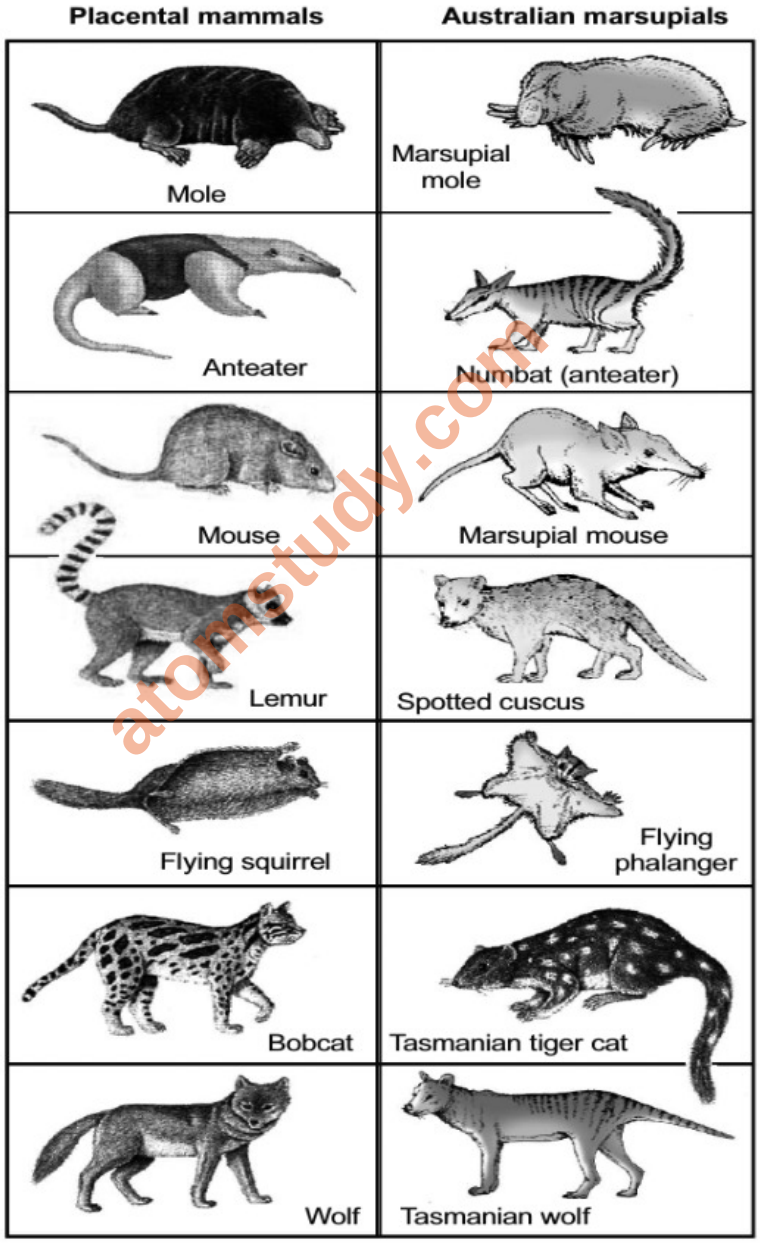


Fig.: Picture showing convergent evolution of Australian marsupials and Placental mammals

BIOLOGICAL EVOLUTION

Biological evolution is defined as any **genetic change** in a population that is **inherited** over several generations. Till now we discussed about the concept of evolution and its different evidences like fossils, homologous structures, artificial and natural selection, etc. Now we will be dealing with the theories of evolution put forward by various biologists.

1. Lamarck's Theory of Evolution

His theory is often called as the **Theory of Inheritance of Acquired Characters or the Theory of Use and Disuse of Organ**.

The first attempt to explain origin of species and their adaptation to the environment was done by **Jean Baptist de Lamarck** (1744-1829). He was the greatest French naturalist. Lamarck's theory was published in 1809 (year of Darwin's birth) in his book '**Philosophie Zoologique**'. According to this theory the organisms undergo changes to adapt themselves to the environment. The changes acquired by the organisms during their life time are passed on to the next generation. He took the example of long neck of **Giraffe**, they continuously stretched their neck to reach to the vegetation on trees. This acquired change was passed to the next generation. He also gave the principle of **Use and Disuse**. Use of an organ leads to strengthening of the organ, and disuse will lead to weakening of the organ.

Lamarck arranged his theory in the form of four postulates.

(i) Internal forces tend to increase size of the body.

(ii) Formation of new organs is the result of the need or want continuously felt by organisms Doctrine of Appetency/Desires.

(iii) Development and power of action of an organ is directly proportional to its use.

(iv) All changes acquired by the organism during its life are transmitted to the offsprings by the process of inheritance.

Knowledge Cloud

Lamarck's theory was discarded by **A. Weismann** who gave the **Theory of Germplasm**. He cut the tail of new born mice generation after generation but could not get tailless mice nor the mice developed shorter and shorter tail.

Today, again the faith in Lamarck's theory has been revived as it is said that if the environment influences the genes of the organisms, the acquired change will be transmitted to the next generation.

He said that evolution of life forms has occurred but the **driving force** according to him was use and disuse of organs. Use of an organ leads to the strengthening and disuse leads to the weakening of that organ. He gave the example of Giraffes and explained that the ancestors of giraffe were bearing a small neck and forelimbs.

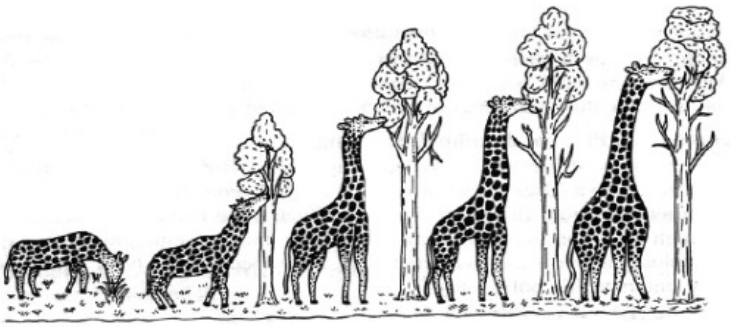


Fig.: Diagram showing elongation of neck in giraffe according to Lamarck

But in an attempt to eat (forage) the leaves on tall trees, they had to stretch their necks. Lamarck proposed that this acquired character, *i.e.*, stretching of neck was passed on to the next generation resulting in the present time long necks. Nobody believes this conjecture any more.

2. Darwin's Theory or Darwinism

The main concept of Darwinian theory is **natural selection**. He presented his theory after Lamarck's theory. It is possible that the work of Thomas Malthus on 'populations' influenced Darwin.

Thomas Malthus, an English economist, is widely known for his theories on **populations** and the increase or decrease in size of populations in response to various factors. One of the factors he studied was natural resources.

Salient feature of Malthusian theory are

(i) Every population has an inherent capacity to increase its number **exponentially** if every individual of that population reproduced maximally. It means that if all born individuals of a population reach their reproductive ages and reproduce at their maximum rate, then there are changes of that population to rise many a times. This fact can be seen in a growing bacterial population as how fastly it grows on getting optimum conditions.

(ii) Nature keeps a **control** over the size of population by posing several challenges like disease, food shortage, death etc.

(iii) Natural resources like forests, water, air, food, etc. are **limited** in the nature and their excessive exploitation badly affects the size of populations.

(iv) The populations remain nearly **stable in size** except during some seasonal fluctuations.

But the fact is that even after full probabilities of populations to grow exponentially, they do not grow so. The population sizes in reality are limited.

Malthus interpreted that if population sizes are limited then there had been a competition or struggle, for acquiring the resources, among individuals of same species or of two different species. The one who had 'better' **adaptibility** survived and produced more progeny. A concept of 'fitness' and 'natural selection' was, thus, reflected in his theories.

According to Wallace's Chart, the main points of Darwin's theory of Natural Selection were as follows:

(i) High rate of reproduction

(ii) Total number almost constant

(iii) Struggle for existence

(iv) Variations

(v) Survival of fittest

(vi) Natural selection

All the successful organisms have a high **Biotic Potential** or Reproductive Rate. The organisms produce a large number of offsprings that can possibly survive, example a mice produces a dozen of mice at one time. A rabbit produces 6 young ones in a litter and there are four litter in a year. A rabbit starts reproducing at the age of six months.

1. Not all but only some individuals which survive, reach adulthood, and those which reach adulthood, reproduce at different rates, this is called '**Differential Reproduction**'.
2. The success in survival and reproduction depends upon the characteristic traits of an organism, example only those rabbits will survive which are fastest. There is **'Struggle for Existence**' and in this there will be '**Survival of Fittest**'. The Phrase '**Survival of Fittest**' was first used by **Herbert Spencer**. The same context was asserted by **Darwin** as **'Natural Selection'**.

So, evolution is the change in the genetic composition of the population which is brought about by natural selection which acts upon the variability in population.

Causes of Variations :

1. **Mutation** is the ultimate source of variations.
2. At the next level is recombination.
3. Intermingling of two widely separated populations.

Weakness of Darwinism : He was not able to explain the cause of discontinuous variations observed by himself in nature and the mode of transmission of variants to the next generation.

In 1868, Darwin put forward the **Theory of Pangenesis**. According to this theory, every organ of the body produces minute hereditary particles, called **Pangenes** or **Gemmules** and they are carried through the blood into the gametes.

Weismann's 'Theory of Germplasm' (1892) **rejected** Darwin's theory of pangenesis. He established that the germ (sex), cells are set apart from other body (somatic) cells early in the embryonic development, so, only the changes in the germplasm affect the characteristics of future generations.

Alfred Wallace had written the book **'On the Tendencies of Varieties to Depart Indefinitely from the Original Type'**. Alfred Wallace (1823-1923), a naturalist from Dutch East Indies, was working on **Malay Archipelago** (present Indonesia).

Darwin's novelty : It is a possibility that these above mentioned ideas of Thomas Malthus inspired Charles Darwin to frame his own theory of evolution based on the natural selection. However there was a novelty in the concepts of Darwin alongwith this. Darwin asserted that variations which are heritable and which make resource utilisation better for few (adapted to habitat better) will enable only these to reproduce and leave more progeny

Darwin said that the 'appearance' of new life forms is due to **accumulation of variations** from one generation to another.

Darwin also talked about the rate (speed) of appearance of new forms. He said that the appearance of new forms is linked to the **life span** of that organism. For example, the microscopic microbes have shorter life spans so they divide faster and become millions of individuals within hours. Hence microbes have more chances to evolve faster. But if we talk about any other organism like fish or fowl, they will take millions of years to evolve because their life spans are much longer (*i.e.*, in years) than microbes.

To explain evolution, Darwin talked about two things

(1) Branching descent

(2) Natural selection

Branching descent explains the 'pattern' of evolution and natural selection explains the 'mechanism' of evolution. Branching descent and natural selection are the two **key concepts** of Darwinian theory of evolution.

Branching descent : He said that the evolution is a branching process. With time, new life forms appear, and these new life forms arise as 'branches' from the previously existing life forms. Hence branching descent points towards the concept of common ancestry.

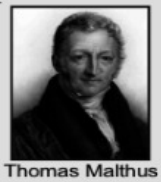
Natural selection : He emphasised that the selection of 'useful variations' by nature is the main (but not exclusive) mechanism for evolution to occur, which has already been discussed.

Knowledge Cloud

Lamarck (1744–1829) was a French naturalist who was also a soldier. He is famous for his theory of inheritance of acquired characters, also called Lamarckism or use/disuse theory.


Lamarck

Thomas Malthus (1766–1834) was an English scholar who was particularly famous for his studies on populations and wrote book, "*An essay on the Principle of Population*".


Thomas Malthus

Example 8 : *What were the key concepts of Lamarckism and Darwinian theory?*

Solution : Key concepts of Lamarckism

(i) Use and disuse of organs

(ii) Inheritance of acquired characters.

Key concepts of Darwinian theory

(i) Branching descent

(ii) Natural selection

Example 9 : *Give two examples of adaptive radiation.*

Solution : (i) Darwin's Finches

(ii) Australian Marsupials

3. Mutation Theory

In 1901, Hugo de Vries proposed the **Mutation Theory** on the basis of his observation on the wild variety of evening primrose *Oenothera lamarckiana*.

According to mutation theory, new species originate as a result of large, discontinuous variations which appear suddenly.

The main features of mutation theory are as follows :

1. Mutations arise from time to time amongst the individuals of a naturally breeding population.
2. Mutations are heritable and establish new forms or species.
3. Mutations are large and sudden and are totally different from fluctuating variations of Darwin, which are small and directional.
4. Mutations may occur in any direction.

Try Yourself

20. All Australian marsupials evolved in the
    (1) Africa (2) Galapagos Islands
    (3) Australian continent (4) North America
21. Fitness, according to Darwin, refers ultimately and only to
    (1) Physically dominant over others
    (2) Ability to defend from others
    (3) Strategy of obtaining food
    (4) Number of offsprings produced
22. The idea not related to the Darwinian theory of evolution is
    (1) Survival of the fittest
    (2) Struggle for existence
    (3) Inheritance of acquired characters
    (4) Origin of species by natural selection
23. Lamarck gave the example of _____ to explain his theory.
    (1) Giraffes (2) Finches
    (3) Marsupials (4) Placental mammals

Knowledge Cloud

- Term **warm little pond** was used by **Darwin** forearly hot sea rich in biomolecules and **hot dilute soup** by **Haldane.**
- **Empedocales–** regarded as "Father of concept of evolution."

Books related to evolution and their authors :

Book	–	**Author**
On the origin of species	–	Charles Darwin
The descent of Man and Selection in relation of sex	–	Charles Darwin
Man's place in Nature	–	Huxley
Origin of life	–	Oparin
The Planet	–	Urey
The cause of evolution	–	Haldane
Philosophique Zoologique	–	Lamarck
Process of organic evolution	–	Stebbins
The evolution of genetic system	–	Darlington

MECHANISM OF EVOLUTION

Speciation is an evolutionary process by which new species arise. When new species arise, evolution is said to occur. Now what is the cause or mechanism of origin of new species? Even though Mendel had talked of inheritable 'factors' influencing phenotype, Darwin either ignored these observations or kept silence. According to Darwin, **inheritable variations** are the cause as they keep on accumulating from one generation to other and, ultimately, give rise to new species. But **Hugo deVries** had different views.

Hugo deVries conducted his study on the **evening primrose** plant in the first decade of twentieth century (1901) and talked about **mutations**. According to him, 'mutations' were the cause of evolution and not the minor variations that Darwin talked about. Mutations are the **large** changes arising **suddenly** in the genomic sequence (the DNA/RNA sequence) of an organism. These mutations arise suddenly in a population and those mutations which arise in the germ cells of an organism pass on to the next generation.

The mutations are random and directionless.

Differences between Variations and Mutations : Although variations and mutations both point towards the speciation but there some differences between them which can be summarised as :

(1) The Darwinian variations are **small** which means they cannot bring the sudden change in the life forms and they can bring the change only when they accumulate. While mutations are **large** and they bring sudden change even in a span of single generation. Mutations do not need the accumulation.

(2) The variations are **directional** whereas the mutations are **random** and **directionless** and they can appear in all possible directions.

(3) Darwin said that evolution is a **slow** and **gradual** process which takes a lot of time to proceed but deVries believed that evolution occurs **suddenly**. The **single step large mutation** which can cause speciation was named **saltation** by deVries.

Knowledge Cloud

Hugo de Vries (1848–1935) was a Dutch botanist and one of the first geneticists. He introduced the term 'mutation'.


Hugo de Vries

EXERCISE

31. Placental wolf and Tasmanian wolf marsupial exhibit
    (1) Adaptive radiation
    (2) Divergent evolution
    (3) Convergent evolution
    (4) Homology

32. Variety of beaks of finches that Darwin found in Galapagos Islands, is an example of
    (1) Adaptive radiation
    (2) Convergent evolution
    (3) Adaptive convergence
    (4) Analogous organs

33. Fitness, according to Darwin refers ultimately and only to
(1) Dominance over others (2) Ability to defend
(3) Strategy for obtaining food (4) Number of offsprings

34. Which one is **correctly** matched?
(1) Hugo de Vries : Natural selection
(2) Darwin : Theory of Pangenesis
(3) Pasteur : Theory of continuity of germplasm
(4) Mendel : Inheritance of acquired characters

35. Select the **correct** statement :
(1) Darwinian variations are small and directionless
(2) Mutations are random and directional
(3) Fitness is the end result of the ability to adapt and get selected by nature
(4) All mammals except whales and camels have seven cervical vertebrae

36. The two key concepts of Darwinian theory of evolution are
(1) Fitness (2) Branching descent
(3) Natural selection (4) Both (2) & (3)

37. In modern synthetic theory, the unit of evolution is
(1) Genus (2) Species
(3) Population (4) Individual

38. Neo-Darwinism believes that new species develop through
(1) Mutations with natural selection (2) Continuous variations with natural selection
(3) Hybridisation (4) Mutations

39. Which is **not** a concept of Lamarckism?
(1) Rate and survival of organisms are different due to variations
(2) Environmental pressure produces variations
(3) An organ in constant use will grow in size
(4) Inheritance of acquired characters

40. Weismann's theory of germplasm rejected
(1) Mutation theory (2) Darwin's theory of natural selection
(3) Darwin's theory of Pangenesis (4) Neo-Darwinism

HARDY-WEINBERG PRINCIPLE

It was proposed by **G.H.Hardy** and **W.Weinberg** in 1908. This principle states that a population is said to be in **genetic equilibrium** if it is not undergoing any kind of evolutionary change. Genetic equilibrium means that the frequency of occurrence of alleles of a gene is supposed to remain fixed and even remain the same through generations. Hardy-Weinberg principle stated it using algebraic equations. Main concepts of this principle are :

(1) This principle says that allele frequencies in a population are stable and is constant from generation to generation.

(2) The gene pool (total genes and their alleles in a population) remains a constant. **This is called genetic equilibrium**.

(3) Sum total of all the allelic frequencies is 1.

This can be explained as follows :

❖ The term **allele** is employed for any of the two forms of a gene, present on the same locus in the two homologous chromosomes and allelic frequency is the frequency with which a particular allele occurs in a population.

For example, in a population of diploid organisms, a gene has two alleles – A and a. Suppose the frequency of occurrence of allele A is p and of a is q. Then what is the probability that allele A will appear on both the chromosomes of a diploid individual? It will be simply the product of its probabilities, *i.e.*, $p \times p = p^2$. Hence, we can say that the frequency of AA individuals in this population is simply $\mathbf{p^2}$.

Similarly the frequency of aa individuals in this population is $\mathbf{q^2}$ and the frequency of Aa individuals (with allele A on one chromosome and allele a on other chromosome) in this population is **2pq** (or $2 \times p \times q$).

We can see that the probability of occurrence of hybrid condition (Aa) is twice ($2 \times pq$) than that of homozygous genotype (AA or aa) having p^2 and q^2 frequencies.

❖ Hardy-Weinberg principle says that the sum total of all the allelic frequencies of a gene is 1 and the possible frequencies of above mentioned genotypes, *i.e.*, AA, aa and Aa are p^2, q^2 and 2pq, respectively. So mathematically this statement can be written as

$$\boxed{p^2 + 2pq + q^2 = 1}$$

We can see that this equation is a binomial expansion of $(p + q)^2$.

Interpretation : Hardy-Weinberg principle can be used to mathematically interpret whether evolution has occurred in a population or not. Disturbance in the genetic equilibrium or Hardy-Weinberg equilibrium, *i.e.*, change in frequency of alleles in a population, would be interpreted as resulting in evolution. When frequency measured, differs from expected values, the difference indicates the extent of evolutionary change.

Factors affecting Hardy-Weinberg principle : Following five factors are known to affect Hardy-Weinberg equilibrium. Therefore, if any of the following phenomena occurs, change in frequency of alleles takes place that may result in the evolution :

(1) Gene migration or gene flow

(2) Genetic drift

(3) Mutation

(4) Genetic recombination

(5) Natural selection

(1) Migration : Migration, defined in genetic terms as the movement of individuals from one population into another, can be a powerful force in upsetting the genetic stability of natural populations. The phenomenon of movement of alleles from one population to another is called gene migration. It can either occur by

(a) Migration of a section of population from one area to another, or by

(b) Interbreeding between members of two populations resulting in interchange of alleles. If the characteristics of the newly arrived animal differ from those already there, the genetic composition of the receiving population may be altered, if the newly arrived individual or individuals can adapt to survive in the new area and mate successfully.

Gene pool : A total collection of all genes and its allele in a population is called **gene pool**. Thus, gene pool will have all genotypes *i.e.*, genes of the organisms.

Gene flow : If genes are exchanged between two different populations of a species, it is **gene flow**.

(2) **Genetic Drift / Sewall Wright Effect / Non-directional factor :** Natural selection is not the only force responsible to bring about changes in gene frequencies. There is the role of chance or **Genetic Drift** also.

Genetic Drift causes the change in gene frequency by **chance in a small population**. In a small population, the individual alleles of a gene are represented by a few individuals in a population. These alleles will be lost if these individuals fail to reproduce. Allele frequencies appear to change randomly, as if the frequencies were drifting, thus, a random loss of alleles in small population is Genetic Drift. A series of small populations that are isolated from one another may come to differ strongly as a result of Genetic Drift. Genetic Drift has two ramifications are described below.

(a) **Bottle neck effect :** It is the decrease in genetic variability in a population, *e.g.*, cheetah population in Africa decreased due to hunting. Their decreased numbers have limited cheetahs genetic variability, with serious consequences. The present cheetah population is susceptible to a number of fatal diseases. If any of these diseases attacks the cheetah population, the path of extinction of cheetah cannot be reversed.

(b) **Founder's effect :** When one or a few individuals are dispersed and become the founders of a new, isolated population at some distance from their place of origin, the alleles that they carry are of special significance. Even if these alleles are rare in the source population, they will be a significant fraction of the new population's genetic endowment. This effect by which rare alleles and combinations of alleles may be enhanced in new populations – is called the **founder's effect**. The founders effect is particularly important in the evolution of organisms on islands, such as **Galapagos** Islands which Darwin visited. Most of the kinds of organisms that occur in such areas were probably derived from one or a few initial founders.

Fixation of new mutations : Genetic drift fixes new alleles, genes that arise by mutation, from time to time and eliminate the original gene, thereby changing the genetic make up of small population.

(3) **Mutation:** Replica Plate Experiment of Lederberg and Lederberg

(i) Mutations are **random** (indiscriminate) with respect to the adaptive needs of organisms.

(ii) Most mutations are harmful or with no effect (neutral) on their bearer.

(iii) Mutation rates are very slow.

The Lederberg Replica Plating Experiment, a beautiful example of the genetic basis of a particular adaptation was demonstrated in bacteria by an ingeneous method devised by Joshua Lederberg and Esther Lederberg. *E.coli* bacteria are usually grown in the laboratory by plating dilute suspensions of bacterial cells on semi-solid agar plates. After a period of growth, discrete colonies appear on the agar plates. Each of these colonies originates from a single bacterium through a large number of cell divisions. The Lederbergs inoculated bacteria on an agar plate and obtained a 'master plate' containing several bacterial colonies. They, then created several replicas of this master plate by a simple procedure. A sterile velvet disc, mounted on a wooden block, was gently pressed on the master plate. Some bacteria from each colony adhered to the velvet. By pressing this velvet on to new agar plates, they obtained exact replicas of the master plate, because the few bacteria transferred by the velvet formed colonies on the new agar plates. However, when they attempted to make replicas using plates containing an antibiotic such as penicillin, most colonies found on the master plate did not grow on the replica plates. The few colonies that did grow were obviously resistant to penicillin. How did the bacteria acquire the ability to grow in a new environment (here, agar medium, containing penicillin)? In other words, what was the origin of this adaptation?

A Lamarckian interpretation of this adaptation would have been that penicillin somehow induced a change in one or more bacteria, enabling them to grow in the presence of penicillin. A Darwinian view is that there were, in the original suspension of bacteria from which the master plates were prepared, a few bacteria carrying mutant genes which conferred on them the ability to survive the action of penicillin and form colonies. These mutations, which had arisen by chance, and not induced by penicillin, were present only is small numbers in the original suspension.

Lederberg's experiment provided evidence that mutations are actually **preadaptive**. These kinds of mutations are regarded as advantageous mutations. They appear without exposure to the environment.

Actually, the preadaptive mutations express themselves only after exposure to the new environment to which the organisms are to adapt themselves.

The **new environment does not induce the mutations, it only selects the preadaptive mutations that occurred earlier.**

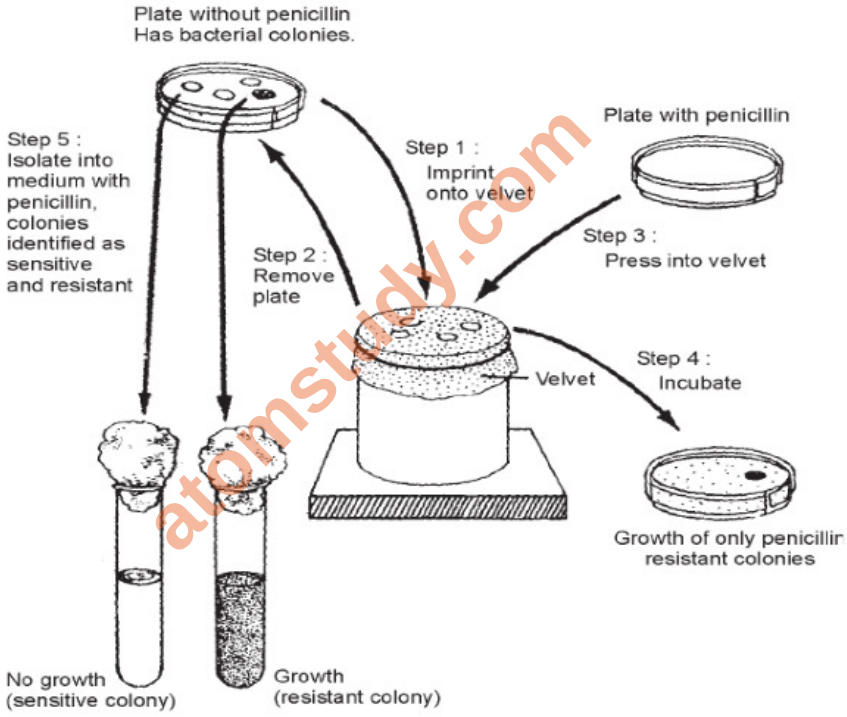


Fig. : Lederberg's replica plating experiment

(4) Genetic recombination : During gamete (sperm or ovum) formation, the alleles present on the parental chromosomes separate and form new combinations. This results in the genetic recombination. The **crossing over** during meiosis is a major source of variations in a population. The offsprings produced from these gametes show 'new' combination of characters and are called **recombinants**.

(5) Natural selection : Nature selects those variations which are heritable (*i.e.*, able to be inherited) and which make the survival more better so that the individuals bearing these useful variations are enabled to reproduce and thence produce more number of progeny. Hence, natural selection also leads to change in allelic frequencies. However the effects of natural selection on different traits can be (a) Stabilising (b) Directional, or (c) Disruptive.

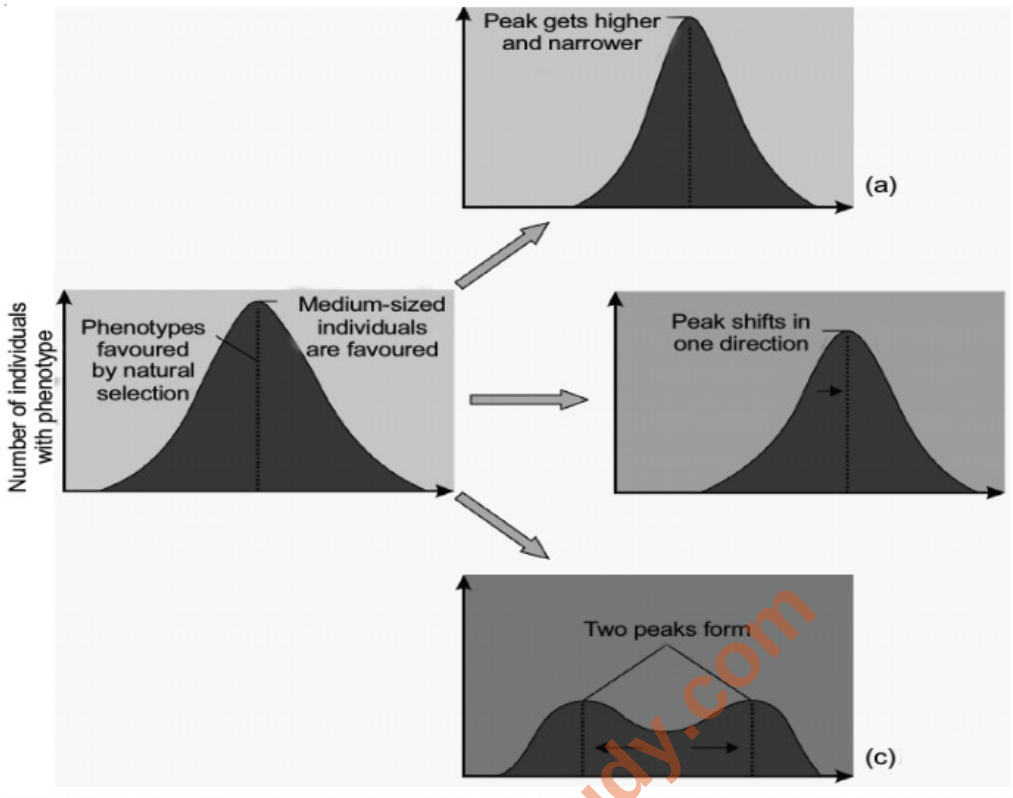


Fig.: Diagrammatic representation of the operation of natural selection on different traits : **(a)** Stabilising, **(b)** Directional and **(c)** Disruptive

(a) Stabilising selection : If nature favours those individuals in the population which possess the **mean character value**, then it is said that natural selection leads to the stabilisation of the traits (figure a). Let us take the example of the character **human height**. Tall, dwarf and medium - sized individuals are the variants of this character. If nature favours or selects the **medium-sized individuals**, then the selection is said to be stabilising. The peak of bell-shaped graph gets higher and narrower as nature tries to decrease the peripheral character values.

Knowledge Cloud

Plants Growing Around Mines : A few plants are now known to grow on the tailings or refuse around mines. Professor A.D. Bradshaw studied one such grass, the bent grass *Agrostis tenuis* growing on tailings of lead mines in Wales, U.K. He took some of these and planted them in soil from a pasture near by. Similarly, he transplanted live *Agrostis* plants from the pasture to the lead-rich soil. The bent grass from the mine soil grew very slowly on normal pasture soil. The one from the pasture, on the other hand, could not survive in the lead-rich soil. A very small percentage (three out of sixty), however, could grow in the soil rich in lead. These were undoubtedly the kind, from which the race of bent grass capable of growing in lead-rich mine soil evolved originally. Plants tolerant to selenium such as *Astragalus* and *Haplopappus* have been reported from the U.S.A. These plants are not only capable of growing in seleniferous soils, but require selenium as an essential element.

In our country, Professor Y.D. Tyagi discovered populations of *Impatiens balsamina* growing around Zwar zinc mines in Udaipur, Rajasthan. The presence of such plants, which have evolved metal tolerance, can indicate the occurrence of specific metal deposits. Such plants are called **bioindicator plants.**

Sickle Cell Anaemia is an example of balancing selection.

(i) In few RBCs, 1–2% became sickle shaped during lack of oxygen.

(ii) The heterozygotes (Hb^A / Hb^S), who have one copy of sickle cell allele, coupled with one normal allele are better survivors in the areas where malaria is endemic; because the malarial parasite spends a part of the life cycle in the RBC; if they enter into the RBC which are sickle shaped, they will die.

(iii) The women who are heterozygote have higher fertility; that's why natural selection has not eliminated the allele.

(iv) The loss of deleterious recessive genes through deaths of homozygotes (Hb^S / Hb^S) is being balanced by the gain resulting from successful reproduction by heterozygotes in malaria prone areas. For this reason, the selection is called balancing selection.

(v) **Heterozygotes enjoy some resistance to malaria, so they survive the malarial parasite more successfully than either normal or sickle cell homozygotes.**

(b) Directional selection : If selection acts to eliminate one extreme form and supports the other extreme then the peak shifts in the direction which is selected by the nature (figure b). For example, in the above mentioned example, if **either tall or dwarf** individuals are selected (rather than medium-sized) then it is called directional selection. **Industrial melanism** in moths also provides good example of directional selection.

(c) Disruptive selection : If the selection does not favour the mean character value, rather favours **both** the **peripheral character values** then this kind of selection is called disruptive selection (figure c). **Two peaks** are formed at the two extremes of curve and a kind of depression forms in the centre. For example, if nature selects both tall as well as dwarf individuals but not the medium-height individuals, this is called disruptive change.

Example 10 : *Enumerate any three factors affecting Hardy-Weinberg equilibrium.*

Solutions : (i) Genetic drift
(ii) Gene migration
(iii) Mutation

Example 11 : *Can non-heritable variations lead to evolution? Explain in brief.*

Solutions : No, non-heritable variations cannot lead to evolution because variations should pass from one generation to other generation to bring any change in the latter. Only heritable variations can accumulate and lead to evolution.

Try Yourself

24. Genetic drift operates in
(1) Small isolated population (2) Large isolated population
(3) Non-reproductive population (4) Slow reproductive population

25. Gene pool is
(1) Genotype of an individual in a population
(2) Different genes of all individuals of a species found in an area
(3) Pool of artificially synthesised genes
(4) Genes of a genus

26. If nature selects both of the peripheral traits of a character then which kind of natural selection is said to be operating?
(1) Stabilising (2) Disruptive
(3) Directional (4) Rotating

27. Saltation means
(1) Single step small mutation (2) Single step small variation
(3) Single step large mutation (4) Single step large variation

EXERCISE

41. Genetic drift
(1) Is random change in gene frequency (2) Has nothing in common with inbreeding
(3) Is appearance of recessive genes (4) Produces greatest fluctuation in large populations

42. Gene pool of a population tends to remain stable if the population is large, without large scale mutations, without migration and with
(1) Random mating (2) Moderate environmental changes
(3) Natural selection (4) No predator control

43. Industrial melanism as found in peppered moth proves that
(1) Melanic form has no selective advantage in industrial area
(2) Lighter form has no selective advantage in polluted industrial area and non-polluted area
(3) Melanism is pollution generated feature
(4) True black melanic form develops by recurring random mutation

44. Which of the following is Sewall Wright effect?
(1) Gene pool (2) Genetic drift
(3) Gene migration (4) Natural selection

45. Lederberg replica plating experiment explains that mutations are
(1) Fast (2) Useful
(3) Gradual change (4) Preadaptive change

46. If nature selects mean character value, it is
(1) Stablising selection (2) Disruptive selection
(3) Directional selection (4) Progressive selection

47. According to Hardy-Weinberg principle, sum total of all the allelic frequencies is
(1) Zero (2) One
(3) Infinite (4) Remain changeable

48. Hardy-Weinberg principle is applicable to
(1) Small population (2) Isolated population
(3) Large population (4) All of these

49. Which of the following is considered as pollution indicator?
(1) Frequency of melanic moth (2) Lichen
(3) Predator birds (4) Frequency of light coloured moth

50. Choose the **incorrect** statement
(1) Before emergence of industrialisation in England, white winged moths were more in number
(2) Sickle cell anaemia in malaria endemic area is an example of directional selection
(3) Long neck of Giraffe is an example of progressive selection
(4) Plant tolerant to selenium is *Astragalus*

SPECIATION AND ISOLATION

Speciation is the formation of one or more new species from an existing species. The crucial episode in the origin of species occurs when the gene pool of a population is severed from other populations of the parent species and gene flow no longer occurs. Speciation can take place in two modes based on the geographical relationship of a new species to its ancestral species.

1. When a population, formerly continuous in range, splits into two or more geographically isolated populations and form new species, the mode of speciation is called **allopatric speciation**. This can happen by subdivision of the original population, when a geographical barrier, such as a creeping glacier, a land bridge (*e.g.*, Isthmus of Panama) or ocean or mountain, cuts across a species range. Alternatively, a small number of individuals may colonise a new habitat which is geographically separated from the original range. Darwin's finches that formed separate species in the Galapagos islands and the Australian marsupials that radiated to form new species are its examples.
2. In the second speciation mode, a subpopulation becomes reproductively isolated in the midst of its parent population; this is **sympatric speciation**. So, sympatric speciation is the formation of species within a single population without geographical isolation. The usually quoted example of sympatric speciation comes from **polyploidy**, which is the multiplication of the normal chromosome number. This can happen when chromosomes fail to segregate at meiosis or replicate without undergoing mitosis.

Knowledge Cloud

(i) **Multiplicative speciation (Cladogenesis) :** It is the formation of two or more species from a single species, example, allopatric speciation, sympatric speciation. This can be gradual or abrupt.

(ii) **Fusion species :** It is an allogenous transformation. Isolation mechanism may break down due to a mutation. The two species will interbreed and merge to form a single species.

(iii) **Phyletic speciation (Anagenesis) :** It is autogenous transformation of a species with passage of time due to piling up of variations.

(iv) **Stasigenesis :** Condition in which lineage neither split nor change but persist as such without any change *e.g.*, turtle, *Sphenodon, Coelocanth, Limulus.*

3. **Species concept :** Species is the basic unit of classification. The term was coined by John Ray (1693). Most taxonomists define species as morphologically distinct and reproductively isolated natural population or group of populations where individuals resemble one another more closely than with members of other species, have a similar anatomy, karyotype and biochemicals, interbreed freely and form a genetically closed system. There are three basic concepts about the species.
4. **Morphospecies concept :** It is the earliest concept of species. Davis and Heywood (1963) have defined it as "assemblage of individuals with morphological features in common and separable from other such assemblages by correlated morphological discontinuities in a number of features." However, the number of morphological characters chosen for separating species varies from taxonomist to taxonomist. "Lumpers" will combine all the populations with broadly similar traits into a single species while "Splitters" will separate various populations with even minor morphological differences into distinct species.
5. **Biological species concept :** Though first proposed by Buffon (1753), biological species concept was formulated by Mayr (1942). According to it, a biospecies (biological species, Biological Species Concept) is sexually interbreeding or potentially interbreeding group of individuals which is reproductively isolated from other species and is therefore, separated from others by absence of genetic exchange. Normally species are distinct from one another by both morphological traits and reproductive isolation. However, **sibling species** are those distinct species which are almost identical morphologically but are distinct from each other due to absence of interbreeding, *e.g.*, *Drosophila pseudoobscura* and *D. persimilis*. Biological species concept is, therefore, mainly based on absence of cross fertilisation between members of two

species. Cross fertilisation tests carried out by taxonomists between individuals of morphological and geographically separated populations have, resulted in revision of species and grouping of many of them into single species, *e.g.,* several species of North American sparrows as subspecies and races of a single song sparrow, *Passarella melodia.* The only problem of using reproductive isolation is the absence of sexual reproduction in several organisms – prokaryotes, some protists, some fungi, some plants (*e.g.,* commercial Banana) and animals. Further, cross fertilisation experiments can not be performed on such a large number of species that occur in varied geographical areas. Reproductive isolation cannot be used as a criterion in case of fossils. The living organisms and fossils can be grouped only on the basis of their morphology and biochemistry. Mayr (1987) has named morphologically grouped asexual species as **paraspecies** while Ghiselin (1987) has named them **pseudospecies.**

6. **Evolutionary species concept :** All evolutionary taxonomist have been in search of a proper definition of species which is basic unit of classification. One such definition has been given by Simpson. According to Simpson (1961) "an evolutionary species is a lineage (an ancestor-descendent sequence of population) evolving separately from others and with its own unitary evolutionary role and tendencies." The concept stresses on evolutionary isolation with sexual isolation being its one aspect. It is more dependent on differences which can be morphological, genetical, behavioural and ecological, to know evolutionary distance. However, evolution does not occur simultaneously in all the traits. Neither its rate nor direction (in which it is occurring) are the same.

7. **Reproductive isolation** may be defined as the existence of intrinsic barrier to the interbreeding in natural populations. Each of these intrinsic barriers is called a reproductive isolating mechanism. According to Mayr (1942), reproductive isolating mechanisms are the *biological properties of individuals which prevent the interbreeding of naturally sympatric populations.*

8. Reproductive isolation in the form of hybrid sterility is known since long. In the laboratory or in zoos, hybrids can be produced between species that do not interbreed in nature. Horses and donkeys are two different species; a hybrid, mule, **is produced from the mating of a male donkey and a mare (female horse).**

9. **Similarly, mating between stallion (male horse) and female donkey results in a hybrid called hinny. Both mule and hinny are sterile.**

10. There are examples of species, which can produce fertile hybrids in captivity. You might have heard about the famous 'tigons', a hybrid of African lioness (*Panthera leo*) and Asian tigers (*Panthera tigris*), which is fertile. No barrier to hybridisation between these species has evolved during their long isolation from each other. Natural selection has not favoured a reduction in hybridisation for the simple reason that no hybridisation has been possible. Other examples of species that breed in captivity and produce fertile hybrids are mallard (a duck) and the pintail duck, the polar bear and the Alaskan brown bear and the platy and swordtail fishes. But these species do not interbreed at all in natural condition.

Knowledge Cloud

BARRIERS TO HYBRIDISATION

Prezygotic Mechanisms : (Prevent mating or formation of zygote)

1. **Ecological isolation** : Two species live in different habitats and do not meet. (One may be living in fresh water and the other in the sea).
2. **Temporal isolation** : Breeding seasons or flowering time may be different in the two species.
3. **Behavioural isolation** : The males of one animal species are unable to recognise the females of another species as potential mates.

4. **Mechanical isolation :** The structural differences in genitalia of individuals belonging to different animal species interfere with mating.
5. **Gametic isolation :** The sperms and ova of different species of animals are unable to fuse. In plants, the pollen coming from a different species may be rejected by the stigma.

Postzygotic Mechanisms : A hybrid zygote is formed but it may not develop into a viable fertile adult.

1. **Hybrid inviability :** Hybrid zygotes fail to develop. In plants, embryos arising from interspecific crosses abort.
2. **Hybrid sterility :** Hybrid adults do not produce functional gametes. (Mules and hinny are common examples in mammals. Several hybrid ornamental plants are sterile.)
3. **Hybrid breakdown :** The offspring of hybrids are inviable or infertile.

A BRIEF ACCOUNT OF EVOLUTION

(a) Origin and Evolution of Plants

A sketch of the evolution of plant forms through geological periods is given below. The given sketch gives an idea of the time periods in which different plant forms originated and evolved. The eras Paleozoic, Mesozoic and Cenozoic are shown alongwith their periods like Silurian, Jurassic, Quaternary, etc., in the order of their occurrence from below upwards.

Chlorophyte ancestors are the **aquatic green algae** which are supposed to give rise to all the **green land plants** (*i.e.*, Bryophytes and Tracheophytes). We can see in the sketch that the Bryophytes (non-vascular land plants) diverged from chlorophyte ancestors in the carboniferous period.

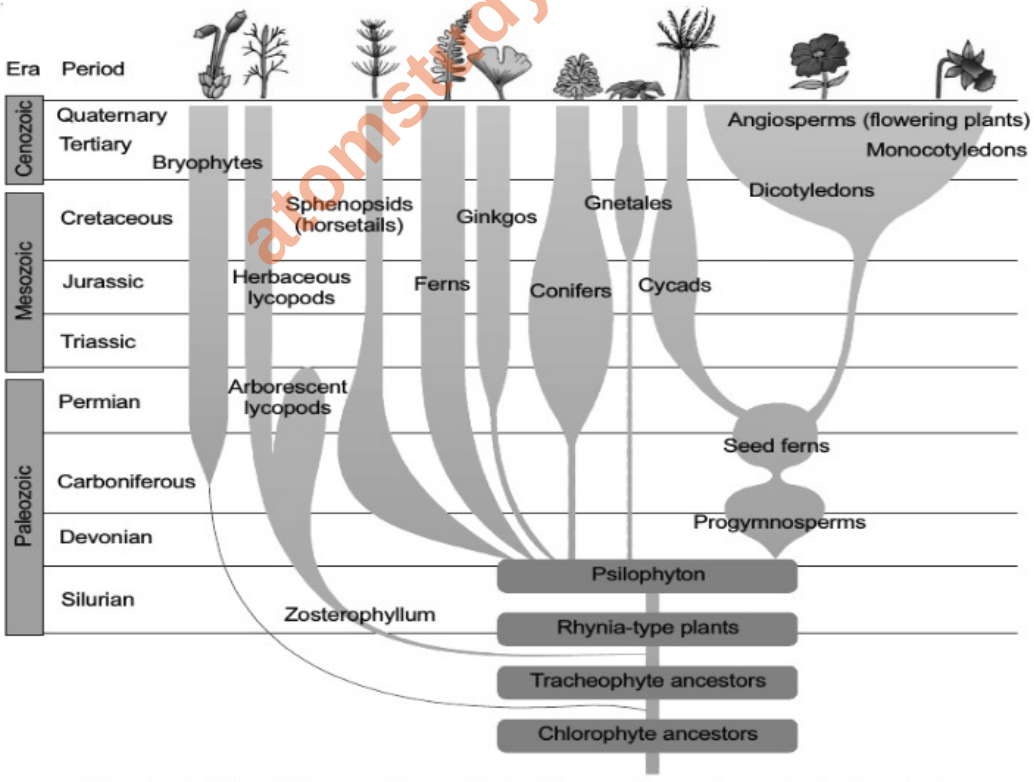


Fig.: A sketch of the evolution of plant forms through geological periods