



## STUDENTS' LEARNING OUTCOMES

After studying this chapter, the students will be able to:

- Explain that evolution happens due to variation in organisms and the selection pressures that organisms face.
- Analyze the evidence of evolution that comes from molecular biology and that is provided by biogeography.
- Differentiate between convergent and divergent evolution on the basis of inheritance of the homologous and analogous structures.
- Describe the endosymbiotic theory about the mechanism of evolution of eukaryotes from prokaryotes.
- Describe the theory of inheritance of acquired characters, as proposed by Lamarck with example of giraffe neck.
- State the drawbacks in Lamarckism.

This chapter would deliver you the concept of evolution of life through the theories put forwarded by different scientists. You will also analytically review the major evidence that form the basis of the most accepted theory of evolution.

According to the theory of **Creationism** ("theory of intelligent design"), all organisms were created as such as they exist today. Creationists claim that each type of organism was created individually and did not go through any change throughout the history.

### 24.1- THE CONCEPT OF EVOLUTION

Evolution is the gradual change in the genetic makeup (allele frequencies) of a population over successive generations, which may lead to the formation of new species. In its earliest form, the concept of evolution had the following basic speculations:

Early people also believed that living creatures can also develop from non-living matter. It was called idea of **spontaneous generation**. With the progress of science, the experiments disproved spontaneous generation but such experiments could not negate creationism.

- The universe and organisms did not always exist in their present form;
- Today's organisms were not created at once; and
- They are the result of innumerable changes from the lower to the higher form.

Evolution takes place due to variations in organisms and natural selection. According to this idea, organisms with beneficial traits are selected to produce next

generations. On the other hand, the individuals with disadvantageous traits cannot produce next generations. It results in the increase in the percentage of individuals with better traits in populations.

## 24.2- THEORY OF EVOLUTION - DARWINISM

Charles Darwin was an English scientist. In 1831, he travelled as a naturalist on scientific expedition on His Majesty's Ship called the HMS Beagle. He made a 5-year voyage around the world.



Figure 24.1: Main stops in the route of HMS Beagle

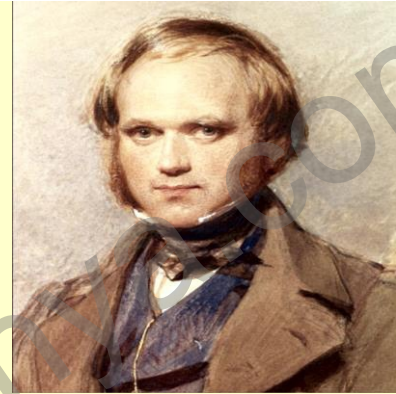


Figure 24.2: Charles Darwin

### Darwin's Observations

During the long voyage, Darwin visited tropical rainforests and other new habitats where he saw great diversity in plants and animals that he had never seen before. He also found rocks containing fossils. These observations suggested that continents and oceans had changed dramatically over time and continue to change. He dug up fossils of gigantic extinct mammals and found that organisms looked very different in the past. It suggested that living things change over time.

When he visited the Galápagos Islands (a group of 16 small islands), he noticed that the plants and animals on different islands were very different. For example, the giant tortoises on one island had saddle-shaped shells, while those on another island had dome-shaped shells. Similarly, many plants and animals resembled more with the plants and animals of South America, rather than with other islands. Moreover, different species of the common birds i.e., finches had different beaks. He found that differences in the sizes and shapes of beaks were actually adaptations for feeding on completely different kinds of food at different islands.

Darwin thought over these adaptations and tried to develop an explanation for the distribution of finches species among the islands. He thought that the origin of new species and adaptations are closely related processes. A new species would arise from an ancestral form by the gradual accumulation of adaptations to different

environment, separated from original habitat. Over many generations, the two populations could become dissimilar enough to be designated as separate species.

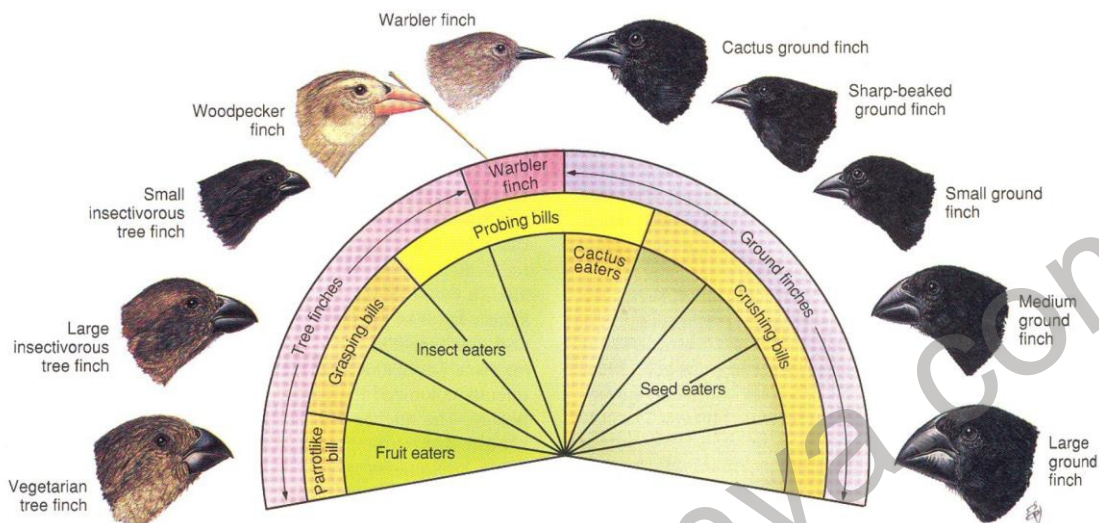


Figure 24.3: Adaptations in beak size and shape in different finches of Galapagos Islands

### 24.2.1- Mechanism of Evolution - Natural Selection

The founder of the modern theory of evolution was **Charles Darwin** (1809 – 1882). In 1859, he published his book “**On the Origin of Species**”. In this book, he proposed that evolution takes place due to variations in organisms through natural selection. The essence of his theory is as follows:

- 1. Overproduction:** All organisms have a far greater reproductive potential than is ever realized. For example, a female sea star releases about 1 million eggs each season. What if all of these eggs were fertilized and developed to reproductive adults by the following year? A half million female sea stars (half of the million eggs would produce females and half would produce males), each producing another million eggs, repeated over just a few generations would soon fill up the oceans!
- 2. Variations:** Genetic variations arise by random mutations. Seldom are any two individuals exactly alike. These genetic variations may be advantageous, harmful or neutral (neither helpful nor harmful). Inherited variations can be passed on to offspring.

Alfred R. Wallace (1823 – 1913) was a British naturalist and biologist who also developed his own theory on the mechanism of evolution. In 1957, he wrote a letter to Darwin. In Wallace’s letter, the proposed mechanism of evolution was very similar to the theory of Darwin. When both Darwin’s and Wallace’s theories were presented to the Linnaean Society in 1858, Wallace agreed to attribute the theory to Darwin. He convinced Darwin to publish his book “**On the Origin of Species**”.

3. **Struggle for survival:** Because many more offspring are produced than resources can support, individuals struggle for survival. The individuals with disadvantageous variations die or cannot reproduce. Individuals with advantageous variations remain successful in reproduction. Such variations are called adaptive traits.
4. **Inheritance of adaptive traits:** Adaptive traits are inherited to next generations. Because organisms with disadvantageous traits are less likely to reproduce, such traits become less frequent in a population and eventually are eliminated.

### 24.2.2- Neo-Darwinism

In the early 20th century, the Darwinism was integrated with modern genetics to develop Neo-Darwinism. According to Neo-Darwinism, a more precise definition of evolution is "a change in the frequency of alleles in a population or in the total genetic makeup of a population (the gene pool)". Neo-Darwinism is based on Hardy-Weinberg Theorem.

#### Hardy-Weinberg Theorem

In 1908, English mathematician **Godfrey Hardy** and German physician **Wilhelm Weinberg** presented Hardy-Weinberg theorem. It states that the frequencies of alleles and genotypes in a large, randomly mating population remain constant from generation to generation, if no evolutionary forces are acting. According to Hardy-Weinber theorem, any of the following conditions is not followed, evolution takes place.

1. The population size must be large.
2. Mating within the population must be random. Every individual must have an equal chance of mating with any other individual.
3. Individuals must not migrate into or out of the population.
4. Mutations must not occur. If they do, mutations from the wild-type allele to mutant allele must be equal to mutations from the mutant form back to the wild type.
5. All genotypes must have an equal chance of survival and reproduction.

#### For Information

**Gene pool** means the total number of all genes for a trait in a population. Example: If a population has 1000 genes for flower colour, this is its gene pool.

**Allele (gene) frequency** is the number or proportion of a specific allele in the population. Example: If 600 out of 1000 genes are for red colour, the allele frequency of red is 0.6 (60%).

**Genotype frequency** is the number or proportion of individuals with a particular genotype in a population. Example: If 40 out of 100 plants are RR, the genotype frequency of RR is 0.4 (40%).

#### Factors that can change the allelic frequencies

The following are the factors due to which the Hardy-Weinberg assumptions are not met and changes in allelic frequencies occur from one generation to the next.

### 1- Genetic Drift or Neutral Selection

When chance events influence the frequencies of genes in populations, such change is called genetic drift. Unlike natural selection, these changes occur by chance - not fitness - and are most obvious in small populations. Genetic drift is often called neutral selection. For example, a population of rabbits is reduced from 100 to 10 by a fire. The survivors happen to be mostly brown, not because they were better adapted, but by chance. The resulting population will have lower genetic diversity.

### 2- Gene Flow

The Hardy-Weinberg theorem assumes that no individuals enter a population from the outside (immigrate) and that no individuals leave a population (emigrate). The entry of individuals from another population can introduce new mutations, instantly changing gene frequencies (evolution). Changes in gene frequency due to migration of individuals are called gene flow.

### 3- Mutation

The Hardy-Weinberg theorem assumes that no mutations occur or that mutational equilibrium exists. Mutations, however, are a fact of life. Most importantly, mutations are the origin of all new genes and a source of variations that may prove adaptive for an organism. Mutations also make sure that variations will be present that allow a group to survive environmental shocks more successfully.

The effects of mutations vary. Most are deleterious. Some may be neutral or harmful in one environment and help an organism survive in another environment. Mutational equilibrium exists when a mutation from the wild-type allele to a mutant form is balanced by mutation from the mutant back to the wild type. This has the same effect on allelic frequency as if no mutation occurred. However, mutational equilibrium rarely exists. Mutation pressure is a measure of the tendency for gene frequencies to change through mutation.

## 24.3- EVIDENCES OF EVOLUTION

### 24.3.1- Evidence from Biogeography

Biogeography (study of the geographic distribution of plants and animals) shows that life-forms in different parts of the world have distinctive evolutionary histories. For example;

- Similar groups of organisms can live in places separated by vast barriers. Obvious similarities suggest a common ancestry, but similarly obvious differences result from millions of years of independent evolution. For example, African lion is very much similar to mountain lion of America. Their similarities suggest a common ancestry. However, obvious differences result from millions of years of independent evolution.

- Organisms separated by geographical barriers, are often very different in spite of similar environments. For example, many animals living in Australia and Tasmania are very different from animals in any other part of the world. Many species of kangaroos are the major herbivores of Australia and Tasmania.
- Islands often have relatively few but unique species due to island colonization and subsequent evolutionary events.

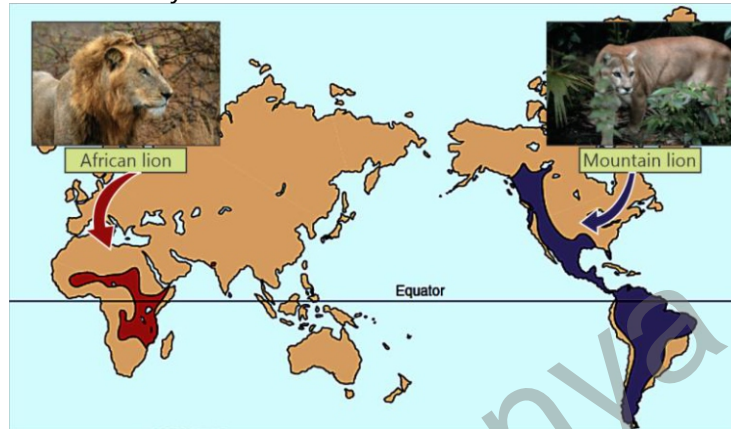


Figure 24.4: Distribution of lions found in Africa and North and South America

### 24.3.2- Evidence from Comparative Anatomy

Comparative anatomists study the structure of fossils as well as living organisms, looking for similarities that could indicate evolutionarily relationships. This study reveals two types of evolution.

**a- Divergent evolution:** Body parts that are similar in structure but different in function are called **homologous** structures and this phenomenon is called **homology**. Homologous structures reveal divergent evolution which means that the organisms with homologous structures have a common ancestor and evolved into different types and used their structures for different functions. For example, vertebrate appendages have a common arrangement of similar bones, even though the function of the

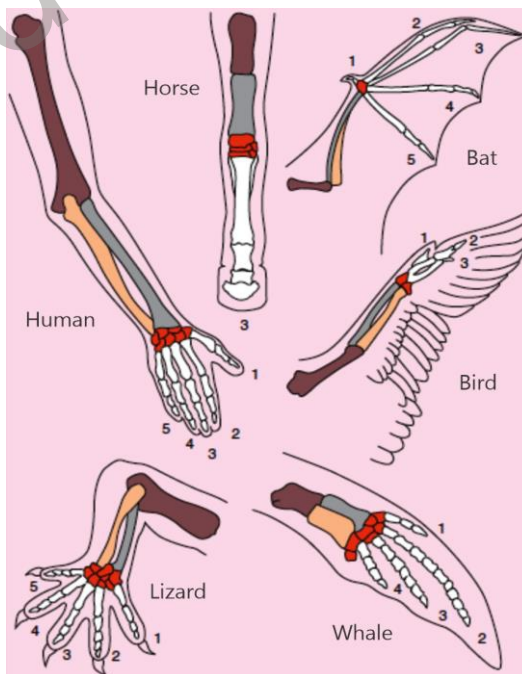


Figure 24.5: Homology in vertebrates forelimbs

appendages may vary i.e., flights (birds and bats), swimming (whales and dolphins), running (horses), climbing (arboreal lizard), or swinging from tree branches.

**b- Convergent evolution:** The organs which are similar in function but differ in structure are called analogous organs. Such structures present in different organisms indicate convergent evolution i.e., the evolution in which different types of organisms have been evolved from different ancestors at a common habitat. For example, the wing of a bird and the wing of an insect are both adaptations for flight, but they are not homologous. Any similarities simply reflect the fact that, to fly, an animal must have a broad, flat gliding surface.

**Vestigial organs:** Organisms often retain structures that have lost their usefulness. These structures are often poorly developed and are called vestigial structures. For example, some snakes like boa constrictors and pythons have minute remnants of hindlimb (pelvic) bones left over from appendages of their reptilian ancestors. Such remnants of once useful structures are clear indications of change i.e., evolution.

### 24.3.3- Evidence from Molecular Biology

Recently, molecular biology has yielded a wealth of information on evolutionary relationships. Just as animals can have homologous structures, they may also have homologous biochemicals. Ultimately, structure and function are based on the genetic blueprint (DNA molecule) found in all living animals.

Related animals have similar DNA derived from their common ancestor. Because DNA carries the codes for proteins that make up each animal, related animals have similar proteins. Scientists can extract and analyse the structure of DNA and proteins of different organisms. By looking for dissimilarities in the structure of related proteins and DNA, and by assuming relatively constant mutation rates, scientists can estimate the elapsed time since evolution from a common ancestral molecule.

#### Vestigial structures in humans

There are about 90 vestigial structures present in human body e.g.,

- Vermiform appendix is a vestige of the cecum.
- Coccyx or tailbone is the remnant of tail.
- The wisdom teeth are vestigial third molars that human ancestors used to help in grinding down plant tissue.
- Ear muscles are minimally developed and non-functional, but some people are able to move their ears in various directions.

#### How microorganisms have evolved resistance to antibiotics?

Antibiotic resistance means that bacteria are able to survive under the exposure of an antibiotic. It may be due to mutations in bacterial genes. A gene for antibiotic resistance which had evolved via natural selection passes to next generations of bacteria.

## 24.4- EVOLUTION FROM PROKARYOTES TO EUKARYOTES

As we know that the earliest organisms on the Earth were prokaryotes who originated in a very unstable environment from the reactions of organic molecules about 3.5 billion years ago. About 2 billion years ago, eukaryotes evolved from prokaryotes. The "Endosymbiotic Theory" is the most acceptable theory for the evolution of prokaryotes into eukaryotes.

### Endosymbiotic Theory

This theory was proposed by **Lynn Margulis**. According to this theory, large prokaryotes engulfed small prokaryotes. The small prokaryotes were not digested by the larger ones. Instead, they lived within the large cells and evolved into organelles.

The large and small prokaryotes formed a symbiotic relationship in which both cells benefited. Some of the small prokaryotes were able to do aerobic respiration. They supplied energy not only to themselves but also to the large cell. They became the mitochondria of eukaryotic cells. Other small cells were able to use sunlight to make food. They shared the food with the large cell. They

became the chloroplasts of eukaryotic cells. Similarly, flagella may have derived through the ingestion of prokaryotes similar to spirochetes.

Eukaryotic cells, evolved by endosymbiosis, were powerful and efficient. Their power and efficiency enabled them to evolve new characteristics e.g., multicellularity, cell specialization, and large size. They were the key to the spectacular diversity of animals, plants, and fungi that populate our world today.

Another theory called "Membrane Invagination Theory" also explains the evolution of eukaryotes. According to this theory, the cell membrane of prokaryotic cell invaginated in the cytoplasm. It gave rise to some membranous structures including nucleus and endoplasmic reticulum inside prokaryotic cell. It resulted in the formation of a prokaryotic cell

#### Evidence for the endosymbiotic theory

- Mitochondria (and chloroplasts) are of the same size as prokaryotic cells.
- Mitochondria (and chloroplasts) have their own DNA. Their DNA is organized in a circular chromosome like a prokaryotic chromosome.
- Mitochondria (and chloroplasts) can reproduce by binary fission like prokaryotes. In contrast, eukaryotic cells reproduce by mitosis.
- The membrane composition of mitochondria (and chloroplasts) is more similar to prokaryotic membranes than to eukaryotic membranes.

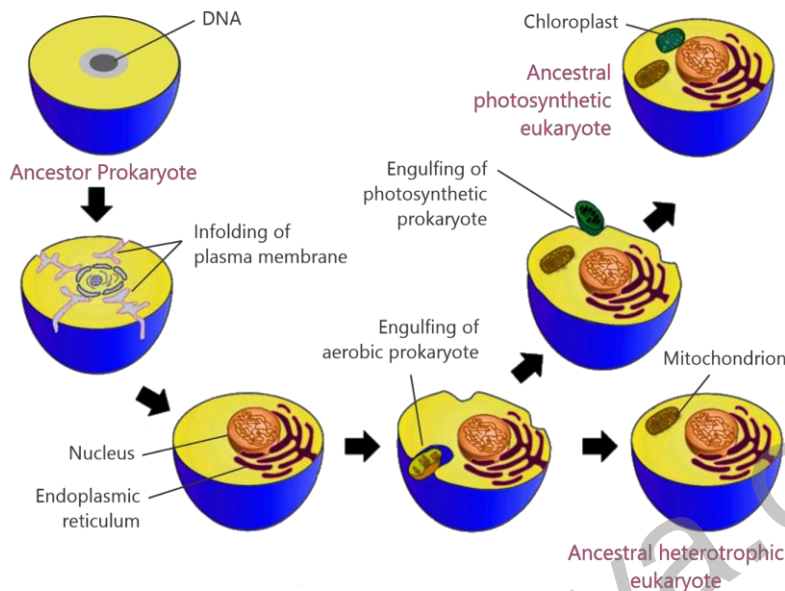


Figure 24.6: Evolution of Eukaryote

## 24.5- LAMARCKISM

The French naturalist **Jean-Baptiste Lamarck** (1744 - 1829) was an early proponent of the idea that evolution. In 1809, he published a book 'Philosophie Zoologique' (Zoological Philosophy). In this book, he presented the idea of progression (change) known as Lamarckism.

According to Lamarckism, organisms changed from simplest to complex. He claimed that changes occur in organisms when they are adapted to environment. The mechanism of evolution proposed by Lamarck can be explained as under;

### 1- Use and disuse of organs

Lamarck believed that when an organism faces changes in its environment, it begins to use some body parts / organs more or disuses some organs. He believed that the organs which are used more frequently are developed and become strong while the organs which are not properly used are deteriorated or become weak. He named such changes in body parts, which occur due to long term use or disuse, as "acquired characters".

### 2- Inheritance of acquired characters

Lamarck believed that the characters acquired during the lifetime of an organism were passed on to the offspring of that organism. When acquired characters are inherited generations to



Figure 24.7: J. B. Lamarck

generations, they ultimately cause modifications in organism to better “cope” the changes in the environment.

### Example of Lamarckism: Evolution of giraffe neck

The evolution of a giraffe's neck is often used as the example to prove Lamarckism. The ancestors of giraffe did not have long necks. They used to eat grass or the leaves of small plants. Changes occurred in the environment and small plants were no more available to them. In the new situation, some individuals of the population began stretching their necks to reach the leaves of tall trees as alternative. When they constantly did so, their necks became strong and long during their lifetime. This was an acquired character. When these individuals reproduced, this acquired character was inherited to their next generation i.e., new individuals were born with slightly longer necks. When these individuals grew up, they continued the same practice of stretching their necks. In this way, their necks became even more stronger and longer. This gave rise to an acquired character. When this acquired character was inherited to many generations, the generation with long necks evolved.

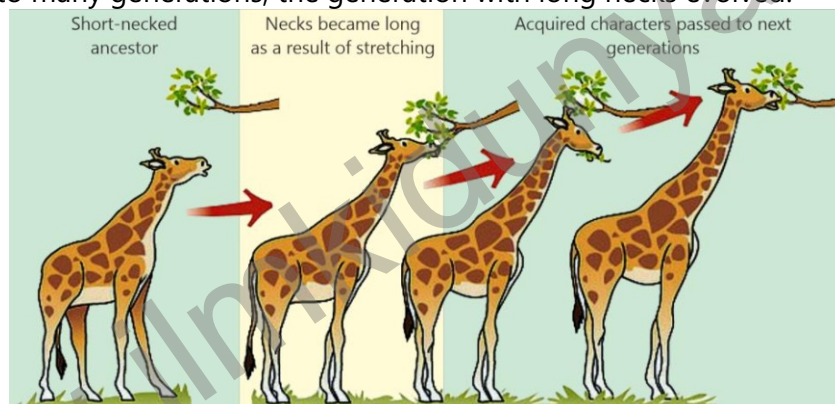


Figure 24.8: Evolution of giraffe neck – according to Lamarckism

### 24.5.1- Drawbacks of Lamarckism

The scientists did not accept the ideas of change as proposed by Lamarck. At the times when Lamarckism was proposed, there was no available evidence that could explain the mechanism of evolution. Thus, Lamarck was criticized more for advocating ideas of evolutionary change than for the mechanism he proposed for that change. After his times, when scientists discovered the inheritance mechanisms, they disproved Lamarckism on the following bases.

#### Initiating and Planning

Hypothesize whether Lamarck was criticized in his day for advocating the ideas of evolution or for the mechanism he proposed.

1. The acquired characters have no genetic basis and therefore cannot be inherited to the next generations.
2. Organs are not modified by the wish or requirements of an organism.

## EXERCISE

## SECTION 1: MULTIPLE CHOICE QUESTIONS

- Who developed a theory of natural selection essentially identical to Darwin's?
  - Hardy-Weinberg
  - Alfred Wallace
  - Malthus
  - Lyell
- Which statement is incorrect?
  - Homologous organs are functionally different but structurally alike
  - Analogous organs are functionally different but structurally alike
  - Examples of analogous structures are arms of a man, forelimb of a cat, flipper of a whale
  - Examples of homologous structures are wings of bats, birds and insects
- Which of the following is an example of homologous organs?
  - Wings of bird and insect
  - Forelimbs of human and whale
  - Fin of fish and wing of bird
  - Eye of octopus and human
- According to the theory of natural selection, variations arise due to;
  - Mutations
  - Use and disuse of organs
  - Selective breeding
  - Splitting of population
- Which condition is NOT required for Hardy-Weinberg equilibrium?
  - Random mating
  - No mutation
  - Natural selection
  - Large population size
- Genetic drift is the change in gene frequency due to;
  - Chance events
  - Natural selection
  - Emigration of individuals
  - Immigration of individuals
- Which of the following ideas is common to both Lamarckism and Darwinism?
  - Mutations are the source of genetic variations
  - Adaptations enable individuals to cope with environmental challenges
  - Use and disuse of organs results in the development of acquired characters
  - Acquired characters are inherited to next generations
- If a massive fire kills 90% of a population and survivors remain by luck. Such a change in allelic frequency will be called;
  - Natural Selection
  - Genetic Drift
  - Gene Flow
  - Mutation
- Changes in gene frequency due to migration of individuals are called;
  - Genetic drift
  - Mutation
  - Gene flow
  - Genetic recombination

10. What may be the best evidence for the endosymbiotic evolution of eukaryotes?

- (a) Presence of a nucleus in eukaryotes
- (b) Circular DNA and 70S ribosomes in mitochondria
- (c) Single-layered membranes around mitochondria
- (d) Large volume of eukaryotic cells

### SECTION 2: SHORT QUESTIONS

1. What is the concept of evolution?
2. How does homology provide an evidence of divergent evolution?
3. How analogous organs represent convergent evolution?
4. What is Hardy-Weinberg theorem?
5. What are the factors that change allele frequencies?
6. Justify Lamarck as an early proponent of evolution.
7. Describe the drawbacks of Lamarckism.
8. Differentiate between;
  - Lamarckism and Darwinism
  - Homologous and analogous
  - Natural selection and neutral selection

### SECTION 3: LONG QUESTIONS

1. Explain that evolution takes place due to variations in organisms and natural selection.
2. Explain the theory of natural selection as proposed by Darwin.
3. Explain how biogeography provides evidence for evolution.
4. Describe the evidences of evolution that come from comparative anatomy.
5. Differentiate between convergent and divergent evolution on the basis of inheritance of the homologous and analogous structures.
6. Describe the evidences of evolution that come from molecular biology.
7. Outline the steps of the evolution of the giraffe, as illustrated in Lamarckism.
8. Describe the endosymbiont theory about the evolution of eukaryotes from prokaryotes.
9. Describe the theory of inheritance of acquired characters, as proposed by Lamarck.

### INQUISITIVE QUESTIONS

1. Interpret different homologous and analogous structures through observation in plants.
2. Hypothesize whether Lamarck was criticized in his day for advocating the ideas of evolution or for the mechanism he proposed.

3. Justify, on the grounds that both Wallace's and Darwin's papers were published in the *Journal of the proceedings of the Linnaean Society*, why the theory was attributed to Darwin.
4. Describe and analyse examples of technology that have extended or modified the scientific understanding of evolution (e.g., the contribution of radiometric dating to the palaeontological analysis of fossils).

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