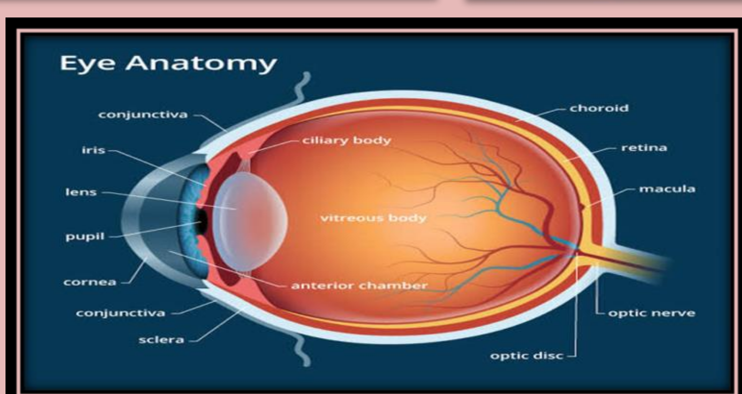
Virtual Study

Learn, Connect, Succeed

Biology

Grade 12



Prepared by: Virtual Study

2016 EC

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UNITE 1

APPLICATIONS OF BIOLOGY IN DAY TO DAY LIFE

1.1 Appreciation of nature

- Nature is the phenomena of the physical world including plants, animals, the landscape, and other features and products of the earth. As a field of science, biology helps us understand the living world and how various species (including humans) function, evolve and interact**.** Nature provides us with the food we eat, the air we breathe, and the water we drink and irrigate our crops.
- In addition, we also rely on it for numerous other goods and services, for our health, happiness and prosperity. We benefit from viewing the scenes of nature to reduce anger, fear and stress and increase pleasant feelings.
- Overall, we learn and appreciate the beauty of nature through:
    - Planting a tree.
    - Hugging a tree.
    - Making a garden.
    - Going for hiking trails.
    - Watching sunrises & sunset
    - Protecting nature.
    - Reducing pollution.

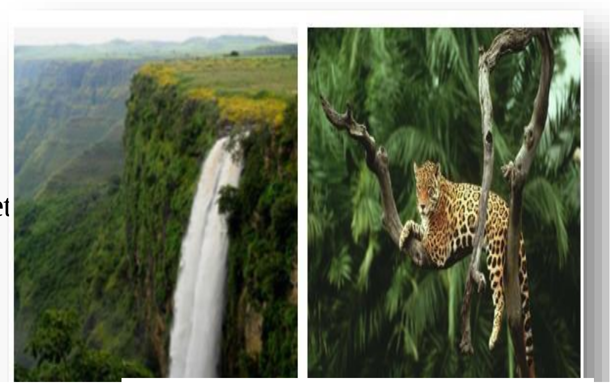


Figure.1: The beauty of nature

1.2 Conservation of natural resources

- Conservation is the careful maintenance and wise use of natural resources to prevent them from disappearing. Natural resources are physical supplies that exist in nature. These include soil, water, air, plants, animals, and energy. Ethiopia has many natural resources, such as), gold, platinum, potash, limestone, natural gas, coal, etc.

- We have timber and many different crop plants and coffee plantations .We have many different species of animals and plants, which make up rich ecosystems and many different breeds of domestic animals.
- Natural resources can be classified as renewable or non- renewable. Renewable resources are mainly living things and their products. When managed carefully, they can be used, reused and replaced. Examples of renewable resources are crop plants, trees, cattle and chickens. Non- renewable resources are not living things, and when they are used, they cannot be replaced. Examples of non-renewable resources include metals such as gold and iron and fossil fuels such as gas, coal and gas oil. Even renewable resources can be lost if we do not manage them carefully.
- Trees can produce new trees and forests can last for about thousands of years. However, if all the trees are cut down and used for timber at once, the forest will not be able to renew itself and all the species within it will be lost. Similarly, if an animal is hunted until there are no more of that species left (extinction) or its habitat is destroyed it can no longer feed or breed. As a result, other natural resources will be lost forever when the species become extinct.
- Species may be lost in a particular area, or they may be lost everywhere in the world when they are extinct. Therefore, biology plays a vital role in creating awareness on the natural resources conservation, development, and genetic resources conservation.

Volcanoes with sulfur deposits in Ethiopia (Ertale)

Awassa Lake

Oromia Region

Figure2: Natural landscapes in Ethiopia

- To protect our natural resources, both here in Ethiopia and around the world, people have become more aware of the need for conservation. Conservation is the protection and preservation of our natural environment so that non-renewable resources are used sparingly and renewable resources are managed properly so that they can last for a long period of time in the future.

a

a

b

c

Figure.3: Some important renewable resources in Ethiopia: Coffee (a), Walia Ibex (*Capra walie*) (b), Sunlight as a source of energy (c), Ethiopian Bush crow (*Zavattariornis stresemanni*).

1.3 Food security

- Food security, as defined by the United Nations' Committee on World Food Security, is a state in which when all the people have physical, social, and economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life at all times. However, food insecurity is often rooted in poverty and has long-term impacts on the potential of families, communities and countries to develop and prosper. Prolonged undernourishment stunts growth, slows cognitive development and increases susceptibility to illness.
- Therefore, food security is ensured only if: enough food is available for all in a county; when all individuals have the capacity to buy food of acceptable quality, and when there is no barrier to access food. Biology plays a key role in producing high-nutrient staple crops and developing new products that can combat malnutrition, and thereby improving food utilization. Biotechnologists design the manufacturing processes and machinery used to produce food and drink. This allows products to have consistent flavor, color and texture to be produced in large quantities.

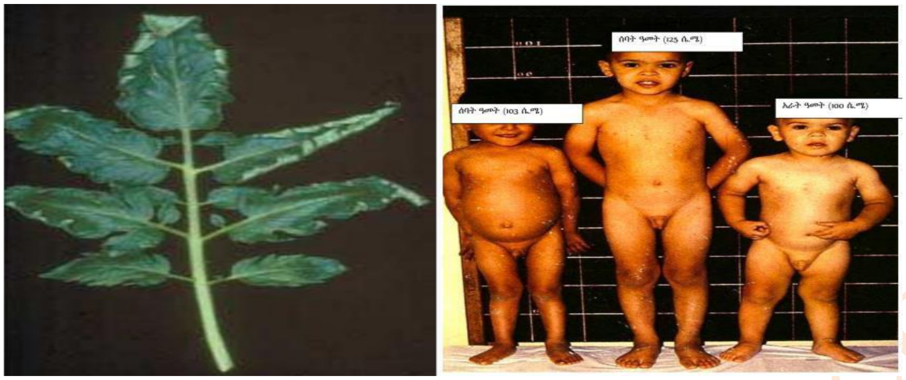


Figure .4 : Chlorine deficient tomato; leaf edges roll upward

1.4 Creating conscious citizens and ensuring sustainable development

- A **conscious citizen** is one who places value on being fully human while connecting with a higher purpose; one who values human life and the relationship with all living things, and one who takes the responsibility for transforming skills into action through ethical decision making, to ultimately improve life and living on the planet.
- Biology has a vital role in creating **conscious citizen** by expanding awareness of the social, global, and environmental conditions, by empowering people to assume personal responsibility, by engaging in, by being committed to and initiating positive impact. Nowadays, the interplay of biology and technology or biotechnology has become vital in working sparingly on the sustainable development and diminution of degradation of nature.
- These are achieved through developing innovative and cost effective bio-based technologies which consume fewer resources, incorporate recycling, reuse components and reduce production of wastes, and use strategies/methods for sustaining greener earth and improving production.

According to the World Conservation Union (IUCN, 2006), the three dimensions of sustainability (economic, social and environmental) are represented either as pillars,

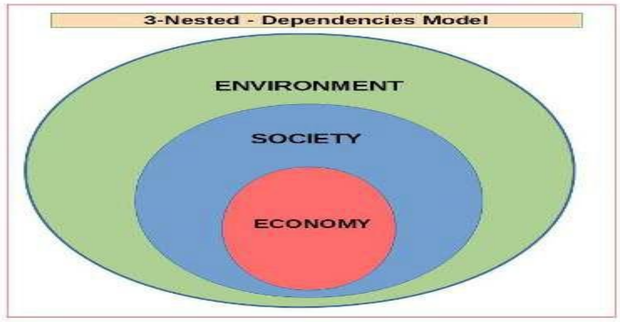


Figure.5 : A model for sustainable development

1.4.1 Development of careers

- Career development is about setting goals and acquiring the skills to achieve those goals or personal improvement, which one undertakes to, achieve their career plan. It enables employees to learn the better aspects of their work and improve their capabilities. In an organization, there are different types of development programs to enrich different skills of human resource.
- These include organization development, employee development, management development, and career development. Therefore, Biology graduates are prepared to pursue many career paths including academic research and teaching, medical and public health, biotechnology, industrial research, environmental sciences, and agricultural research.

1.4.2 Medicine

- The World Health Organization (WHO) defines health as 'a state of complete physical, mental and social wellbeing, which is not merely the absence of disease or infirmity'. For this, the application of biology in medicine and other health sciences (for example, Fast diagnosis tools, drug and vaccine production, gene therapy, immuno-diagnosis, immunotherapy, transplantation, medicinal plants, etc.) have a big role.
- Biotechnology contributes much towards the growing public and global health needs. It has revolutionized the lives of humankind since its existence. It has provided effective diagnostics, prevention and treatment measures including the production of novel drugs and recombinant vaccines. It gives effective drug delivery approaches, new methods for therapeutics, nutritionally enriched and genetically modified crops and efficient methods for environmental cleanup.
- Accordingly, life quality and expectancy have been increased worldwide through the

services provided by biotechnology. Polymerase chain reaction (PCR), PCR results) is a broadly applied laboratory test for the diagnosis of a wide variety of central nervous system (CNS) diseases, including genetic and autoimmune diseases, malignant neoplasms, and infections.

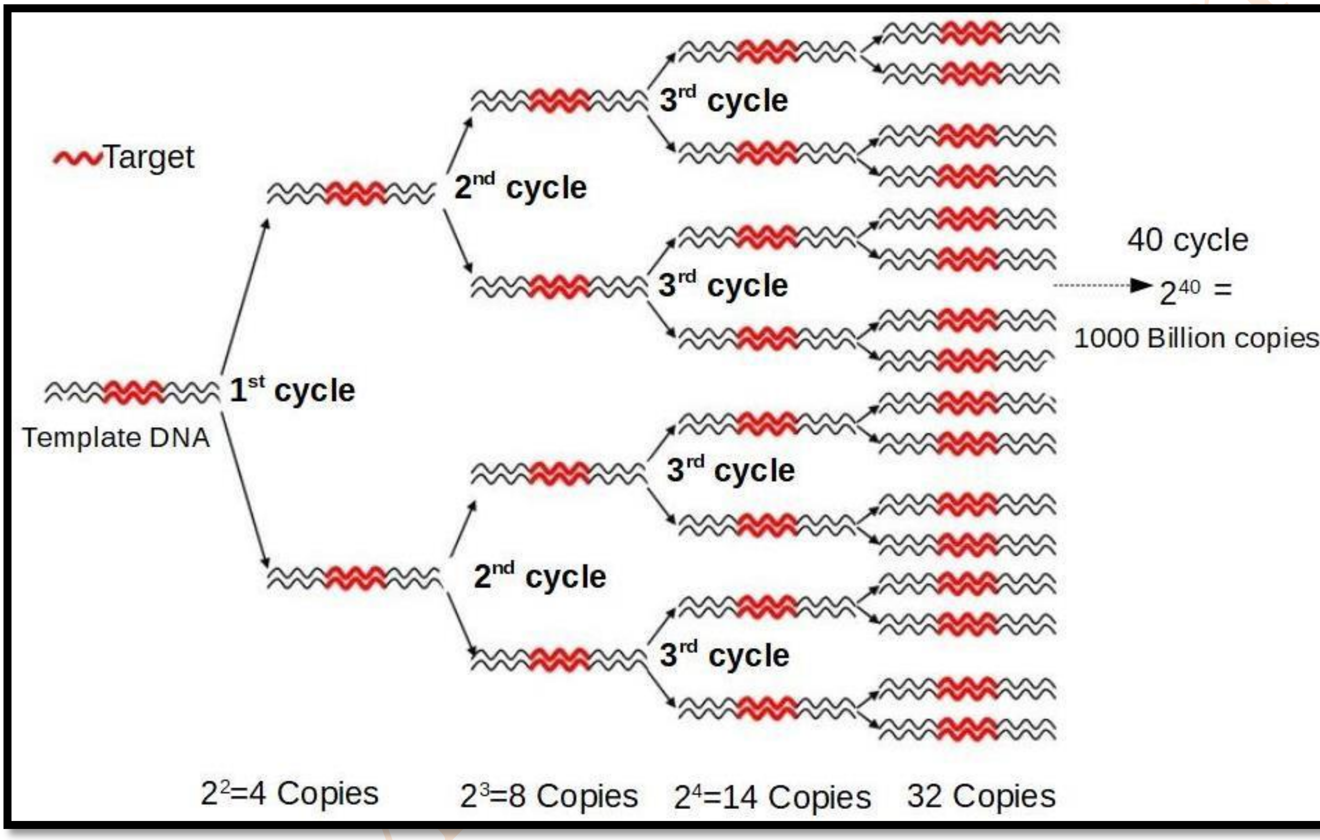


Figure .6 : Amplification of DNA by the PCR technique. Source: David and Hernández, 2013).

- Infectious diseases like Acquired Immunodeficiency Syndrome (AIDS) and tuberculosis (TB) have been diagnosed rapidly at relatively low cost. Molecular diagnostic tools including polymerase chain reaction (PCR), recombinant antigens and monoclonal antibodies have been used for this purpose. Biotechnology has also offered modern diagnostic test kits, rickettsial, bacterial, and viral vaccines along with radiolabeled biological therapeutics for imaging and analysis. Vaccination by making recombinant vaccines has the potential to eradicate non-communicable diseases like cancer. Naked DNA vaccines, viral vector vaccines and plant-derived vaccines are found to be the most effective against a number of bacterial and viral diseases.

- The biosensor devices used to detect COVID-19 and describe the ways it detect the presence or absence of the virus?

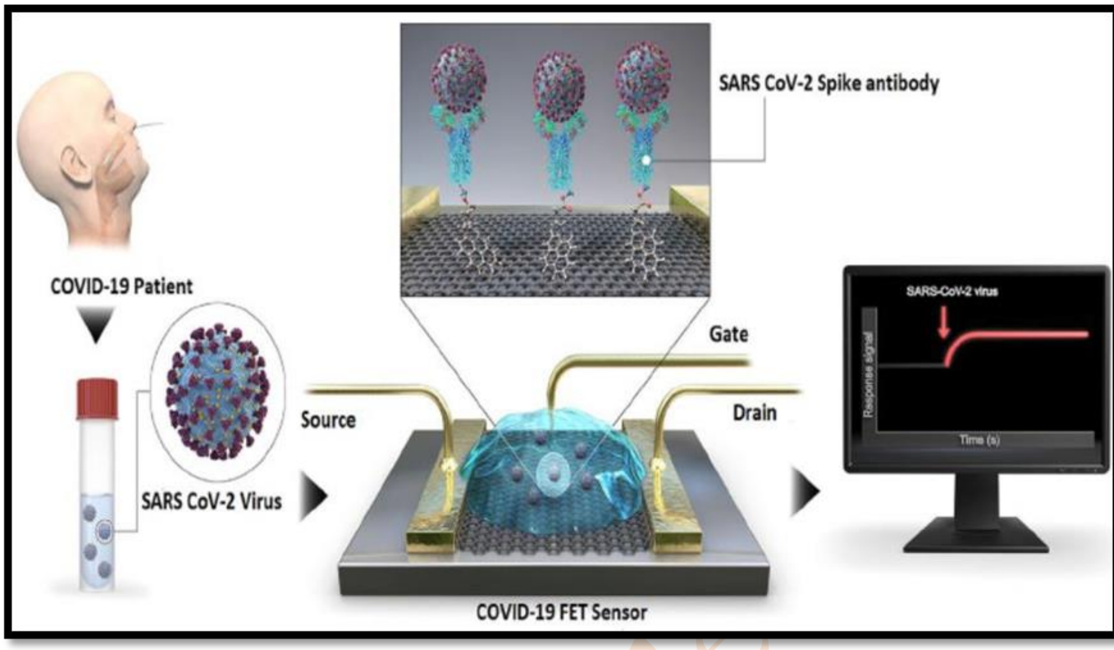


Figure 7: Bio sensing device for detection of Coronavirus. Source: Behera *et al*., 2020).

1.5 Waste treatment

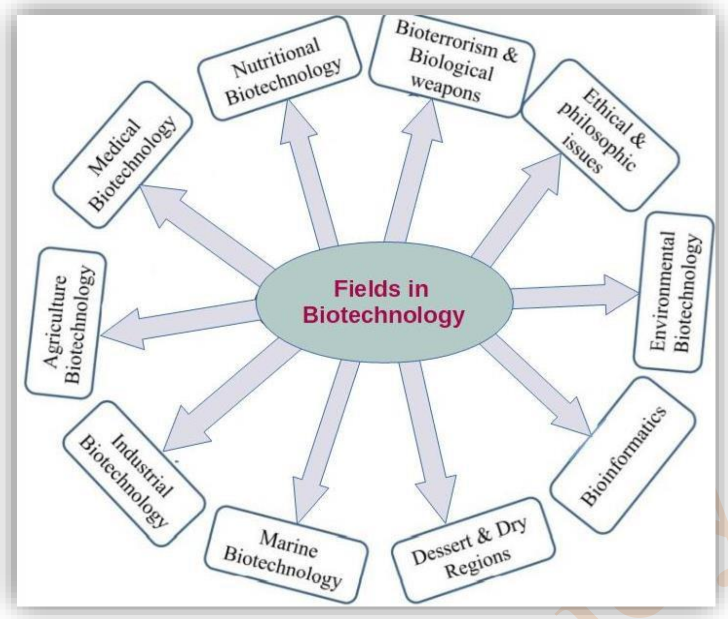
Biotechnological processes are used for wastewater treatment and reuse. This area involves engineers, biologists, chemists. Appropriately designed waste management system can be utilized to remove hazardous wastes from the environment and to produce of renewable energy such as bio- fuels and hydrogen (Fig 1.8). Particularly, for preventing environmental pollution through environmental engineering, activated sludge process, trickling filters, bio-trickling filters, oxidation ponds, anaerobic treatment, composting units and biogas reactors are used extensively among the waste treatment technologies.

Figure .8: Biogas Generation system in Ethiopia. Source: OBN, 2022)

- Bio-mining is also one area of interest where chemical mining that can efficiently extract minerals from natural ores is substituted by microorganisms. Note that chemical mining generates many pollutants in the environment.

1.6 Biotechnology

- Biotechnology is the "science and technology of harnessing the natural and biological capabilities of plants, animals, and microbes for the benefit of people". This means the application of biological knowledge, techniques and use of living organisms to make a product or run a process for human use.
- Generally, biotechnology is divided into traditional and the new or modern biotechnologies. Traditional applications of biotechnology involve the domestication and traditional fermentations (brewing beers, making wines, making bread, and making cheese and yoghurt).
- Modern applications of biotechnology include using genetic engineering to change crops and animals; producing new medicines; and helping to provide new energy sources. It has enormous significance in helping people to improve and control their lives.



- Microbes a common inhabitants of soil, water, food, and animal intestines, as well as in more extreme settings such as rocks, glaciers, hot springs, and deep-sea vents. Microbial biotechnology, enabled by genome studies, will lead to breakthroughs such as improved vaccines and better disease-diagnostic tools, improved microbial agents for biological control of plant and animal pests, modifications of plant and animal pathogens for reduced virulence, development of new industrial catalysts and fermentation organisms, and development of new microbial agents for bioremediation of soil and water contaminated by agricultural runoff.

1.6.1 Technology

- **Biological engineering:** is the application of principles of biology and the tools of engineering to create usable, tangible, economically viable products. Biological engineering employs knowledge and expertise from a number of pure and applied sciences such as organ transfer, biocatalysts, bioinformatics, separation and purification processes, bioreactor design, and polymer science.

- Bioengineers can apply their expertise to other applications of engineering and biotechnology, including genetic modification of plants/animals and microorganisms, bioprocess engineering, and bio-catalysis. Working with doctors, clinicians and researchers, bioengineers use traditional engineering principles and techniques and apply them to solve real-world biological and medical problems.

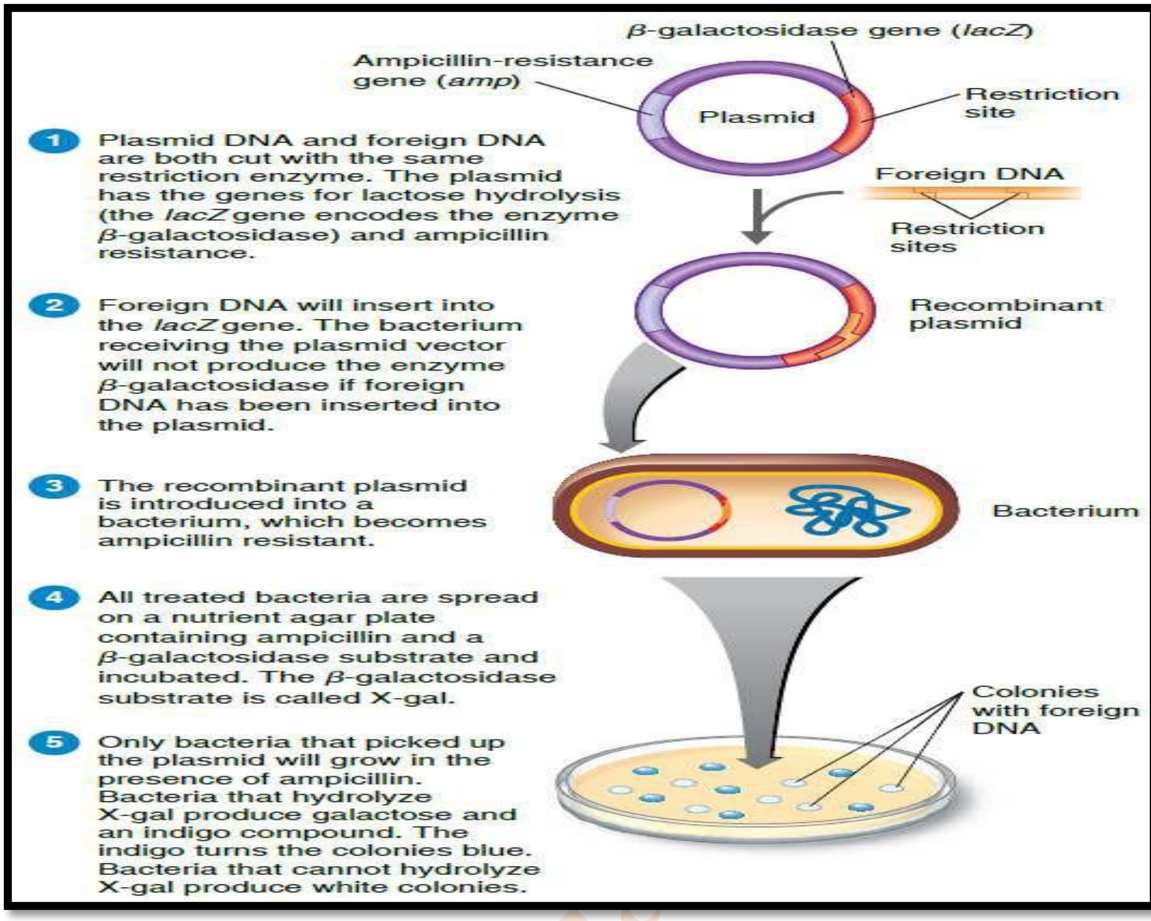


Figure.9 Method of selecting recombinant bacteria plant (Source: Tortora et al., 2016).

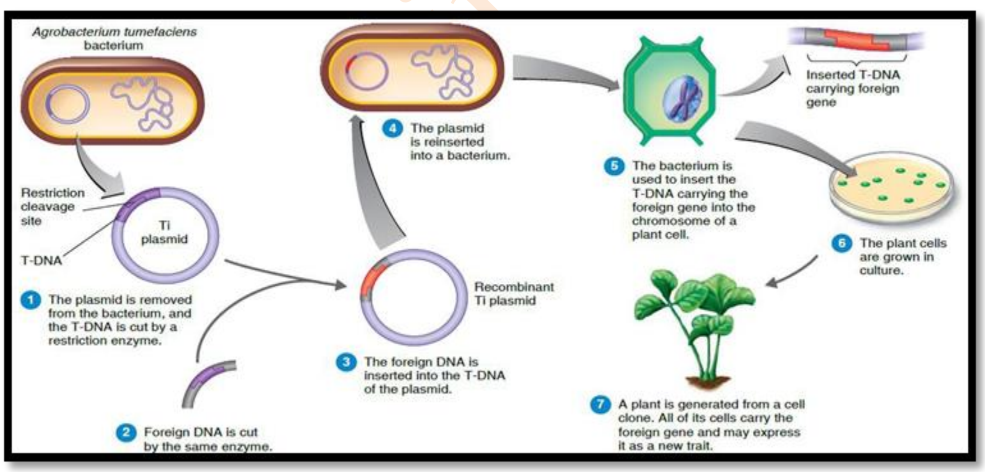


Figure 10 Techniques for Genetic modification in plant (Source: Tortora et al., 2016)

1.6.2 Soil fertility, tissue culture, animal breeding and transgenic animals, plant, and disease, and pest management

- Food supply for the fast growing population has mainly been constrained by the loss of soil fertility and diseases of crops and animals. In addition, lack of advanced tool has remained a problem. The multiple applications of biology in agriculture have substantially improved the production and supply of food for human as well as animals. The following are some of the few examples of the advancements of agricultural production integrating knowledge of biology and technology.

Soil fertility

- Soil fertility management practices using biological knowledge include the use of organic fertilizers (bio-fertilizers), vermicomposting, crop rotation with legumes and the use of improved germplasm, combined with the knowledge on how to adapt these practices to local conditions.

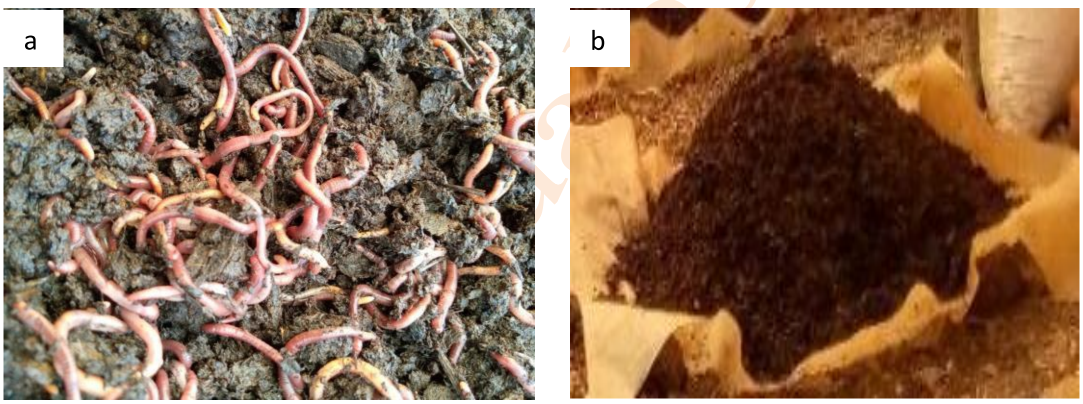


Figure.11 : Vermicomposting from Water hyacinth, Earthworm rearing (a); compost produced (b)

Tissue culture

- Plants can be propagated quickly and in large quantity by tissue culture technique. Plants produced in large amount using this technique include palm trees, orchids, bananas, and carrots. Using this technology large quantity of food with desired quality can be produced in reasonably little area.
- Genetic Engineering has produced seedless fruits such as watermelon, papaya, orange and grape. This will significantly reduce the crop cycle. Moreover, farmers used to plant

crops traditionally using conventional tools. With the advancement of biology and technology, they can now plant crops along with more efficient cultivation methods in many different cultivation ground (Figure 1.12).

Figure.12: Tissue culture

Animal breeding and transgenic animals, and plants and disease, and pest management

- Animal breeding addresses the genetic value of livestock. Selecting for breeding animals with superior traits in growth rate, egg, meat, milk, or wool production, or with other desirable traits has revolutionized the livestock and plant production throughout the entire world.
- Animals can also be genetically modified (transgenic animals) for valuable traits. There are many potential applications of transgenic methodology in developing new and improved strains of livestock.
- Practical applications of transgenic technology in livestock production include enhancing the prolificacy and reproductive performance, increasing feed utilization and growth rate, improving carcass composition, improving milk production and/or composition, modification of hair or fiber, and increasing disease resistance in animals.

- The development of transgenic farm animals will allow more flexibility in the direct genetic manipulation of livestock. Gene transfer is a relatively rapid way-of altering the genome of domestic livestock.

Figure 13 Biotechnology improves the quality of breeds

- The use of these tools will have a great impact toward improving the efficiency of livestock production and animal agriculture in a timely and more cost-effective manner. Such effective means of increasing food production are promising for the ever-increasing world population and changing climate conditions.
- Applications of animals in research are also another area of animal biotechnology. Biomedical research involving the use of animals has been the cornerstone of medical progress for the past several centuries, but ethical concerns about the use of vertebrates, which are more commonly understood to be sentient animals, have led researchers, veterinarians, and others in laboratory animal sciences to search for alternatives. Hence, invertebrates can serve as replacements for their vertebrate counterparts in many areas of research, testing, and education.

Food, brewery, pharmaceuticals, tannery, and textile, single cell production, preservation

- Industrial biotechnology, also known as white biotechnology is the modern use and application of biotechnology for the sustainable production and processes of bio-products such as food substances, chemicals, biomaterials and fuels from renewable sources using living cells and/or their enzymes. Primarily, the enormous capability of microorganisms and their enzymes are utilized for the production of food supplements such as vitamin B2, many other pharmaceuticals such as drugs and vaccines, bioplastics such as polylactic acid, energy carriers such as biogas and bioethanol, detergents, pulp and paper, quality textiles fibers, and many agricultural products.

- Most importantly, single cell proteins (SCP) can be produced from wide range of microorganisms. Best examples are mushroom, spirulina, yeast, green algae. SCP technology is a promising area in alleviating food security in ever-growing population.

- Food preservation is another area of industrial biotechnology whose processes helps to stop food spoilage due to microbial action. The biological methods of food preservation have become increasingly important. These consist of adding cultures of innocuous microorganisms of high purity to the food. The cultures have an inhibitory effect on the undesirable decomposition of microorganisms.

1.7 Forensic science

- Forensic biologists inspect crime scenes to examine potential sources of evidence using blood, saliva, and hair, and then they analyze the specimens in a laboratory, focusing on DNA analysis. Additionally, fingerprints are also important tools to investigate crime and determine the paternity case of a child. This is because each individual has unique fingerprints that do not change throughout life.

- Based on their investigations, forensic biologists write up their findings in technical reports and are called upon to testify in court. Finally, this data is used to investigate the related transgression, and then these facts are put forward in the court that‘s quite helpful in order to castigate the criminal. These days 'bioinformatics is widely acceptable in the field of forensic science because, with the help of computational tools, it has become quite easer and reliable to gather evidence regarding a particular crime scene.

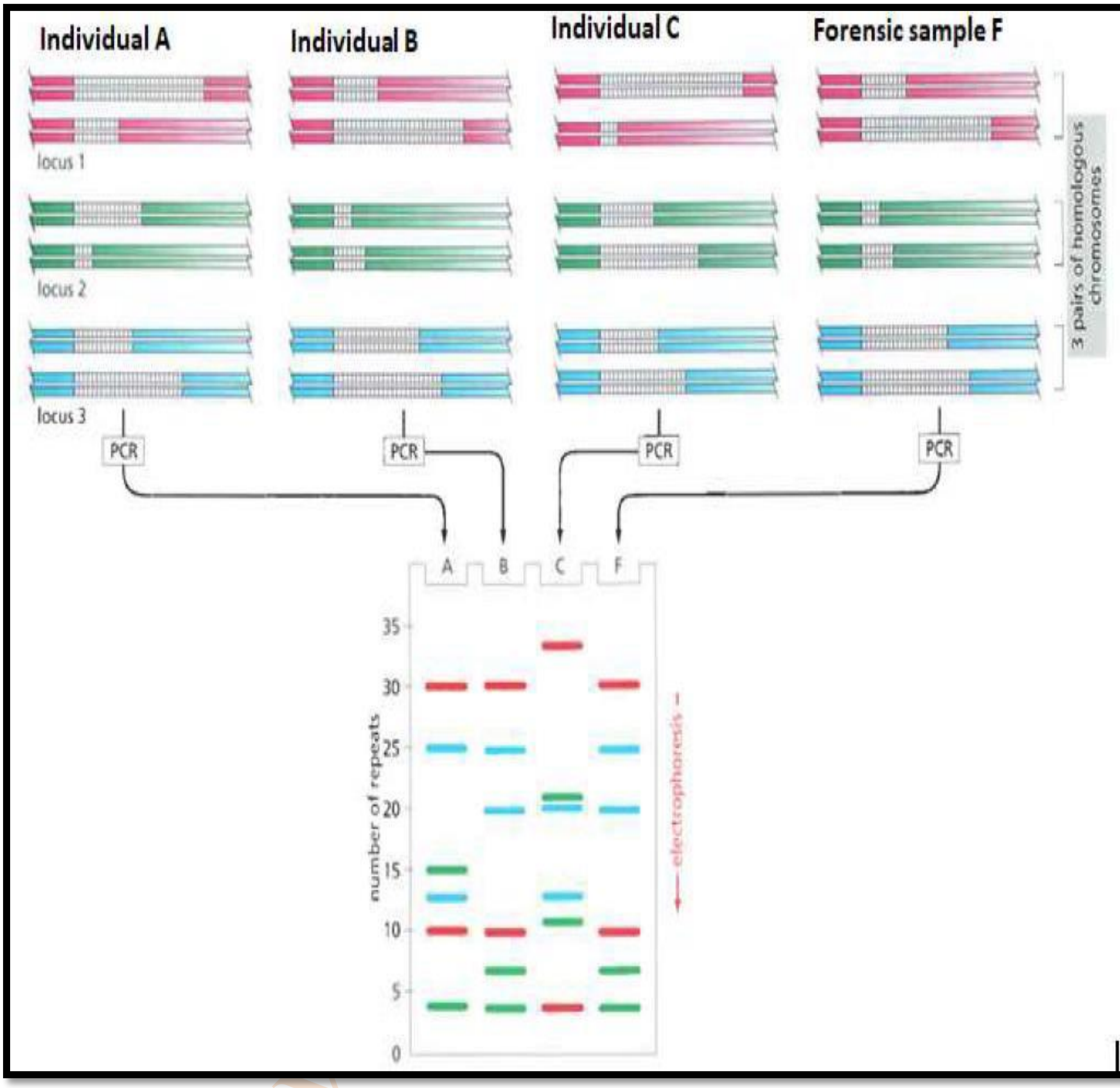


Figure.14: PCR as a forensic science tool

When examining the variability at 5-10 different Variable Number of Tandem Repeat (VNTR) loci, the odds that two random individuals would share the same genetic pattern by chance can be approximatel1y 1 in 10 billion. In the case shown here, individuals A and C can be eliminated from further enquiries whereas individual B remains a clear suspect for committing the crime. A similar approach is now routinely used for paternity testing. The gel electrophoresis results of two-suspected paternity tests (Figure 1.14)

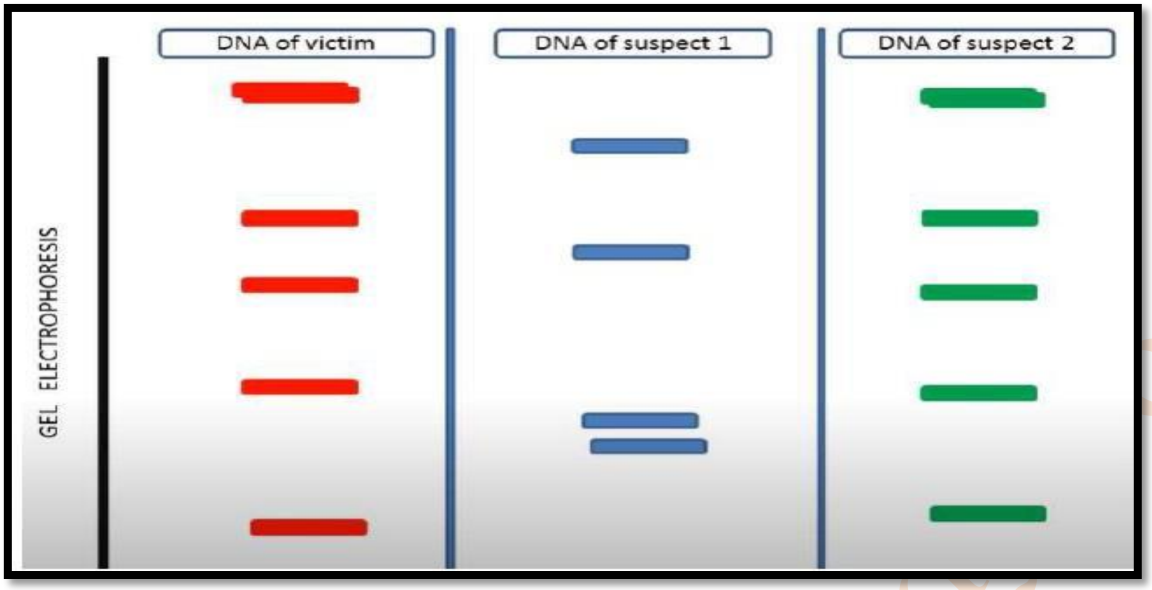


Figure .17. PCR in forensic application Therefore, suspect 2 is the father of the baby (victim).

1.8 Biological warfare

- **Biological warfare** (BW) also known as germ warfare is the use of biological toxins or infectious agents such as bacteria, viruses, and fungi with the intent to kill or incapacitate humans, animals or plants as an act of war.
- Biological weapons include any microorganism (such as bacteria, viruses, or fungi) or toxin (poisonous compounds produced by microorganisms) found in nature that can be used to kill or injure people. The act of bioterrorism can range from a simple hoax to the actual use of these biological weapons, also referred to as agents.
- A number of nations have or are seeking to acquire biological warfare agents, and there are concerns that terrorist groups or individuals may acquire the technologies and expertise to use these destructive agents.
- Biological agents may be used for an isolated assassination, to cause incapacitation or death to thousands. If the environment is contaminated, a long-term threat to the population could be created.

1.9 Promises of biology to the society

- Biology is an important science in dealing with the issues of overpopulation, food security, environmental wellbeing, health care, biodiversity and others. It is particularly more relevant in Ethiopia where the country needs to address the problem in a scientific way. Thus, practical biological knowledge is of special relevance to Ethiopia, and hence special attention should be given for education in biology.

- The biological wealth of Ethiopia is rich but its knowledge is limited. Good understanding of the diverse flora, fauna and microbial resources together with the underlying biological principles is required for the development and sustained use biological wealth.
- Along with biological resources, there is a wealth of indigenous biological knowledge that could be systematically introduced into the modern science. This can be achieved by training army of competent biologists and introducing biological literacy campaign.
- Effective control of land degradation, biodiversity loss, diseases and other menaces, as well as the development of the biological and agricultural potentials needs to be used.
- Biologists take positions in different fields including in teaching/education, research, agriculture, medical areas, fisheries, conservation, industry, natural resource development biodiversity and genetic resources conservation and the control of pests and diseases.
- Much contribution to the growth and advancement of biological knowledge is expected, since the country has important biological materials regarding human evolutionary history and crop domestication, the pattern and abundance of species distribution especially endemic plant and animal species. The endemic plants, animals (mammals and birds) are known to date and crop genetics have demonstrated interesting biological processes helpful for developing the biological sciences.

Unit summary

- Nature refers to the phenomena of the physical world and life in general. It ranges from the subatomic to the cosmic. It encompasses living plants and animals, geological processes, weather, and physics, such as matter and energy.

- Conservation is the careful maintenance and upkeep of a natural resource to prevent it from disappearing. A natural resource is the physical supply of things that exist in nature. These include, soil, water, air, plants, animals, and energy.

- Food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Sustainable development is an economic development that is conducted without depletion of natural resources. It is an organizing principle for meeting human development goals while simultaneously sustaining the ability of natural systems to provide the natural resources and ecosystem services on which the economy and the society depend.

- A conscious citizen is one who places value on being fully human while connecting with a higher purpose; one who values human life and the relationship with all living things, and takes responsibility for transforming skill into action through ethical decision making, to ultimately improve life and living on the planet.

- Conscious citizenship is developed by expanding awareness of the social, global, and environmental conditions while being empowered to assume personal responsibility by engaging in, committing to, and initiating positive impact.

- A conscious citizen of the world sees the interconnection of one's actions and their consequences. A conscious citizen is continuously in a state of becoming and ideally reaches a developmental, emotional, and spiritual level of being in harmony with life.
- Career Development is the process an individual may undergo to evolve their occupational status. It is the process of making decisions for long term learning to align with the person needs of physical or psychological fulfillment with career advancement opportunities. Health and wellbeing-is a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity.

- Waste treatment is the activities required to ensure that waste has the least practicable impact on the environment. The technology that we use in waste management systems (such as biological and thermal treatment technology) has effective overall waste management systems.

- Biotechnology is technology based on biology – biotechnology harnesses cellular and bio- molecular processes to develop technologies and products that help improve our lives and the health of our planet. We have used the biological processes of microorganisms for more than 6,000 years to make useful food products, such as bread and cheese, and to preserve dairy products.
- Applications of Biotechnology: biotechnology is applied for, Nutrient supplementation, Abiotic stress resistance, Industrial product processing, Biofuels, Healthcare, Food processing, Fuel from waste, etc.

Review questions

Choose the correct answer for the following questions

1. Which of the following is a non-renewable resource?

   A. Timber B. Gold C. Coffee D. Khat

2. Which of the following is a renewable resource?

   A. Oil B coal C gas D wood

3. Write about the natural resources of Ethiopia and why we need to take care of them.

Answer

I. Answer for multiple choice: 1. B 2. D

II. Answer for discussion questions

3. Write about the natural resources of Ethiopia and why we need to take care of them?

- **Answer:** Ethiopia has many natural resources, such as), gold, platinum, potash, limestone, natural gas, coal, timber, crop plants and coffee plantations, rich ecosystems and many different breeds of domestic animals.
- Natural resources are physical supplies that exist in nature. These include soil, water, air, plants, animals, and energy. Ethiopia has many natural resources, such as gold, platinum, potash, limestone, natural gas, coal, etc.

  So, protect our natural resources, in Ethiopia, people have become more aware of the need for conservation. So that non-renewable resources are used sparingly and renewable resources are managed properly so that they can last for a long period of time in the future.

UNITE 2

MICROORGANISMS

2.1 What are Microorganisms?

- Microorganisms (also called microbes) are life forms including acellular viruses that are too small to be seen with the naked eye. These microscopic organisms are diverse in form and function and they inhabit every environment on Earth that supports life. Many microbes are simple single-celled organisms, but some can form complex structures, and some are even multicellular.
- Microorganisms typically live in complex microbial communities and their activities are regulated by interactions with one another, with their environments, and with other organisms. The science of **microbiology** is all about microorganisms: what they are, how they work, and what they do. Microorganisms are everywhere, and though small, their activities have tremendous impacts on everything in our biosphere. To realize microbial activities, you may think about how that many of our day-to-day interactions with the world are influenced for better or worse.
- The rich diversity of microorganisms is reflected in their profound influence on all aspects of life. Most microorganisms are harmless or indeed beneficial. For example, they are essential to the recycling of nutrients that form the bodies of all organisms that sustain all the metabolic cycles of life. Also, they produce about 50% of the oxygen gas we breathe and provide other nutrients to many other organisms.
- Microorganisms survive in, or are purposely put in, many of the foods we eat. Microorganisms and viruses are also in the air we breathe and in the water we drink. Even, some 100 billion microorganisms inhabit in/on our skin and grow in our mouth, ears, nose, throat, and digestive tract. Fortunately, the majority of these microbes, called our natural **microbiota** are actually beneficial in helping us resist diseases, and regulating development and nutrition. When most of us hear the word "bacterium" or "virus", we think infection or disease although such **pathogens** (disease-causing agents) are rare.

2.2 Types of microorganisms

- In the life sciences, high priority is placed on the identification and recognition of the different types of microorganisms to treat or use them for various purposes. For example, antibiotics treat a bacterial infection but have no effect on viruses or other microbes.
- Based on evolutionary lines, there are three main kinds of microorganisms, and these are bacteria, archaea, and eukarea (Figure 2.1)

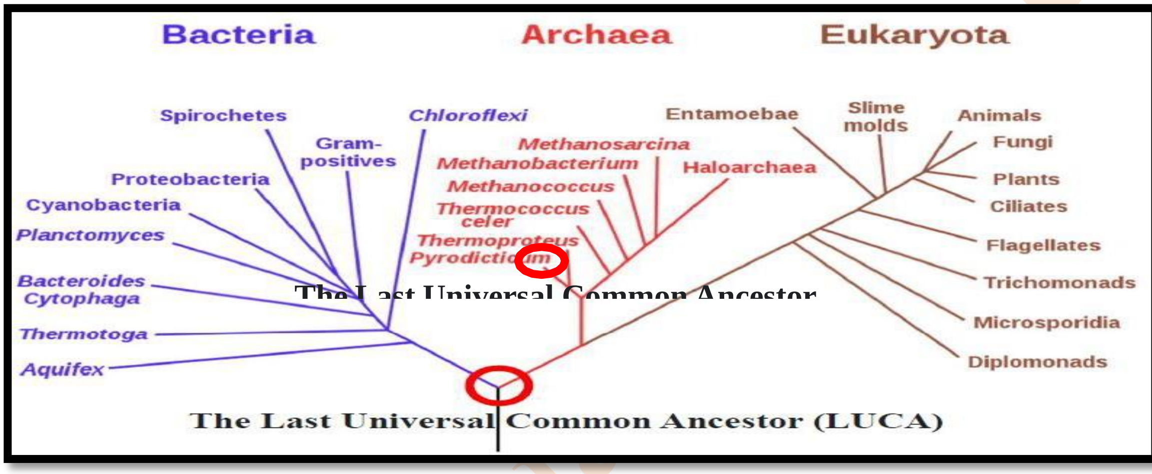


Figure.15 Universal phylogenetic tree life constructed from small subunit of rRNA (SSU rRNA) gene sequence analysis, after Karl Woese. Image credit: Modified from Eric Gaba, Wikimedia Commons.

- In general, there are five main groups of microorganisms, although each group can be subdivided (Figure 2.2). These groups are:

A. Bacteria
B. Fungi
C. Viruses
D. Protozoa
E. Some algae

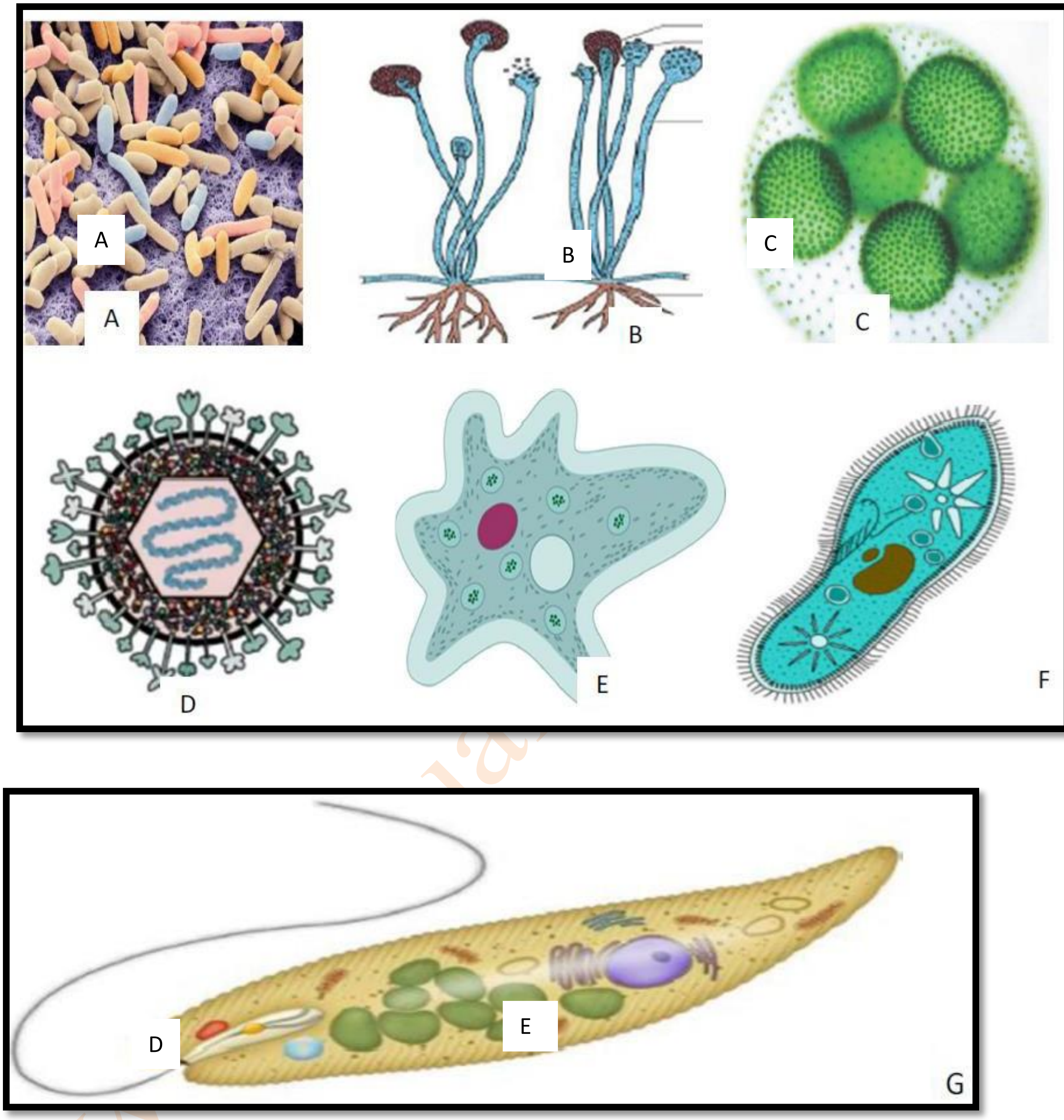


Figure.16 Microbial community structure: Prokaryotes Bacteria (A); Eukaryotes Fungi (B), Algae (C), Amoeba (E), Paramecium (F), Flagellates (G) and Acellular Viruses (D).

2.2.1 Eubacteria

- Eubacteria (biology = definition): Literally means "**true bacteria**". They include all bacteria (except for archaea bacteria). Bacteria (singular: bacterium) are relatively simple, single celled (unicellular) organisms. Because their genetic material is not enclosed in a special nuclear membrane, bacterial cells are called prokaryotes (Figure 2.3). Prokaryotes include both bacteria and archaea. Millions of bacteria exist in every environment both inside and outside other organisms. The bacteria include cyanobacteria, which have bluish pigments in addition to chlorophyll that enable them to photosynthesize. Some bacteria are harmful, but most serve a useful purpose. They support many forms of plant and animal life, (Figure 2.4), and they are used in industrial and medicinal processes. Bacteria are thought to have been the first organisms to appear on earth, about 4 billion years ago. The oldest known fossils are of bacteria-like organisms.

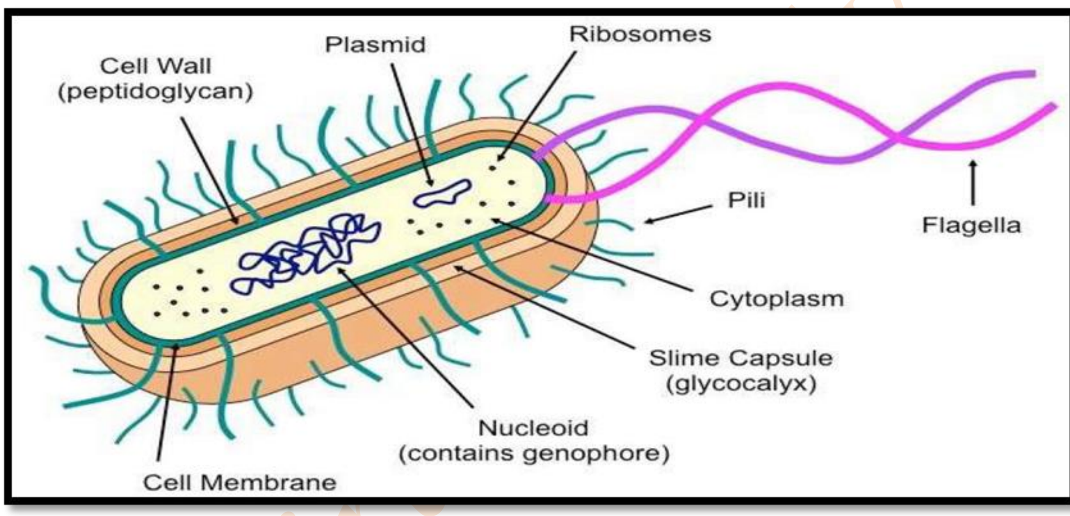


Figure .17 Major features of a prokaryotic cell, Bacteria. Source: BioNinja)

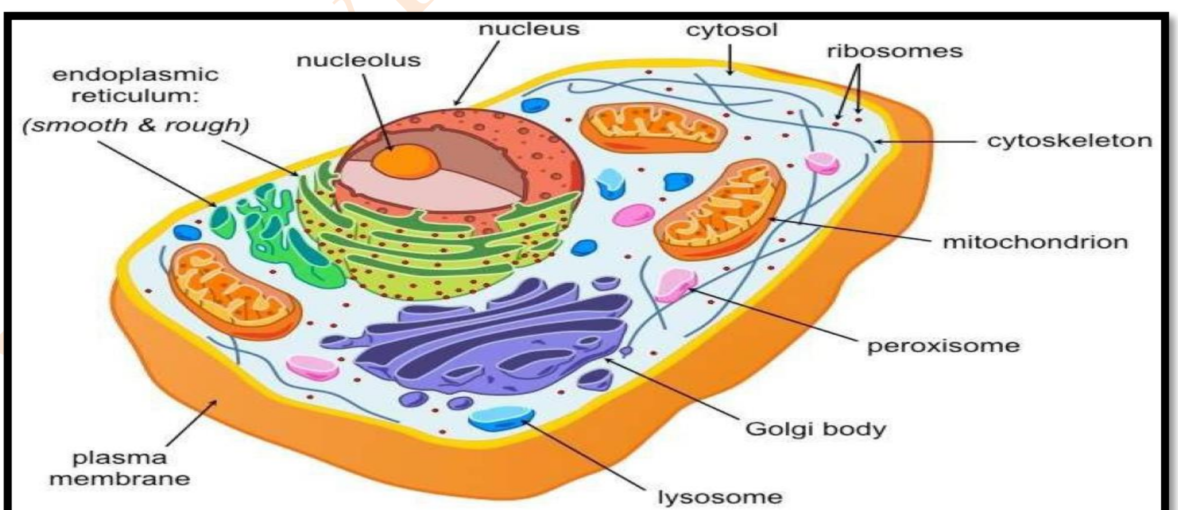


Figure.18 Major features of a eukaryotic cell. Source: BioNinja)

Bacterial Shapes

- In fact, phenotypically bacteria are classified based on numerous features. For example, cell shape (Figure 2.5), nature of multi cell aggregates, motility, formation of spores, and reaction to the gram stain are some of the most important features that are used to classify bacteria. Therefore, bacterial cells can be grouped into the following three main shapes: Cocci (singular, coccus) – spherical bacteria, Bacilli (singular, bacillus) – rod-shaped bacteria, Spirochaetes–spiral or corkscrew-shaped bacteria

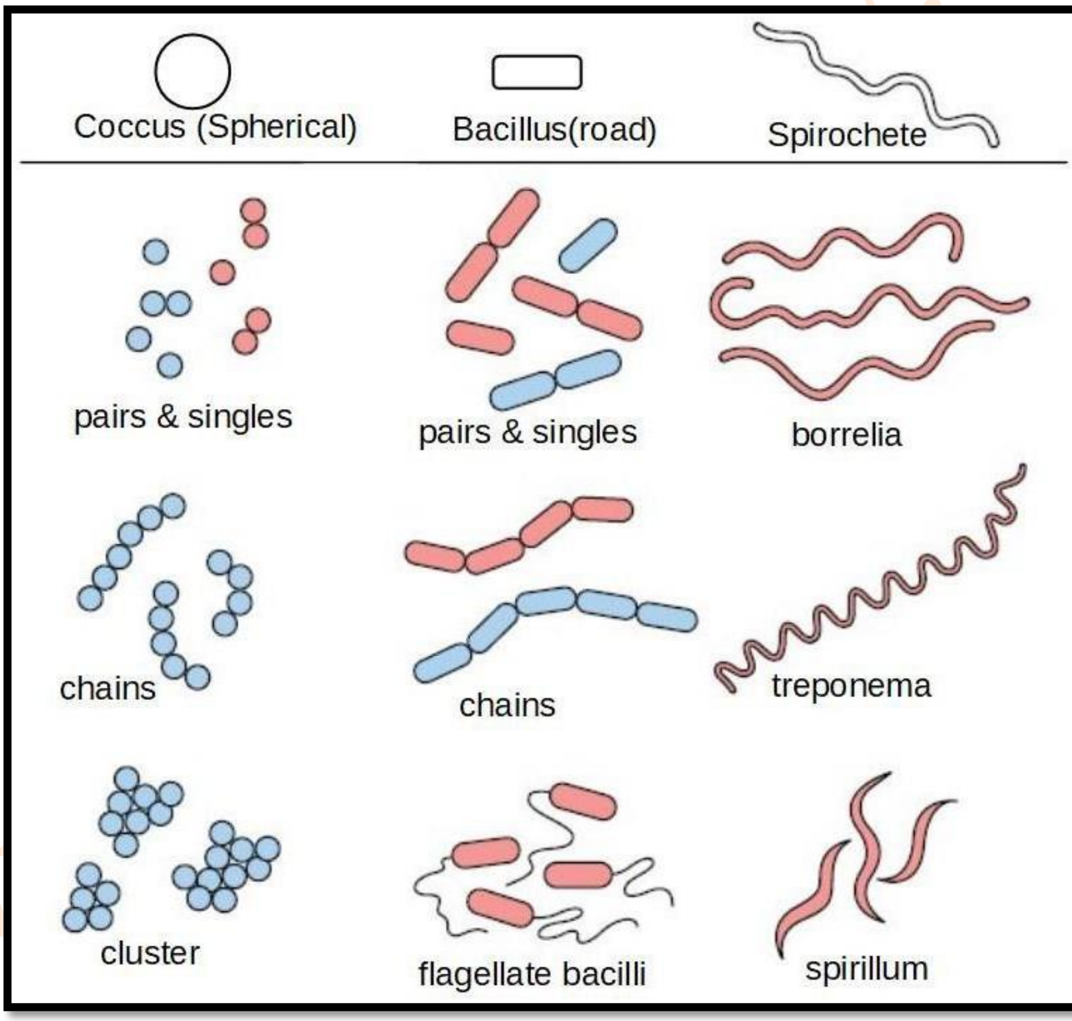


Figure.19: Basic bacterial shape and their clustering

Bacterial cell wall

- Besides their shape bacteria can be classified based on their cell wall composition. One of these ways is whether they are retaining dyes during Gram's stain (Figure 2.6). In this case, bacteria can be categorized into two:

- **Gram-positive** – Gram-positive bacteria have a distinctive purple appearance when observed under a light microscope following **Gram staining**. This is due to retention of the purple crystal violet stain in the thick peptidoglycan layer of the cell wall. Examples of Gram-positive bacteria include **all staphylococci**, all **streptococci** and some **listeria** species.
- **Gram-negative** – Gram-negative bacteria **lose the crystal violet** stain (and take the color of the red counterstain) in Gram's Method of staining. This is characteristic of bacteria that have a cell wall composed of a thin layer of a particular substance (called **peptidoglycan**).

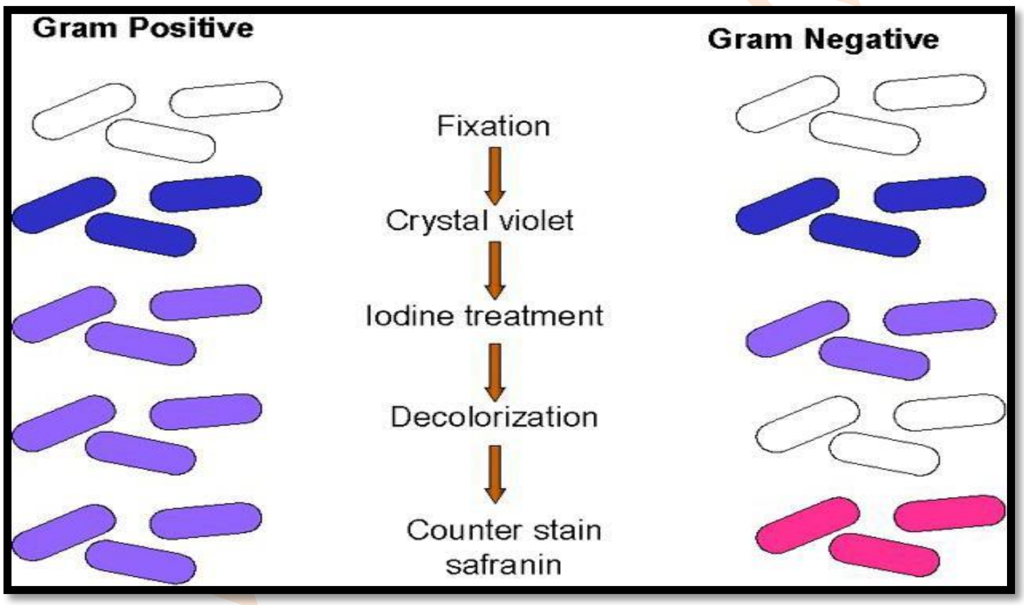


Figure 20: Gram staini

2.2.2 Archaea

- **Archaea** are inhabitants of some of the most extreme environments on the planet. Diversity of methanogens exists within the domain Archaea. Methanogens are among the oldest microbes on Earth and have a tremendous impact on our biosphere. Methanogens in nature promote the anaerobic decomposition of organic matter by consuming the products of fermentative and syntrophic metabolisms.

Methanogens release methane as a waste product, and this methanogenesis is a natural part of Earth's carbon cycle. Though **archaea** (Figure 2.7) are involved in many important ecological processes and present across

Earth's ecosystems, they are most known for being **extremophiles**, existing in conditions that prevent most organisms from functioning

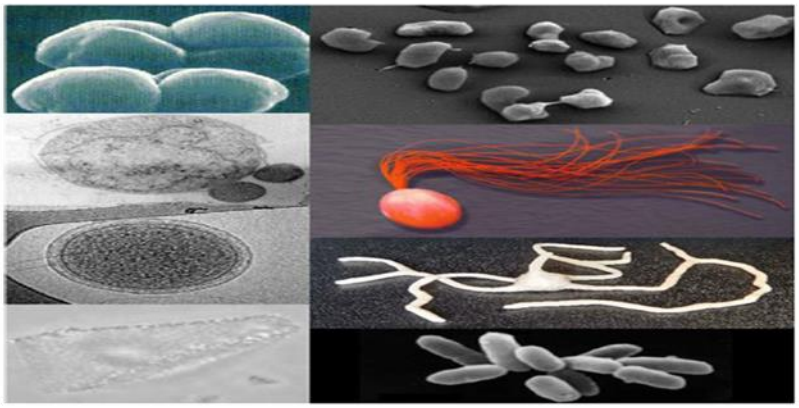


Figure21 Diversity of Archaea.

In Ethiopia *extreme thermophiles* of archaea are expected to live in places like *Danakil Depression (Dallol), Lake Basaka (Basaqaa), Gargdi, Filwoha, Sodere, Wondo Genet, Woliso*, and *Lake Abijata*. The hot spring temperature found in Ethiopia varies with season ranging from 42-98 ^{O}C

Importance of archaea

- Because of their tolerance to high temperatures and relatively extreme environments, some members of the domain have already been exploited for a wide variety of commercial uses.

A. These Archaea become the source of enzymes that are usually added to detergents in order to help it maintain its activity even at higher temperature and pH.

B. Some enzymes from Archaea are also used to convert cornstarch into the fiber *dextrin*.

C. Some Archaea also bear the potential for bioremediation or help in cleaning contaminated sites.

D. The thermophilic Archaea, Thermus aquaticus, is an essential part of the development of molecular biology as a science. As a result, Archean has become the source of the enzyme harnessed as the basis for the amplification of the DNA in a technique called Polymerase Chain Reaction (PCR).

2.2.3 Fungi

- **Fungi** (singular: **fungus**) are **eukaryotic**, organisms whose cells have a distinct nucleus containing the cell's genetic material (DNA), surrounded by a special envelope called the *nuclear membrane*. Organisms in the Kingdom Fungi may be unicellular or multicellular.

- Large multicellular fungi, such as mushrooms, may look somewhat like plants, but unlike most plants, fungi cannot carry out photosynthesis. True fungi have cell walls composed primarily of a substance called *chitin*. The unicellular forms of fungi, *yeasts*, are oval microorganisms that are larger than bacteria. The most typical fungi are *molds*.
- Molds form visible masses called mycelia, which are composed of long filaments (hyphae) that branch and intertwine. The cottony growths sometimes found on bread and fruit are mold mycelia. Fungi can reproduce sexually or asexually. They obtain nourishment by absorbing organic materials from their environment, whether soil, seawater, freshwater, or an animal or plant host. Organisms called slime molds are actually ameba-like fungi grown on decayed plant and wet areas.

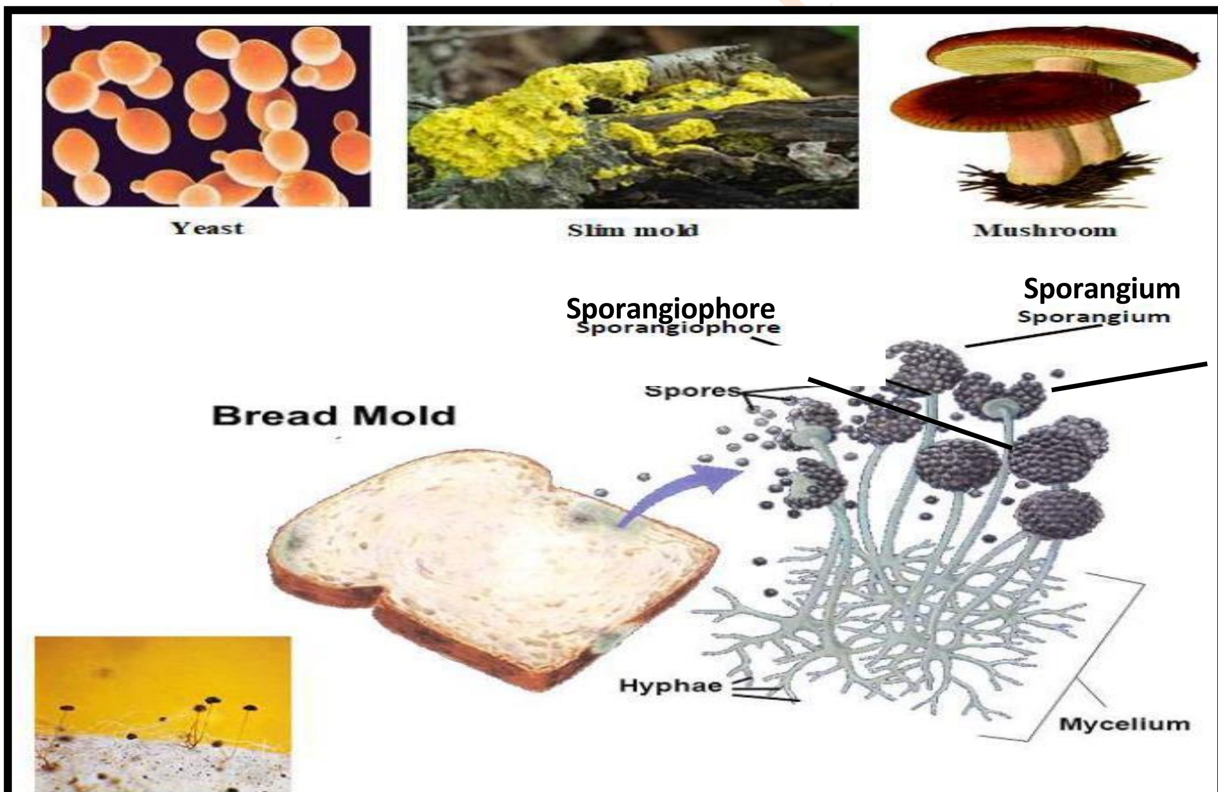


Figure 22 Different forms of Fungi

- Fungi play a crucial role in the balance of the ecosystems. They colonize most habitats on earth, preferring dark, moist conditions. In these environments, fungi play a major role as decomposers and recyclers and making it possible for members of the other kingdoms to be supplied with nutrients and to live. Inevitably, the food web would be incomplete without organisms that decompose organic matter.
- Apart from this benefit, fungi cause disease and immense economic losses. Their harmful activities as saprotrophs include damage to timber, fuel, food, and manufactured goods. As parasites, they cause heavy crop losses and diseases of humans and domestic animals. The beneficial activities of yeasts and other fungi, however, are also of great economic significance. They have long been exploited as food, as a component in the processing of food, and as biological mechanisms in the process of alcohol production and traditional fermentation. For example, their role in Enjera (Buddeenaa), Tej (Daadhii), Tella (Farsoo), and Kocho fermentation. In the present century, as the fermentation industry has developed, the applications of fungi have produced an increasing range of valuable products, including antibiotics and other drugs of great pharmaceutical value, agricultural fungicides and plant growth regulators, vitamins and enzymes.
- Recently, with the advent of genetic manipulation, fungi are being used to produce hormones and proteins which is available only from mammals. The utilization of fungi to benefit humans can be regarded as a part of biotechnology.

Figure 9. Some Ethiopian traditional fermented products (A= staple foods; B, beverages; and C, condiments)

Figure 10. Fungal diseases affecting human and plants

2.2.4 Protozoa

- **Protozoa** (singular: **protozoan**) are unicellular eukaryotic microscopic animals which may be free-living or parasitic, and/or get their energy from the organic carbon. Some of them are free- living and the others are parasitic in nature. All protozoa contain a "true," or membrane-bound, nucleus and membrane-bounded organelles within their cytoplasm. Protozoa contain flagella, cilia, or pseudopodia means they are motile (Figure 11). Amebae move by using extensions of their cytoplasm called *pseudopods* (false feet). Other protozoa have long *flagella* or numerous shorter appendages for locomotion called *cilia*.

- Protozoa have a variety of shapes and live either as free entities or as *parasites* (organisms that derive nutrients from living hosts) that absorb or ingest organic compounds from their environment. Some protozoa, such as *Euglena*, are photosynthetic. They use light as a source of energy and carbon dioxide as their chief source of carbon to produce sugars. Protozoa can reproduce *sexually or asexually*.

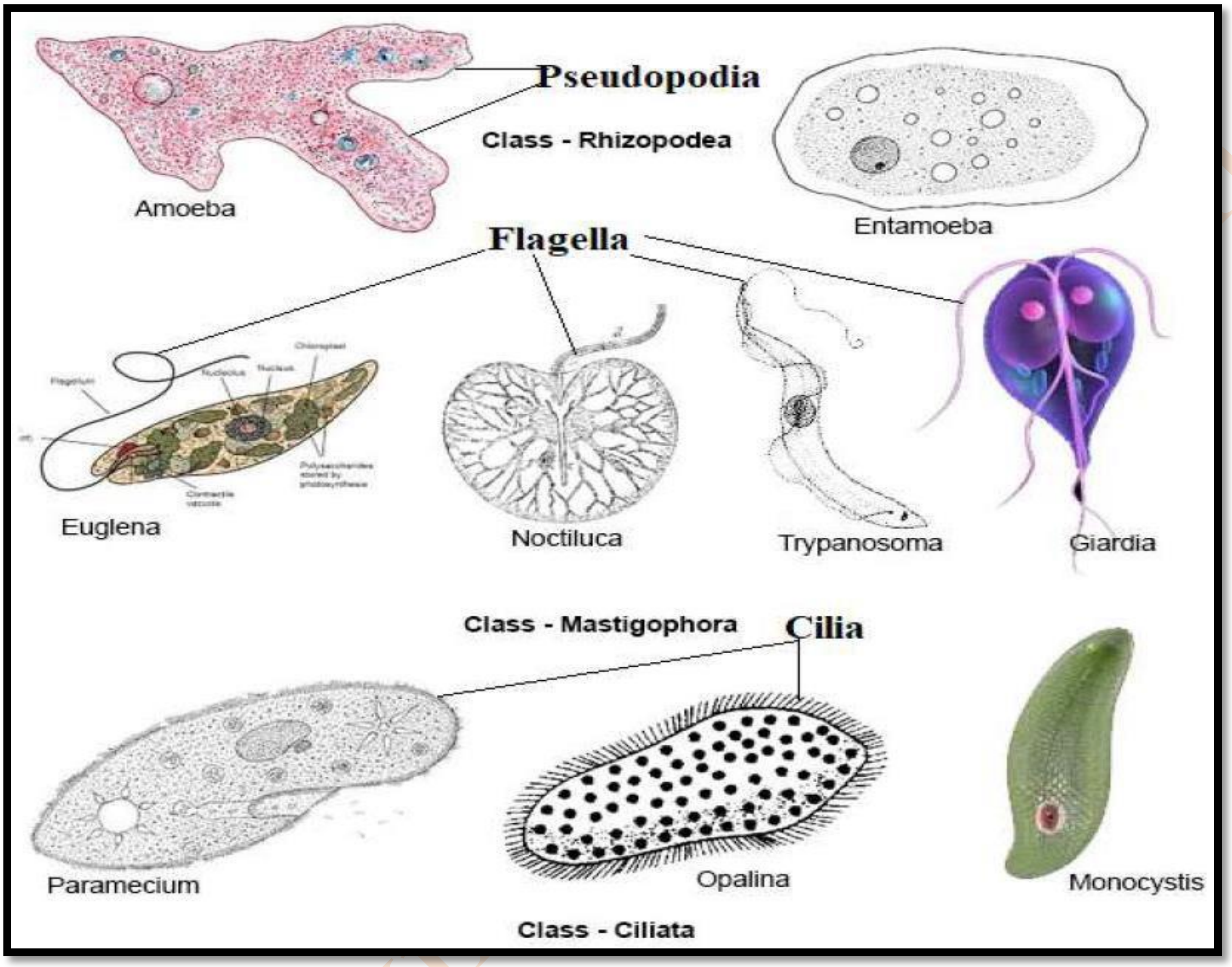


Figure 11. Common protozoa

- Most **protozoa** living in the environment are not **harmful**, except for the disease-producing **protozoa**. Many types of **protozoa** are even **beneficial** in the environment because they help make it more productive. They improve the quality of water by eating bacteria and other particles. However, some are able to multiply in humans, which contribute to their survival and permits serious infections to develop from just a single organism. For example, Malaria, African trypanosomiasis, Chagas disease, Leishmaniosis, Toxoplasmosis, and Cryptosporidiosis are diseases caused by a protozoon.

Table 1. Major protozoal parasites of human and other organisms

Disease	Some Representative Etiological Agents	Geographical Localization	Clinical Features
Malaria	*Plasmodium falciparum,* *P. vivax*	Over 100 countries in the tropic and subtropics	**Fever, shivering, cough, respiratory distress, pain in the joints, headache, watery diarrhea, vomiting, convulsions, severe anemia**
African trypanosomiasis	*Trypanosoma brucei*	36 countries in sub- Sahara Africa	**Initial haemolytic phase (fever, joint pains followed by neurological disorder, somnolence)**
Chagas disease	*Trypanosoma cruzi*	From northern Mexico to South Argentina	**Acute phase (fever and splenomegaly) Chronic phase (irreversible damage to heart, esophagus and colon)**
Leishmaniasis	*Leishmania donovani,* *L. major, L. mexicana,* *L. braziliensis*	Over 88 countries in tropic and subtropics	**Skin ulcers, mucocutaneous complications and visceral diseases (hepatosplenomegaly)**
Toxoplasmosis	*Toxoplasma gondii*	Worldwide	**Blindness and mental retardation can result in congenitally infected children. Immunosuppressed patients can present more severe symptoms: splenomegaly, polymyositis, dermatomyositis, chorioretinitis, myocarditis, pneumonitis, hepatitis, encephalitis, and multisystem organ failure.**
Trichomoniasis	*Trichomonas vaginalis*	Worldwide	**Vaginal discharge, odor and edema or erythema**
Intestinal protozoan	***Giardia lamblia,*** ***Entamoeba histolytica,*** ***Cryptosporidium parvum,*** ***Cyclospora cayetanensis***	**Worldwide**	**Hematuria, anemia, impaired growth. Renal, hepatic and spleen failure**

- Therefore, protozoa cause serious diseases to **human beings and other domestic animals** including; Cattles, Equids, Poultry, and fishes. The disease they causes include:

❖ **Giardiasis** is a diarrheal disease caused by the microscopic parasite ***Giardia duodenalis*** (or "Giardia" for short). Once a person or animal has been infected with Giardia, the parasite lives in the intestines and is passed in stool (poop). Once outside the body, Giardia can sometimes survive for weeks or even months.

❖ **Amoebiasis**, a type of gastro, is a cause of diarrhoea. It is caused by a parasite known as *Entamoeba histolytica* that infects the bowel. Amoebiasis most commonly affects young to middle-aged adults. Proper handwashing helps prevent the spread of amoebiasis.

❖ **Trypanosomiasis** or **trypanosomosis** is the name of several diseases in vertebrates caused by parasitic protozoan trypanosomes of the genus ***Trypanosoma***. In humans this includes **African trypanosomiasis (**Africa sleeping sickness) and **Chagas disease.** In livestock, cattle Trypanosomiasis -Nagana (in Afaan Oromo - Gandii), (Amaharic - Gendi).

❖ Leishmaniasis is a **parasitic disease** that is found in parts of the tropics, subtropics, and southern Europe. It is classified as a neglected tropical disease (NTD). Leishmaniasis is caused by infection with Leishmania parasites, which are spread by the bite of phlebotomine sand flies (Figure 2.12a).

❖ Cutanious leshimaniasis – (In Afaan oromoo-Sinbira halkanii = lamxii), Amharic- Kunchir). Mucocutanious leshimaniasis , Visceral leshimaniasis are some.

Figure 12a. Leishmaniasis and Trypanosomiasis

❖ **Malaria** is a serious and sometimes fatal disease caused by a parasite that commonly infects a certain type of mosquito which feeds on humans. People who get malaria are typically very sick with high fevers, shaking chills, and flu-like illness. Four kinds of malaria parasites infect humans: *Plasmodium falciparum, P. vivax, P. ovale, and P. malariae*. The malaria parasite life cycle involves two hosts. During a blood meal, a malaria-infected female **Anopheles mosquito** inoculates sporozoites into the human host. Sporozoites infect liver cells and mature into schizonts, which rupture and release merozoites (Figure 2.12b).

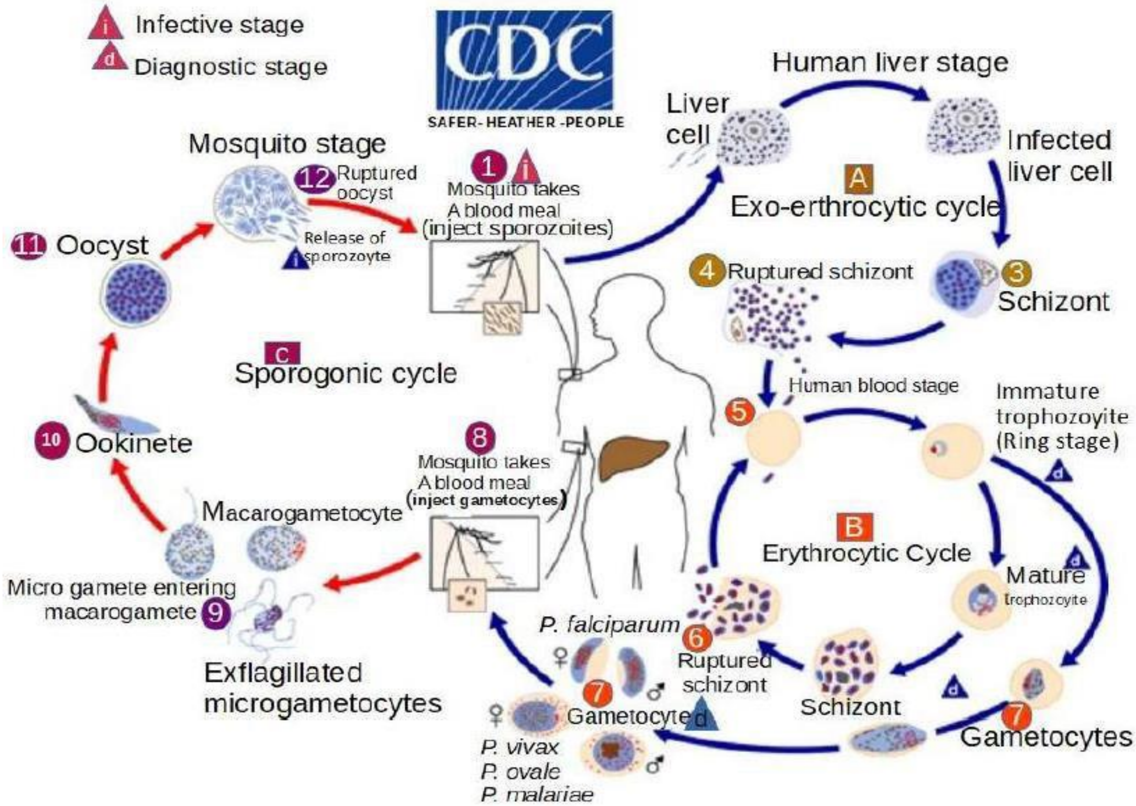


Figure 12b. Malaria parasite life cycle (Source: CDC centers for disease control and prevention).

2.2.5 Virus

- A **virus** is a small parasite particle that cannot reproduce by itself. Once it infects a susceptible cell, however, a **virus** can direct the host cell machinery to produce more viruses. Most viruses have either **RNA** or **DNA** as their genetic material.
- The **nucleic acid** may be single-stranded (ss) or double-stranded (ds). The entire infectious virus particle, called a **virion**, consists of the nucleic acid and an outer shell of protein called **capsid**. The simplest viruses contain only enough RNA or DNA to encode four proteins. The most complex can encode 100 – 200 proteins.

Characteristics of virus

- Viruses have an inner core of nucleic acid surrounded by protein coat known capsid

- Most viruses range in sizes from 20 – 250 nm
- Viruses are inert outside their host cell.
- Viruses are obligate intracellular parasites and filterable agents
- Virus occupy a space in between living and non-living, because they are crystallizable and non-living outside the body of host.
- Viruses depend fully on the host's cell machinery to continue their life – metabolically inefficient.
- They are responsible for a number of dreadful diseases in human and plants.

Structure of viruses

- A basic structure of virus is nucleic acid core (either DNA or RNA but not both) surrounded by protein coat (Figure 2.13). Central core of nucleic acid of a virus is called **genome** and the protein coat surrounding is called **capsid**. In some virus, an **envelope** made up of glycoprotein and phospholipid bilayer is present outside the capsid.

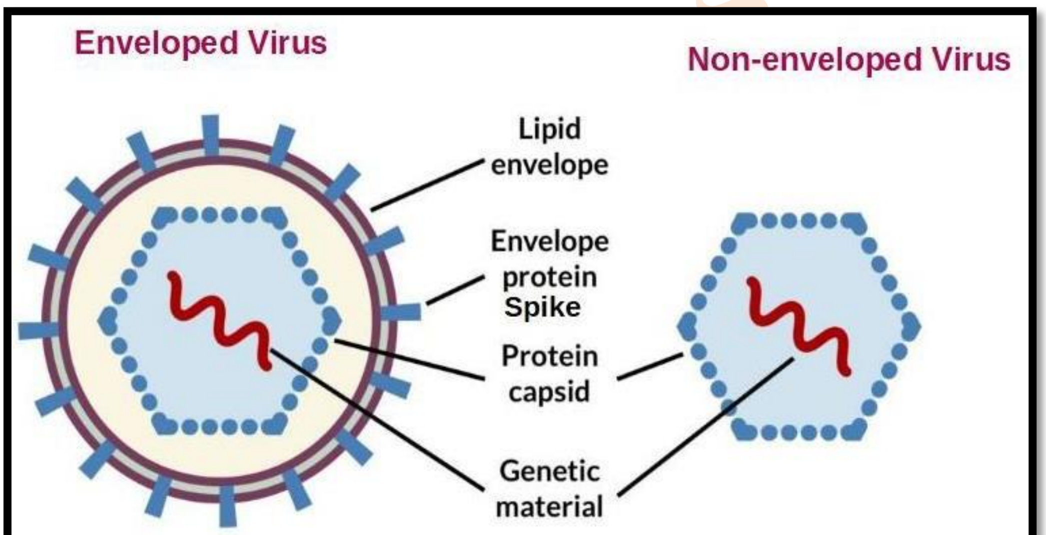


Figure 13. Viral Structure:Source:Ispersa 2022

The basic structural components of viruses are

1. Genome:

- Virus contains either DNA or RNA as genetic material but not both. Virus which contains DNA as genetic material are called DNA virus and those containing RNA are called RNA virus. Unlike other living cell where ds DNA is always a genetic material, a viral genome may consist of linear or circular ds DNA, single stranded DNA, ss linear RNA or ds linear RNA.

- Examples; Reovirus is a RNA virus which contains ds RNA genome. Parvovirus contains ss DNA, Papovavirus contains ds circular DNA as genetic materials.

2. Capsid:

- Capsid is the outer layer of viruses. Sometime it is referred as coat or shell. Capsid serves as impenetrable shell around the nucleic acid core. Capsid also helps to introduce viral genome into host cell during infection. The protein coat or capsid is made up of number of morphological similar sub units called capsomere. Each capsomere is further composed of protomer. Capsomeres are arranged precisely and tightly together in a repetitive pattern to form complete capsid. The number of capsomeres in a capsid varies from virus to virus. The complete complex of nucleic acid and protein coat of a virus particle is called as virus nucleocapsid. Structure of capsid gives the symmetry to the virus. Virus particle may be helical**,** icosahedral or spherical, complex in symmetry.

3. Envelope:

- Some virus contains envelope that surrounds nucleocapsid. The virus without envelope is called naked virus. The envelope is a bilayer of lipoprotein and glycoprotein. The envelope is acquired by the progeny virus from host cell during virus release by budding process. In some virus the glycoprotein projects out in the form of spike called peplomer. Some of the peplomers or glycoprotein spike such as Hemagglutinin and Neuraminidase which are involved in binding of virus to host cell.

4. Enzymes:

- Some viruses contain enzymes which play a central role during the infection process. E.g., Some bacteriophage contains an enzyme **lysozyme**, which makes small hole in bacterial cell that allows viral nucleic acid to get in. Some virus contains their own nucleic acid **polymerase** which transcribe the viral genome into mRNA during replication process. E.g., Retroviruses are RNA viruses that replicate inside the host cell as DNA intermediate. These viruses possess an **RNA dependent DNA polymerase** called **reverse transcriptase**.

Viral symmetry

1. Helical symmetry

- There are several viruses found with a **helical** morphology. These viruses consist of identical protein subunits or protomers which assembled in a **helical** structure around the genome. This type of protein subunits generally forms a rigid nucleocapsid. Moreover, the helical structure provides flexibility to the filaments. The most common example of a helical virus is the tobacco mosaic virus (Figure 2.14). Apart from that Sendai virus is also reported to have a helical structure.

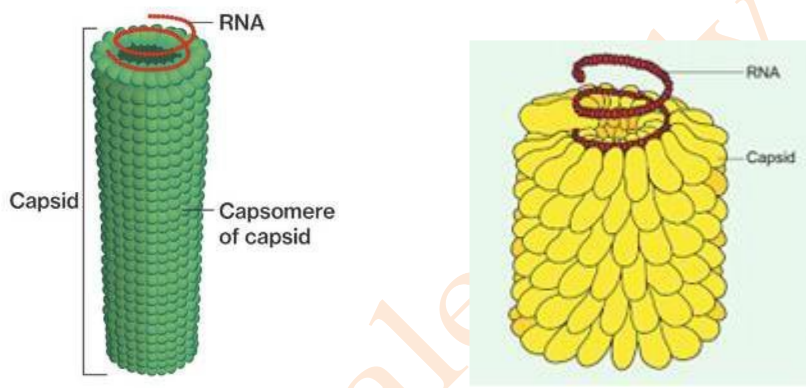


Figure 14. Tobacco mosaic virus .Source: BioNinja)

2. Icosahedral Symmetry

- An icosahedron structure refers to a type of **polyhedron** with 20 equilateral triangular faces and 12 vertices. The rigid structure provides protection to the genome (Figure 2.15). The common examples of viruses reported to have an icosahedral structure are papovavirus, picornavirus, adenovirus, toga virus, etc.

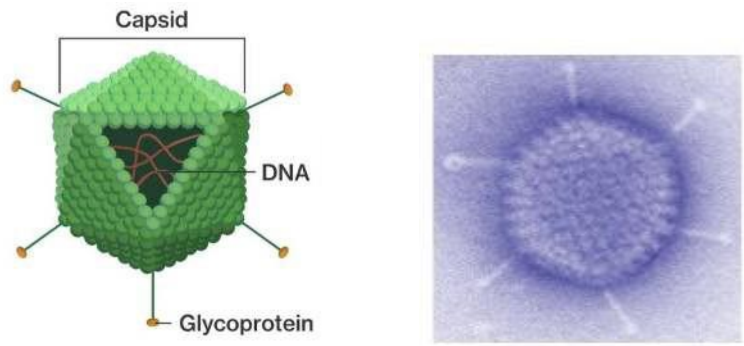
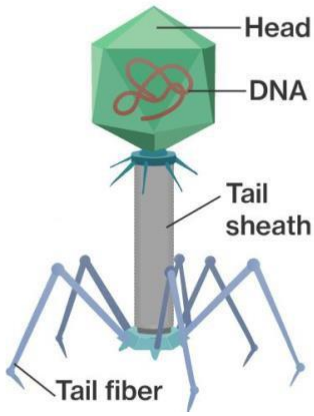


Figure 15. Adenovirus .Source: BioNinja)

3. Complex Symmetry

- These groups of viruses do not come under the above-motioned groups. These viruses consist of complex structural components which made it different from the other two groups (Figure 2.16). A common example of this group of the virus is the bacteriophages.



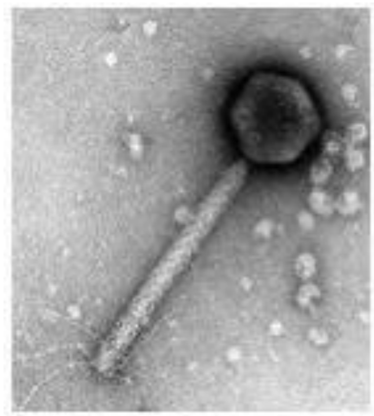


Figure16. Bacteriophages.Source: BioNinja)

Difference between DNA & RNA Viruses

A. The genetic material of a virus can be either DNA or RNA.
B. The viruses that contain DNA as their genetic material are called the DNA viruses.
C. RNA viruses, on the other hand, contain RNA as their genetic material.
D. DNA viruses are mostly double-stranded while RNA viruses are single-stranded.
E. RNA mutation rate is higher than the DNA mutation rate.
F. DNA replication takes place in the nucleus while RNA replication takes place in the cytoplasm.
G. DNA viruses are stable while RNA viruses are unstable.

- Viruses infect all cellular life forms: eukaryotes (vertebrate animals, invertebrate animals, plants, fungi) and prokaryotes (bacteria and archaea). The viruses that infect prokaryotes are often referred to as bacteriophages, or phages for short. HIV (human immunodeficiency virus) is a virus that attacks the body's immune system. If HIV is not treated, it can lead to AIDS (acquired immunodeficiency syndrome). Learning the basics about HIV can keep you healthy and prevent HIV transmission

Common viral diseases in Ethiopia

- A **viral disease** is any condition that's caused by a **virus**. There are several types of **viral disease**, depending on the underlying **virus**. Ethiopia is endemic for many viral diseases. Serosurveys have demonstrated the high prevalence rate of **hepatitis B virus**. There are also indications of high transmission for **hepatitis C**, **hepatitis E** and **human immunodeficiency virus (HIV)**. The population is exposed to **poliomyelitis**, **hepatitis A**, **measles**, **rubella** and **mumps** early in life. **Rotaviral diarrhoea** is an important cause of infant morbidity and mortality. Vast areas of the country are endemic for **yellow fever** and **rabies**. The extent of many other viral diseases in the country is unknown.

2.3 Reproduction in microorganisms

- Cellular microbes replicate asexually and/or sexually. In **asexual reproduction**, a single microbe produces two identical offspring (clones) without the help of a partner. In **sexual reproduction**, two microbes mix their genetic information and so their offspring are genetically different.

2.6.1 How prokaryotes replicate

- Bacteria and archaea reproduce asexually by splitting one cell into two equal halves in a process called **binary fission** (Figure 2.17). Before a cell divides, it must first replicate the genome so that each daughter cell gets a copy of the DNA instruction manual. Prokaryotes do not undergo sexual reproduction, but they are able to exchange genetic information through other processes.

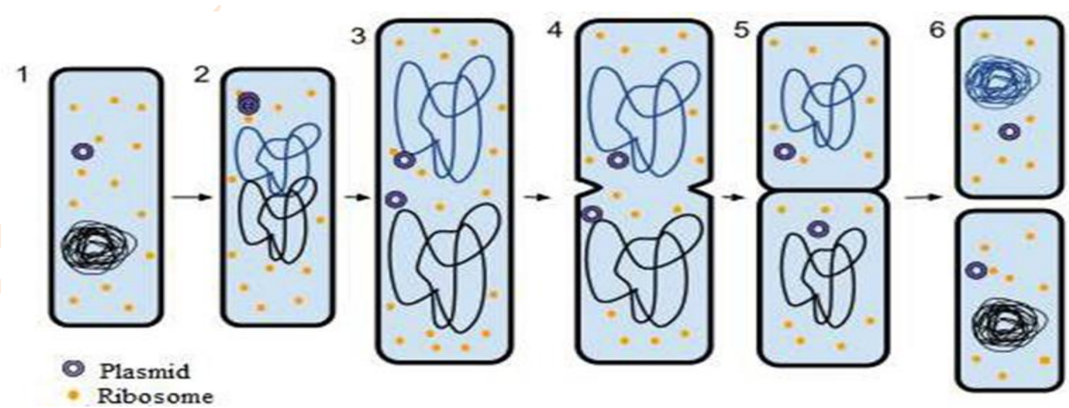


Figure 17. The stages of binary fission in prokaryotic cell replication The diagram above shows the process of binary fission.

A. The parent cell contains a large circular chromosome and a smaller plasmid.

B. The chromosome and plasmid are replicated

C. A copy of the chromosome and plasmid move to each end (pole) of the cell.

D. The cell wall begins to grow inwards at the middle point (septation).

E. The growing cell walls meet in the middle to form a septum.

F. The cells separate into two identical daughter cells (cytokinesis).

- Under optimal growth conditions, the bacterium *Escherichia coli* divides once every 20 minutes. If it takes 20 minutes for a single cell to divide and produce two cells: after 40 minutes there will be 4 cells; after 6 hours there will be 262,144 cells; after 12 hours the population will soar to 68,719,476,736 cells.

- During **conjugation**, DNA is directly transferred from one prokaryote to another by means of a conjugation pilus, which brings the organisms into contact with one another. In *E. coli*, the genes encoding the ability to conjugate are located on a bacterial plasmid called the F plasmid, also known as the fertility factor, and the conjugation pilus is called the F pilus. The F-plasmid genes encode both the proteins composing the F pilus and those involved in rolling circle replication of the plasmid. Cells containing the F plasmid, capable of forming an F pilus, are called F+ cells or donor cells, and those lacking an F plasmid are called F− cells or recipient cells (Figure 18).

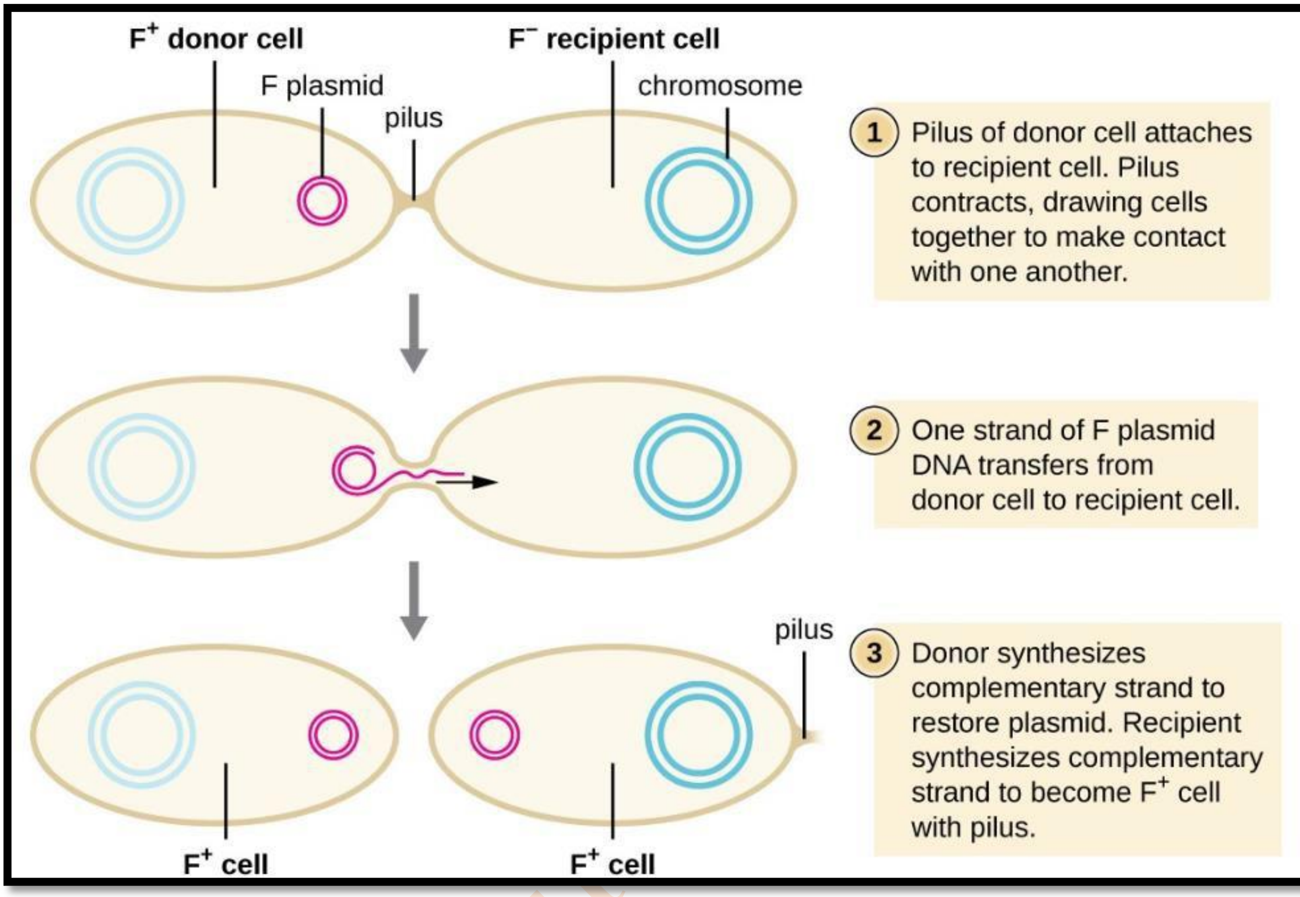


Figure 18. Bacterial reproduction by Conjugation. Source: OpenStax Microbiology. Provided by: OpenStax CNX

2.6.2 How eukaryotic microbes replicate

- Many unicellular fungi, like the Brewer's yeast *Saccharomyces pombe*, also replicate asexually by a process similar to binary fission. In eukaryotes the DNA genome is packaged in chromosomes within the nucleus and so the process of asexual replication in yeast looks a bit more complicated than binary fission in prokaryotes. The first step is to replicate the chromosomes to form two copies of each chromosome (two sets of sister *chromatids*), which are then separated to the two poles of the cell via the process of mitosis (Figure 19).

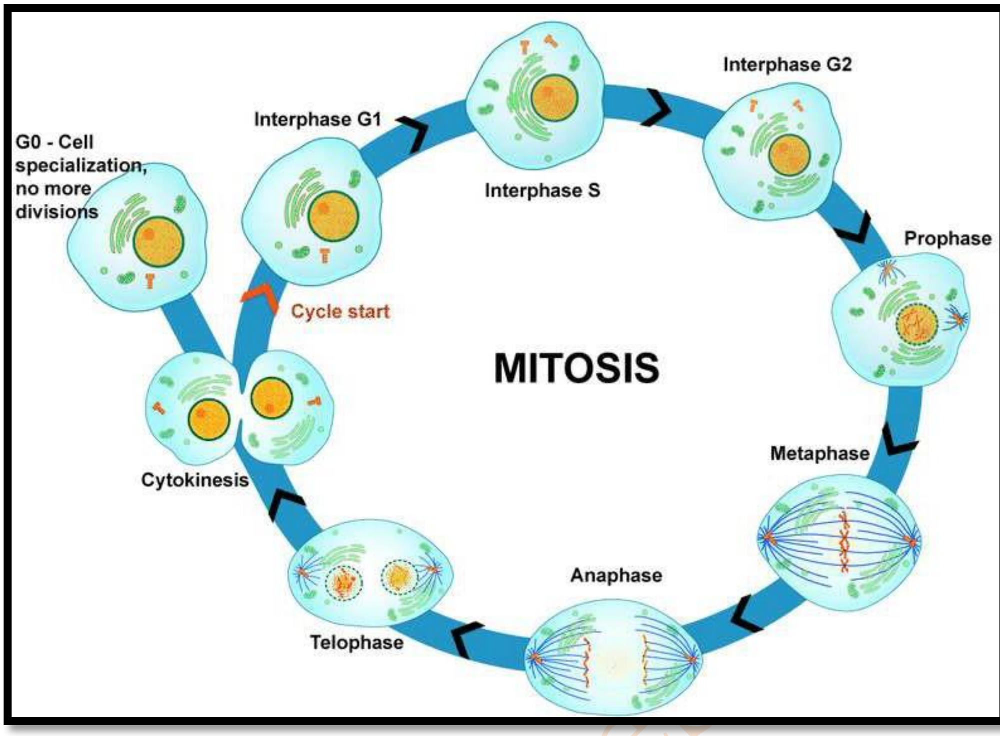


Figure 19. The stages of mitosis in eukaryotic cell replication. Source: The LibreTexts libraries)

The diagram above shows the process of mitosis in eukaryotic cells.

A. The chromosomes condense and the mitotic spindle begins to form (prophase).

B. The nuclear envelope disintegrates, and the chromosomes bind to microtubules in the mitotic spindle (prometaphase).

C. The chromosomes align in the middle of the cell (metaphase).

D. The two sister chromatids separate and move to the opposite poles of the cell (anaphase).

E. Two new nuclear envelopes form (telophase).

F. The cell divides into two identical daughter cells (cytokinesis).

- Other unicellular fungi, like the bakery yeast (*Saccharomyces cerevisiae)*, replicate in a different asexual process called **budding**. A daughter cell grows out as a small bud from the mother cell, which starts to replicate the chromosomes via mitosis. The daughter cell receives one of the two nuclei generated via mitosis and a few membrane-bound organelles and then

- separates, leaving a scar on the surface of the mother cell (Figure 2.20). Under conditions of stress, some yeasts can switch from asexual to sexual reproduction

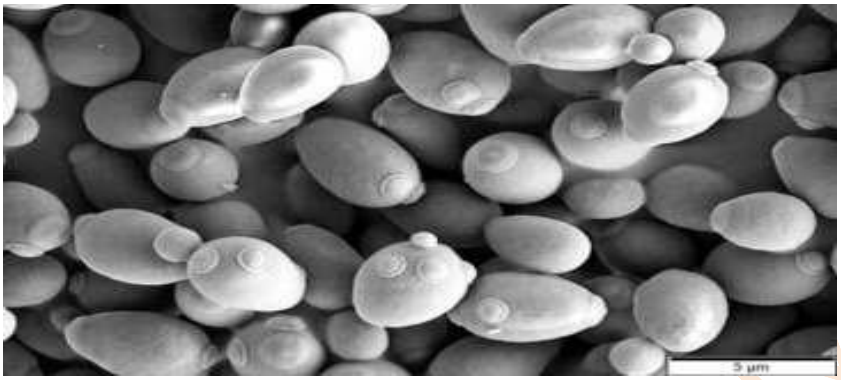


Figure 20. Scanning electron micrograph (SEM) image of Baker's yeast (*Saccharomyces cerevisiae*)

2.6.3 How viruses replicate

- In order to replicate, viruses need to infect a host cell and hijack the host machinery to make many copies of the viral genome, and lots of viral proteins which are then assembled into new virus particles (Figure 2.21). There are six main stages in a typical virus replication cycle

A. **Attachment** of the virus to a host cell,

B. **Penetration** of the host cell;

C. **Uncoating** of the viral genome;

D. **Replication** of viral genome and production of viral proteins;

E. **Assembly** of new virus particles;

F. **Release** of new virus particles from the cell.

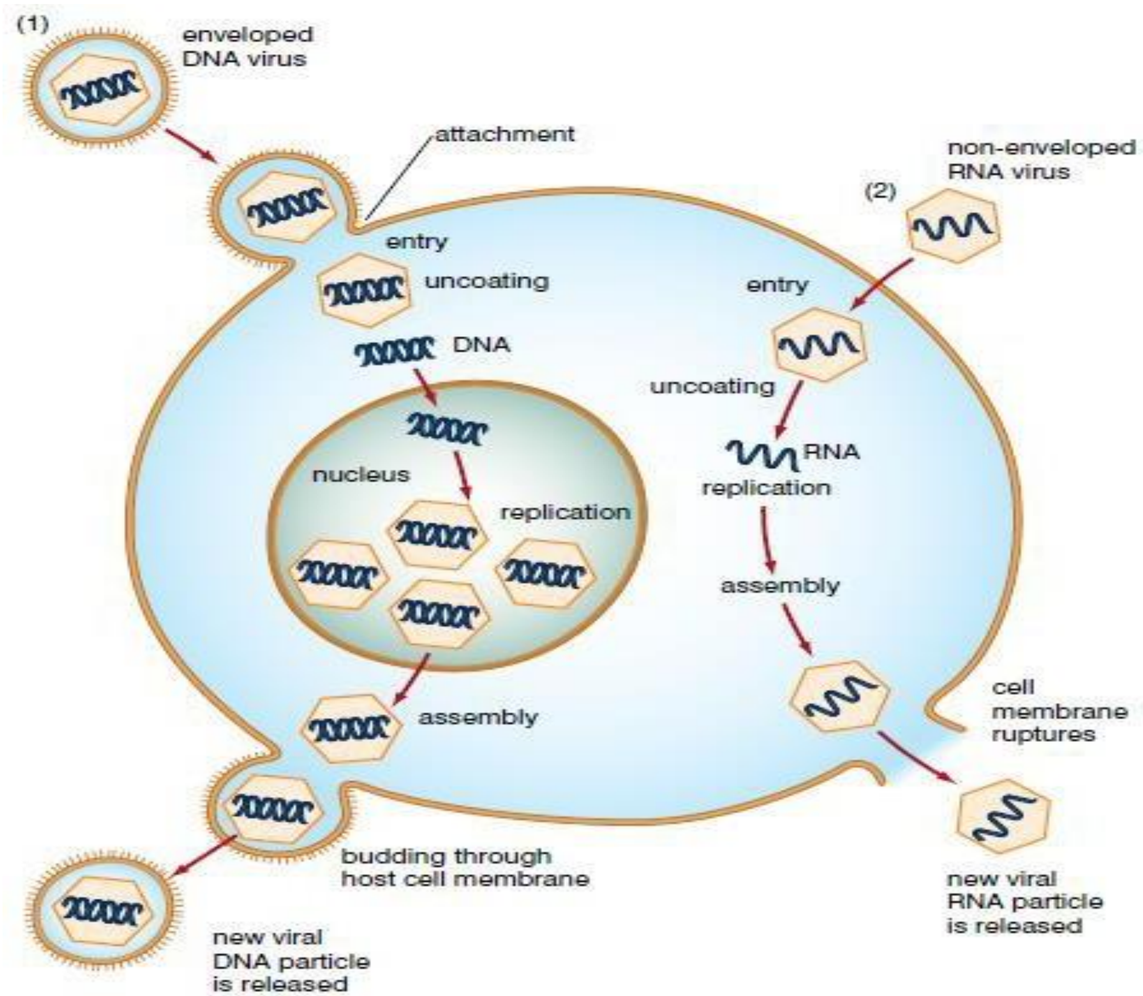


Figure 21. Stages of viral infection.

2.4 Economic importance of microorganisms

- Through the years, microbiologists have made great steps in discovering how microorganisms work, and application of this knowledge has greatly advanced human health and welfare. Besides understanding microorganisms as agents of disease, microbiology has made great advances in understanding the important role that microorganisms play in food and agriculture, and microbiologists have been able to exploit microbial activities to produce valuable products, generate energy, and clean up the environment.

2.4.1 Agriculture

- Microorganisms play an important role in agriculture. The microorganisms include bacteria, fungi, algae, protozoa, viruses. Microorganisms help in organic matter decomposition, humus formation.
- The important role of microorganisms includes – Nitrogen fixation, phosphate solubilization, potassium mobilization, antagonism towards pathogens, and pests. Hence, the role of microorganisms in agriculture is indispensable.
- The chemical elements carbon, nitrogen, oxygen, sulfur, and phosphorus are essential for life and abundant, but **not necessarily in forms that organisms can use.** Therefore, microorganisms are primarily responsible for converting these elements into forms that plants and animals can use. Microorganisms, especially bacteria and fungi, return carbon dioxide to the atmosphere when they decompose organic wastes and dead plants and animals. Algae, cyanobacteria, and higher plants use the carbon dioxide during photosynthesis to produce carbohydrates for animals, fungi, and bacteria. Nitrogen is abundant in the atmosphere but in a form not usable by plants and animals. Only bacteria can naturally convert atmospheric nitrogen to a form available to plants and animals (nitrate) (Figure 22).

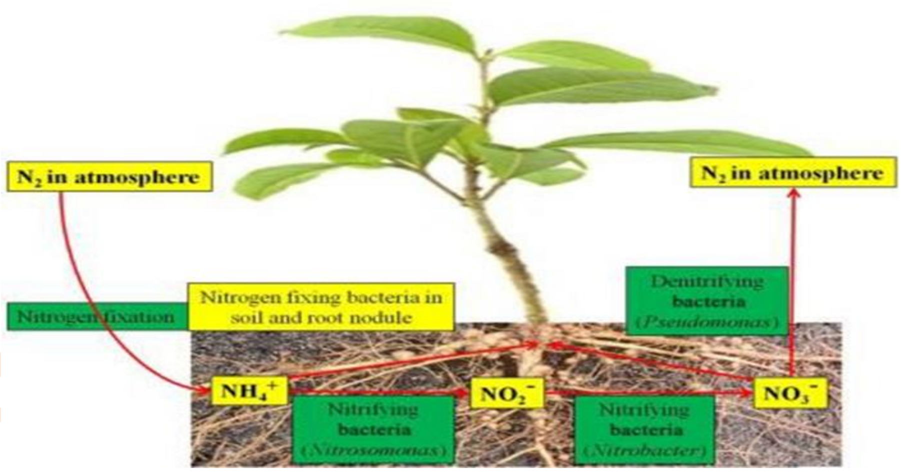


Figure 22. The role of micororganisms in agriculture

2.4.2 Sewage treatment

- Anaerobic bacteria are used in wastewater treatment on a normal basis. The main role of these bacteria in sewage treatment is to reduce the volume of sludge and produce **methane gas** from it (Figure 2.23).
- The great thing about this type of bacteria and why it is used more frequently than aerobic bacteria are that the **methane gas**, if cleaned and handled properly, can be used as an **alternative energy source**. This is a huge benefit considering the already high wastewater treatment energy consumption levels. Unlike aerobic bacteria, this type of bacteria is able to get more than enough oxygen from its food source and will not require adding oxygen to help do its job. **Phosphorus removal** from wastewater is another benefit of anaerobic microbes used in sewage treatment.

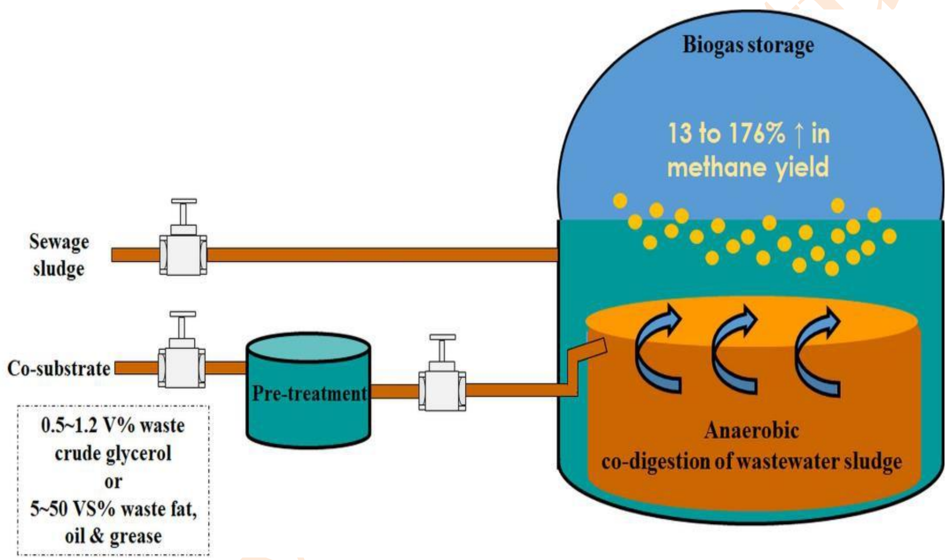


Figure 23. Anaerobic co digestion of waste water. Source: https://doi.org/10.3390/pr8010039

2.4.3 Bioremediation

- Bioremediation is a natural process that relies on microorganisms and plants and/or their derivatives (enzymes or spent biomass) to degrade or alter environmental contaminants as these organisms carry out their normal life functions. Therefore, microbial bioremediation makes use of microorganisms and/or their derivatives (enzymes or spent biomass) to clean-up environmental contaminants.

- It is important to note that microorganisms are everywhere and as such pollutants in the different environmental compartments always come into contact with microorganisms. Microbes break down/transform pollutants via their inherent metabolic processes with or without slight pathway modifications to allow the pollutant to be channeled into the normal microbial metabolic pathway for degradation/and biotransformation.
- Applied bioremediation methods therefore focus on tapping the naturally occurring microbial catabolic capabilities to degrade, transform or accumulate most of the synthetic compounds such as hydrocarbons (e.g., oil), polychlorinated biphenyls (PCBs), polyaromatic hydrocarbons (PAHs), radionuclides and metals. The natural existence of a large diversity of microbial species expands the variety of chemical pollutants that are degraded or detoxified.
- Bioremediation is a natural process; it takes a little time, as an acceptable waste treatment process for contaminated material such as soil. Microbes are able to degrade the contaminant and increase in numbers when the contaminant is present. When the contaminant is degraded, the bio degradative population declines. The residues for the treatment are usually harmless products including water, carbon dioxide, and cell biomass.

2.4.4 Food

- Production of many foods is possible with the help of microorganisms. For example, foods like bread, beer, and cheese are produced with the help of yeasts. Similarly, bacteria are involved in the production of butter (Figure 2.24), yogurt, and many kinds of traditional fermented staple foods, beverages, and condiments of foods of daily life.

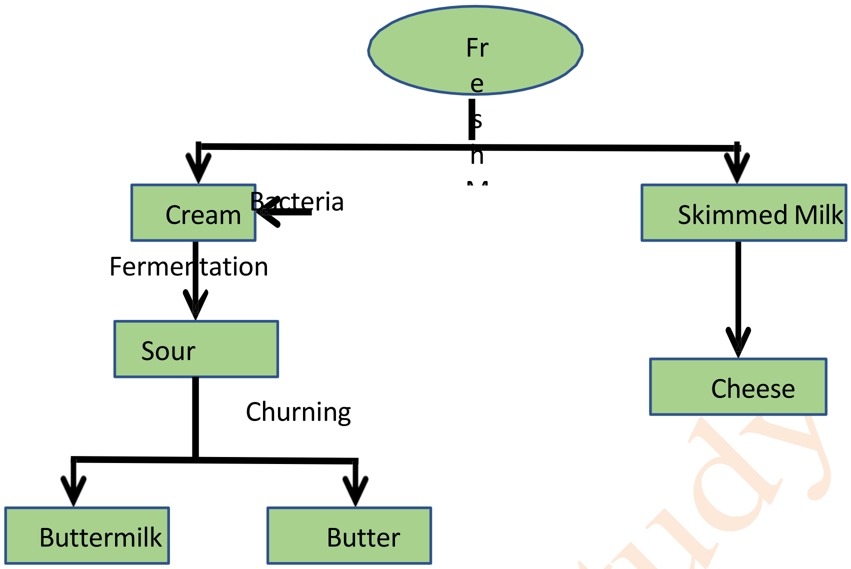


Figure 24. The role of Bacteria in Butter production

2.4.5 Medicine

- It is very difficult to decode the human genome if any disorders occur in it as humans are the eukaryotic organisms. It means their body consists of various types of cells and they are all differentiated into different tissues and organs. Microorganisms have made it **possible to make such medicines** which when enter the body, target the defected genes and make healthy changes in them and they become functional again (Figure 2.25). There is a common example of human insulin. Insulin is a medicine, which is prescribed for the diabetic patients. Now it is possible to synthesize the insulin in microorganisms like bacteria and yeast.
- These microorganisms are inserted in the body in the form of vectors and cure the defected genes. Due to the availability of microorganisms in the environment, scientists have made use of them for making many medicines and drugs, and used them for drug delivery.

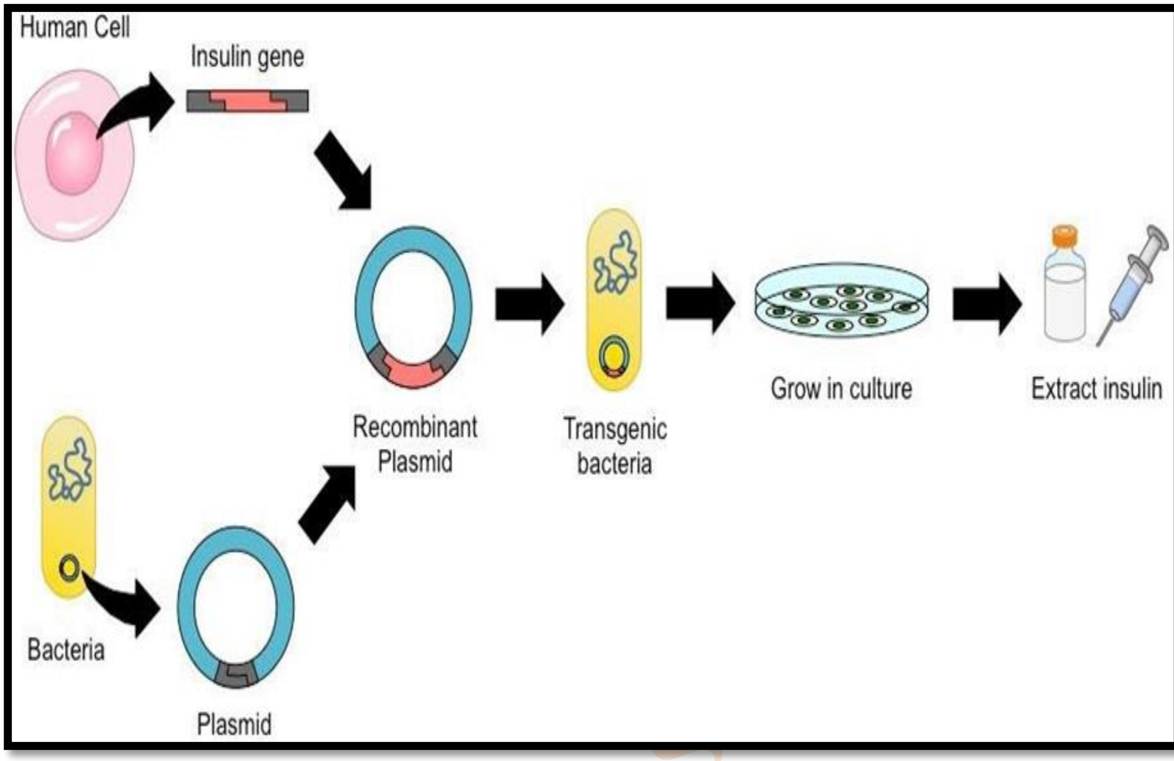


Figure 25. Gene transfer to produce human insulin in bacteria. Source. BioNInja

2.4.5 Health

- People will be surprised if they get to know that their body contains ten times more microorganisms than the body cells. These microorganisms are useful for the body and perform various useful functions, for example, E. *coli* (specie of bacteria) resides in the intestine and releases such components, which help in the digestion of the food. If microorganisms help in performing different body functions, then they also take something from the body that is they take nutrients from the body. One purpose of bacteria in the body is to fight against those harmful bacteria, which can cause diseases. For example, there is also a bacterium in the gut, which helps in synthesizing the vitamins like biotin, vitamin K and folic acid.

2.5 Biotechnology

- Biotechnology is one field which has made use of microorganisms most. By using the techniques of biotechnology, scientists have succeeded in developing human insulin, growth hormones and other useful components of the body. Biotechnological processes use microorganisms for the drug delivery in the form of vectors and plasmids. Microorganisms have provided many beneficial things to agriculture as they are responsible for increasing the fertility of the soil (Figure 2.26). Due to this, the production of the plants increases and economy becomes strong.

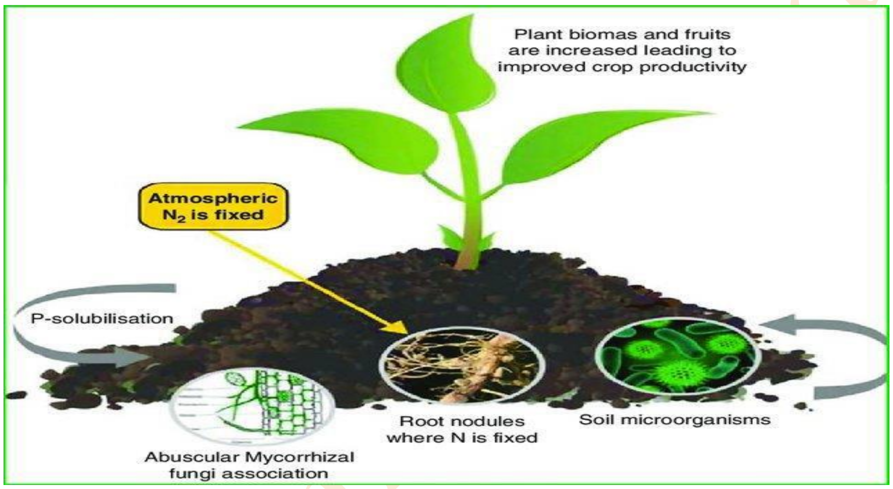


Figure 26. Biofertilizer technology utilizes plant-microbe interactions. Source: Ali *et al.*, 2020).

- Generally, microorganisms (MOs) have a big role in, suppression of soil-borne pathogens, recycling and increased availability of plant nutrients, and degradation of toxicants including pesticides, production of antibiotics and other bioactive compounds, production of simple organic molecules for plant uptake. In addition, MOs are essential in alleviating complexation of heavy metals to limit plant uptake, solubilization of insoluble nutrient sources, and production of polysaccharides to improve soil aggregation
- Bacteria are found in every ecosystem, they are pretty well everywhere around us and inside our body as well! There are ten bacterial cells inside us for every one of our own cells. Most of these are found in the alimentary canal.
- Bacteria are important because they:

- Cause diseases
- Are used in many industrial processes
- Recycle mineral elements such as carbon, nitrogen and sulfur through ecosystems

2.6 The role of bacteria in recycling minerals through ecosystems

- Many bacteria are decomposers. When organisms die, these bacteria break down the complex molecules that are found in the bodies of the dead organisms into much simpler molecules. The bacteria use some of these for their own metabolism, but in the process, they release some minerals (Figure2. 27), in various forms, into the environment.
- Almost, 90% all living organisms are made up of C, O, N and H and these substances are limited in their availability. Thus in order for life to continue the substances should be recycled. This is done by decomposers.

The carbon cycle

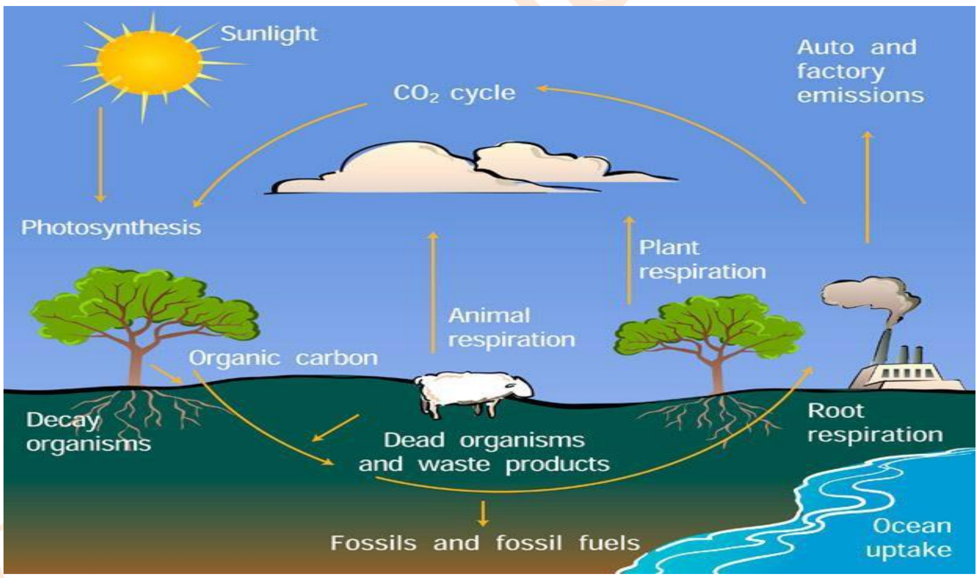


Figure 27. The carbon cycle

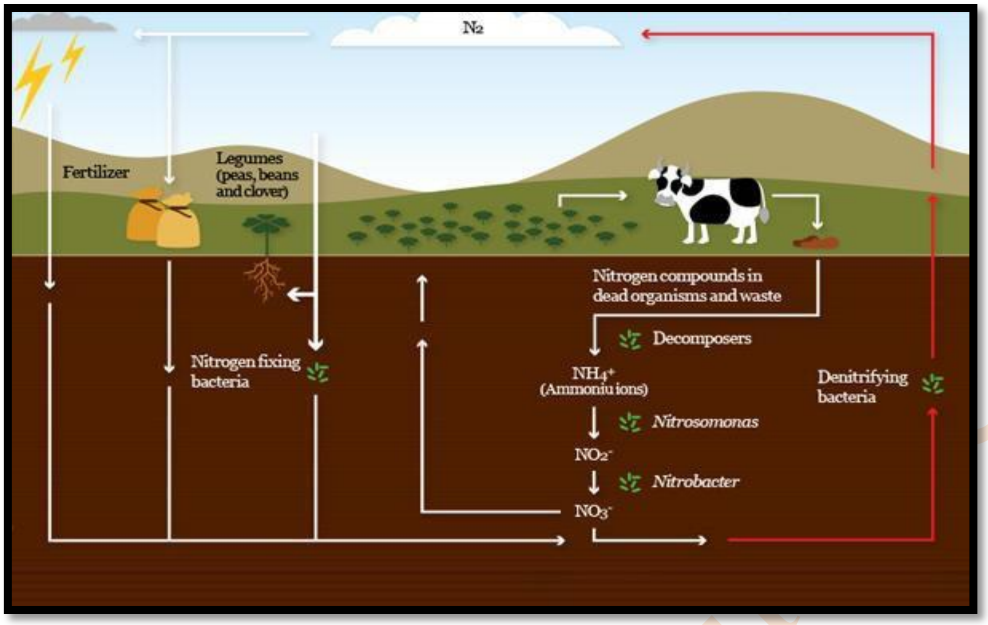


Figure 2.28. The nitrogen cycle

- Root nodules are found on the roots of plants, primarily legumes, which form a symbiosis with nitrogen-fixing bacteria (Figure 2.28). Under nitrogen-limiting conditions, capable plants form a symbiotic relationship with a host-specific strain of bacteria known as rhizobia. Nitrogen fixation in the nodule is very oxygen sensitive.

The sulfur cycle

- Sulfur is found in fewer types of organic molecules than nitrogen, but it is found in many proteins. Table 2 and Figure 29 shows the bacteria involved in the sulfur cycle and the roles they play.

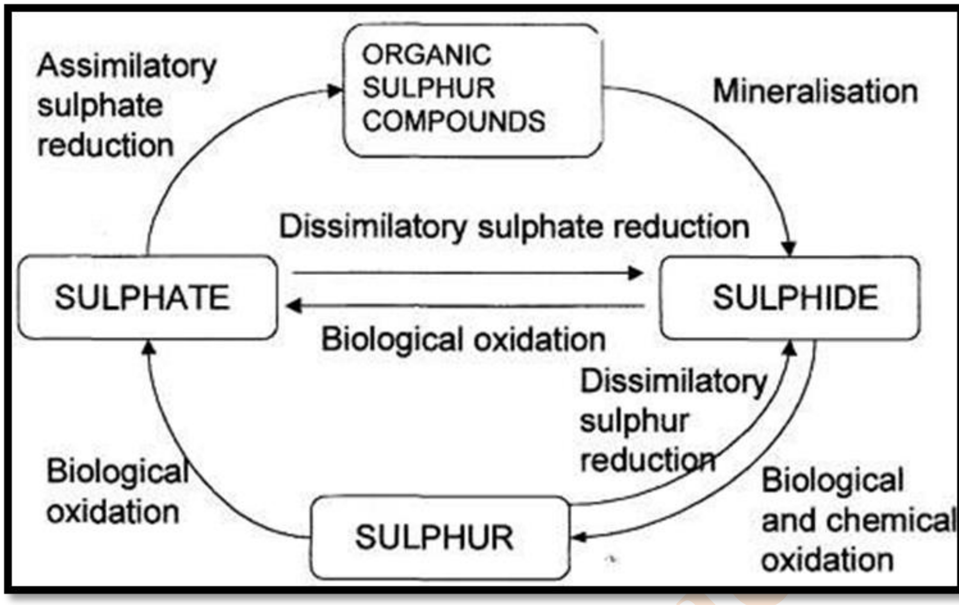


Figure 29. The sulfur cycle

The phosphorus cycle

• Phosphorus (P) occurs in soils as both organic and inorganic forms (Figure 2.30). Phosphorus can be found dissolved in the soil solution in very low amounts or associated with soil minerals or organic materials. The relative amounts of each form of phosphorus vary greatly among soils, with the total amount of P in a clayey-textured soil being up to ten times greater than in a sandy soil.

- **Organic P in soils**. A large number of compounds make up the organic P in soils, with the majority being of microbial origin. Organic P is held very tightly and is generally not available
- for plant uptake until the organic materials are decomposed and the phosphorus released via the mineralization process. Mineralization is carried out by microbes, and as with nitrogen, the rate of P release is affected by factors such as soil moisture, composition of the organic material, oxygen concentration and pH.

Inorganic P in soils. The concentration of inorganic P (orthophosphates) in the soil solution at any given time is very small, amounting to less than 1 lb. /A. Phosphorus in the inorganic form occurs mostly as aluminum, iron or calcium compounds.

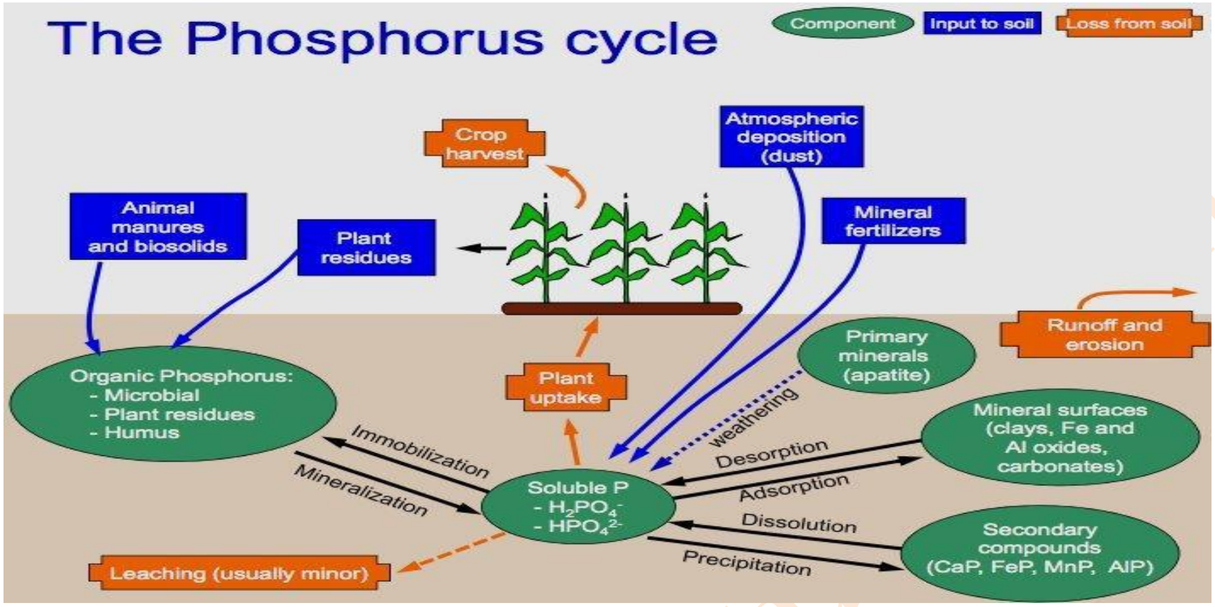


Figure 30. The phosphorus cycle

2.7 Common disease-causing microorganisms

- We all live from birth until death in a world filled with microbes, and we all have a variety of microorganisms on and inside our bodies. These microorganisms make up our **normal microbiota** or **flora**. The normal microbiotas not only do us no harm, but also in some cases can actually benefit us. For example, some normal microbiota protects us against diseases by preventing the overgrowth of harmful microbes, and others produce useful substances such as vitamin K and some B vitamins. Unfortunately, under some circumstances e.g., when some normal microbiotas leave their habitat, they can cause diseases.
- Of the thousands of species of viruses, bacteria, fungi, and parasites, only a tiny portion is involved in diseases of any kind. The theory that disease can be caused by microorganisms is called the **germ theory**. Organisms that cause disease are called **pathogens (Figure2.31) & (Figure32)**. A disease that is caused by a microorganism infecting the body is an infectious disease.

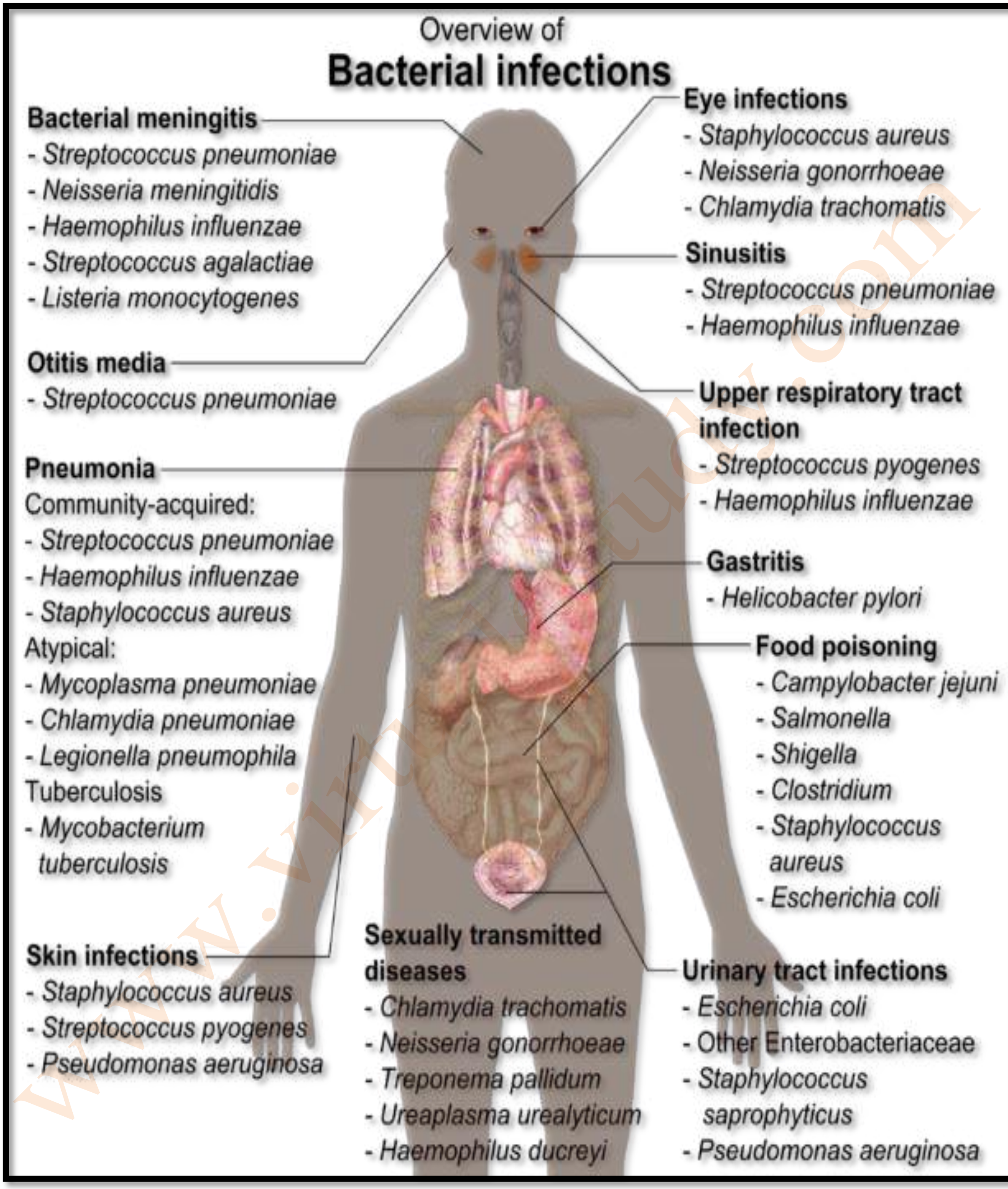


Figure 31. Human bacterial infection. Source: Wikimedia Commons, the free media repository

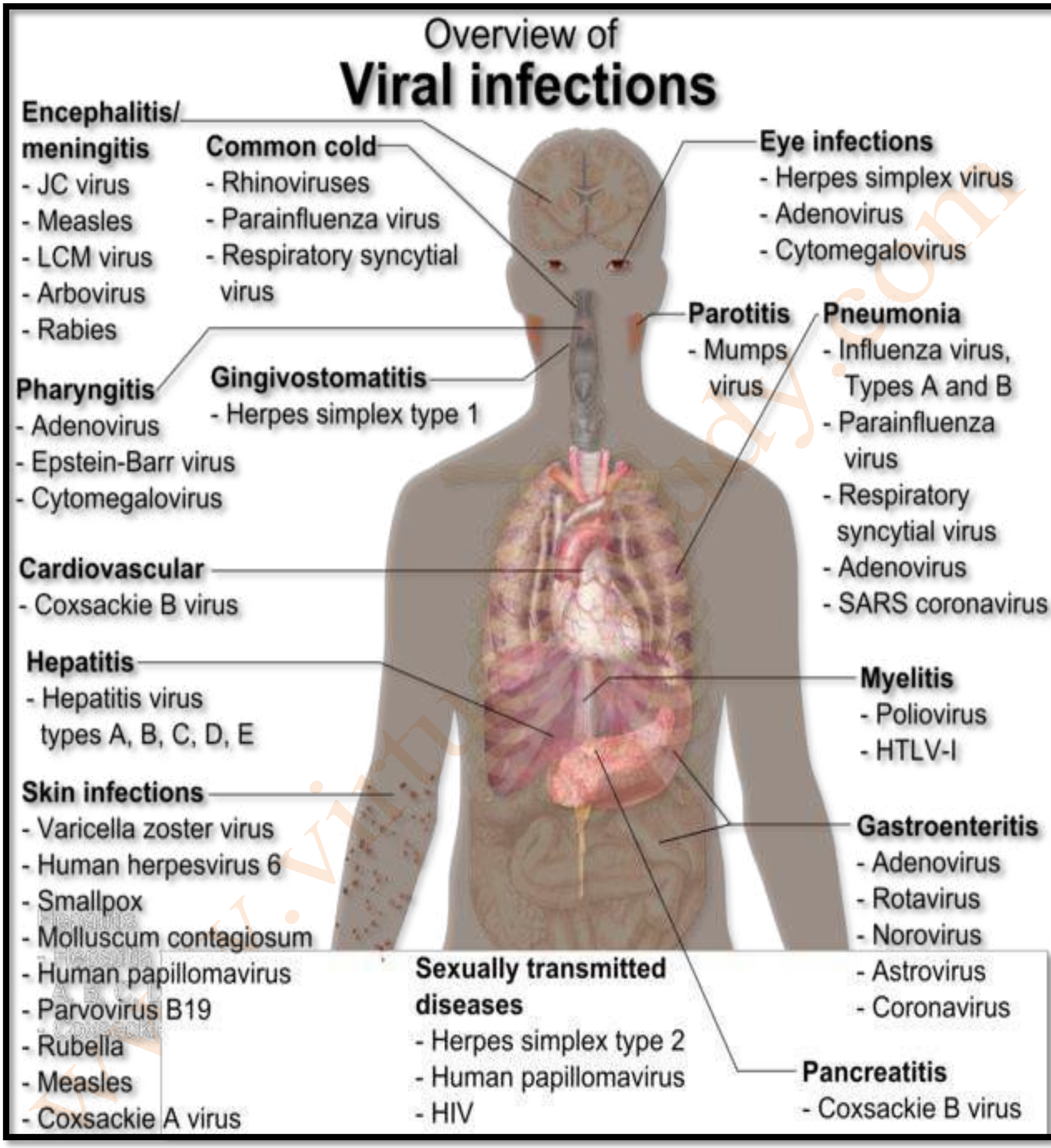
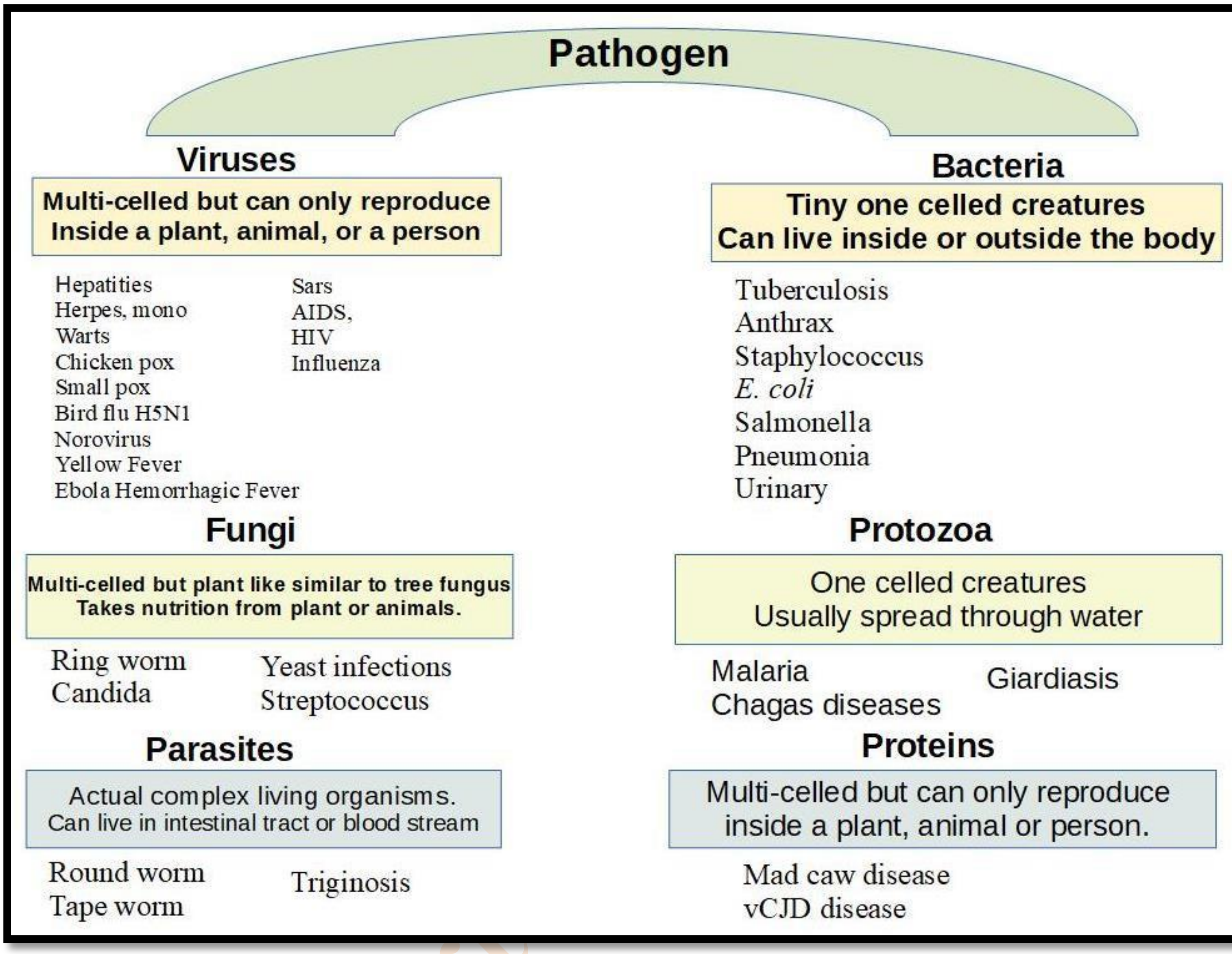


Figure 32. Human viral infection. Source: Wikimedia Commons, the free media repository



2.8 Modes of disease transmission

Microorganisms are transmitted in health care settings by four main routes:

A. Contact

B. Droplet

C. Airborne

D. Common vehicle

Table 2. Modes of disease transmission

Method of transmission	How the transmission route works	Examples of diseases
Droplet infection	Many of these diseases are 'respiratory diseases' – diseases affecting the airways of the lungs. The organisms are carried in tiny droplets through the air when an infected person coughs orsneezes. They are inhaled by other people.	**Common cold, 'flu, pneumonia**
Drinking contaminated water	The micro-organisms transmitted in this way often infect regions of the gut. When unclean water containing the organisms is drunk,they colonise a suitable area of the gut and reproduce. They are passed out with faeces and find their way back into the water.	**Cholera, typhoid fever**
Eating contaminatedfood	Most food poisoning is bacterial, but some viruses are transmittedthis way. The organisms initially infect a region of the gut.	**Salmonellosis,typhoid fever,listeriosis, botulism**
Direct Contact	Many skin infections, such as athlete's foot, are spread by direct contact with an infected person or contact with a surface carryingthe organism.	**Athlete's foot,ringworm**
Sexual intercourse	organisms infecting the sex organs can be passed from one sexualpartner to another during intercourse. Some are transmitted by direct body contact, such as the fungus that causes candidiasis (thrush). others are transmitted in semen or vaginal secretions, such as the AIDS virus. Some can be transmitted in saliva, such assyphilis.	**Candidiasis, syphilis, AIDS,gonorrhoea**
Blood-to- blood contact	Many of the sexually transmitted diseases can also be transmitted by blood- to-blood contact. Drug users sharing an infected needle can transmit AIDS.	**AIDS, hepatitis B**
Animal vectors	**Many diseases are spread through the bites of insects. Mosquitoesspread malaria and tsetse flies spread sleeping sickness. in both cases, the disease- causing organism is transmitted when the insect bites humans in order to suck blood. Flies can carry micro- organisms from faeces onto food.**	**Malaria, sleeping sickness**

Unit summary

- **Microbiology** is the study of bacteria, viruses, fungi, protozoa, and algae, which are collectively called **microorganisms**, or **microbes**. In general, microorganisms are microscopic and, unlike macroscopic organisms, which are readily visible, they require magnification to be adequately observed or studied.
- **Microbes** live in most of the world's habitats and are indispensable for normal, balanced life

on earth. They play many roles in the functioning of the earth's ecosystems. Most organisms are free-living, but a few are parasites. Microbes are involved in nutrient production and energy flow. Algae and certain bacteria trap the sun's energy to produce food through photosynthesis. Other microbes are responsible for the breakdown and recycling of nutrients through decomposition. Microbes are essential to the maintenance of the air, soil, and water. Microbes have been called upon to solve environmental, agricultural, and medical problems. Biotechnology applies the power of microbes toward the manufacture of industrial products, foods, and drugs. Microbes form the basis of genetic engineering and recombinant DNA technology, which alter genetic material to produce new products and modified life forms. With bioremediation, microbes are used to clean up pollutants and wastes in natural environments.

- The simplicity, growth rate, and adaptability of microbes are some of the reasons that microbiology is so diverse and has branched out into many sub-sciences and applications. Important sub-sciences include immunology, epidemiology, public health, food, dairy, aquatic, and industrial microbiology.
- Microbiology as a science is about 200 years old. Hundreds of contributors have provided discoveries and knowledge to enrich our understanding. With his simple microscope, Leeuwenhoek discovered organisms he called animalcules. Because of his findings and the rise of the scientific method, the notion of spontaneous generation, or abiogenesis, was eventually abandoned for biogenesis. The scientific method applies inductive and deductive reasoning to develop rational hypotheses and theories that can be tested. Principles that withstand repeated scrutiny become law in time. Early microbiology blossomed with the conceptual developments of sterilization, aseptic techniques, and the germ theory of disease. Characteristics and Classification of Microorganisms Organisms can be described according to their morphology and physiology. The genetics of organisms reveals an ancestral evolutionary relationship among these kingdoms. Cells of eukaryotic organisms contain a nucleus, but those of prokaryotic organisms do not. Taxonomy is a hierarchy scheme.

Unit review questions

Choose the correct answer from A to D for the following equations.

1. Protozoa are:

A. Multicellular organisms B. One-celled animals C. Members of the group protoctista

2. Unicellular plant pathogen micro-organisms include:

   A. Bacteria and some fungi B. Viruses C. Protozoa D. All of the above

3. Viruses are sometimes not considered as living organisms because:

   A. They do not have any of the organelles found in cells

   B. They are incapable of independent reproduction

   C. They cannot carry out any metabolic processes D. All of the above

4. Gram's stain is called a differential stain because:

   A. It stains bacterial cells, but not fungi C. It stains some bacteria purple and others pink

   B. It stains viruses, but no other organisms D. It stains some fungal cells purple and others pink

5. Bacterial cells are different from animal cells because the bacterial cells:

   A. Are larger than animal cells. B. have no nucleus

6. The three main shapes of bacterial cells are:

   A. Comma (vibrios**)** , staphylococci, and bacilli C. Diplococci, streptococci, and bacilli

   B. Corkscrew, spirochaetes, and bacilli D. Cocci, bacilli, and spirochaetes

7. Compared to Gram-positive bacteria, Gram-negative bacteria:

   A. Have an extra membrane outside the cell wall C. Are more resistant to antibiotics

   B. Produce more endotoxins that are dangerous D. All of the above

8. Viruses can parasitize:

   A. Only animal cells B. Only plant cells C. Only bacterial cells D. Animal cells, plant cells and bacterial cells

9. It is true to say of bacterial cells that:

   A. None can photosynthesize B. Only some can respire. C. None contain ribosomes D. None contain chloroplasts

10. Membrane-bound organelles includes:

   A. The Nucleus B. Chloroplasts C. Mitochondria D. All of the above

A. Sources of infectious organisms that spread to infect others are called:

   A. hosts of infection B. sources of infection C. reservoirs of infection D. sites of infection

11. Disease-causing bacteria can be transmitted by: A. sexual intercourse B. droplet infection

C. eating contaminated food D. all of the above

12. Which of the following is not an infectious disease? A tuberculosis B. AIDS C. coronary heart disease D. the common cold

13. Which if the following statements are NOT true about nitrogen-fixing bacteria?

A. They are often found in nodules on the roots of legumes B. They convert nitrogen gas into ammonium ions C. They break down nitrate ions into ammonium ions D. They play a vital role in the nitrogen cycle in nature

14. In the sulphur cycle, the main source of sulphur for plants is:

A. sulphur in rocks B. sulphates in the air C. Sulphur in water D. sulphates in soil

15. In the percolating filter method of sewage treatment:
A. the sewage is screened to remove large pieces of waste B. the sewage trickles through stones covered in microorganisms C.the micro-organisms oxidise the organic matter in the sewage D. all of the above

16. DNA can be transferred into maize using: A plasmids B. the gene gun

C. Agrobacterium D.viruses

17. In genetic engineering, a section of DNA is removed from a DNA molecule using:

A. ligase enzymes B. plasmids C. restriction enzymes D. polymerase enzymes

18. Which of the following is NOT a term used to describe organisms that have had foreign genes added to them?

A. transgenic organisms B. genetically modified organisms

C. pathogenic organisms' D. genetically engineered organisms

19. Which of the following were important in developing the germ theory of disease?

A. Louis Pasteur, showing that excluding micro-organisms from wine prevented it from going sour

B. Joseph Lister, showing that using carbolic acid, which killed bacteria, reduced infection during surgery

C. Robert Koch, identifying specific micro-organisms associated with specific diseases

D. all of the above

- **Answers : 1, C 2, A 3, D 4, C 5, B 6, D 7,D 8, D 9, D 10, D 11, D 12, C 13,C 14, D 15, D 16, B 17, C 18, C 19.D**

UNITE 3

ENERGY TRANSFORMATION

3.1 Energy

- All living things require energy to carry out life processes. It may seem obvious that cells need energy to grow and reproduce, but even non-growing cells need energy simply to maintain them.
- Cells obtain energy in many forms, but that energy can seldom be used directly to power cell processes. For this reason, cells have mechanisms that convert energy from one form to another. The ordered systems of the cell provide the information that makes these energy transformations possible. Because most components of these energy conversion systems evolved very early in the history of life, many aspects of energy metabolism tend to be similar in a wide range of organisms.

3.1.1 Carbohydrates

- **Carbohydrates** are generally classified into three groups: **monosaccharides** (and their derivatives), **oligosaccharides**, and **polysaccharides.** The monosaccharides with the formula **$[C(H_2O)]_n$** are also called simple sugars**, where n = 3–7** . Monosaccharides cannot be broken down into smaller sugars under mild conditions.
- **Oligosaccharides** derive their name from the Greek word oligo, meaning "few," they are composed of four to ten simple sugar molecules.
- **Disaccharides** are common in nature, and tri-saccharides occur frequently. Four to six-sugar-unit oligosaccharides including glycoproteins are usually bound covalently to other molecules. As their name suggests, polysaccharides are **polymers** of the simple sugars and their derivatives. They may be either **linear or branched** polymers and may contain hundreds or even thousands of monosaccharide units.

Classification

- **Monosaccharides** are carbohydrate molecules that cannot be broken down into simpler carbohydrate molecules by a chemical process called **hydrolysis**. Hence, monosaccharides are referred to as "**simple sugars**" or just **sugars**," which infers that they are the simplest (smallest) carbohydrates. The simplest sugars are monosaccharides. Six-carbon monosaccharides are prevalent but monosaccharides can have from 3 to 7 carbons in their structures.

For example:

A. **Triose** sugars: 3-carbon skeleton
B. **Tetrose** sugars: 4-cabon skeleton
C. **Pentose** sugars: 5-carbon skeleton
D. **Hexose** sugars: 6-carbon skeleton are monosaccharides.

- All carbohydrates along with a number of hydroxyl functional groups (C—OH) are characterized by the carbonyl functional group (C=O). Based on the location of the carbonyl functional group (C=O), they are classified as aldoses or ketoses. If the carbonyl group is at the end of the chain, the monosaccharide is an aldehyde; if the carbonyl group is at any other position,

the monosaccharide is a ketone.

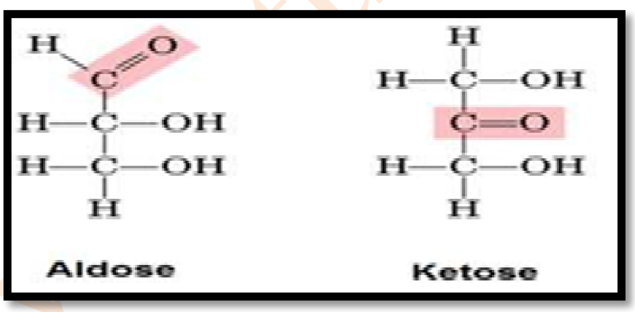


Figure1. Structure of aldoses and ketoses

- **Aldehyde Sugars (Aldoses):** They have the carbonyl group at the end of the molecule. As shown in the following (**Figure 3.8**), glucose is an example of an aldehyde sugar (aldose). It is the most common monosaccharide in living things. Note how the carbon atoms are numbered beginning at the aldehyde functional group. In **Ketone Sugars (Ketoses), the** carbonyl group **is not at the end of the sugar. Fructose** is one of the most common examples of monosaccharide ketone sugars (**Figure 3.8**).

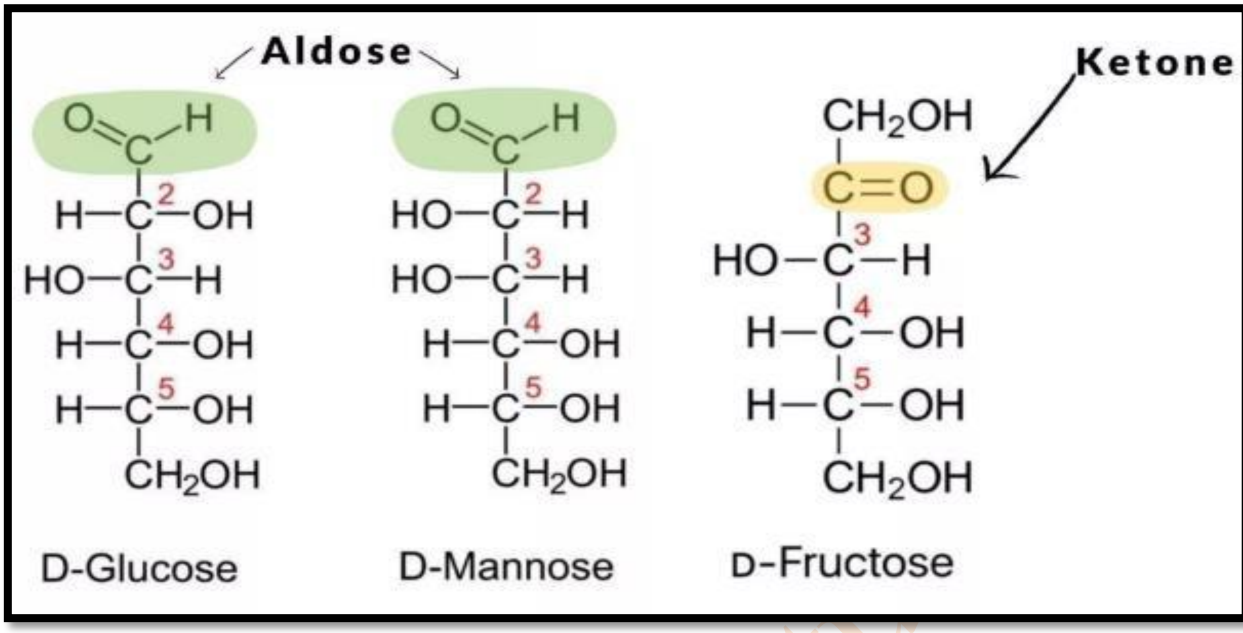
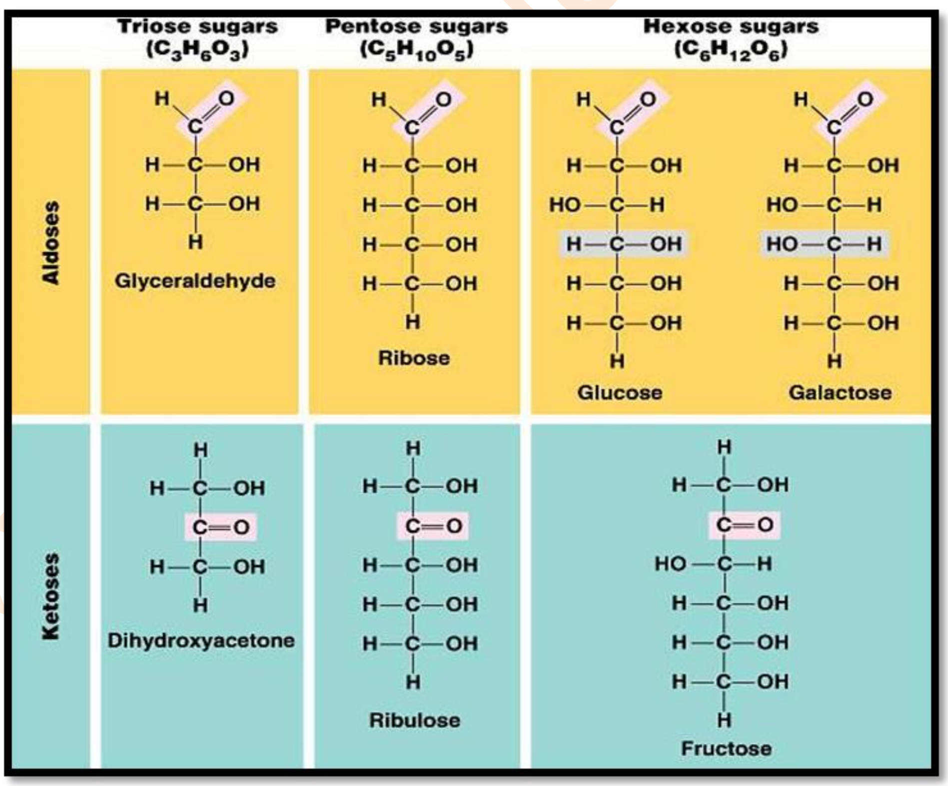


Figure2. Common aldoses and ketoses

Table 3.1. Classification of Monosaccharides



- **Disaccharides:** Disaccharides consist of two monosaccharide units. The most common types of disaccharides, which include sucrose, lactose, and maltose, have 12 carbon atoms, with the general formula of $\mathbf{C_{12}H_{22}O_{11}}$.
- A **disaccharide** (two sugars) contains two monosaccharide rings joined by a glycosidic linkage, consisting of central oxygen covalently bonded to two carbons, one in each ring (**Figure 3.9**). The **glycosidic linkage** of a disaccharide generally forms between carbon 1 of one molecule and carbon 4 of the other molecule. The disaccharide maltose (malt sugar) consists of two covalently linked a-glucose units.

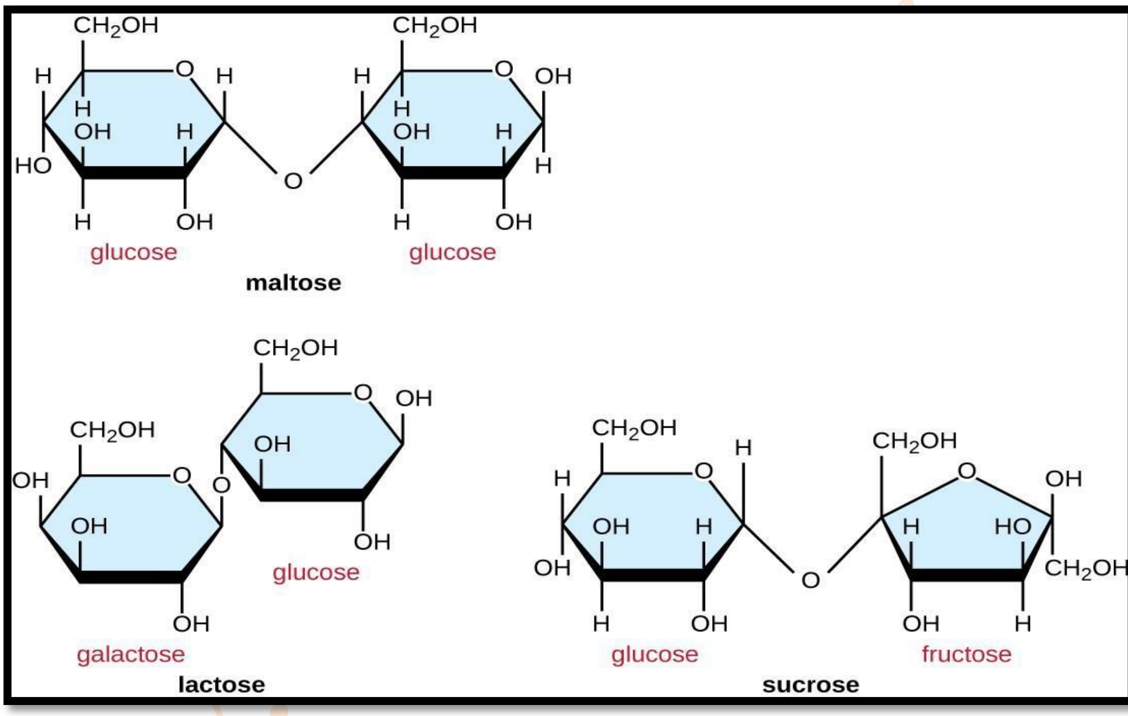


Figure 3. Common disaccharides.

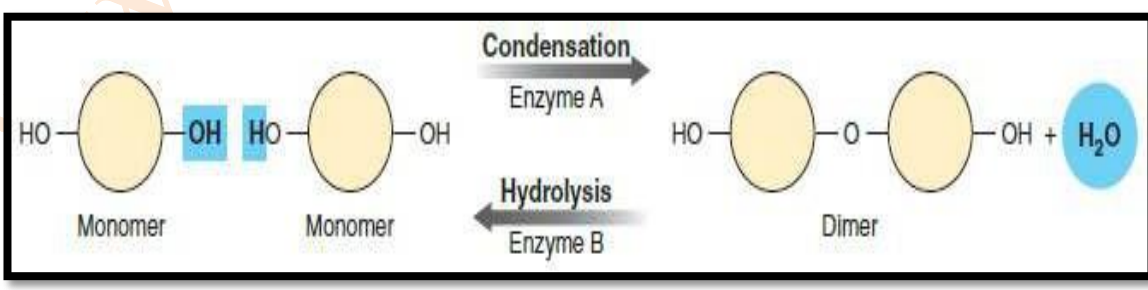


Figure4. Dehydration synthesis (condensation reaction)

- Disaccharides are formed when two monosaccharides undergo a **dehydration synthesis (condensation reaction)** by releasing a molecule of water (H_2O), ("i.e., they are made by losing water") (**Figure 3.10**). In the opposite reaction of **hydrolysis** ("breaking with water"), a disaccharide and water react to form two monosaccharides (**Figure 3.11**).

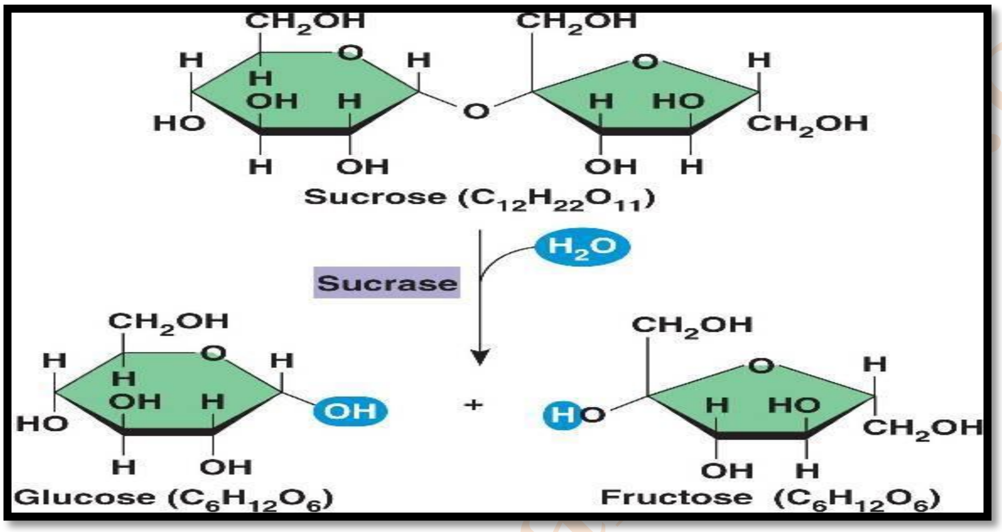


Figure 5. Hydrolysis of sucrose into glucose and fructose

- **Oligosaccharides**: Oligosaccharides represent carbohydrates that contain between 3 and 10 single sugar residues and are not relatively abundant in the diet when compared to other more common carbohydrates like those in the disaccharide category. Common oligosaccharides include raffinose, stachyose, and verbascose.
- **Polysaccharides** ("many sugar") are long polymers of monosaccharides (sugar) linked by dehydration synthesis. They are also complex carbohydrates. The most common polysaccharides such as glycogen, starch, and cellulose, are all long chains of glucose, but they differ from one another by their branching patterns.
    - **Glycogen** is a readily mobilized storage form of glucose. It is a very large, branched polymer of glucose residue that can be broken down to yield glucose molecules when energy is needed. Most of the glucose residues in glycogen are linked by α-1,4-glycosidic bonds. Branches at about every tenth residue are created by α-1, 6-glycosidic bonds.

- **Starch** is a polysaccharide carbohydrate $(C_6H_{10}O_5)_n$ consisting of a large number of glucose molecules joined together by α-1,4-glycosidic bonds. Starch is found especially in seeds, bulbs, and tuber. It is the principal carbohydrate composed of the polysaccharides, amylose (10%–30%) and amylopectin (70%–90%) in plants.

- **Cellulose** and **chitin** are familiar complex carbohydrates that use glucose polymers. Cellulose forms wood and parts of plant cell walls. It consists of long polymer chains of glucose units connected by a beta acetal linkage. All of the monomer units are beta-D glucose, and all the beta acetal links connect the first carbon of glucose to the 4th carbon of the next glucose. **Chitin,** which is found in the exoskeletons of insects, the cell walls of fungi, and certain hard structures in invertebrates and fish, is a large, structural polysaccharide made from chains of modified glucose. Cellulose is one of the most common organic compounds in nature, whereas chitin is the second. **Pictin** is a polysaccharide found in the cell walls of fruits and vegetables.

A. **What is the difference between alpha and beta bonds?**

- The D-glucose that can be used by cells is biologically active. The D-glucose can exist in two forms alpha-D-glucose and beta-D-glucose. They differ only in the direction that -H and -OH groups point on carbon 1 (Figure 3.12). When alpha-glucose molecules are joined chemically to form a polymer, starch and glycogen are formed. When beta-glucose molecules are joined to form a polymer, cellulose and chitin are formed.

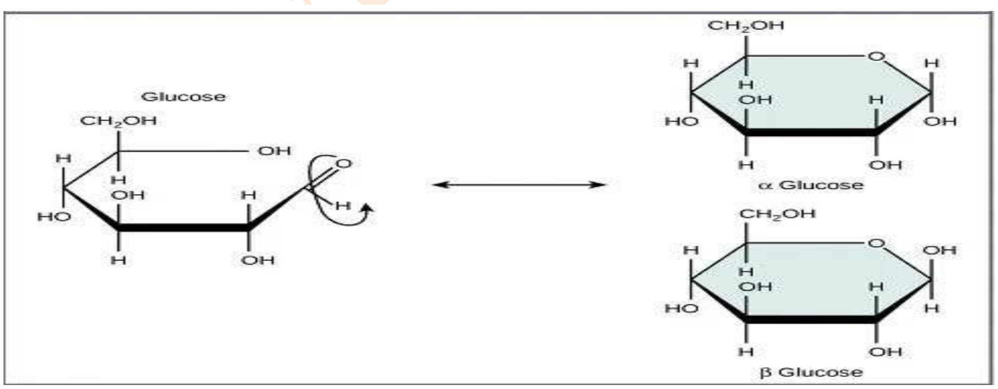


Figure 3.12. The alpha-D-glucose and beta-D-glucose

- The 1, 4 glycosidic bonds are formed between the carbon-1 of one monosaccharide and carbon- 4 of the other monosaccharide. There are two types of glycosidic bonds - 1,4 alpha and 1,4 beta glycosidic bonds. 1,4 alpha glycosidic bonds are formed when the OH on the carbon-1 is below the glucose ring; whereas 1,4 beta glycosidic bonds are formed when the OH is above the plane (Figure 3.13).

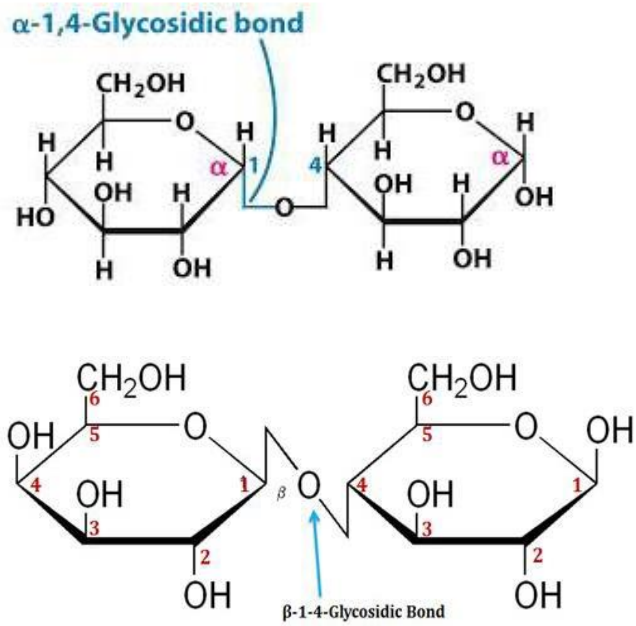


Figure 6. alpha and beta glycosidic bonds

3.1.2 Lipids

- Lipids contain the same elements as carbohydrates. However, they are made of proportionately less oxygen. Lipids are diverse molecules that dissolve in organic solvent but not in water. Within the body, lipids are used as cell membrane components, energy storage molecules, insulation, hormones, and cushion vital organs. Lipids are also used to transmit nerve impulses, and transport fat-soluble nutrients. They are excellent energy sources, by providing more than double the amount of energy than equal weight of carbohydrates or proteins.

Classification of lipids

- Lipids can be classified based on their hydrolysis products and similarities in their molecular structures. Three major subclasses are recognized:

Simple lipids

(a) Fats and oils yield fatty acids and glycerol upon hydrolysis.

(b) Waxes, yield fatty acids and long-chain alcohols upon hydrolysis.

- **Fats and Oils**: both types of compounds are called **triacylglycerols** because they are esters composed of three fatty acids joined to glycerol, which is trihydroxy alcohol (**Figure 3.14**). The difference is on the basis of their physical states at room temperature. It is customary to call a lipid a fat if it is solid at 25°C and oil if it is liquid at the same temperature. These differences in melting points reflect differences in the degree of unsaturation of the constituent fatty acids (**Figure 3.15**).

- A fatty acid is **unsaturated** if it has at least one double bond and **polyunsaturated** if it has more than one double bond. A **monounsaturated** fatty acid has just one double bond. Olive oil is a monounsaturated fat. Lipids in plants are less saturated than those in animals.

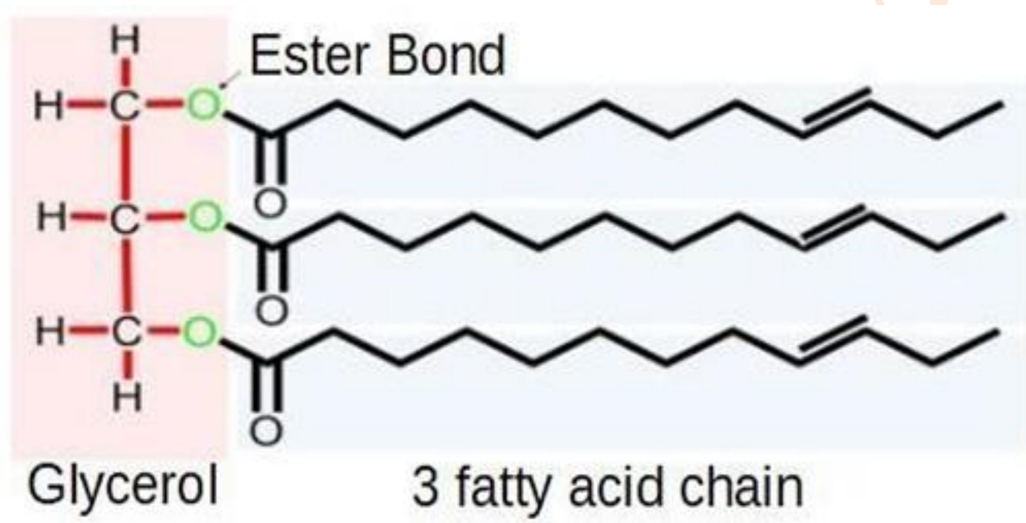


Figure 7, A triglyceride

- Waxes: Wax is an ester of long- chain alcohol (usually mono- hydroxy) and a fatty acid. The acids and alcohols normally found in waxes have chains of the order of 12-34 carbon atoms in length.

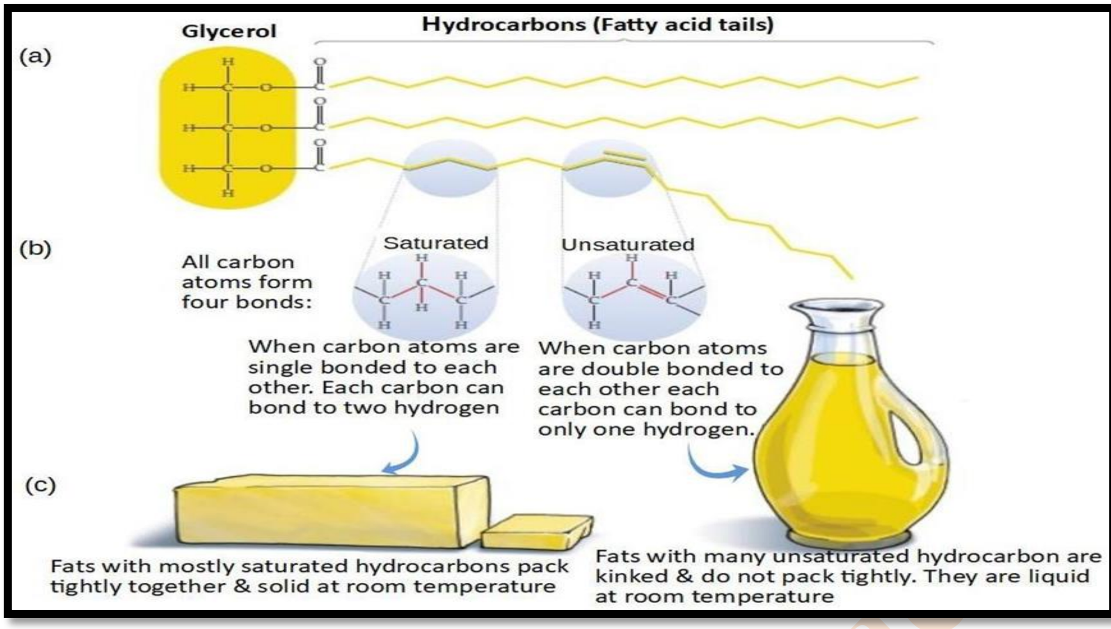


Figure 8, Saturated and unsaturated fats

Compound lipids

- Phospholipids are made up of fatty acid, glycerol or other alcohol, and phosphoric acid. Phospholipids are the significant lipid constituents of **cell membranes**. Like fats, phospholipids are amphipathic in nature, i.e., each has a hydrophilic or polar head (phosphate group) and a long hydrophobic tail (containing two fatty acid chains) (**Figure 3.16**).

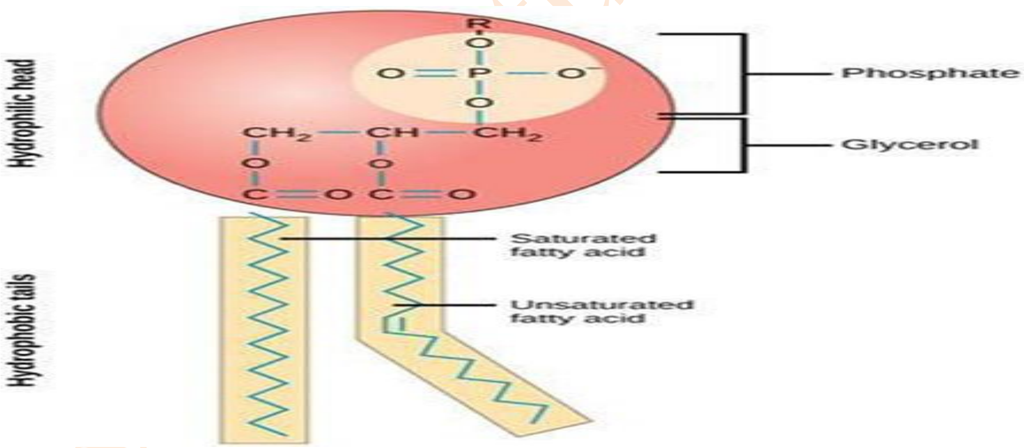
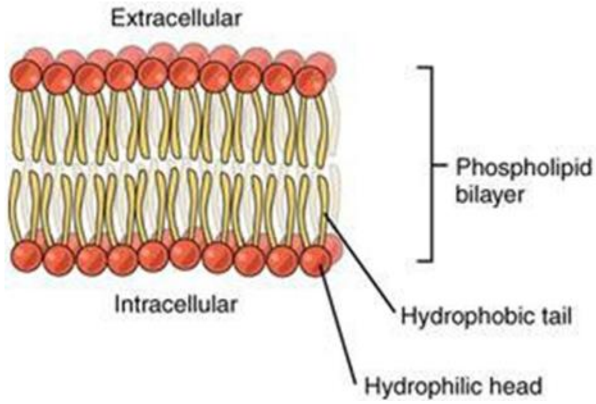


Figure 8, Phospholipid (left) and plasma membrane (right



- **Glycolipids** are lipids with a carbohydrate attached by a glycosidic (covalent) bond. Their role is to maintain the stability of the cell membrane and to facilitate cellular recognition, which is crucial to the immune response and in the connections that allow cells to connect to one another and thereby form tissues. Glycolipids are found on the surface of all eukaryotic cell membranes, where they extend from the phospholipid bilayer into the extracellular environment (Figure 3.17).

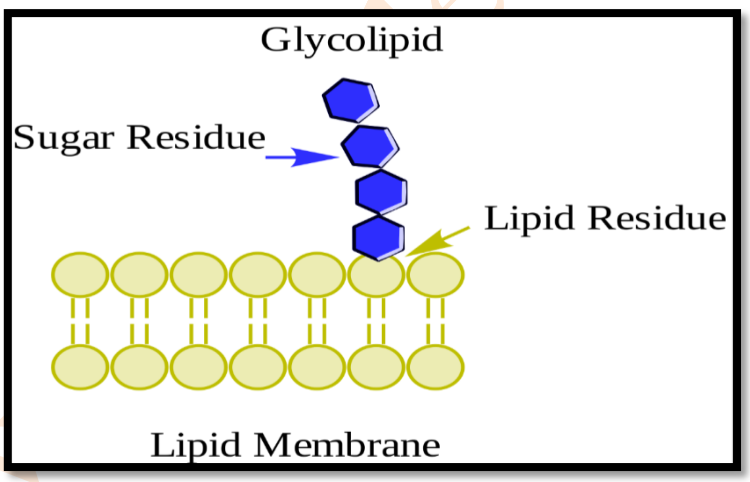


Figure 9. A glycolipid

Derived lipids

- The hydrolysis product of simple and compound lipids is called derived lipids. They include fatty acid, glycerol, sphingosine and steroid derivatives. Steroid derivatives are phenanthrene structures that are quite different from lipids made up of fatty acids.

Sterols

- Sterols such as vitamin D and cortisone are lipids that have four-carbon rings. A very familiar sterol, cholesterol, is part of cell membranes. Cells use cholesterol as a starting material to synthesize other lipids, including the sex hormones testosterone and estrogen. Liver cells manufacture cholesterol when they break down saturated fats. The excess cholesterol collected on the inner linings of the blood vessels and eating foods containing cholesterol can impede blood flow (Figure 3.18). Because the liver essentially converts saturated fats into cholesterol, it is important to limit dietary intake of saturated fats as well as cholesterol.

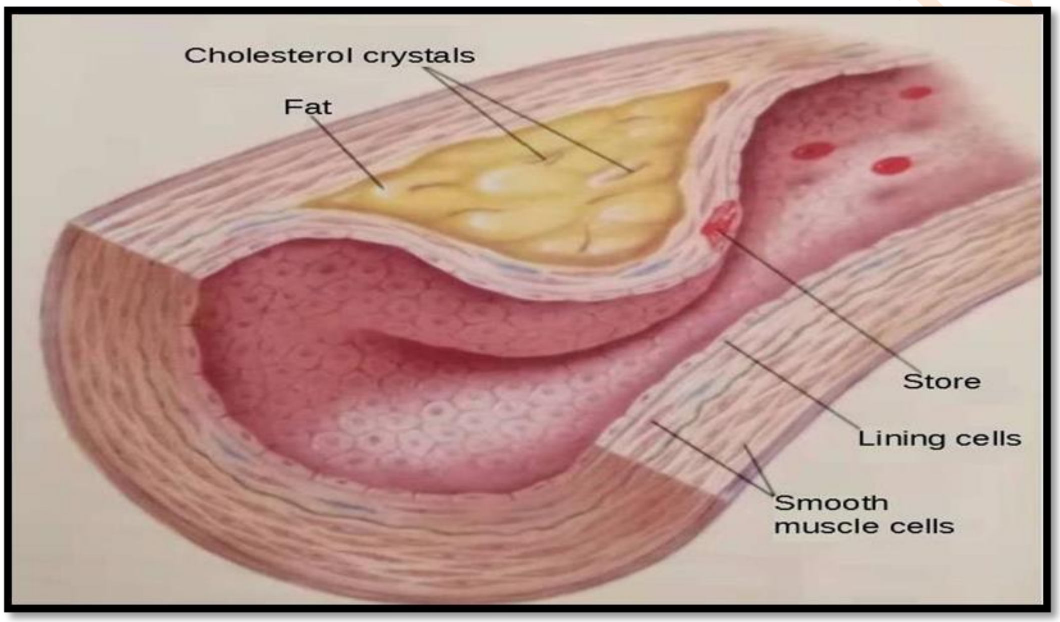


Figure10 Cholesteroplaque in arteries (left) and structure of cholesterol (right)

3.2 Cellular metabolism

Metabolism, Greek word for “change,” consists of the chemical reactions that change or transform energy in a cell. The reactions of metabolism are organized into a step – by - step sequences called **metabolic pathways**, in which the product of one reaction becomes the starting point or substrate of another (**Figure 19**).

- In a metabolic pathway, a specific molecule is altered in a series of defined steps, resulting in a certain product.

- A specific enzyme or a macromolecule that speeds up a chemical reaction, catalyzes each step. Enzymes enable metabolic reactions to proceed fast through to sustain life.

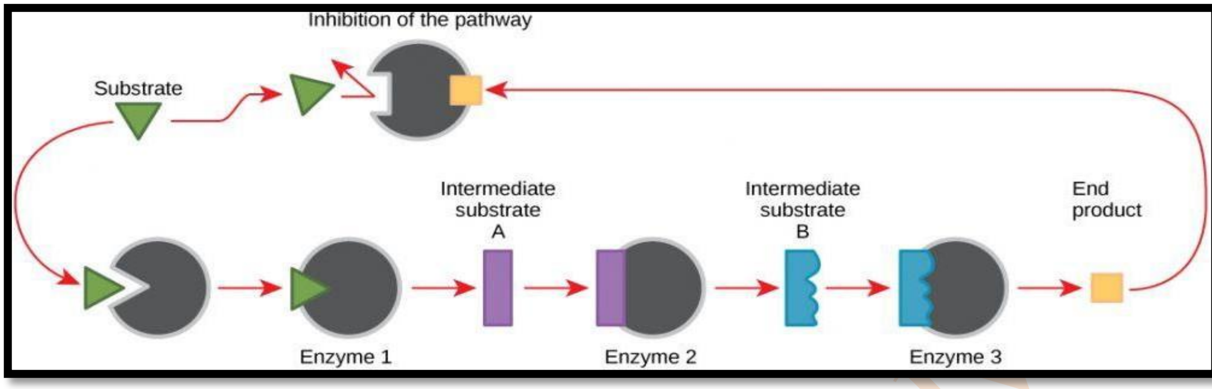


Figure 11, Metabolic pathways

- Metabolic pathways are a series of reactions catalyzed by multiple enzymes. Feedback inhibition, where the end product of the pathway inhibits an upstream process, is an important regulatory mechanism in cells.

- To maintain a good metabolism rate nutrition is required. The metabolism has two subcategories; **anabolism** and **catabolism** (Figure 3.20). The main goal of nutrition is to keep anabolism always greater than catabolism. Anabolism means growth whereas, catabolism means breakdown

3.2.1 Anabolism (synthesis)

- Anabolism is another subcategory of metabolism, which helps in the construction of molecules from smaller units. It is the chemical process in which nutrients are used in the formation of comparatively complex molecules in the living cells with moderately simpler structures.

- This process includes making components of cells such as proteins, carbohydrates, lipids, which require energy in the form of ATP. Anabolism is a buildup feature, whereas catabolism is a breakdown feature of metabolism. It is also known as biosynthesis.

- Anabolism helps in the building of macromolecules like proteins, nucleic acids, and polysaccharides. These macromolecules are produced from small molecules using enzymes and non- protein chemical compound that is required for an enzyme's activities.

3.2.2 Catabolism (Degradation)

- Catabolism is the subcategory of metabolism, which breakdowns large or complex molecules such as proteins, polysaccharides, and fats into small molecules like amino acids, monosaccharides, and fatty acids. It is a destructive state of metabolism. This process includes glycolysis and citric acid cycle.
- The glycolysis is the metabolic process that converts glucose pyruvic acid and a hydrogen ion. It is a chain of ten enzyme-catalyzed reactions. The energy released in this process is used in the formation of NADH (nicotinamide adenine dinucleotide) and ATP (adenosine triphosphate). The citric acid cycle is a sequence of chemical reactions used by aerobic organisms to stored energy derived from the oxidation of carbohydrates, fats, and proteins.

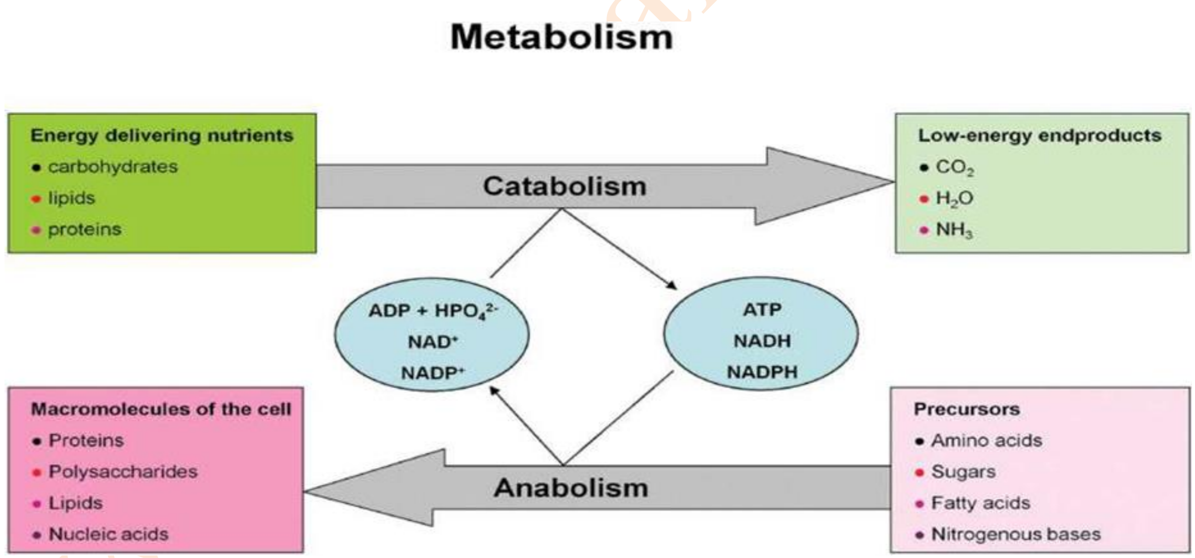


Figure 12. Comparison of catabolism with anabolism Table

3.3.The difference between Catabolism and Anabolism

CATABOLISM	ANABOLISM
All the catabolic reactions in a cell	**All the catabolic reactions in a cell**
Catabolic reactions release	**Anabolic reactions require**
Catabolic reactions involve the breaking of bonds; whenever chemical bonds ; are broken, energy is Released	**Anabolic reactions; involve the creation of bonds; it takes energy to create chemical bonds released**
Larger molecules are broken down into smaller molecules (sometimes referred to as degradative reactions)	**Smaller molecules are bonded together to create larger molecules (sometimes referred to as biosynthetic reactions)**

3.3 Photosynthesis

- A plant is an autotroph **("self-feeder")**, which uses inorganic substances such as water and carbon dioxide (CO_2) to produce organic compounds. The opposite of an autotroph is a heterotroph, which is an organism that obtains carbon by consuming preexisting organic molecules. We, human beings are heterotrophs, and so are all other animals, all fungi, and many other microbes.

- Organisms that can produce their own food underlie every ecosystem on Earth. It is not surprising, therefore, that if biologists were asked to designate the most important metabolic pathway; most of the biologists would not hesitate to cite photosynthesis, which is the process by which plants, algae, and some microbes harness solar energy and convert it into chemical energy.

- **Photosynthesis** is a series of chemical reactions that uses light energy to assemble CO_2 into glucose ($C_6H_{12}O_6$) and other carbohydrates (**Figure 3.21**). The plant uses water in the process and releases oxygen gas (O_2) as a byproduct. The reactions of photosynthesis are summarized as follows:

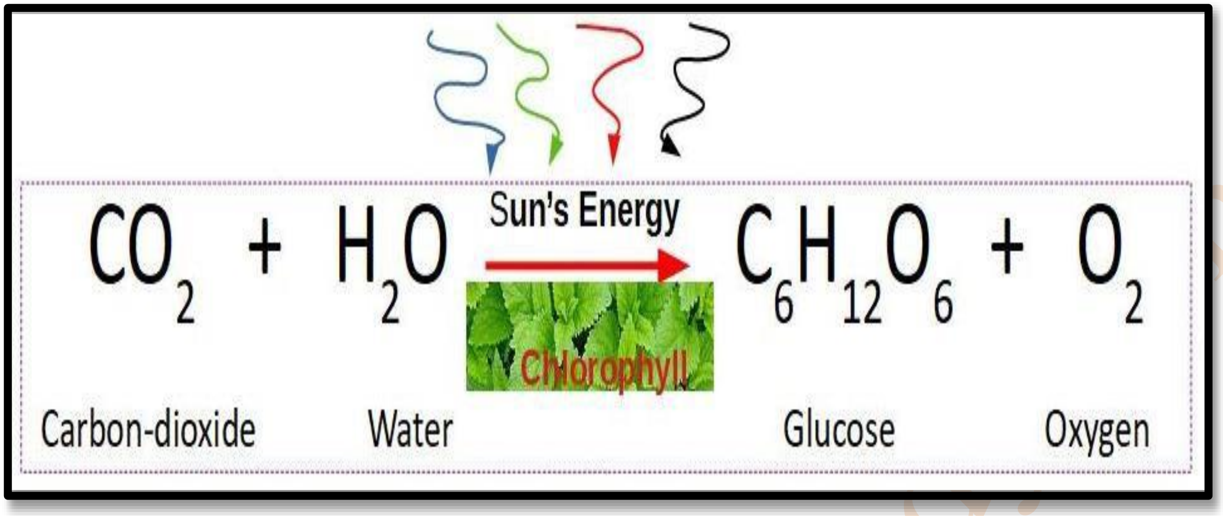


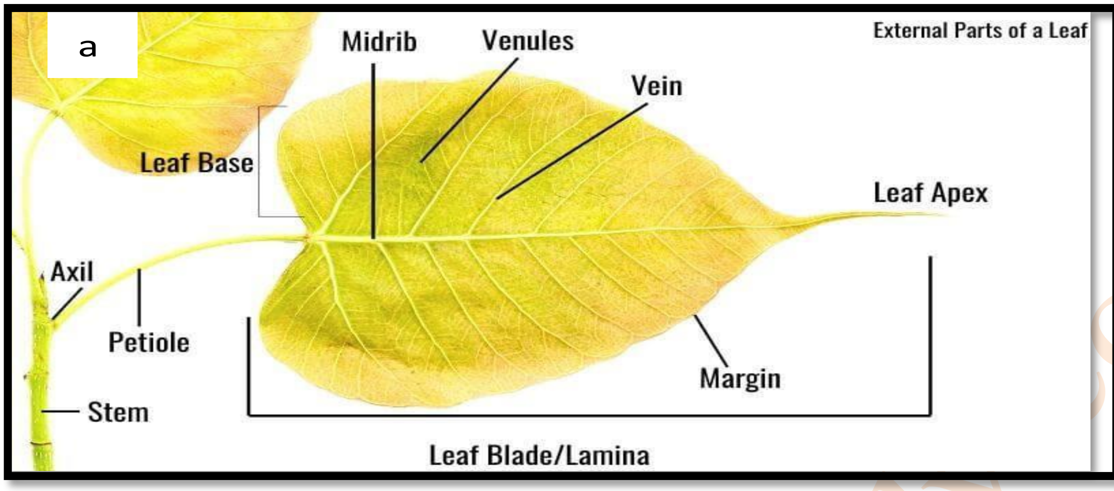
Figure 13. The chemical equation of photosynthesis

- This process provides not only food for the plant but also the energy, raw materials, and O_2 that are used to support most heterotrophs. Animals, fungi, and other consumers eat the leaves, stems, roots, flowers, nectar, fruits, and seeds of plants. Even the waste product of photosynthesis, O_2, is essential to much life on the earth. Furthermore, photosynthesis is important because it is the number one source of oxygen in the atmosphere; it contributes to the carbon cycle among the earth, the oceans, plants and animals; it contributes to the symbiotic relationship among plants, humans and animals; it directly or indirectly affects most living things on earth; it serves as the primary energy process for most trees and plants. Plants, multicellular algae, unicellular protests, Cyanobacteria, and Purple sulfur bacteria are Photoautotrophs.

3.3.1 External and Internal Structure of the Leaf

The outer leaf layer is known as the epidermis. The epidermis secretes a waxy coating called the cuticle that helps the plant retain water. A leaf has three main parts– Leaf base, leaf lamina, and petiole (Figure a).

The epidermis in plant leaves also contains special cells called guard cells that regulate gas exchange between the plant and the environment. The internal structure of the leaf contains three main parts, they are epidermis with stomata, mesophyll cells and vascular system (xylem vessels and phloem) (Figureb).



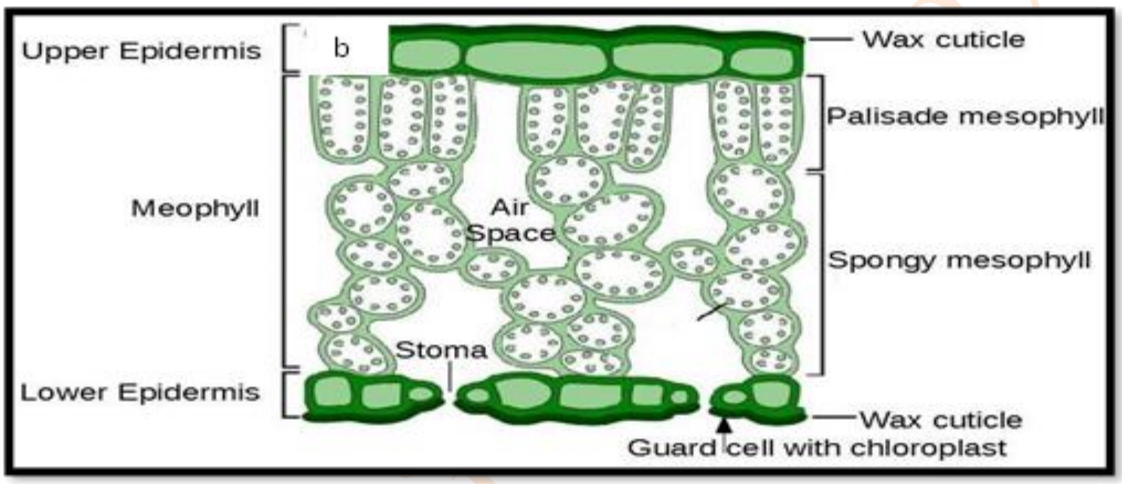
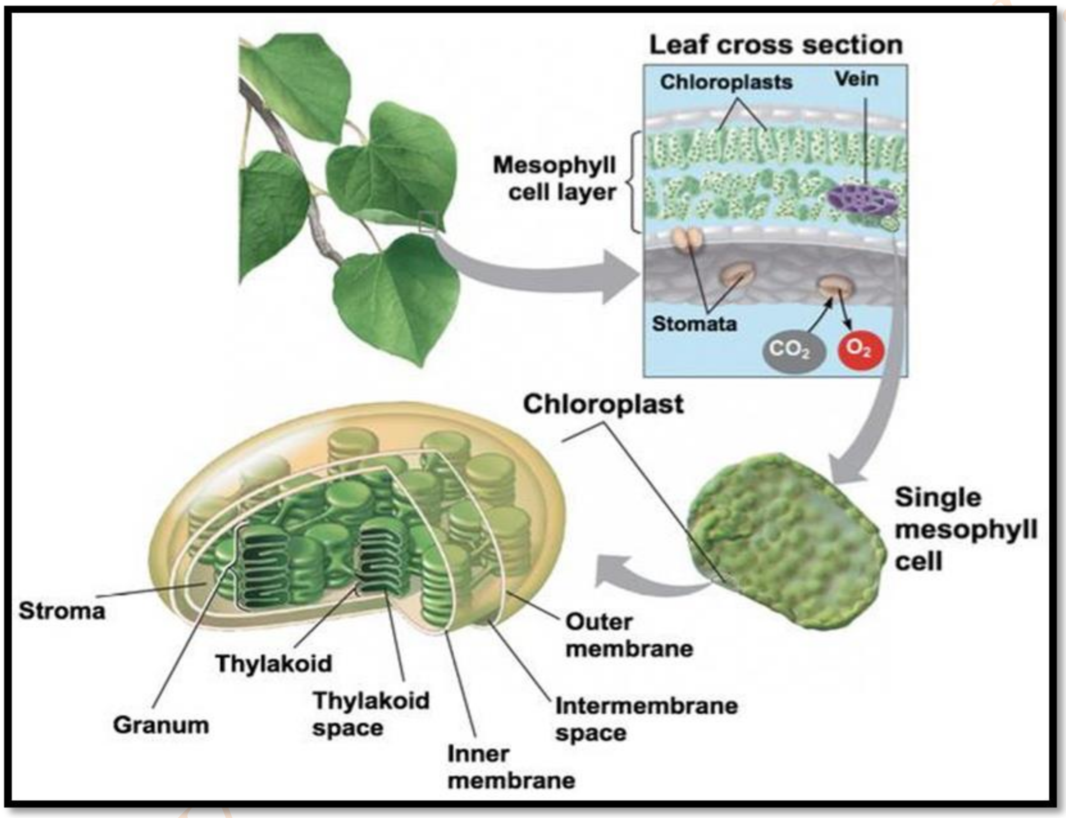


Figure a. External and internal structure of the leaf. Source: (Barragán Campos *et al.*, 2018)

The place/site of photosynthesis

- All green parts of a plant, including green stems and un-ripened fruit, have chloroplasts, but the leaves are the major sites of photosynthesis in most plants (Figure 3.22b). There are about half a million chloroplasts in a chunk of leaf with a top surface area of 1 mm^2. Chloroplasts are found mainly in the cells of the mesophyll, the tissue in the interior of the leaf. CO_2 enters the leaf, and O_2 exits, by way of microscopic pores called stomata (singular, stoma; from the Greek, meaning "mouth"). Water absorbed by the roots is delivered to the leaves in veins. Leaves also use veins to export sugar to roots and other non-photosynthetic parts of the plant.

A typical mesophyll cell has about 30–40 chloroplasts, each measuring about 2–4 µm by 4–7 µm. A chloroplast has two membranes surrounding a dense fluid called the stroma. Suspended within the stroma is a third membrane system, made up of sacs called **thylakoids**, which segregates the stroma from the thylakoid space inside these sacs. In some places, thylakoid sacs are stacked in columns called **grana** (singular, granum). Chlorophyll, the green pigment that gives leaves their color, resides in the thylakoid membranes of the chloroplast. The internal photosynthetic membranes of some prokaryotes are also called thylakoid membranes (Figure). It is the light energy absorbed by chlorophyll there. Drives the synthesis of organic molecules in the chloroplast.



Figure, The structure of a chloroplast and its location within a plant cell and leaf

- In plants, the highest density of chloroplasts is found in the mesophyll cells of leaves. A double membrane surrounds chloroplast, where the outer membrane faces the cytoplasm of the plant cell on one side and the inter-membrane space of the chloroplast on the other. The inner membrane separates the narrow inter-membrane space from the aqueous interior of the chloroplast, called the **stroma**.
- Within the stroma, another set of membranes form disk-shaped compartments known as **thylakoids**. The interior of a thylakoid is called the **thylakoid lumen**. In most plant species, the thylakoids are interconnected to form stacks called **grana**.

3.3.2 Photosynthetic pigments

- Photosynthetic cells contain special pigments that absorb light energy. Different pigments respond to different wavelengths of visible light. **Pigments** are chemical compounds which reflect only certain wavelengths of visible light. This makes them appear "colorful". Flowers, corals, and even animal skin contain pigments which give them their particular colors. More important than their reflection of light is the ability of pigments to **absorb** certain wavelengths.

- Because they interact with light to absorb only certain wavelengths, pigments are useful to plants and other **autotrophs.** In plants, algae, and cyanobacteria, pigments are the means by which the energy of sunlight is captured for photosynthesis. However, since each pigment reacts with only a narrow range of the spectrum, there is usually a need to produce several kinds of pigments, each of a different color, to capture more solar energy. There are three basic classes of pigments.

Chlorophylls are greenish pigments which contain a **porphyrin ring**. This ring has the potential to gain or lose electrons easily and whereby providing energized electrons to other molecules. There are several kinds of chlorophyll, which the most important one is **chlorophyll "a".** It is a green pigment found in all plants, algae, and cyanobacteria. The second kind of chlorophyll, **chlorophyll "b"** occurs only in "green algae" and in plants. The third form of chlorophyll called **chlorophyll "c"**, is found only in the photosynthetic members of the Chromista and dinoflagellates.

- **Carotenoids** are usually red, orange, or yellow pigments and they include the familiar compound carotene, which gives carrots their color. Carotenoids cannot transfer sunlight energy directly to the photosynthetic pathway, but must pass their absorbed energy to chlorophyll. For this reason, they are called **accessory pigments**. One very visible accessory pigment is **fucoxanthin,** the brown pigment whose colors keep in other brown algae as well as the diatoms.

- **Phycobilins** are water-soluble pigments, and are, therefore, found in the cytoplasm, or in the stroma of the chloroplast. They occur only in Cyanobacteria and Rhodophyta.

Absorption spectra of photosynthetic pigments

- An absorption spectrum is a graph that shows absorption from a spectrophotometer.absorption at wavelengths from 400-700 nm by three pigments; ***Chlorophyll a***, ***Chlorophyll b***, and the carotenoids. ***Chlorophyll a*** absorbs violet-blue and reddish orange-red wavelengths. ***Chlorophyll b*** absorbs mostly blue and yellow light. Both ***Chlorophyll a*** and ***Chlorophyll b*** also absorb light of other wavelengths with less intensity. However, none of them absorbs green, so that the leaf looks green because light is reflected to our eyes instead of being absorbed by the leaf. Carotenoids are ubiquitous and essential pigments in photosynthesis. They absorb in the **blue-green region** of the solar spectrum and transfer the absorbed energy to (bacterio) chlorophylls, and thereby expanding the wavelength range of light that is able to drive photosynthesis. Only absorbed light (largely blue and red) is useful in photosynthesis.

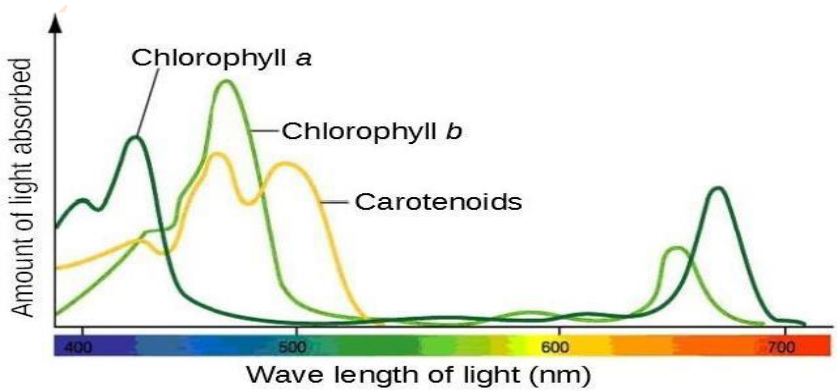


Figure . Absorption spectrum of *Chlorophyll a*, *Chlorophyll b*, and carotenoids

3.3.3 Light-dependent and light-independent reactions

Inside a chloroplast, photosynthesis occurs in two stages: the light-dependent reactions and the light-independent (or Calvin Cycle) reactions.

- **Light dependent reaction (cyclic and non-cyclic photophosphorylation)**

- The light reactions are the steps of photosynthesis that convert solar energy to chemical energy. Water is split, providing a source of electrons and protons (hydrogen ions, H^+) and giving off O_2 as a by-product (Figure 3.25). Light absorbed by chlorophyll drives a transfer of the electrons and hydrogen ions from water to an acceptor called NADP1 (nicotinamide adenine dinucleotide phosphate), where they are temporarily stored. (The electron acceptor NADP + is first cousin to NAD^+, which functions as an electron carrier in cellular respiration; the two molecules differ only by the presence of an extra phosphate group in the NADP $^+$ molecule.) The light reactions use solar energy to reduce NADP $^+$ to NADPH by adding a pair of electrons along with an H^+. The light reactions also generate ATP, using chemiosmosis to power the addition of a phosphate group to ADP, a process called photophosphorylation. Thus, light energy is initially converted to chemical energy in the form of two compounds: NADPH and ATP. NADPH, a source of electrons, acts as "reducing power" that can be passed along to an electron acceptor, reducing it, while ATP is the versatile energy currency of cells. Notice that the light reactions produce no sugar; that happens in the second stage of photosynthesis, the Calvin cycle.

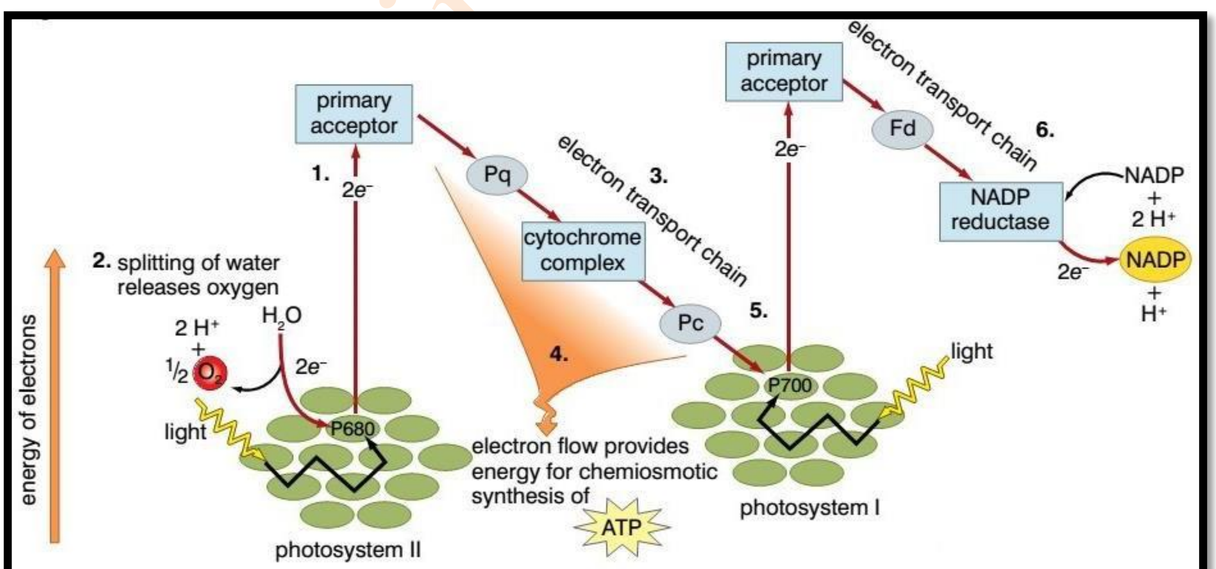


Figure. Light dependent reaction of photosynthesis

Photosystem I and photosystem II

1. Electrons (e–) in chlorophyll molecules in photosystem II are excited by the energy in photons of light – they become more energetic. Because of the extra energy, they escape from the chlorophyll and pass to an electron acceptor (the **primary electron acceptor**).
2. The conditions created in the chloroplast cause the following reaction to occur:

$$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$$

This light-dependent splitting of water is called **photolysis**. The electrons replace those lost from the chlorophyll molecule.

3. The primary electron acceptor passes the electrons to the next molecule in an electron transport chain (plastoquinone or 'Pq'). The electrons then pass along a series of cytochromes (similar to those in the mitochondrial electron transport chain) and finally to plastocyanin (Pc) – the last carrier in the chain. The electrons lose energy as they are passed from one carrier to the next.
4. One of the molecules in the cytochromes complex is a proton (hydrogen ion) pump. As electrons are transferred to and then transferred from this molecule, the energy they lose powers the pump which moves protons from the stroma of the chloroplast to the space inside the thylakoid. This leads to an accumulation of protons inside the thylakoid, which drives the chemiosmotic synthesis of ATP.
5. Electrons in chlorophyll molecules in photosystem I are excited (as this photosystem absorbs photons of light) and escape from the molecule. They are replaced by the electrons that have passed down the electron transport chain from photosystem II.
6. The electrons then pass along a second electron transport chain involving ferredoxin (Fd) and NADP reductase. At the end of this electron transport chain, they can react with protons (hydrogen ions) and NADP in the stroma of the chloroplast to form reduced NADP.

A summary of the light-dependent reactions

- **Light energy is used to excite electrons when:**

- The light-dependent reactions produce oxygen gas and convert ADP and $NADP^+$ into the energy carriers ATP and NADPH.
- ATP and NADPH provide the energy needed to build high-energy sugars from low-energy carbon dioxide.

Light-Independent Reactions (Calvin cycle)

- In the light-independent reactions or Calvin cycle (Figure 3.26), the energized electrons from the light- dependent reactions provide energy to form carbohydrates from carbon dioxide molecules. The light- independent reactions are sometimes called the Calvin cycle because of the cyclical nature of the process.

- Although the light-independent reactions do not use light as a reactant (and as a result can take place at day or night), they require the products of the light-dependent reactions to function. The light- independent molecules depend on the energy carrier molecules, ATP and NADPH, to drive the construction of new carbohydrate molecules. After the energy is transferred, the energy carrier molecules return to the light-dependent reactions to obtain more energized electrons. In addition, several enzymes of the light-independent reactions are activated by light.

- The second part of photosynthesis or the Calvin cycle is light-independent and takes place in the stroma of the chloroplast. The Calvin cycle captures CO2 and uses the ATP and NADPH to ultimately produce sugar by which chloroplasts coordinate the two stages of photosynthesis. Photosynthesis releases oxygen and sugars the basis of plant biomass which directly or indirectly feeds most living things on earth. The Calvin cycle reactions can be divided into three main stages: carbon fixation, reduction, and regeneration of the starting molecule. Here is a general diagram of the cycle:

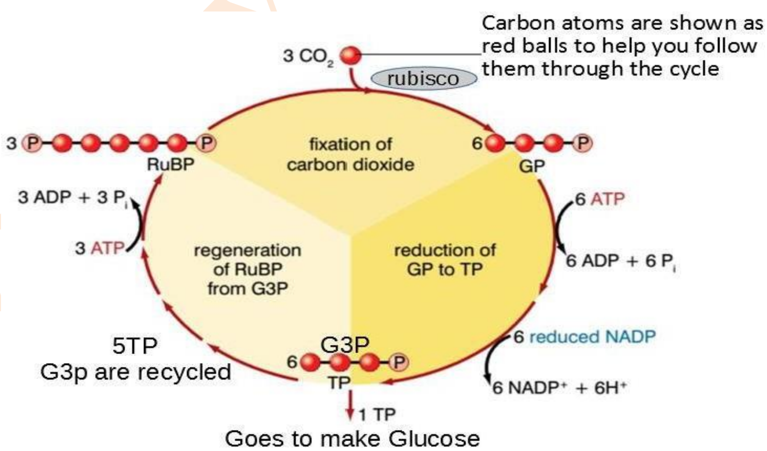


Figure. The light independent reactions

- **Carbon fixation.** A CO_2 molecules with five carbon acceptor molecules, ribulose-1, 5-bisphosphate (**RuBP**). This step makes a six-carbon compound that splits into two molecules of a three-carbon compound, 3-phosphoglyceric acid (3-PGA). This reaction is catalyzed by the enzyme RuBP carboxylase/oxygenase, or **rubisco**.
- **Reduction.** In the second stage, ATP and NADPH are used to convert the 3-PGA molecules into molecules of a three-carbon sugar, glyceraldehyde-3-phosphate (**G3P**).
- This stage gets its name because NADPH donates electrons to, or **reduces**, a three-carbon intermediate to make G3P.
- **Regeneration.** Some G3P molecules go to make glucose, while others must be recycled to regenerate the **RuBP** acceptor. Regeneration requires ATP and involves a complex network of reactions, which my college bio professor liked to call the "carbohydrate scramble." In order for one G3P to exit the cycle (and go towards glucose synthesis), three CO_2 molecules must enter the cycle, providing three new atoms of fixed carbon. When three molecules enter the cycle, six G3P molecules are made. One exits the cycle and is used to make glucose, while the other five must be recycled to regenerate three molecules of the RuBP acceptor.

Summary of Calvin cycle reactants and products

- Three turns of the Calvin cycle are needed to make one G3P molecule that can exit the cycle and go towards making glucose. When we summarize the quantities of key molecules that enter and exit the Calvin cycle as one net G3P is made. In three turns of the Calvin cycle:

A. **Carbon.** $3CO_2$ combine with 3RuBP acceptors, making 6 molecules of glyceraldehyde-3-phosphate (G3P).

B. 1- G3P molecule exits the cycle and goes towards making glucose.

C. 5- G3P molecules are recycled, regenerating 3RuBP acceptor molecules.

D. **ATP.** 9 ATP are converted to 9 ADP (6 during the fixation step, 3 during the regeneration step).

NADPH. 6 NADPH are converted to 6 $NADP^+$ (during the reduction step).

- A G3P molecule contains three fixed carbon atoms, so it takes two G3Ps to build a six-carbon glucose molecule. It would take six turns of the cycle, or 6 CO_2, 18 ATP, and 12 NADPH, to produce one molecule of glucose.

C3, C4, and CAM Plants Use Different Carbon Fixation Pathways

- The Calvin cycle is also known as the **C3 pathway** because a three-carbon molecule 3-phosphoglyceric acid (3-PGA), is the first stable compound in the pathway. Although all plants use the Calvin cycle, C3 plants use *only* this pathway to fix carbon from CO_2. About 95% of plant species are C3, including cereals, peanuts, tobacco, spinach, sugar beets, soybeans, most trees, and some lawn grasses.
- **C3 photosynthesis** is obviously a successful adaptation, but it does have a weakness: inefficiency. Photosynthesis has a theoretical efficiency rate of about 30% in ideal conditions, but a plant's efficiency in nature is typically as low as 0.1% to 3%.

How do plants waste so much solar energy? One contributing factor is a metabolic pathway called **photorespiration,** a series of reactions that begin when the rubisco enzyme adds O_2 instead of CO_2 to RuBP. The product of this reaction does not continue in the Calvin cycle. The plant therefore loses CO_2 that it fixed in previous turns of the cycle, wasting both ATP and NADPH.

- In hot, dry climates, plants that minimize photorespiration have a significant competitive advantage. One way to improve efficiency is to ensure that rubisco always encounters high CO_2 concentrations. The C4 and CAM pathways are two adaptations that do just that. C4 plants physically separate the Calvin cycle from the O_2-rich air spaces in the leaf. The light reactions occur in mesophyll cells, as does a carbon-fixation reaction called the C4 pathway.
- In the **C4 pathway,** CO_2 combines with a three-carbon "ferry" molecule to form a four-carbon compound (hence the name C4). This molecule then moves into adjacent **bundle-sheath cells** that surround the leaf veins (Figure 3.27).
- The CO_2 is liberated inside these cells, where the Calvin cycle fixes the carbon a second time. Meanwhile, at the cost of two ATP molecules, the three-carbon "ferry" returns to the mesophyll to pick up another CO_2.

- About 1% of plants use the C4 pathway. All are flowering plants growing in hot, sunny environments, including crabgrass and crop plants such as sugarcane and corn. C4 plants are less abundant, however, in cooler, moister habitats. In those environments, the ATP cost of ferrying each CO_2 from a mesophyll cell to a bundle-sheath cell apparently exceeds the benefits of reduced photorespiration.

- Another energy- and water-saving strategy is crassulacean acid metabolism (CAM). Plants that use the **CAM pathway** add a new twist: They open their stomata only at night, fix CO_2, then fix it again in the Calvin cycle during the day. Unlike in C4 plants, both fixation reactions occur in the same cell.
- A CAM plant's stomata open at night, when the temperature drops and humidity rises. CO_2 diffuses in. Mesophyll cells incorporate the CO_2 into a four-carbon compound, which they store in large vacuoles. The stomata close during the heat of the day, but the stored molecule moves from the vacuole to a chloroplast and releases its CO_2. The chloroplast then fixes the CO_2 in the Calvin cycle.

- The CAM pathway reduces photorespiration by generating high CO_2 concentrations inside chloroplasts. About 3% to 4% of plant species, including pineapple and cacti, use the CAM pathway. All CAM plants are adapted to dry habitats. In cool environments, however, CAM plants cannot compete with C3 plants. Their stomata are open only at night, so CAM plants have much less carbon available to their cells for growth and reproduction.

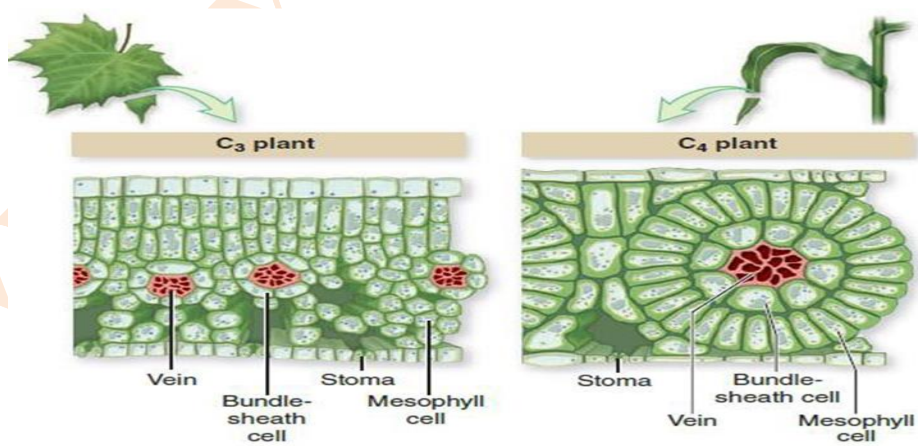


Figure. C3 and C4 Leaf Anatomy.

- In C3 plants, the light reactions and the Calvin cycle occur in mesophyll cells. In C4 plants, the light reactions occur in mesophyll, but the inner ring of bundle-sheath cells houses the Calvin cycle.

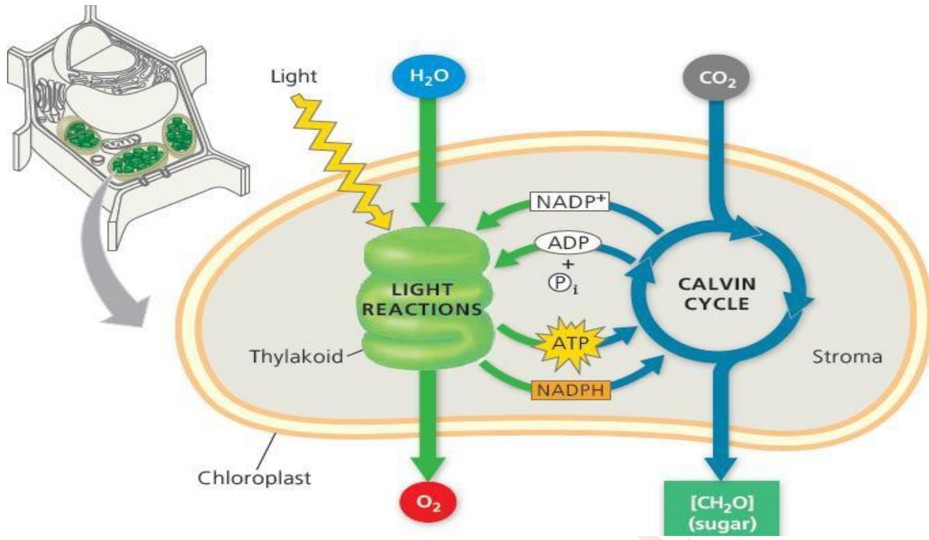


Figure. Light-dependent reaction (left) and light-independent reaction (right) (Source: Campbell 2020)

- **Contributions of photosynthesis for the continuity of life, for O2 and CO2 balance and global warming**

  - The oxygen in the air comes from photosynthesis. Plants continue to replenish oxygen in the air. All of our food comes directly or indirectly from photosynthesis. Human beings are also dependent on ancient products of photosynthesis (fossil fuels, natural gas, coal & petroleum); needed for modern industrial energy; complex mix of hydrocarbons; represent remains of organisms that relied on photosynthesis millions of years ago; carbon, oxygen, and hydrogen atoms are recycled in the environment where a constant input of solar energy is needed for energy to continue flowing to support life remove carbon dioxide from the atmosphere (inhibit global warming).

Review questions

Choose the correct answer for the following questions.

1. Where does the energy come from to drive photosynthesis?

A. A chloroplast B. ATP C. The sun D. Glucose

2. Algae in a swimming pool are ____; Escherichia coli bacteria in the human intestine are

A. autotrophs; autotrophs B. heterotrophs; heterotrophs C. autotrophs; heterotrophs

D. heterotrophs; autotrophs

3. Photosynthesis is essential to animal life because it provides

A. CO_2 for respiration. B. Organic molecules. C. O_2. D. Both b and c are correct.

4. Only high-energy light can penetrate the ocean and reach photosynthetic organisms in coral reefs. What color light would you predict these organisms use?

A. Red B. Blue C. Yellow D. Orange

5. Which molecules are used to connect the light reactions and the carbon reactions?

A. ATP and ADP B. NADPH and NADP C. Glucose D. Both a and b are correct.

6. A plant that only opens its stomata at night is A. C2 plant. B. C3 plant. C. C4 plant. D.CAM plant.

Answer

1. C	**2.C**	**3. B**	**4.B**	**5. D**	**6. D**

3.4 Cellular Respiration

- In the process of photosynthesis, plants and other photosynthetic producers create glucose, which stores energy in its chemical bonds. Accordingly, both plants and consumers, such as animals, undergo a series of metabolic pathways—collectively called cellular respiration. Cellular respiration extracts the energy from the bonds in glucose and converts them into a form that all living things can use. The energy released by cellular respiration is temporarily captured by the formation of Adenosine Triphosphate (ATP) within the cell.
- ATP is the principal molecule for storing and transferring energy in cells. It is often referred to as the energy currency of the cell, and this can be compared to depositing cash in a bank. ATP can be used to store energy for future reactions or be withdrawn to pay for reactions when energy is required by the cell. Animals store the energy obtained from the breakdown of food as ATP. Likewise, plants capture and store the energy they derive from light during photosynthesis in ATP molecules. ATP is a nucleotide consisting of an adenine base attached to a ribose sugar, which is attached to three phosphate groups.

- These three phosphate groups are linked to one another by two high-energy bonds called phosphoanhydride bonds. When one phosphate group is removed by breaking a phosphoanhydride bond in a process called hydrolysis, energy is released, and ATP is converted to adenosine diphosphate (ADP). Similarly, energy is also released when a phosphate is removed from ADP to form adenosine monophosphate (AMP). This free energy can be transferred to other molecules to make unfavorable reactions in a cell favorable. AMP can then be recycled into ADP or ATP by forming new phosphoanhydride bonds to store energy once again. In the cell, AMP, ADP, and ATP are constantly interconverted as they involve in biological reactions.

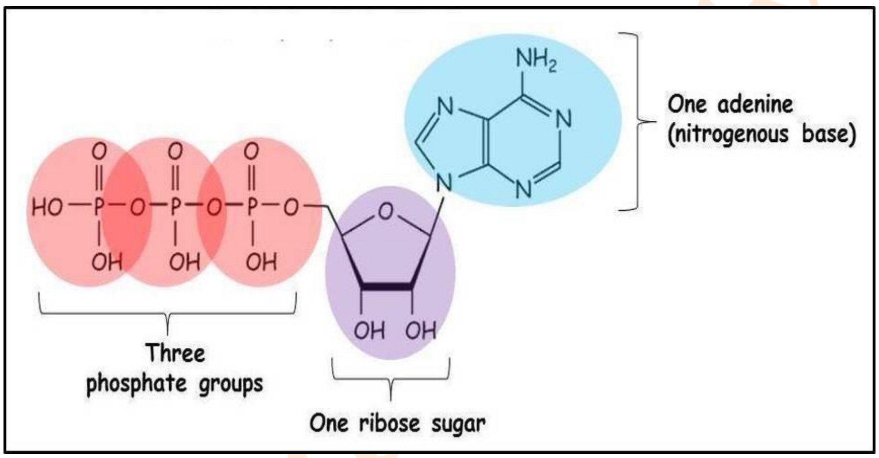


Figure. Adenosine triphosphate.

Coupled Reactions

- Many biochemical reactions in which energy is given off- (is called **exothermic**), whereas many others reactions that require energy (are called **endothermic**). In order for both processes to be carried out efficiently, they must be "coupled". Usually, a **coupled reaction** will involve ATP or some similar molecules. A coupled reaction is carried out when two reactions occur nearly simultaneously. The first reaction must be exothermic and that gives off energy. The second reaction is endothermic, which immediately uses the energy produced from the first reaction.
- An example of a coupled reaction is the hydrolysis of ATP and the contraction of muscle tissue. Two proteins, actin and myosin, form a loose complex called actomyosin. When ATP is added to isolated actomyosin, the protein fibers contract. The hydrolysis of ATP releases energy which is used by muscles to contract. The coupled reaction is:

- **ATP + H_2O →→ ADP + P + energy**
- Relaxed muscle + energy →→ contracted muscle

- When the ATP is used up by the muscles, a further supply of energy is released from creatine phosphate. Another example of a coupled reaction is the hydrolysis of creatine phosphate to release energy which in turn is used for the formation of more ATP. The coupled reaction is:

1. Creatine --- $PO_3 + H_2O$ →→ creatine H + HPO_4^{-3} + energy
2. ADP + HPO_4^{-3} + energy →→ ATP + H_2O

- During periods of low muscular activity, the reactions are reversed to replenish the supplies of ATP and creatine phosphate. The energy for the formation of ATP is supplied by other metabolic reactions.

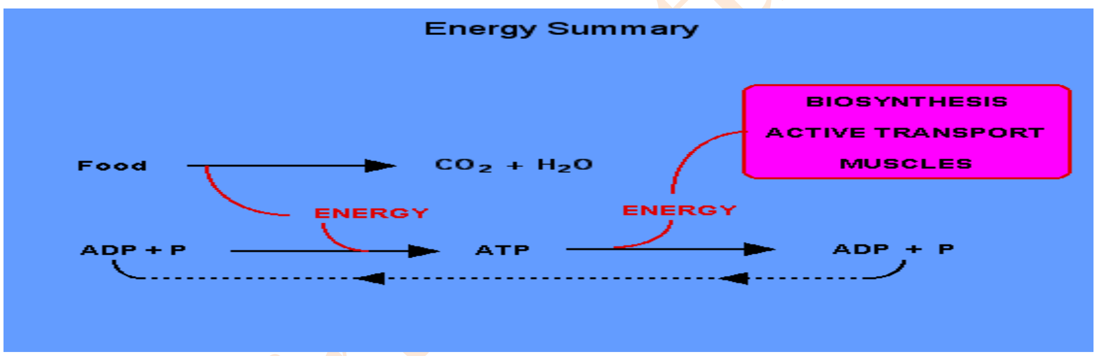


Figure:

3.4.1 Stages of Cellular Respiration

- Cellular respiration involves many chemical reactions. The reactions can be summed up in this equation:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + 6O_2 \longrightarrow 6CO_2 + 6H_2O + ATP$$

- The reactions of cellular respiration can be grouped into three stages: **glycolysis** (stage

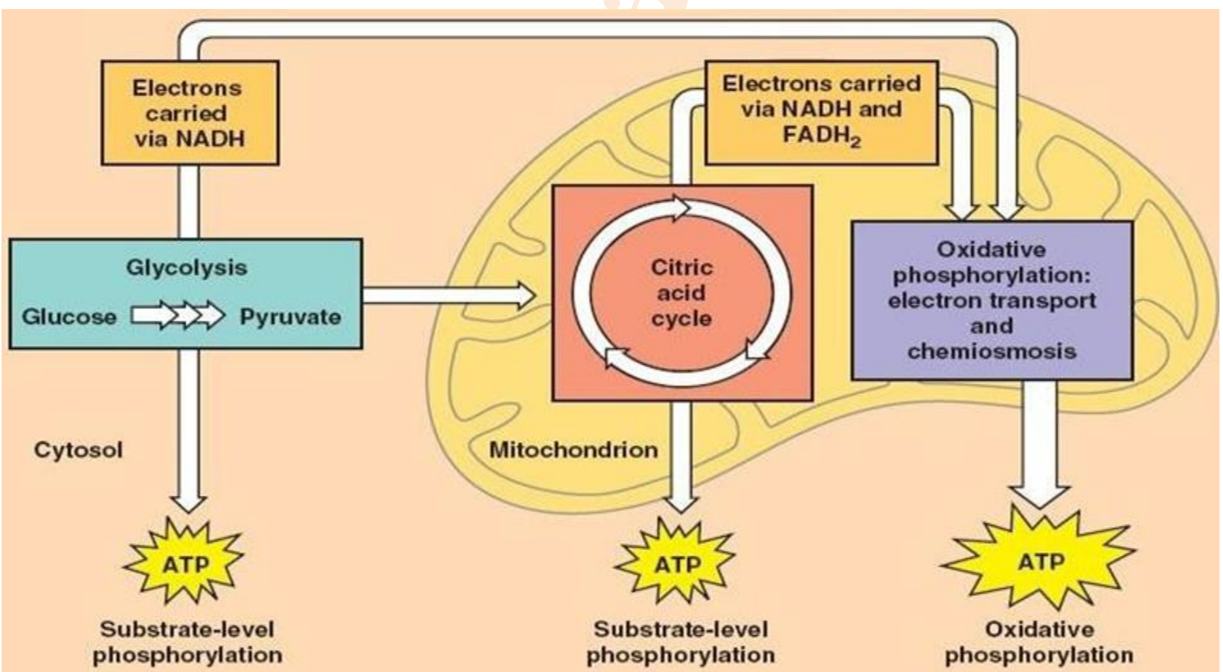
1), the **Krebs cycle**, also called the **citric acid cycle** (stage 2), and **electron transport** (stage 3).

The site/place of cellular respiration

- Glycolysis occurs in the cytosol of the cell and does not require oxygen, whereas the Krebs cycle and electron transport occur in the mitochondria and requires oxygen. **Cellular respiration** is carried out by both prokaryotic and eukaryotic cells. In prokaryotic cells, it is carried out in the **cell cytoplasm**, whereas in eukaryotic cells it begins in the **cytosol** then is carried out in the mitochondria.
- In eukaryotes, the four stages of cellular respiration include glycolysis, transition reaction (pyruvate oxidation), the Krebs cycle (also known as the citric acid cycle), and oxidative phosphorylation through the electron transport chain.

Stages of respiration

- Cellular respiration consists of a sequence of many chemical reactions that vary during aerobic and anaerobic conditions. Aerobic respiration is divided into three main stages: Glycolysis, Citric acid cycle and Electron transport chain (Figure.29).



Figure, Stages of cellular respiration

Stage 1: Glycolysis

- As shown with a teal background throughout this chapter, it occurs in the cytosol of the cell. Glycolysis begins cellular respiration by breaking glucose into two molecules of a three-carbon compound called pyruvate (Figure).

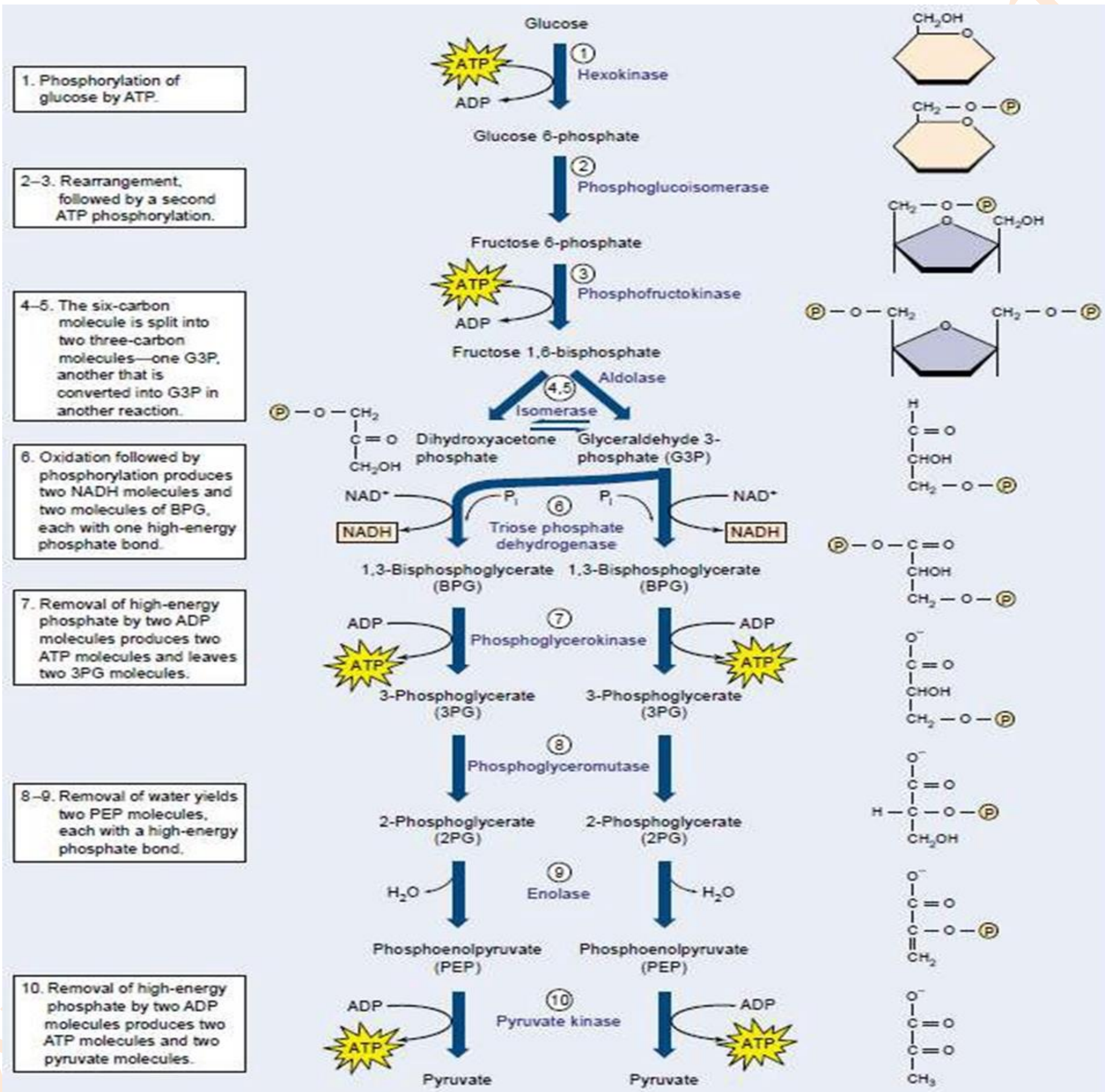


Figure . Glycolysis pathway. (Raven and Johnson, xxxx)

- Glycolysis pathway divided into two parts. a) The preparatory phase where glucose is converted into three-carbon sugar phosphates. b) The pay-off phase with generation of the high-energy molecules ATP and NADH. The end product is pyruvate.

Net reaction of glycolysis

$$\text{Glucose} + 2\ \text{ADP} + 2\ \text{NAD}^{+} + 2\ \text{P}_i \longrightarrow 2\ \text{Pyruvate} + 2\ \text{ATP} + 2\ \text{NADH} + 2\ \text{H}^{+} + 2\ \text{H}_2\text{O}$$

Stage 2: Pyruvate oxidation (link reaction)

- In order to oxidize to pyruvate, which is the product of glycolysis and enter the next pathway, it must undergo several changes to become acetyl Coenzyme A (acetyl CoA). Acetyl CoA is a molecule that is further converted to oxaloacetate, which enters the citric acid cycle (Krebs cycle). The conversion of pyruvate to acetyl CoA is a three-step process (Figure 3.31).

- Step 1. A carboxyl group is removed from pyruvate, releasing a molecule of carbon dioxide into the surrounding medium. (Note: carbon dioxide is one carbon attached to two oxygen atoms and is one of the major end products of cellular respiration).

- Step 2. The hydroxyethyl group is oxidized to an acetyl group, and the electrons are picked up by NAD+, forming NADH (the reduced form of NAD+). The high- energy electrons from NADH will be used later by the cell to generate ATP for energy.

- Step 3. The enzyme-bound acetyl group is transferred to CoA, producing a molecule of acetyl CoA. This molecule of acetyl CoA is then further converted to be used in the next pathway of metabolism, or the citric acid cycle.

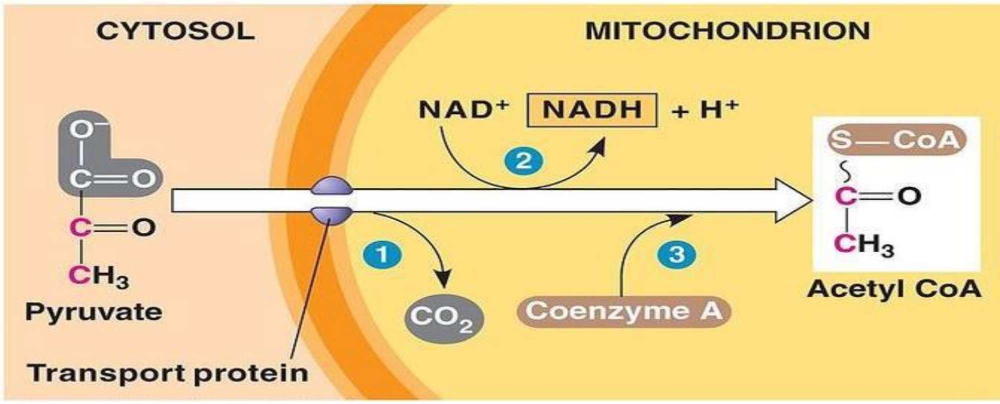


Figure. Pyruvate oxidation (link reaction)

- The overall reaction: 2pyruvate + 2NAD+ + 2 CoA --> 2 acetyl-CoA + 2NADH + 2H+ + $2CO_2$. The Acetyl-coA molecules enter the Kreb cycle, NADH goes to the electron transport chain to produce ATP. Carbon dioxide diffuses out of the cell as a waste product. The protons (2H+) stay in the matrix.

Stage 3: Kreb cycle

- The Krebs cycle itself actually begins when acetyl-CoA combines with a four-carbon molecule called OAA (oxaloacetate) (Figure 32). This produces citric acid, which has six carbon atoms. This is why the Krebs cycle is also called the citric acid cycle. After citric acid forms, it goes through a series of reactions that release energy. The energy is captured in molecules of NADH, ATP, and $FADH_2$, another energy-carrying compound. Carbon dioxide is also released as a waste product of these reactions. The final step of the Krebs cycle regenerates OAA, the molecule that began the Krebs cycle. This molecule is needed for the next turn through the cycle. Two turns are needed because glycolysis produces two pyruvate molecules when it splits glucose.

Net reaction:

$3NAD^+ + FAD + GDP + Pi + \text{acetyl-CoA} + 2\,H_2O \rightarrow 3NADH + FADH_2 + GTP + 2CO_2 + 4H^+$

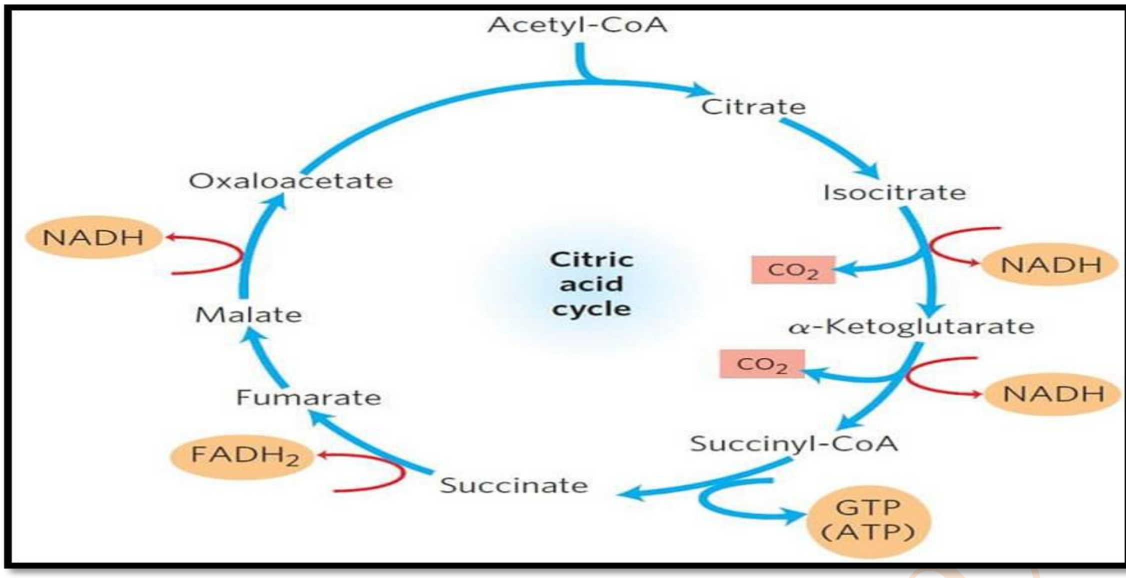


Figure. Kreb (Citric acid) cycle

Stage 4: Oxidative phosphorylation

- It is the process in which ATP is formed as a result of the transfer of electrons from NADH or $FADH_2$ to O_2 by a series of electron carriers. This process, which takes place in mitochondria, is the major source of ATP in aerobic organisms. Oxidative phosphorylation generates 26 out of the 30 molecules of ATP that are formed when glucose is completely oxidized to CO_2 and H_2O. The three major steps in oxidative phosphorylation are **(a)** oxidation-reduction reactions involving electron transfers between specialized proteins embedded in the inner mitochondrial membrane; **(b)** the generation of a proton (H+) gradient across the inner mitochondrial membrane (which occurs simultaneously with step (a)); and **(c)** the synthesis of ATP using energy from the spontaneous diffusion of electrons down the proton gradient generated in step
- The NADH and $FADH_2$, formed during glycolysis, the link reaction, and the TCA cycle, give up their electrons to reduce molecular O_2 to H_2O. Electron transfer occurs through a series of protein electron carriers, the final acceptor being O_2 and the pathway is called the electron transport chain (ETC). The function of ETC is to facilitate the controlled release of free energy that was stored in reduced cofactors during catabolism. Energy is released when electrons are transported from higher energy NADH/$FADH_2$ to lower energy O_2. This energy is used to phsophorylate ADP. There are 3 sites of the chain that can give enough

energy for ATP synthase. These sites are:

- Site I between FMN and Coenzyme Q at enzyme complex I.
- Site II between cyt b and cyt C1 at enzyme complex III
- Site III between cyt a and cyt a3 at enzyme complex IV

- Because energy generated by the transfer of electrons through the electron transport chain to O_2 is used in the production of ATP, the overall process is known as oxidative phosphorylation. This oxidation process refers to the coupling of the electron transport in respiratory chain with phosphorylation of ADP to form ATP. It is a process by which the energy of biological oxidation is ultimately converted to the chemical energy of ATP. Oxidative phosphorylation is responsible for 90% of the total ATP synthesis in the cell. Oxidative phosphorylation is the process in which ATP is formed as a result of the transfer of electrons from NADH or $FADH_2$ to O_2 by a series of electron carriers.

Mechanism

- Mechanism suggests that the transfer of electrons through the electron transport chain causes protons to be translocated (pumped out) from the mitochondrial matrix to the intermembrane space at the three sites of ATP production (i.e. it acts as a proton pump) resulting in an electrochemical potential difference across the inner mitochondrial membrane.
- The electrical potential difference is due to the accumulation of the positively charged hydrogen ions outside the membrane, whereas the chemical potential difference is due to the difference in pH when it is more acidic outside the membrane. This electrochemical potential difference drives (forces) ATP synthase to generate ATP from ADP and inorganic phosphate.

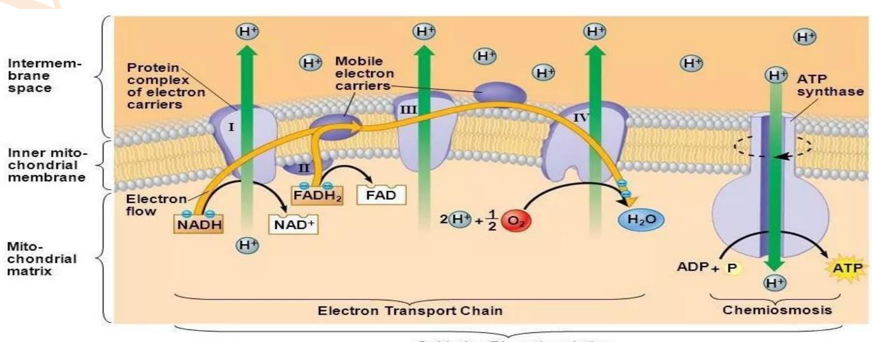


Figure . Electron transport and oxidative phosphorylation

The energy budget of one glucose molecule

- As from one glucose molecule, two pyruvate molecules are formed so that two cycles will be formed for the complete breakdown. So, the total yield will be **6 NADH, 2FADH2, and 2 GTP**.

Phase 1: Glycolysis

A. Glucose +2 NAD+NAD+ +2Pi + 2ADP→→ 2Pyruvate +2 H+ + 2NADH + 2 ATP + $2H_2O$

B. 2ATP + 2NADH (Since, 1 NADH = 3 ATP) →→ 2 ATP + 2×3 ATP = 8 ATP

Phase 2: Oxidative decarboxylation

A. Conversion of 2pyruvate to 2acetyl-CoA →→ 2NADH and $2CO_2$.

B. As, 1 NADH = 3 ATP; therefore 2 NADH = 2×3 ATP = 6 ATP.

Phase 3: Citric acid cycle (Kreb's cycle or tricarboxylic acid cycle)

A. The net gain from a single cycle is 3NADH, $1FADH_2$, and 1 GTP.

B. As one glucose →→ two pyruvate molecules →→ the total yield will be 6 NADH, $2FADH_2$, and 2 GTP.

C. Total ATP = 6 NADH + $2FADH_2$ +2 GTP. (1 GTP = 1 ATP; $1FADH_2$= 2 ATP)

D. Total ATP = 6×3 ATP+ 2×2ATP +2×1ATP

E. 18ATP + 4ATP + 2ATP = 24 ATP

F. Total ATP = ATP yield in glycolysis + ATP yield in oxidative decarboxylation + ATP yield in a citric acid cycle.

G. Total ATP = 8ATP + 6ATP +4 ATP = 38 ATP

H. So, after looking at the whole derivation of ATP molecules during the three phases of aerobic respiration, it can be concluded that only option (D) i.e., 38 ATP is correct while the other options are incorrect

Two ideas to keep in mind

1. The idea of net gain of ATP is like the profit a business person makes. It invests in money materials, advertising and building the capacity of staff. He/ She sell his/her product where the extra money is profit – net gain. In a similar vein, glycolysis 'invests' in two molecules of

ATP to make the glucose reactive, then, later, produces **four molecules of ATP** – a net gain of two molecules of ATP.

2. There are two molecules of pyruvate made from each molecule of glucose. So, all the gains of ATP and the reduced NAD and reduced FAD that accrue from each pyruvate must be doubled to give the gain from each molecule of glucose.

- A summary of the overall reaction of the electron transport system:

6 reduced NAD (from Krebs' cycle) + 2 reduced NAD (from glycolysis) + 2 reduced FAD (from Krebs' cycle) + 30 ADP + 30 Pi – 2ATP (used in proton pumps) ➞36 ATP + 8 NAD + 2FAD

- For aerobic reaction: $C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2$+ energy released

Respirometers

- Respirometers come in several different forms, but they all work on the principle that oxygen is used in aerobic respiration and carbon dioxide is produced.
- The overall summary equation for the aerobic respiration of glucose is:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + 36ATP$$

- This equation predicts that the volume of oxygen used ($6O_2$) is equal to the volume of carbon dioxide produced ($6CO_2$). This is the basis of how respirometers work.
- For every molecule of oxygen the organism uses, a molecule of carbon dioxide will be produced, but the carbon dioxide will be absorbed by the potassium hydroxide (KOH). Therefore, over time, there will be a reduction in volume inside the respirometer.

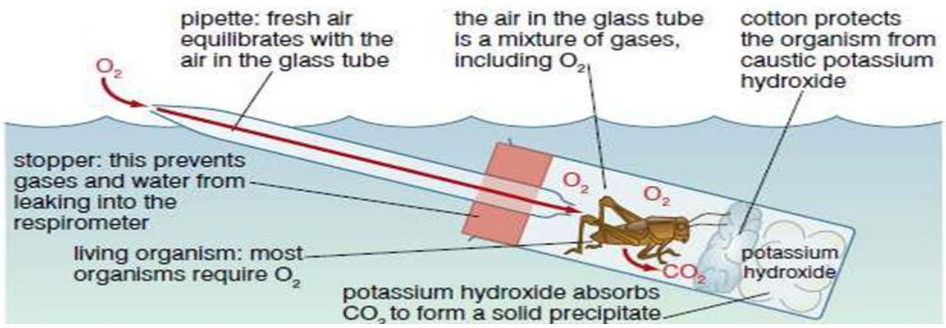


Figure , A basic respiromete

3.5 Fermentation

- **What happens in the anaerobic pathway?**
- In the process of glycolysis, a net profit of two ATP was produced, two NAD+ were reduced to two NADH + H+, and glucose was split into two pyruvate molecules. When oxygen is not present, pyruvate will undergo a process called fermentation. In the process of fermentation, the NADH + H+ from glycolysis will be recycled back to NAD+ so that glycolysis can continue. In the process of glycolysis, NAD+ is reduced to form NADH + H+. If NAD+ is not present, glycolysis will not be able to continue. During aerobic respiration, the NADH formed in the glycolysis will be oxidized to reform NAD+ for use in glycolysis again. When oxygen is not present or if an organism is not able to undergo aerobic respiration, pyruvate will undergo a process called fermentation. Fermentation does not require oxygen and is therefore anaerobic. Fermentation will replenish NAD+ from the NADH + H+ produced in glycolysis.

3.5.1 Alcoholic Fermentation

- One type of fermentation is alcohol fermentation. First, pyruvate is decarboxylated (CO_2 leaves) to form acetaldehyde. Hydrogen atoms from NADH + H+ are then used to help convert acetaldehyde to ethanol where NAD+ results. Facultative anaerobes are organisms that can undergo fermentation when they are deprived of oxygen. Yeast is an example of a facultative anaerobe that will undergo alcohol fermentation (Figure 3.35).

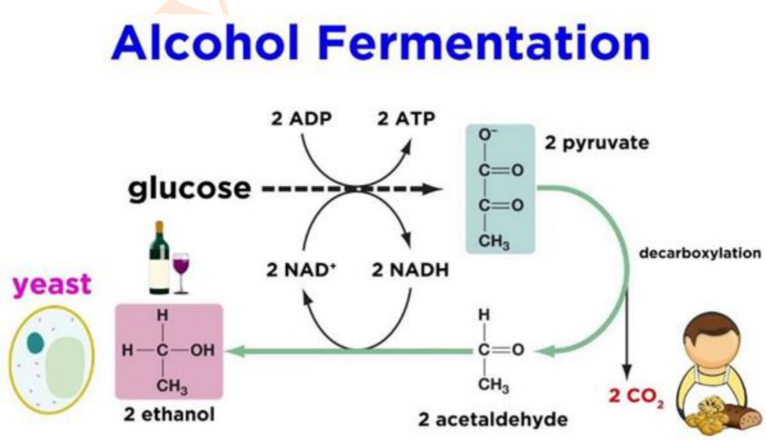


Figure. Alcohol fermentation

3.5.2 Lactic acid fermentation

- Some organisms, such as some bacteria, will undergo lactate fermentation. Two pyruvates are converted to two lactic acid molecules, which ionize to form lactate. In this process two NADH + H+ are converted to two NAD+. Our muscle cells can undergo this process when they are in oxygen debt. If enough oxygen is not present to undergo aerobic respiration,pyruvate will undergo lactic acid fermentation (Figure 3.36)

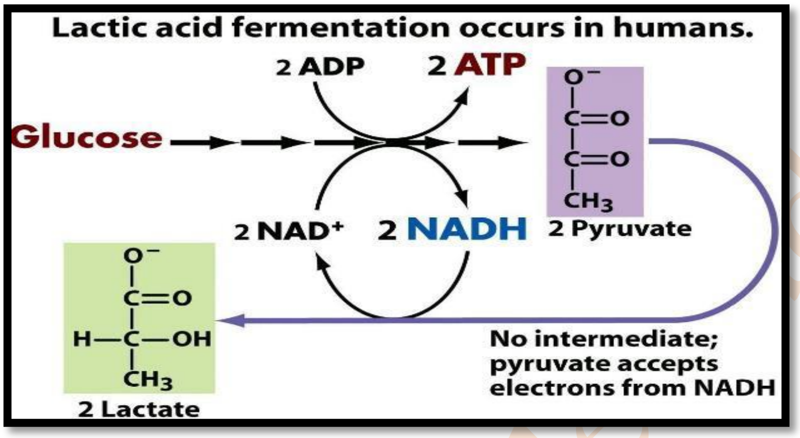


Figure. Lactic acid fermentation

Unit review questions

<u>**Choose the correct answer among the alternatives**</u>

1. The ATP molecule is sometimes described as:

   A). A phosphorylated nitrogenous base.

   B). A phosphorylated nucleotide.

   C). A glycosated nucleotide.

   D). A glycosated nitrogenous base

2. ATP is formed from:

   A). AMP and Pi,

   B). ADP and AMP

   C). ADP and P

   D). AMP and A.

3. Examples of processes that require ATP include:

A). Simple diffusion and active transport

B). Active transport and facilitated diffusion

C). Conduction of nerve impulses, osmosis

D). Active transport, and protein synthesis

4. The ATP synthase molecule produces ATP when:

A). Electrons turn the rotor to activate sites in the catalytic knob.

B). Hydrogen ions spin the catalytic knob.

C). Electrons spin the catalytic knob.

D). Hydrogen ions turn the rotor to activate sites in the catalytic knob

5. ATP is an ideal energy transfer molecule in cells because it:

A). Releases energy in small amounts.

B).Releases energy quickly.

C). Can move freely in, but not escape from, the cell.

D). All of the above

6. Which one of the following does not take place during the Krebs cycle?

A).O phosphorylation

B). Substrate-level phosphorylation

7. In fermentation:

A). Oxidative phosphorylation does not take place

B). Substrate-level phosphorylation does take place

C). NAD is reduced in glycolysis

D). All of the above

8. Which of the following statements about mitochondria is NOT true?

A). The carrier molecules of the electron transfer chain are found on the inner mitochondrial membranes

B). The reactions of the Krebs cycle take place inside the mitochondria

C). All of the ATP needed by the cell is made in the mitochondria

D). Much of the ATP needed by the cell is made in the mitochondria.

9. In the electron transport chain, electrons move:

A). From the lumen of the mitochondrion to the intermembrane space

B). From the inter-membrane space to the lumen of the mitochondrion

C).Through ATP synthase

D). Along a series of electron carriers

10. Oxidative phosphorylation includes:

A). The electron transport chain and chemiosmosis

B). The electron transport chain and the Krebs cycle

C). The Krebs cycle and chemiosmosis

D). None of these

11. In the Krebs cycle:

A). Some ATP is made by oxidative phosphorylation

B). The four-carbon compound oxaloacetate is regenerated.

C). ATP is used

D). The six-carbon compound citrate is split into two three- carbon compounds

12. When compared to aerobic respiration, fermentation of glucose by yeast:

A). Yields less ATP per molecule of glucose.

B). Produces lactate.

C). Produces more CO_2.

D). None of the above

13. Which one of the following statements about aerobic respiration is correct?

A). Glycolysis takes place in the matrix of the mitochondrion.

B). Carrier molecules of the electron transport chain exist on the outer membrane of the mitochondrion.

C). A high concentration of hydrogen ions builds up in the matrix of the mitochondrion.

D).The Krebs cycle takes place in the matrix of the mitochondrion.

14. In a respirometer…

A). The amount of oxygen used by the organism is replaced with an equal amount of carbon dioxide.

B). the carbon dioxide given off is absorbed by potassium hydroxide.

C). The breathing rate of an organism is measured.

D). We measure the uptake of oxygen by an organism

15. Which one of the following occur in both aerobic respiration and fermentation in mammals:

A). Substrate-level phosphorylation.

B). Chemiosmosis.

C). Link reaction.

D). Decarboxylation

- **ANSWERS:**

➢ **1.B 2. C 3.D 4. D 5. D 6. A 7. A 8. B 9. D 10. A 11. B 12. A 13. D 14. A 15.C**

UNITE 4

EVOLUTION

4.1. Definition

- Evolution is the gradual change in genetic composition of a population over successive generations, which may be caused by meiosis, hybridization, natural selection or mutation. This leads to a sequence of events by which the population diverges from other populations of the same species and may lead to the origin of a new species.

4.2 Theories of the origin of life

- The origin of life means the emergence of heritable and evolvable self-reproduction. "Origin of Life" is a very complex subject, and oftentimes controversial. Two opposing theories that existed on this complex subject for a long time were the so called **intelligent design** and **creationism**. The **big bang theory of the origin of the Universe** gave new ideas about the topic of biological evolution. In big bang theory, it has been hypothesized that complex life-forms on Earth, including humans, arose over a period of time from simple bacteria like tiny cells by a process of self-organization similar to the evolution of the Universe of simple material structures toward more and more complex structures. There are several theories about the origin of life. The creation of life on Earth will always leaving more questions than answer. Some of them are mentioned below.

4.2.1 Special creationism

- Special creationism explained that the formation of life on earth may have been taken place due to **supernatural** or **divine forces**. However, this idea is not linked to scientific thinking. There are fundamental differences between special creationism and scientific thinking. It is unlikely that the difference between the two will ever be resolved. Special creation states that at some stage, some supreme being created life on Earth. There are many different versions of special creation, linked with different religions. Often, there is considerable variation as to how rigidly the special creation theory is interpreted within a religion.

4.2.2 Spontaneous generation

- Spontaneous generation suggests that life can evolve spontaneously from non-living objects. The

Greek philosopher Aristotle (384–322 BC) was one of the earliest scholars to articulate the theory of spontaneous generation. It was once believed that life could come from nonliving things, such as mice from corn, flies from bovine manure, maggots from rotting meat, and fish from the mud of previously dry lakes.

- The theory of spontaneous generation persisted into the 17th century. Jan Baptista van Helmont (1580 – 1644) a Flemish scientist proposed that mice could arise from rags and wheat kernels left in an open container for 3 weeks. However, in 1668, Francesco Redi, an Italian scientist, designed a scientific experiment to test the spontaneous creation of maggots by placing fresh meat in jars (Figure 4.1), One jar was left open; the others were covered with a cloth. Days later, the open jar contained maggots, whereas the covered jars contained no maggots. He did note that maggots were found on the exterior surface of the cloth that covered the jar. Redi successfully demonstrated that the maggots came from fly eggs and thereby helped to disprove spontaneous generation.

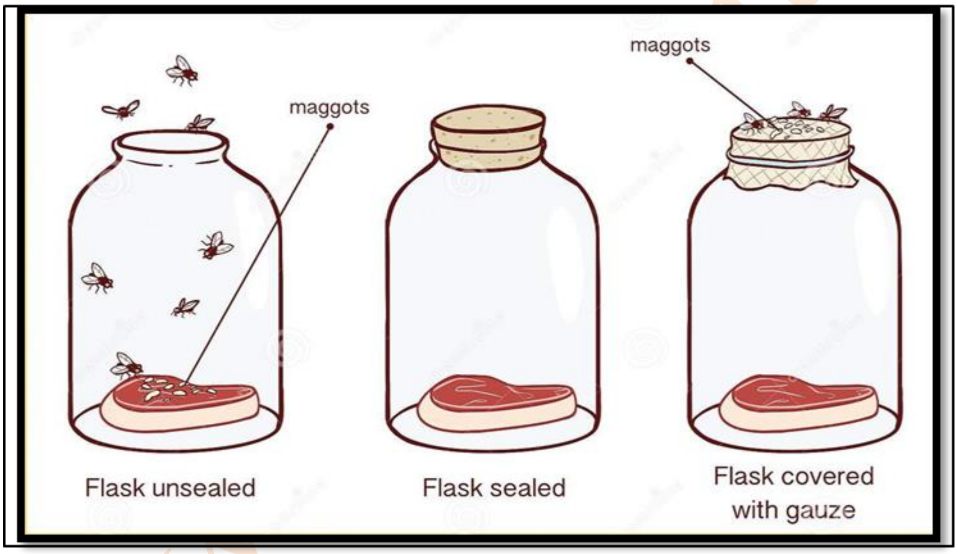


Figure 23 Fransesco Redi's experiment set up.

- Louis Pasteur, the notable French scientist, showed that broth (or wine) only went sour if micro- organisms were allowed to enter. Also no micro-organisms appeared in the broth unless they were allowed to enter from the outside (Figure 4.2).

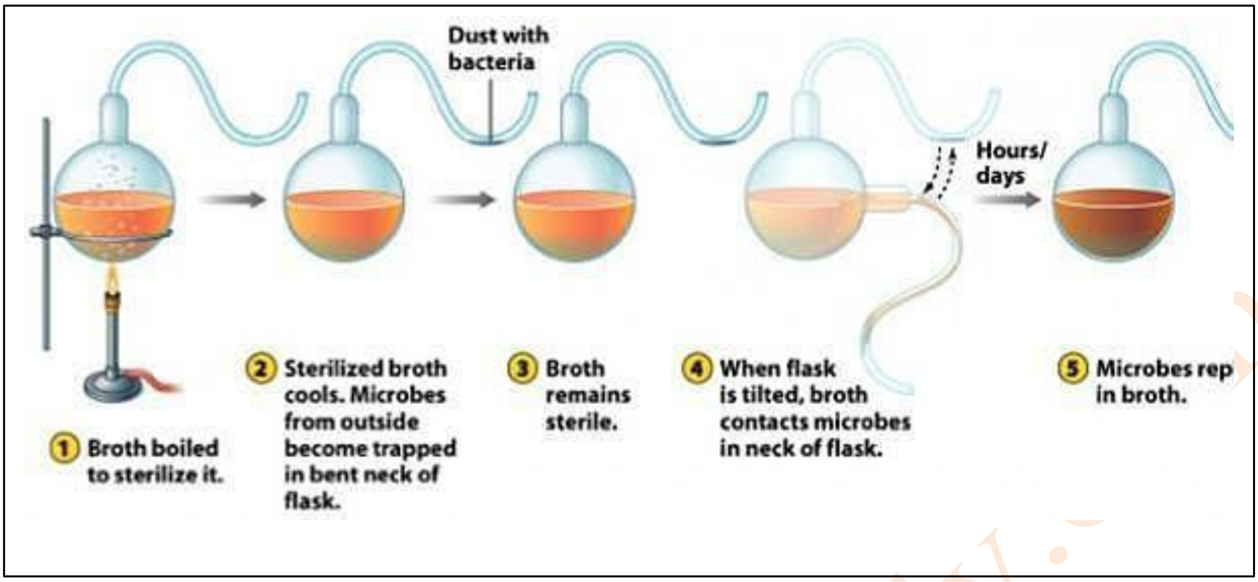


Figure 24 Louis Pasteur's experimental set up to disprove spontaneous generation

- These two scientists showed that both macro-organisms (Redi) and micro-organisms (Pasteur) could only arise from pre-existing organisms, disproving the theory of spontaneous generation. But what about the first ever cell? Unless we believe that life is eternal, with no beginning and no end, there had to be a first cell. It could not have come from a pre-existing cell because it was the first.

4.2.3 Eternity of life

- In this theory of life, there is no beginning and no end to life on Earth and so life neither needs special creation nor does it need to be generated from non-living matter. Supporters of this theory believe that life is an inherent property of the Universe and it has always existed as has the Universe.
- At the time when such theories were being propounded, many eminent scientists – including Albert Einstein – believed that the Universe was unchanging. They reasoned that 'if life is found today in an unchanging Universe, then it must always have been there'.

4.2.4 Cosmozoan theory, Panspermia or Spore broth theory

- According to Cosmozoan theory life has reached this planet Earth from other cosmological structures, such as meteorites, in the form of highly resistant spores. This theory was proposed by Richter (1865). According to this theory, 'protoplasm' reached the earth in the form of spores or germs or other simple particles from some unknown part of the universe with the cosmic dust, and subsequently evolved into various forms of life. Helmholz (1884) speculated that 'protoplasm' in some form reached the earth with falling

4.2.5 Biochemical origin

- The current ideas we have about how life may have evolved on Earth as a result of biochemical reactions (sometimes called abiogenesis) owe much to two biologists working early in the twentieth century.

- **Aleksandr Oparin**, a Russian biologist who first put forward his ideas in 1924, and **John Haldane**, an English biologist independently put forward almost identical ideas in 1929 (before Oparin's book had been translated into English). They proposed that common gases in the early Earth atmosphere combined to form simple organic chemicals, and these in turn combined to form more complex molecules. Then, the complex molecules became separated from the surrounding medium, and acquired some of the characters of living organisms. They became able to absorb nutrients, to grow, to divide (reproduce), and so on. Later Miller had apparently approved the Oparin-Haldane model by mixing the basic elements to produce simple organic compounds, and then combining these to produce the building blocks of proteins and nucleic acids (Figure .3).

Figure 25 Coacervate droplets – pre-cells

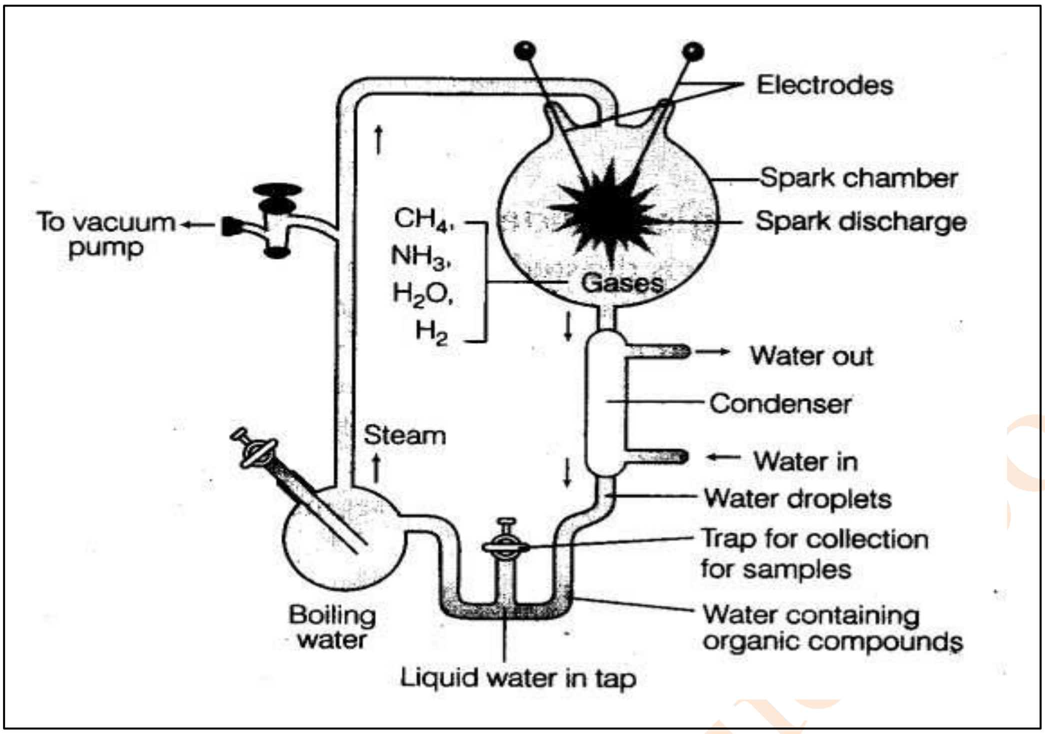


Figure 26 Stanley Miller's spark-discharge

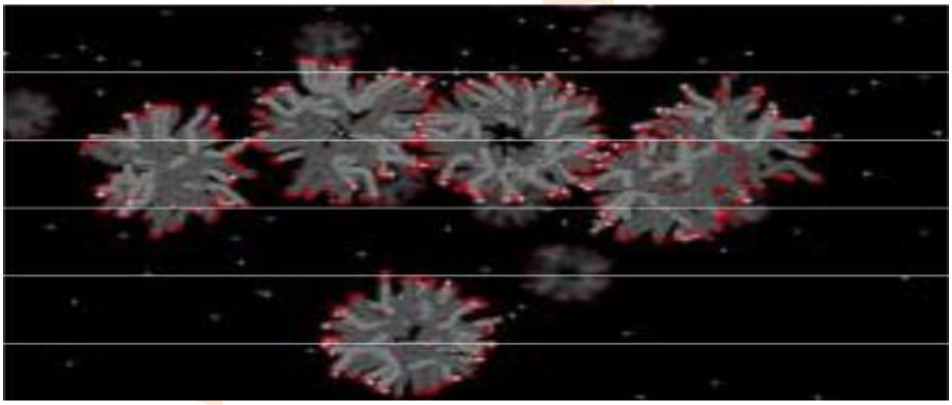


Figure 27 Could pre-cells have looked like this when they were dividing?

4.2.6 Autotrophs

- The first organisms appeared about 4 billion years ago. They were **prokaryotes**. They had no true nucleus. It seems likely also that they had RNA rather than DNA as their genetic material. It seems likely that they gave rise to three distinct lines of evolution leading to:

- **Archaebacteria** – prokaryotes including thermophilic sulphobacteria, methanobacteria and halophilic bacteria
- **Eubacteria** – prokaryotes; ordinary bacteria and cyanobacteria (blue-green bacteria and sometimes known as blue-green algae).

- **Eukaryotes** – eventually evolving into protoctistans, fungi, plants, animals (nearly all are aerobic).
- One great change that affected the evolution of early life forms was the shift from the reducing atmosphere to an atmosphere containing oxygen. This took place about 2.4 billion years ago. Where did this oxygen come from?

Chemoautotophs

- Other primitive autotrophs used not light as a source of energy but chemical reactions and are called chemo-autotrophs. Chemoautotrophs use the energy from chemical reactions to synthesise all necessary organic compounds, starting from carbon dioxide.
- They generally only use inorganic energy sources. Most are bacteria or archaea that live in hostile environments such as deep sea vents and are the primary producers in ecosystems on the sea beds. Scientists believe that the some of first organisms to inhabit Earth were chemo-autotrophs. The primitive sulphobacteria use hydrogen sulphide as the energy source. Hydrothermalism, particularly in deep sea vents, maintains the bacterial life of sulphobacteria and/or methanobacteria. Bacteria are the only life forms found in the rocks for a long time, 3.5 to 2.1 billion years ago. Eukaryotes became numerous 1.9 to 2.1 billion years ago and fungi-like organisms appeared about 0.9 billion years ago. The oxygen produced by the photo-autotrophs had made it possible for aerobic respiration to evolve as an energy-releasing pathway. As this process releases far more energy than does the anaerobic pathway more active organisms could now evolve – the animals, perhaps 600 to 700 million years ago.

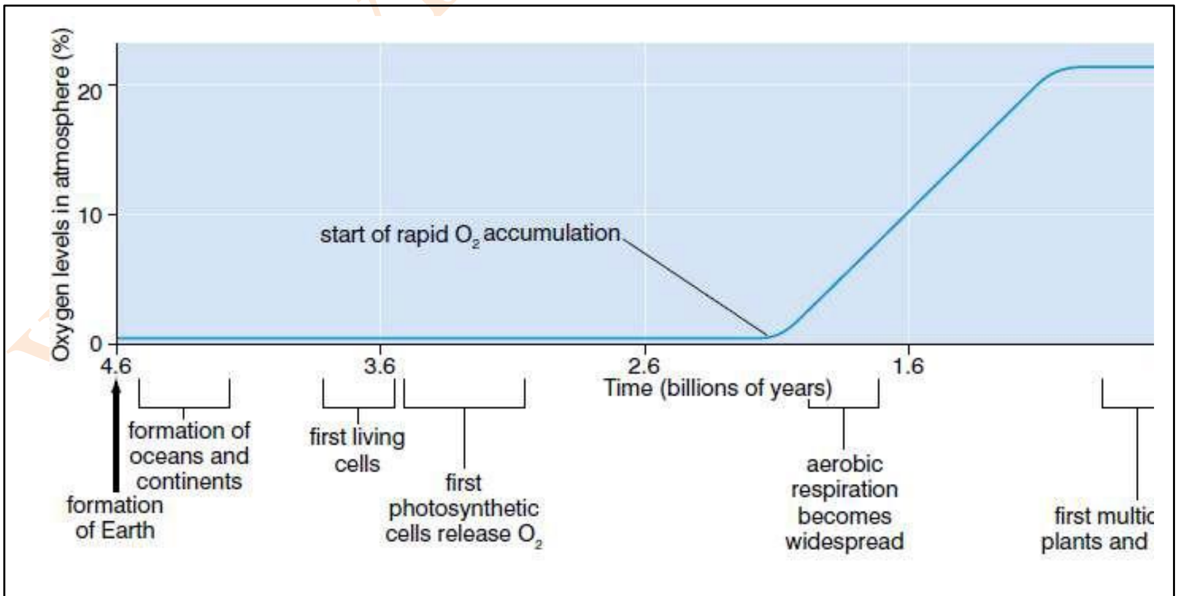
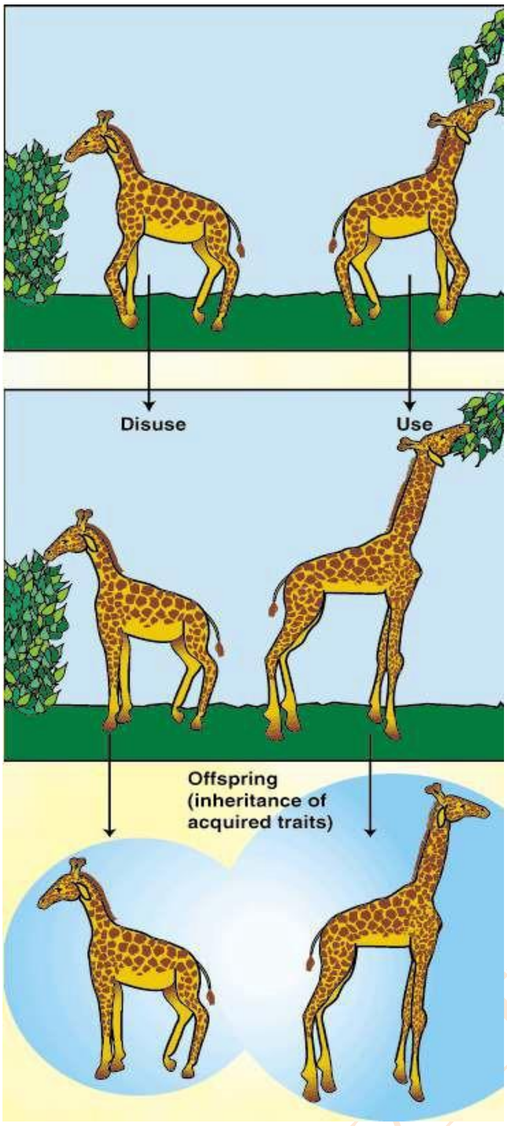


Figure 28 Life on Earth has evolved over billions of years

4.3 Theories of evolution

4.3.1 Lamarckism

- **Jean-Baptiste De Lamarck** (1744 - 1829) was a great French naturalist. Lamarck sought a naturalistic explanation for the diversity of modern organisms and the animals seen in the fossil record. ′ He proposed ‘the theory of inheritance of acquired characters’ in 1809. He postulated:
- **New Needs**: Changes in environment factors like light, temperature, medium, food, air etc or migration leads to origin of new needs in living organisms. To fulfill these new needs, living organisms have to exert special efforts like changes in habits or behavior.
- **Use and disuse of organs:** The new habits involve the greater use of certain organs to meet new needs, and the disuse or lesser use of certain other organs which are of no use in new conditions.
- **Inheritance of acquired characters:** he believed that the favorable acquired characters are inheritable and are transmitted to the offspring’s so that these are born fit to face the changed environmental conditions and the chances of their survival are increased.
- **Speciation:** Lamarck believed that in every generation, new characters are acquired and transmitted to next generation, so that new characters accumulate generation after generation. After a number of generations, a new species is formed.



Use and disuse theory

- In this part of his theory, Lamarck suggests that when a structure or process is continually used, that structure or process will become enlarged or more developed. Conversely, any structure or process that is not used or is rarely used will become reduced in size or less developed. The classic example he used to explain the concept of use and disuse is the elongated neck of the giraffe. According to Lamarck, a given giraffe could, over a lifetime of straining to reach high branches, develop an elongated neck. However, Lamarck could not explain how this might happen.

Inheritance of acquired traits theory

- Lamarck believed that traits changed or acquired during an individual's lifetime could be passed on to its offspring. Giraffes that had acquired long necks would have offspring with long necks rather than the short necks their parents were born with. This type of inheritance, sometimes called

Figure 29 Lamarck's ideas of use and disuse and the inheritance of acquired traits of evolution

- Lamarckian inheritance has since been disproved by the discoveries of genetics.

Significance of Lamarckism

a) It was the first comprehensive theory of biological evolution.
b) It nicely explains the existence of vestigial organs in animals due to their continuous disuse.
c) It explains the development of strong jaw muscles and claws in the carnivores due to their continued extra use.
d) It stimulated other biologists to look for the mechanism of organic mechanism.

4.3.2 Darwinism (Theory of natural selection)

- Charles Darwin and Alfred Russel Wallace jointly proposed that evolution occurs because of a phenomenon called natural selection. In the theory of natural selection, organisms produce more offspring to survive in their environment. Those individuals that are better physically equipped to survive grow to maturity and reproduce. Those that are lacking such fitness, on the other hand, either do not reach an age when they can reproduce or produce fewer offspring than their counterparts. Natural selection is sometimes summed up as "survival of the fittest" because the "fittest" organisms—those most suited to their environment—are the ones that reproduce most successfully, and are most likely to pass on their traits to the next generation.
- Darwin was highly influenced by essay entitled 'Principle of geology'written by Charles Lyell. Some of Darwin's evidence came from a visit to the Galapagos Islands. These are a small group of islands in the Pacific Ocean about 600 miles off the coast of Ecuador in South America. Darwin visited five of the Galapagos Islands and made drawings and collected specimens. In particular, Darwin studied the finches found on the different islands and noted that there were many similarities between them, as well as obvious differences. He concluded that an 'ancestral finch' had colonized the islands from the mainland and, in the absence of predators, were able to adapt to the different conditions on the islands and, eventually, evolved into different species (Figure 4.12). Some of the finches had, he suggested, evolved into insect eaters, with pointed beaks. Others had evolved into seed eaters with beaks capable of crushing the seeds.

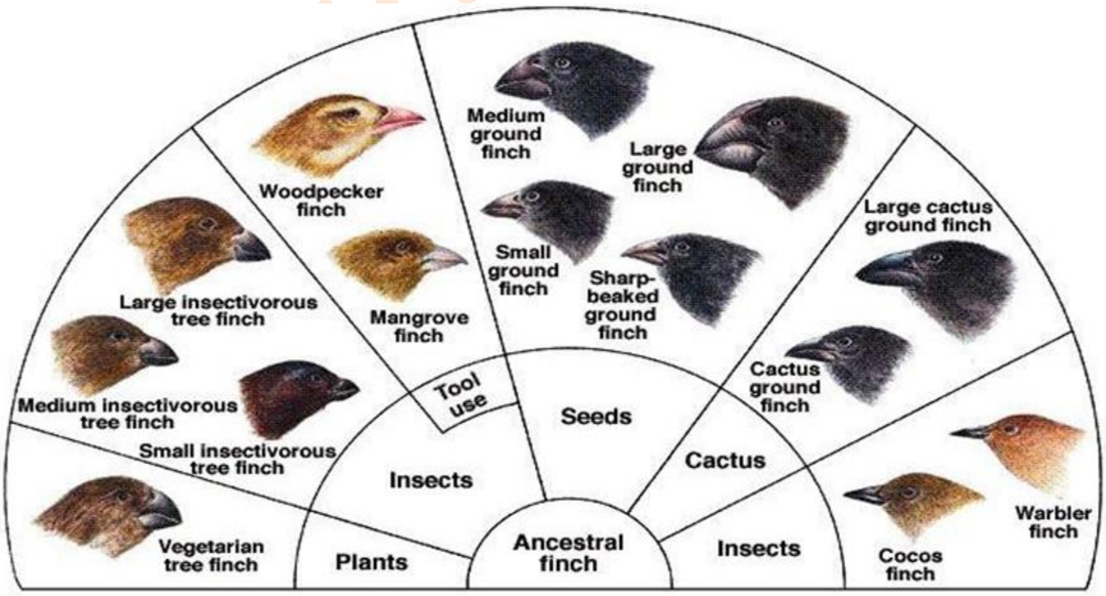


Figure 30 Darwin's Theory of Finches on the Galapagos Islands

Basic postulates of Darwinism

- **Geometric increase**: All species tend to produce more offspring than can possibly survive. However, the space and the availability of food supply is limited to support the number of organisms that increase in a geometric ratio.
- **Struggle for existence**: Since the number of individuals produced is far more than the number that can be supported, there is an everlasting competition between organisms at all levels of life.
- **Variation under nature**: No two individuals of a species are exactly similar and they have some differences. These differences are called variations and without evolution are not possible. Variations give rise to new characters and heredity passes them on to the next generation (inheritance of useful variations).
- **Natural selection** or **survival of the fittest**: Due to struggle for existence and useful heritable variations, only those individuals survive which show high selective value and in the course of time they develop various adaptive modifications to suit the changed conditions of life. Such selection was called natural selection by Darwin.

- **Origin of species**: In the course of long periods of time the best fitted and suitable individuals survived and adjust to the nature. As environment is ever changing, further changes occur and thus new adaptations appear in organisms. The later descendants after several generations become quite distinct from their ancestors. On this way new species appear.

Antibiotic resistance – a modern example of selection in action

Mutations in bacteria can make them resistant to an antibiotic, for example, penicillin. If they are resistant to penicillin, it will have no effect on their growth and reproduction. What happens next depends on whether the bacterial population is exposed to the antibiotic, or not. This is summarized in Figure 9 below

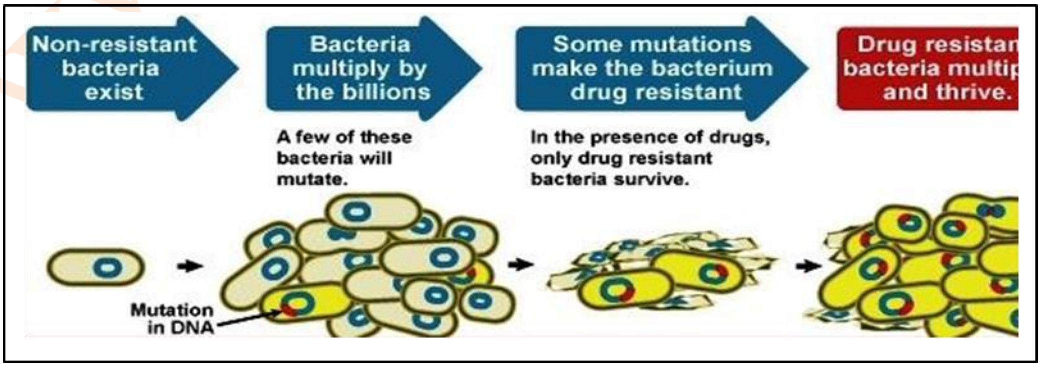


Figure 31: Drug resistance in bacteria is often the result of a genetic mutation

4.3.3 Neo-Darwinism theory

- Charles Darwin knew very little of genetics. Mendel had not carried out his ground-breaking work on inheritance at the time Darwin published his book On the Origin of Species. However, it is possible now to incorporate our knowledge of genes and gene action into the theory of natural selection to give a better understanding of what drives evolution.

- Genes determine features. But when we think about how a population might evolve into a new species, we need to think not just in terms of the alleles each individual might carry, but also in terms of all the alleles (all the genes) available in the population. We call this the **gene pool** of the population.

- Neo-Darwinism is a modified version of the theory of natural selection and is a sort of reconciliation between Darwin and de Vries theory. Scientist contributed to this theory is Huxley and R.A. Fischer. Postulates of Neo-Darwinism are:

1. Genetic variability
2. Natural selection
3. Reproductive Isolation

Review questions

Provide answer for the following questions

1. **Describe in detail the Darwin's theory on the origin of species.**

Answer:

- Darwin viewed evolution by **natural selection** as a very gradual mechanism of change within populations, and postulated that new species could be the product of this very same process, but over even longer periods of time. He proposed a model whereby lineages form from their ancestors by evolving different characters over relatively long periods of time. Darwin indicated that species could form by the evolution of one species splitting into two, or via a population diverging from its surviving ancestor to the point it was a new species.

2. **Explain Lamarck theory how new species emerge.**

Answer:

- Lamarck believed that living things evolved in a continuously upward direction, from dead matter, through simple to more complex forms, toward human "perfection. "Species didn't die out in extinctions; instead, they changed into other species. Since simple organisms exist alongside complex "advanced" animals today, Lamarck thought they must be continually created by spontaneous generation.

3. **Explain what Neo-Darwinism theory is.**

Answer:

- **Neo-Darwinism** is a theory of evolution that represents a synthesis of Charles Darwin's theory in terms of natural selection and modern population genetics. The term was first used after 1896 to describe the theories of August Weismann (1834–1914), who asserted that his germ-plasm theory made impossible the inheritance of acquired characteristics and supported natural selection as the only major process that would account for biological evolution.

4.4 The evidence for evolution

4.4.1 Comparative anatomy

- Comparative anatomy is one of the strongest forms of evidence for evolution. It looks at the structural similarities of organisms and uses these similarities to determine their possible evolutionary relationships. It assumes that organisms with similar anatomical features are closely related evolutionarily, and that they probably share a common ancestor. Some organisms have anatomical structures that are very similar in form, but very different in function. We call such structures **homologous structures**. Because they are so similar, they indicate an evolutionary relationship and a common ancestor of the species. Perhaps the best-known example of homologous structures is the forelimb of mammals. When examined closely, the forelimbs of humans, whales, cats and bats are all very similar in structure (Figure 4.10).

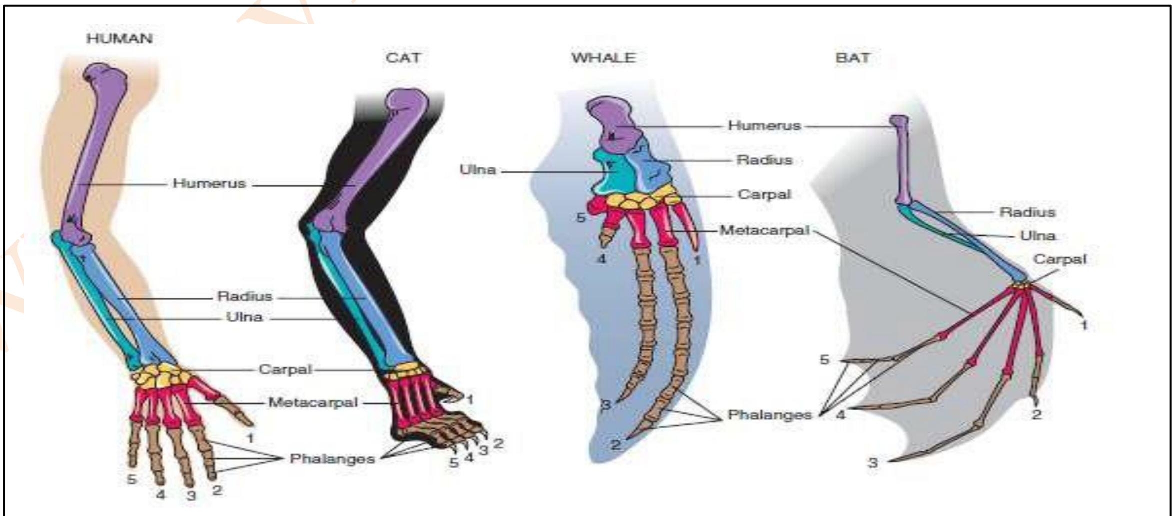


Figure 32 The homologous forelimbs of mammals.

- Each possesses the same number of bones, arranged in almost the same way while they have different external features that function in different ways as:

- arm for manipulation in humans
- leg for running in cats
- flipper for swimming in whales
- wing for flying in bats
- By comparing the anatomy of these limbs, scientists have determined that the basic pattern (called a **pentadactyl limb**) must have evolved just once and that all organisms with this kind of limb were descended from that original type, which they share a common ancestor
- However, comparative anatomy needs to be used carefully as evidence for evolution. This is because while sometimes organisms have structures that function in very similar ways, morphologically and developmentally these structures are very different. We call these **analogous structures**. Because they are so different structurally, even though they have the same function, they cannot indicate that two species share a common ancestor. Although, the wings of a bat, bird and mosquito all serve the same function, yet their anatomies are very different. For example, the bird wing has bones inside and is covered with feathers while the mosquito wing has neither of these (Figure 4.11). They are analogous structures that have evolved separately.

Figure 33 Analogy in animals

4.4.2 Comparative embryology

- Comparative embryology studies the way in which the embryos of vertebrates develop before they hatch or born. This development shows similarities which supports a common ancestry.

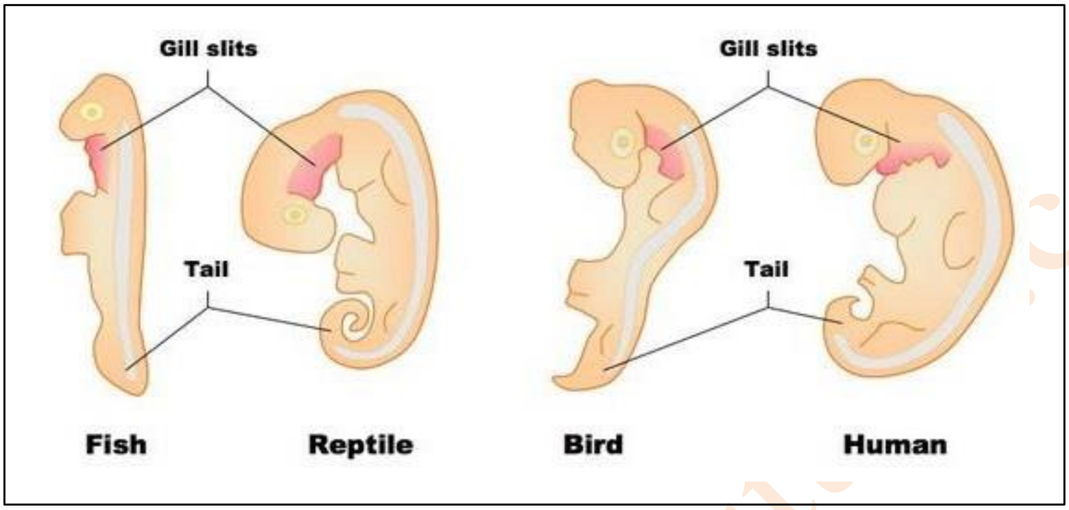


Figure34 Similarities in development of embryos.

- For example early in development, all vertebrate embryos have gill slits and tails (Figure 4.12). However, the 'gill slits' are not gills; they connect the throat to the outside, but in many species they disappear later in the embryonic development. However, in fish and larval amphibians they contribute to the development of gills.
- The embryonic tail does not develop into a tail in all species. In humans, it is reduced during development to the coccyx, or tailbone. The more similar the patterns of embryonic development, the more closely related species are assumed to be. The similarity in the development of vertebrates also suggests a common ancestor.

4.4.3 Palaeontology

- The study of fossils is known as palaeontology. Fossils are formed when certain remains of organisms or plants get embedded in the soil or water and are preserved for many hundreds of years. They appear either as skeletal remains, footprints, moulds or intact structures as found in the snow. By studying fossils, we are able to establish similarities between the organisms in the present to its ancestor in the past. There can be many similarities that prove the common origins between different closely related animals and the differences can be studied to establish how they differ now and why. Fossils are very important evidence to prove the theory of evolution and common ancestry. We can group fossils into two categories:

- **Category 1:** The remains of dead animals or plants or the imprint left from the remains, including: bones, teeth, skin impressions, hair, the hardened shell of an ancient invertebrate such as a trilobite or an ammonite an impression of an animal or plant, even if the actual parts are missing
- **Category 2**: Something that was made by the animal while it was living and that it has hardened into stone since then; these are called trace fossils and include: footprints, burrows, coprolite (animal faeces).
- Type I fossils can be the actual organism or part of an organism, like a piece of bone or hair or feather as it actually was. For example, this spider (Figure 4.17) has been trapped, completely unchanged, inside the amber for millions of years. Amber is fossilised resin from trees. This spider probably became stuck inside the sticky resin and could not escape. As the amber became fossilised, the spider was protected from micro-organisms and the air which would have led to its decomposition. In many fossils like this, the soft parts of the body have been lost, but the exoskeleton is perfectly preserved. In some cases, however, the entire body remains.

Dating of fossils

- Sedimentary rocks are laid down in layers (strata) which help to deduce how the organisms have changed over time. This is called **stratigraphy**. The oldest strata and the oldest fossils are found in the lowest layers and more recent rocks and fossils in the layers above them nearest to the surface. Represents the sequence of the strata at a site in southern England. The depth of the strata is related to their age. The thickness of each stratum (shown in the diagram) is a measure of the time period during which that stratum was formed. The words 'Tertiary', 'Cretaceous' and 'Jurassic' refer to the geological periods of time.
- Some minerals in rocks and organic matter (e.g., wood, bones, and shells) can contain radioactive isotopes. The abundances of parent and daughter isotopes in a sample can be measured and used to determine their age. This method is known as radiometric dating. The amount of time it takes for half of the parent isotopes to decay into daughter isotopes is known as the half-life of the radioactive isotope.
- Fossil age can be determined using two ways; **absolute dating** which determines the number

of years that have elapsed since an event occurred or the specific time when that event occurred.

- On the other hand, **relative dating** determines the age by analyzing rocks and structures placed into chronological order, establishing the age of one thing as older as or younger than another.

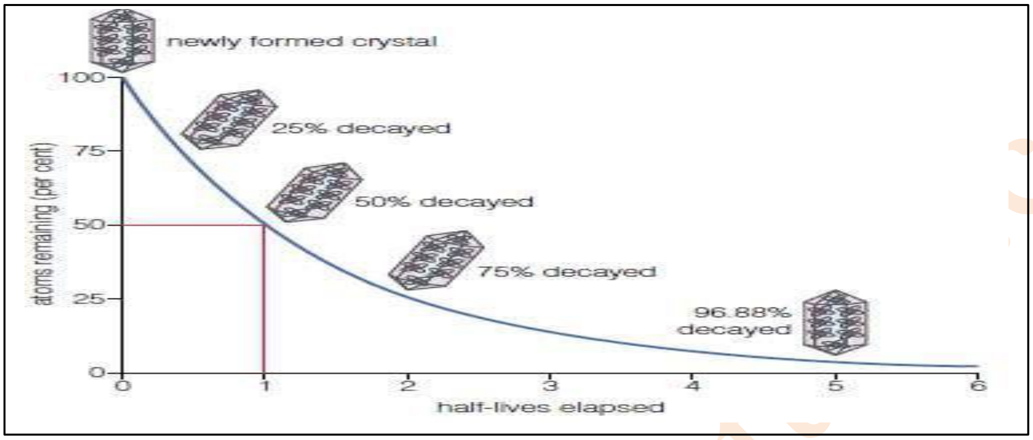


Figure.35, Half-life of a radioactive element

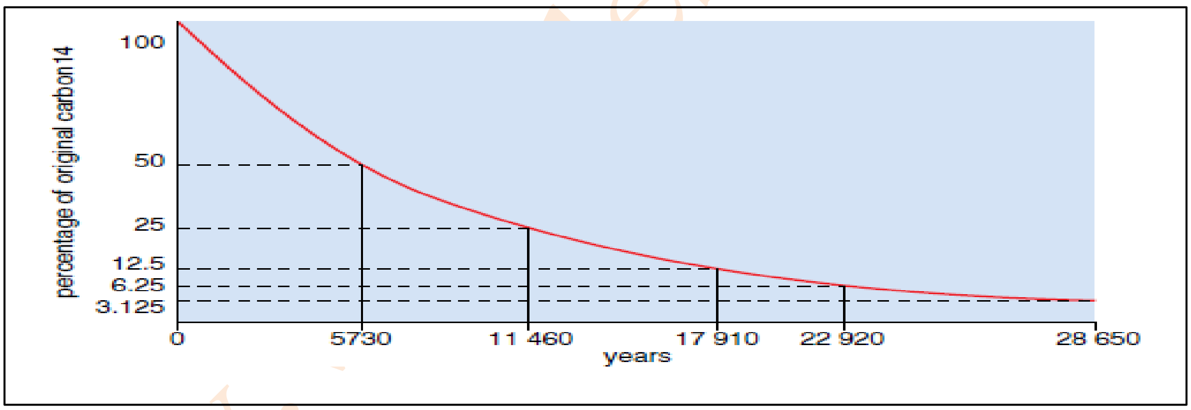


Figure 36, Converting the percentage of carbon 14 in a fossil to an age.

- How do scientists actually date rocks? How do they find out how old each layer is? To do this, scientists use one of the two techniques:

- Radiocarbon dating or Potassium–argon dating.
- Both techniques rely on the principle that radioactive atoms decay into other atoms over time. Radioactive carbon atoms (C14) decay into non-radioactive nitrogen atoms (N).
- Radioactive potassium atoms (K40) decay into argon atoms (A40). Each has what is known as a **half-life**. During this period, half of the radioactive atoms decay. So, starting with a certain number of radioactive potassium atoms, after one half-life, 50% will still

be radioactive. After a second half-life, 50% of this will have decayed and 25% of the original number will still be radioactive.

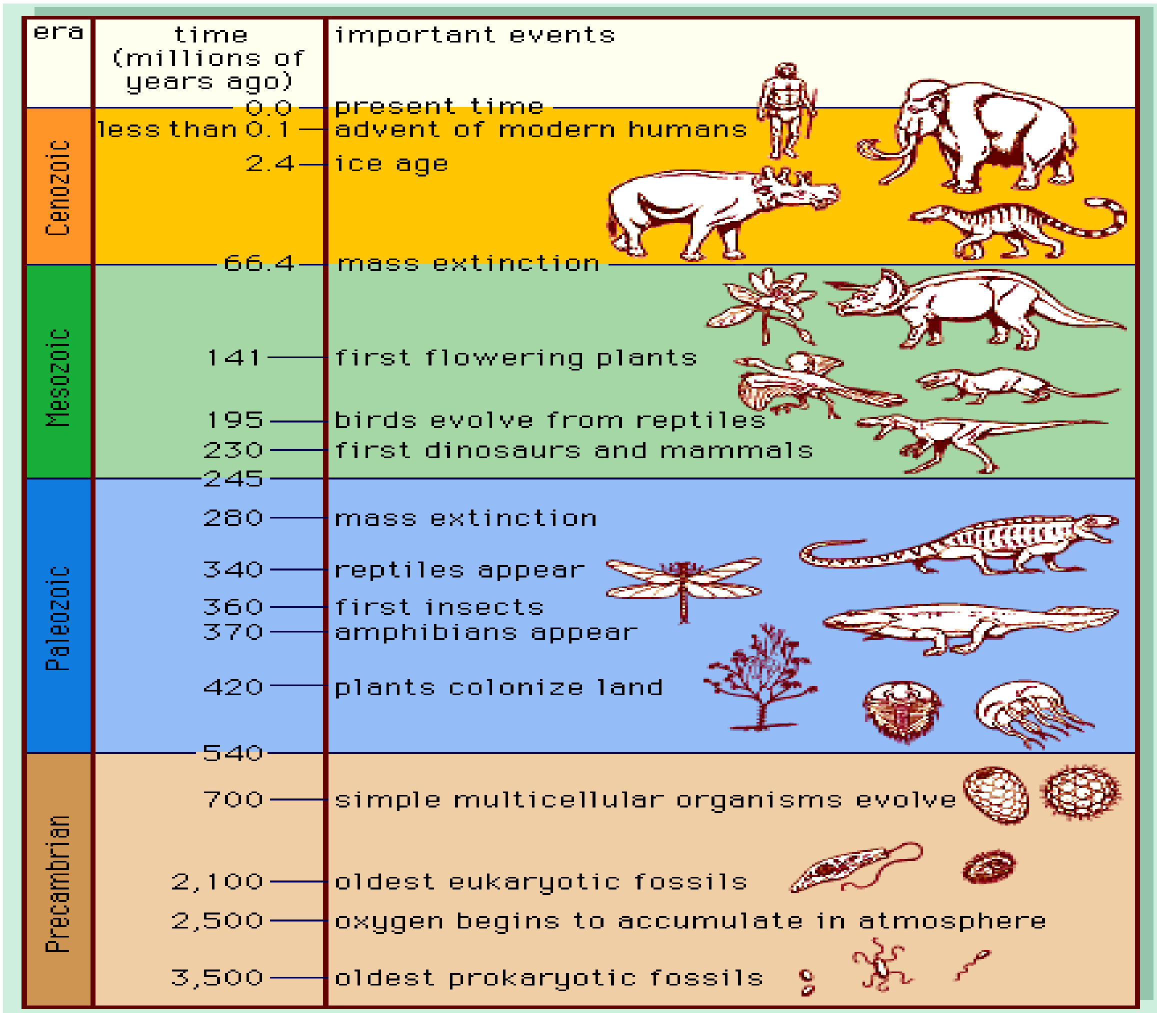


Figure 37, Key events in the fossil record of animal evolution

4.4.4 Biochemistry

- Organisms that share very similar molecules and biochemical pathways are closely related evolutionarily. Chemicals that have been used in such analysis include DNA and haemoglobin, among others.

- Species that are closely related are believed to have the most similar DNA and proteins; those that are distantly related are assumed to share fewer similarities. For example, a comparison of DNA sequences shows that 98% of our DNA is the same as chimpanzees which confirms that chimpanzees are the closest relatives of humans (Figure 4.15).

- To measure the similarity of the DNA of one species with the DNA of another species, we use a technique called **DNA hybridisation**. The technique measures the extent to which a strand of DNA from one species can hybridise with a strand of DNA from another species. In this technique, the double helix of the DNA molecule is heated to separate it into single strands and then the single-stranded DNA (ssDNA) from both species is mixed and the mixture cooled. Although the ssDNA from species A and species B will hybridise (bind) as it cools, it will not do so along all its length.

- If there are regions that are mismatched (the base pairs are not complementary) and so do not bind, there are techniques available to measure the percentage of this mismatching. The information can then be used to calculate the percentage similarity of the DNA samples.

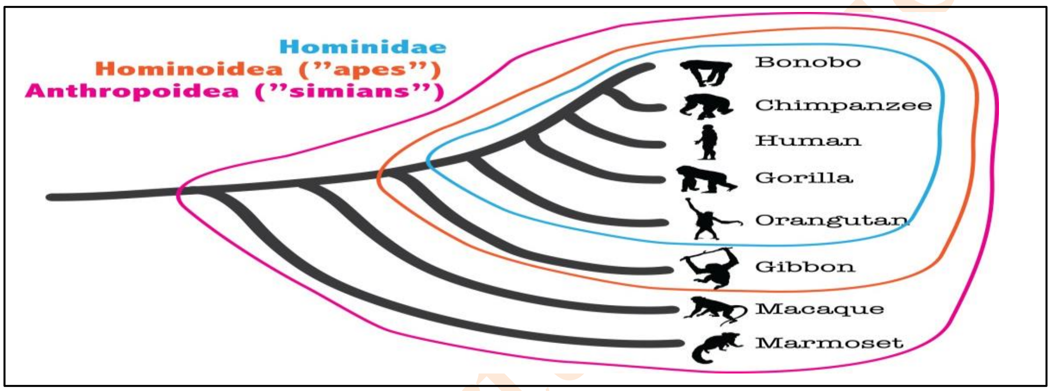


Figure 38, A phylogenetic (evolutionary) tree of some animals based on differences in DNA.

- The **haemoglobin** molecule is similar in all animals that possess it, but there are differences. For example, the haemoglobin of the lamprey (a primitive fish-like animal) has only one polypeptide chain, not four. Most animals have haemoglobin with four chains, but the chains do vary. Figure 4.23 shows the differences in the amino acid sequences of the α chains of haemoglobin of the human and several other animals. The diagram (Figure 4.17) is presented to show how different animals may have diverged from the evolutionary line that led to humans.

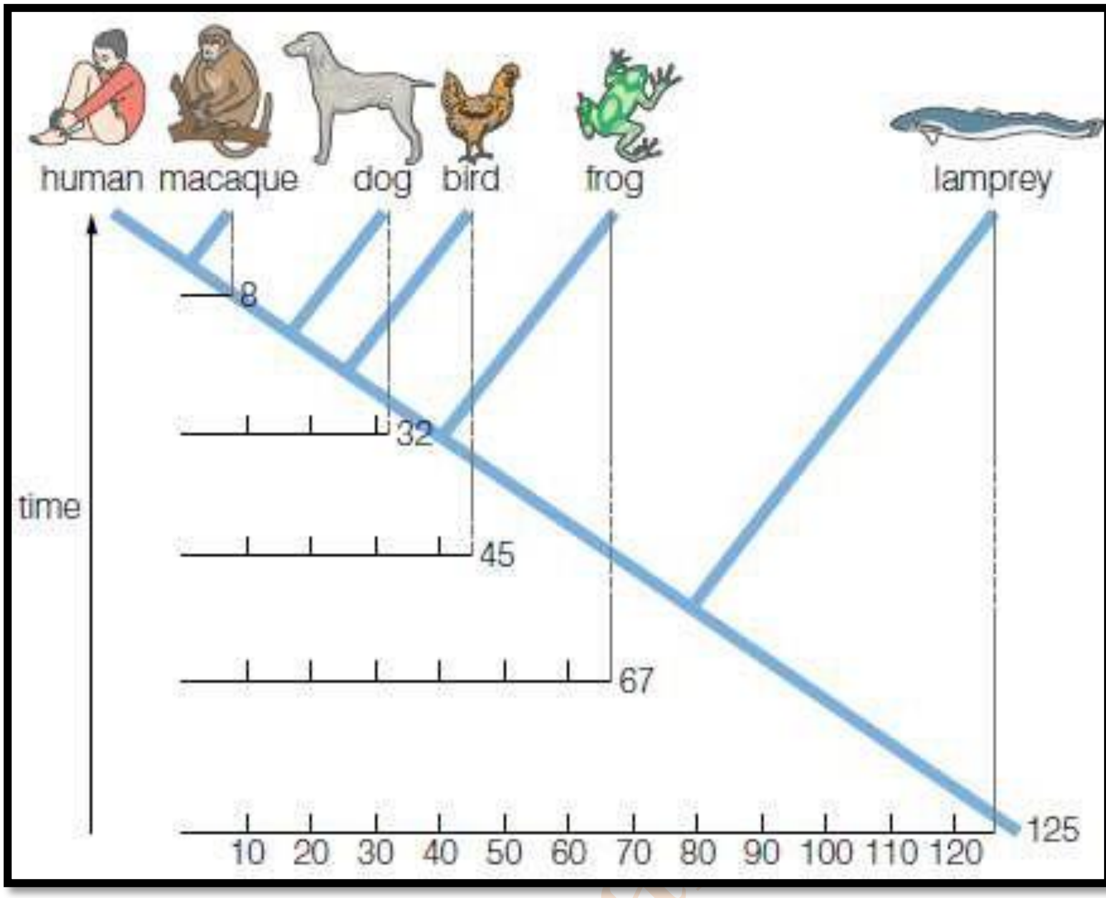


Figure 39 The evolutionary relationships of some animals shown by differences in haemoglobin

- The molecules that are used to show evolutionary relationships are those that are common to large numbers of organisms. But, clearly, haemoglobin analysis cannot be used to include plants and algae in any phylogenetic tree.

Review questions

Answer the following questions

1. How can fossils provide evidence for evolution?

Answer:

- Fossils are preserved remains or traces of animals, plants, and other organisms from the past. Fossils are important evidence for evolution because they show that life on earth was once different from the existence of life on earth today. Usually only a portion of an organism is preserved as a fossil, such as body fossils (bones and exoskeletons), trace fossils (feces and footprints), and chemofossils (biochemical signals). Paleontologists can determine the age of fossils using various methods including radiometric dating and categorize them to determine the evolutionary relationships between organisms.

2. Explain in detail how embryology provides evidence for evolution.

Answer:

- **Embryology** is a branch of comparative anatomy which studies the development of vertebrate animals before birth or hatching. Like adults, embryos show similarities which can support common ancestry. For example, all vertebrate embryos have gill slits and tails. The "gill slits" are not gills, however. They connect the throat to the outside early in development but eventually close in many species; only gill slits in fish and larval amphibians contribute to the development of gills. In mammals, the tissue between the first gill slits forms part of the lower jaw and the bones of the inner ear. The embryonic tail does not develop into a tail in all species; in humans, it is reduced during development to the coccyx, or tailbone.

3. How does comparative biochemistry support the theory of evolution?

Answer:

- A common definition of comparative biochemistry is the study of evolutionary relationships between organisms. All living organisms share a common genetic code in the form of DNA, which provides information for making the protein machines that do the day-to-day work of cells. Comparative biochemistry studies protein machines and enzymes, but both are encoded by DNA sequences. By comparing similarities and differences in these genes, scientists can piece together and explain evolutionary relationships between organisms.

4.5 Natural selection

- **Natural selection** is the 'driving force' behind evolution. It is the process that brings about changes (over time) in populations that can, eventually, lead to different populations of the same species to become different species. Those members of a species which are best adapted to their environment will survive and reproduce in greater numbers than others that are less well adapted. They will pass on their advantageous alleles to their offspring and, in successive generations, the frequency of these alleles will increase in their gene pool. The advantageous types will, therefore, increase in frequency in successive generations.

- To appreciate how natural selection can eventually lead to **speciation** (the formation of new species), we must be clear what do we mean by the term species. Obviously humans are different species from chimpanzees.

4.5.1 Speciation

- Our current definition of species is therefore, is a group of similar organisms with a similar biochemistry, physiology and evolutionary history that can interbreed to produce fertile offspring. This explains why all humans are members of the same species, but belongs to a different species from the chimpanzee. So how can there be different types of natural selection? All types of natural selection work in the same manner, but their influence on a population is different. The different types of natural selection include
- Directional selection
- Stabilizing selection and
- Disruptive selection

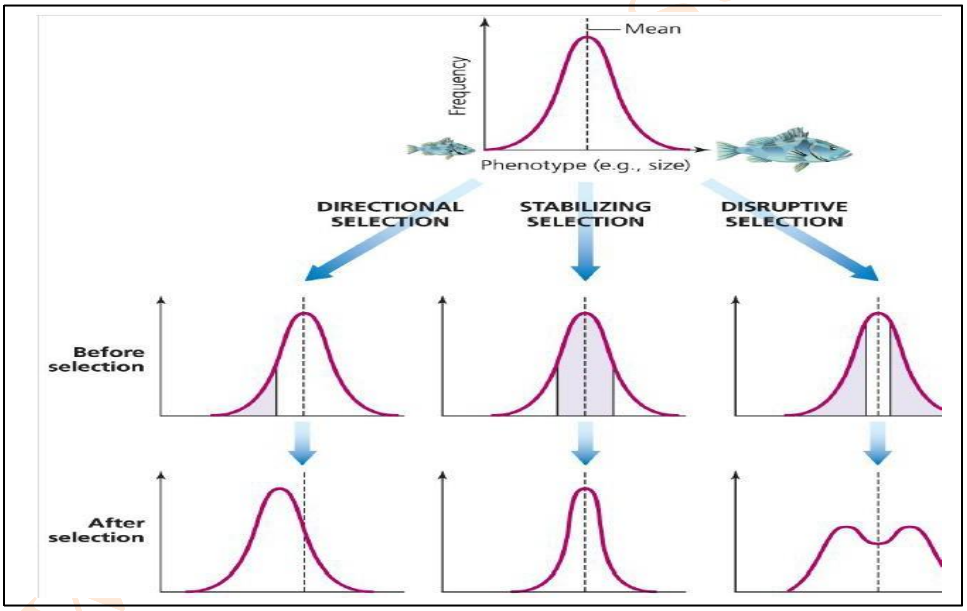


Figure 40 A summary of the different types of natural selection

- Natural selection provides a mechanism by which new populations of a species can arise. But, at what point can these populations be considered as distinct species?

- If two populations become so different, individuals from these different populations cannot interbreed to produce fertile offspring, and then we must think of them as different species.

There are a number of ways in which this can occur. The two main ways are:

- **Allopatric speciation** and
- **Sympatric speciation**.
    - As long as two populations are able to interbreed, they are unlikely to evolve into distinct species. They must somehow go through a period when they are prevented from interbreeding. Both allopatric and sympatric speciation involves isolating mechanisms that prevent different populations from interbreeding for a period of time. During this period, mutations that arise in one population cannot be passed to the other. As a result of this, and the different selection pressures in different environments, genetic differences between the two populations increase. Eventually, the two populations will become so different that they will be unable to interbreed or they are 'reproductively isolated'.

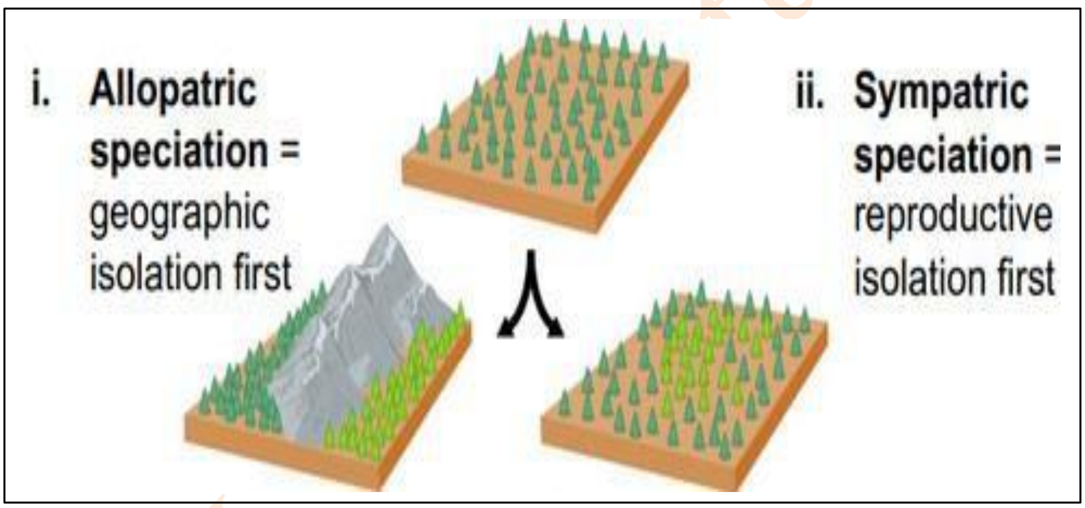


Figure 41: The difference between Allopatric and Sympatric speciation

4.5.2 Polyploidy and its important in plant evolution

- Poly- means many. Polyploidy cells have many sets of chromosomes per cell – sometimes four sets, sometimes eight or more. Some human liver cells have 92 chromosomes per cell – they are tetraploid and have four sets of chromosomes per cell.
- Polyploidy has been important in plant evolution because it has allowed infertile hybrids to become fertile. When different species form hybrids, very often the hybrid cannot produce offspring because all the chromosomes cannot form bivalents (homologous pairs) in meiosis.

So, they cannot form sex cells and cannot reproduce. If the chromosome number were to double, then all chromosomes would be able to form homologous pairs. Meiosis and sex-cell formation can take place and the hybrid is now fertile.

4.5.3 Divergent, convergent, and parallel evolution

- Evolution over time can follow several different patterns. Factors such as environment and predation pressures can have different effects on the ways in which species exposed to evolve. There are three main types of evolution: divergent, convergent, and parallel evolution.

Divergent Evolution

- When people hear the word "evolution," they most commonly think of divergent evolution, the evolutionary pattern in which two species gradually become increasingly different. This type of evolution often occurs when closely related species diversify to new habitats. On a large scale, divergent evolution is responsible for the creation of the current diversity of life on earth from the first living cells. On a smaller scale, it is responsible for the evolution of humans and apes from a common primate ancestor.

Convergent Evolution

- Convergent evolution causes difficulties in fields of study such as comparative anatomy. Convergent evolution takes place when species of different ancestry begin to share analogous traits because of a shared environment or other selection pressure. For example, whales and fish have some similar characteristics since both had to evolve methods of moving through the same medium: water.

Parallel Evolution

- Parallel evolution occurs when two species evolve independently of each other, maintaining the same level of similarity. Parallel evolution usually occurs between unrelated species that do not occupy the same or similar niches in a given habitat.

Review questions

Provide answer for the following questions.

1. Explain the similarities and differences between allopatric and sympatric speciation?

Answer:

- Both allopatric and sympatric speciation is a process that leads to new species but they are different in many ways.

Basis of comparison	Allopatric speciation	Sympatric speciation
Speed of Evolution	Speed of evolution of new species is slow.	Speed of the emergence of new species is fast with autopolyploidy and slow with allopolyploidy.
Geographical Isolation	The populations are geographically separated.	The populations are not geographically separated
Common	Common in nature.	Common in plants.
Major Differentiation Mechanism	Major differentiation mechanism is natural selection.	Major differentiation is polyploidy.
Examples	Some examples include: Darwin's finches Squirrels in the Grand Canyon.	Some examples include: Cultivated wheat Corn Tobacco African tilapia
Entails	Allopatric speciation involves one population.	Sympatric speciation involves two or more populations.

2. **Compare and contrast divergent and convergent evolution**.

Answer:

- The development of similar structures within different species that live in the same environment is known as **convergent evolution**. For example, the wing is an adaptation to flight. Wings can be found in bats as well as insects. The wings of bats and the wings of insects are evolved from completely different original structures. Thus, the convergent evolution causes similar structures in different lineages of organisms.
- **Divergent evolution** is a process of developing two or more species from a common ancestor. The branching begins with the selective breeding of naturally or artificially chosen traits, which occurs gradually. Thus, divergent evolution is a process of macroevolution that creates more diversity of species in the biosphere. Divergent evolution produces important changes within individuals for their survival within a changing environment.

3. **Explain the different types of natural selection and how they can impact the distribution of phenotypes within a population.**

Answer:

- In directional selection, one extreme of a range of values for a feature has a survival advantage; the range of values for the population shifts towards the extreme with the selective advantage.

- In stabilizing selection, the two extremes are at a selective disadvantage compared to those showing the mean values for a particular feature; the range is compressed around the mean.
- In disruptive selection, both extremes have a selective advantage compared with the mean; two distinct types begin to emerge showing the extreme values of the original population.

4.6 Human evolution

Who are we and where have we come from?

- There is often a lot of very loose language used in describing human evolution. You will hear people say 'we evolved from monkeys' or 'we evolved from apes' or 'we evolved from chimpanzees'. None of these statements are accurate. There has been a 'line of evolution' for millions of years that has given rise to old world monkeys, new world monkeys, the great apes and the different species of humans that have lived. But, we are Homo sapiens and we are the latest of several humans to live on the planet.
- We have two features in particular that distinguish us from other primates. These are:
  - A very large brain, and
  - Bipedalism – the ability to truly walk on just two legs.
- There was a lot of debate amongst biologists as to which of these came first and also about exactly how this 'evolutionary tree' (Figure 4.27) has given rise to the various groups although they may disagree.

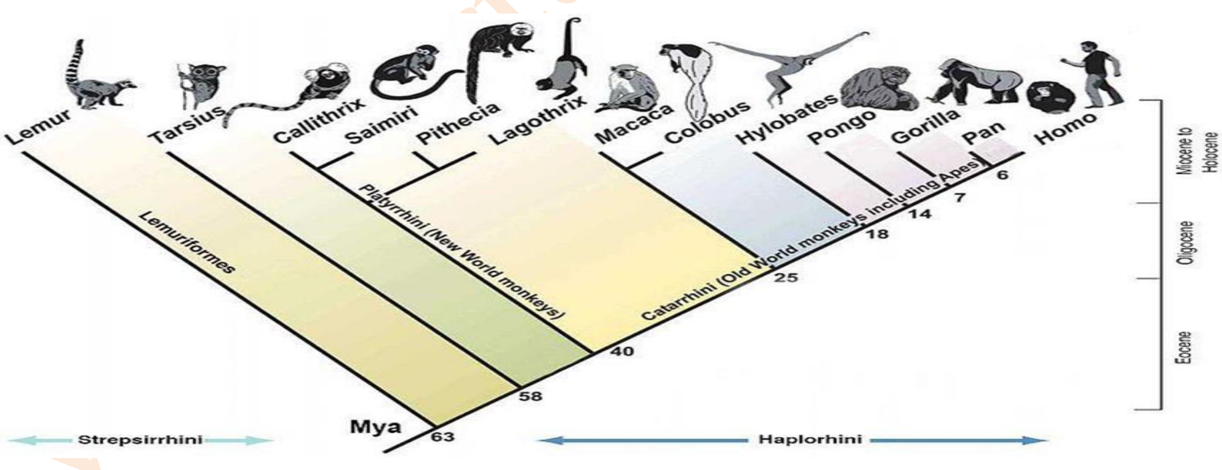
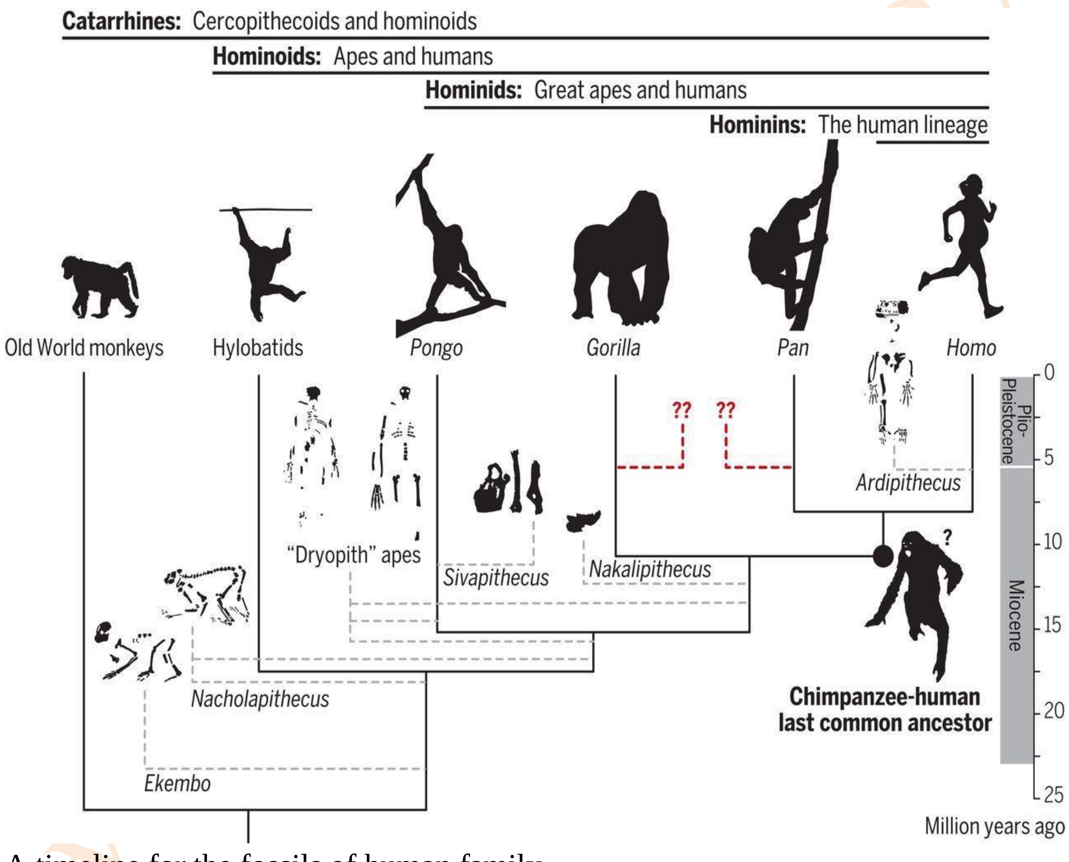


Figure 42, the evolutionary tree for modern primate

- Over the details, they all agreed about the idea – a line evolution that has branched to give the different groups of primates (including apes and humans) that exist today has existed in not too distant past. Figure 28 shows the part of the evolutionary tree of humans and the living great apes in more detail.

- Branching points in the evolutionary tree represent ancestors. At these points it is assumed that an ancestral type became divided into at least two populations which subsequently evolved along different lines. For example, humans and chimpanzees both evolved from a common ancestor that lived about 6 million years ago.

- So far, we have talked about 'humans' rather than the one specific type of human (ourselves – *Homo sapiens*) that now inhabits the planet. There were other humans before us and, before them, what we might call 'pre-humans'. However, all humans belong to the **genus** *Homo*. Fossils of many of the species along the early part of the timeline were found in Ethiopia. The country is therefore, the 'cradle of mankind'.



A timeline for the fossils of human family

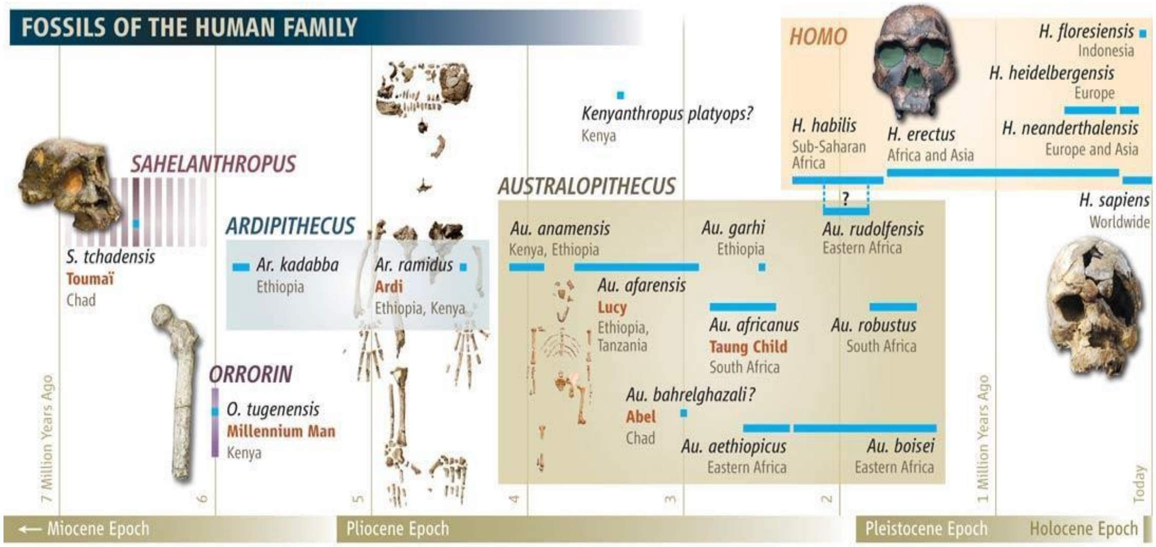


Figure 21 A timeline for the major hominin and hominid species

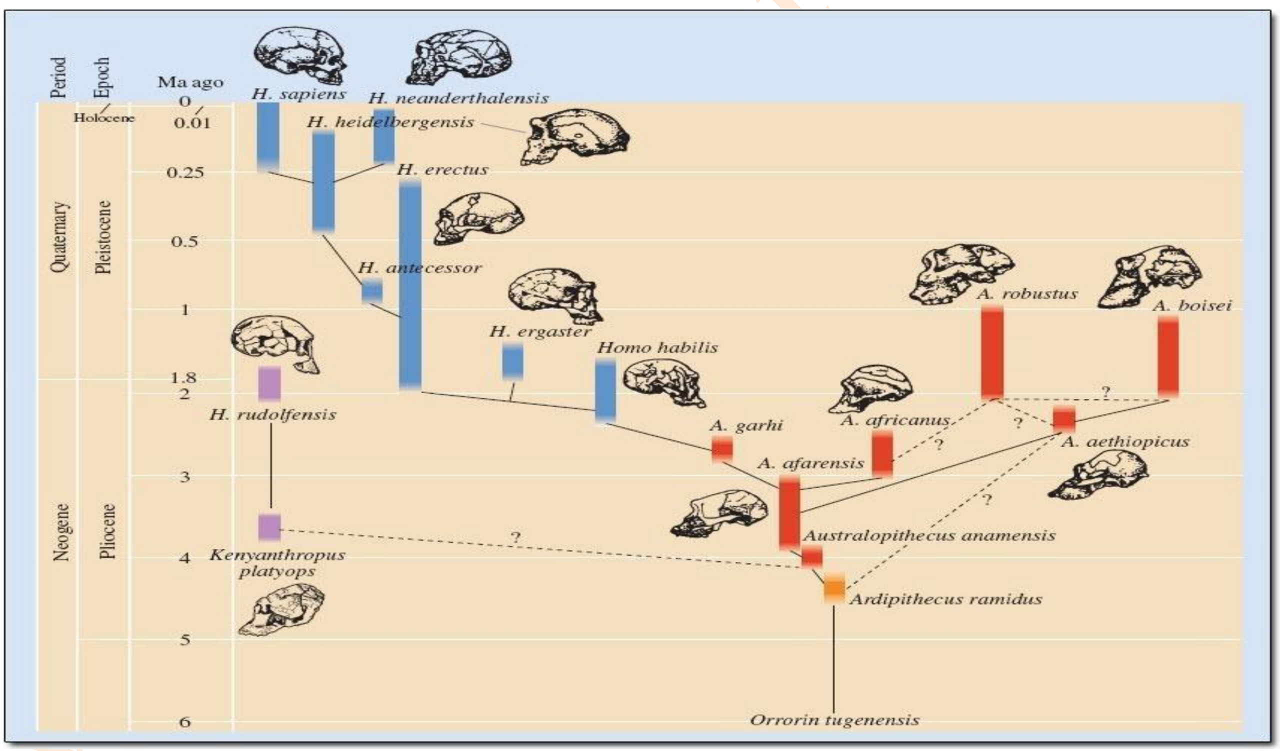


Figure 22: A timeline for the fossils of human family.

Ardi (Ardipithecus ramidus) and Dinkinesh "Lucy" (Australopithecus afarensis)

- Both Dinkinesh (Lucy) and Ardi are important fossils in explaining the evolution of modern humans and chimpanzees from a common ancestor. Lucy was discovered by Donald Johanson and Tom Gray in 1974 at Hadar, Ethiopia. Dinkinesh is a fossil dated at about 3.2 million years. She was an adult female of about 25 years and belonged to the species *Australopithecus afarensis*. Her skeleton was about 40% complete, an unusually high proportion for a fossil skeleton. Her pelvis, femur (the upper leg bone) and tibia show that she was bipedal (could walk upright on two legs).

- However, there is also evidence that Dinkinesh (Lucy) was partly arboreal (tree-dwelling). She was about 107 cm (42″) tall and about 28 kg (62 lbs) in weight. At the time she was discovered, Lucy represented one of the oldest fossil hominins. The proportions of her humerus and femur were mid-way between those of modern humans and chimpanzees.

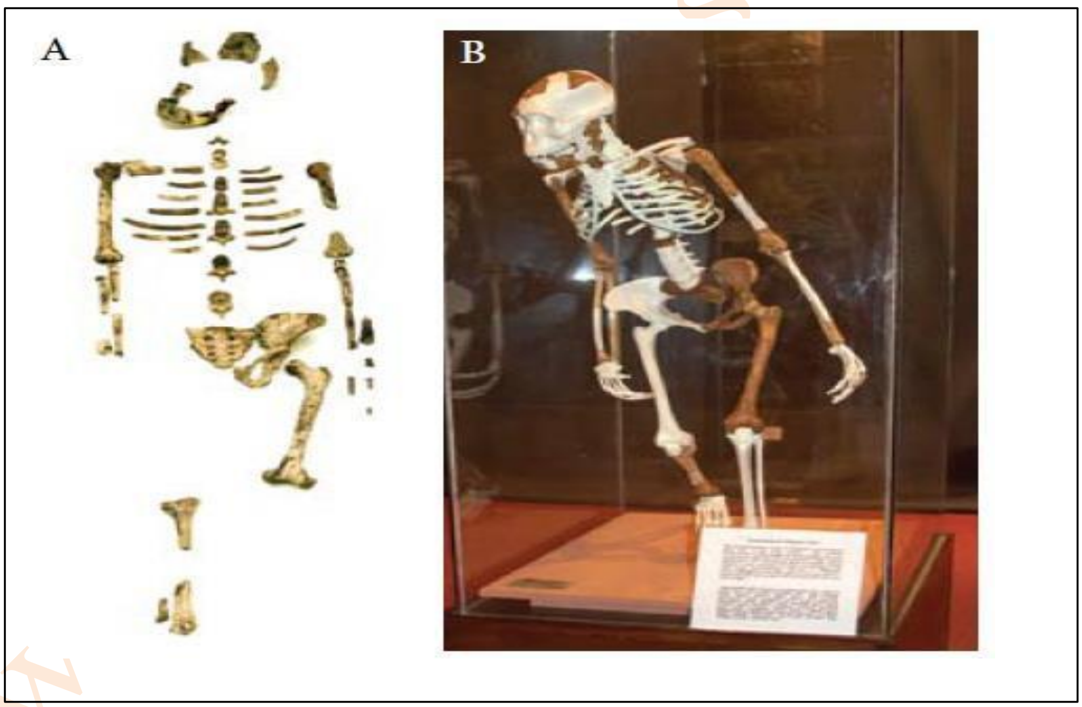


Figure 23: A. The original Dinkinesh (Lucy) fossil; B – The Dinkinesh display including reconstructed parts

- Dinkinesh (Lucy) had a brain about the same size as that of a chimpanzee, so her discovery was able to settle a debate amongst biologists at the time– which came first, large brain or bipedalism? Clearly bipedalism came before big brains.

- The Ardi fossil (together with many other similar fossils) was first discovered in 1992, in the Afar dessert in Ethiopia, but it was only in 2009 after many years' analysis, that research papers were finally published that gave Ardi a unique position in the human evolution. Ardi was 1.2 million years older than Lucy, was also female who belonged to the species. *Ardipithecus ramidus*. One significant feature about Ardi was that she was also bipedal.
- At million years old, Ardi is the nearest fossil to the 'common ancestor' of humans and chimpanzees that has so far been found. This finding finally proved that the common ancestor of humans and chimpanzees could not have resembled a chimpanzee, as chimpanzees are not truly bipedal. However, there was a sign of being adapted for both bipedal walking and arboreal life (Figure 24).

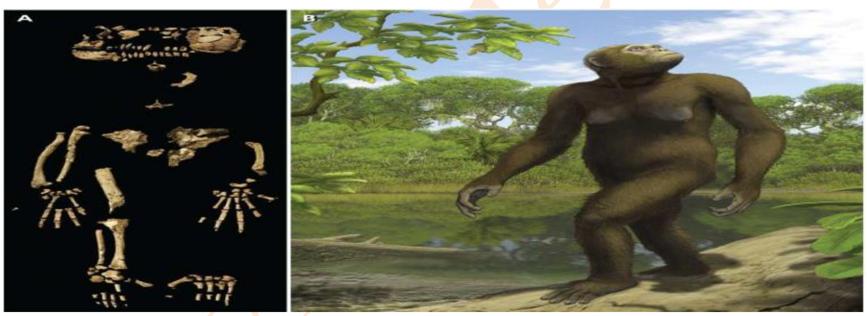


Figure 24 A relatively complete skeleton of *Ardipithecus*, which lived 4.4 million years ago. *Ardipithecus* shows signs of being adapted for both bipedal walking and arboreal life.

How brain size changed during human evolution?

- During the course of human evolution, the brain has got bigger. Studies on comparative anatomy of fossils revealed that the cranial capacity has increased with each new hominid species evolved however; the brain has increased in size as a proportion of body mass.
- Species of Australopithecus have a brain that is between 0.7% and 1.0% of their body mass, whereas modern humans have a brain size between 1.8% and 2.3% of their body mass. The brain of Homo sapiens uses 25% of the resting energy requirement, compared with 8% in the great apes.

- A larger brain allows humans to:
  - run faster and in a more upright posture
  - plan in advance to avoid attack
  - develop and use tools and weapons

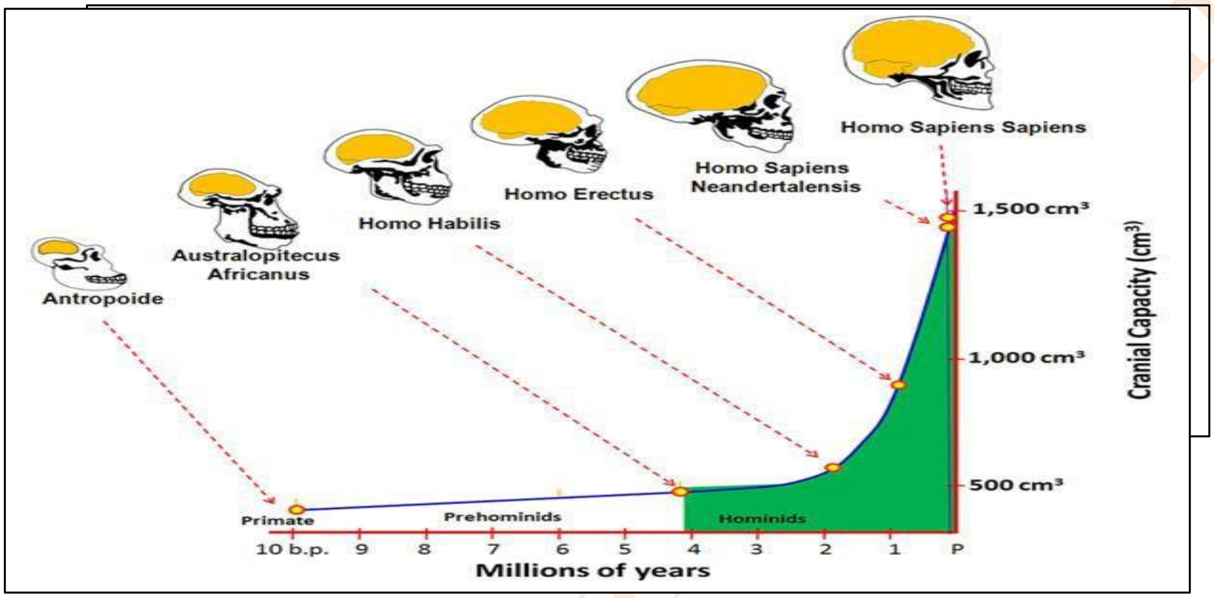


Figure 43: Brain size in different hominids

- These abilities clearly depend on other physical adaptations such as longer legs, more nimble fingers and a straighter spine, but, without the larger brain to co-ordinate the activities; the physical changes would not confer the same advantage.

Are we still evolving?

- *Homo sapiens* (modern humans) first appeared in Africa and have since migrated to all other parts of the world. Figure 4.34 shows these migratory patterns together with the time (thousands of years ago) when they took place.

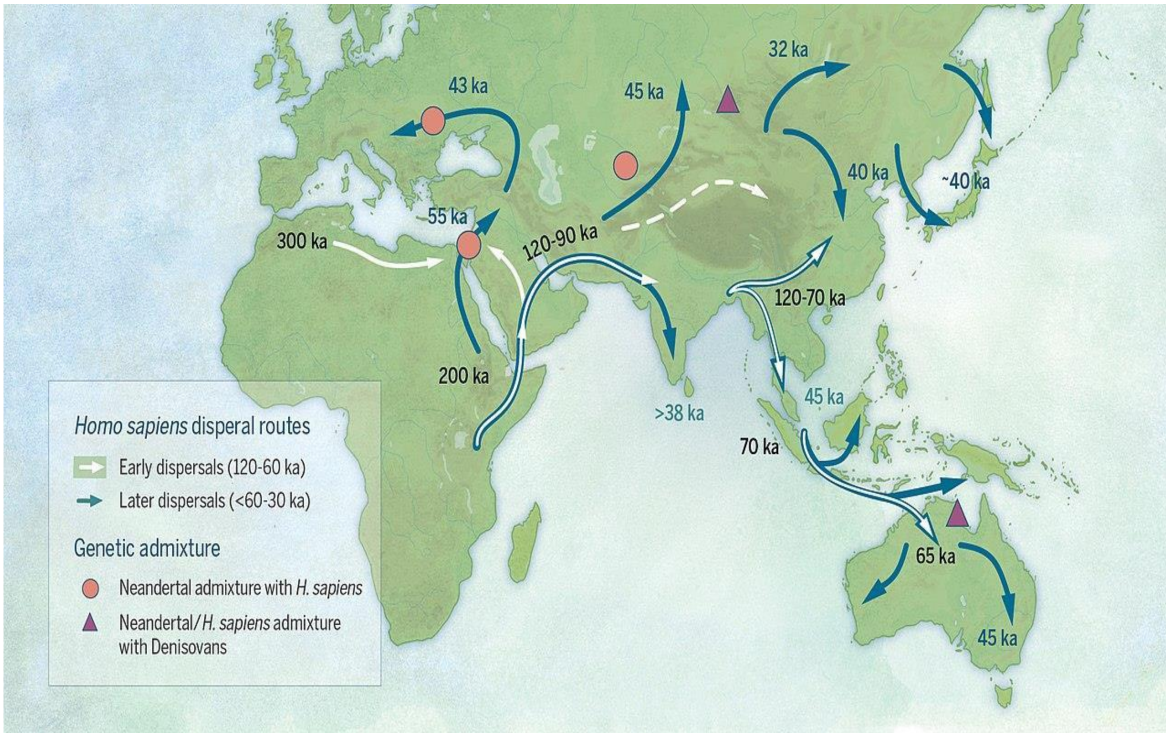


Figure 44: The migration of modern humans out of Africa – it all begins near Ethiopia. Numbers indicate the time (in years) since each stage of the migration.

- As humans moved from Africa into different areas of the world, they encountered different environments. Different selection pressures in the different environments resulted in the different human populations evolving along different lines.
- For example, as humans encountered colder climates, body features that gave a survival advantage to conserve heat were selected for. These included:
- A shorter, squatter body shape; this reduces the surface-area-to-volume ratio and so reduces the rate of heat loss by radiation
- An increased layer of adipose tissue under the skin to act as insulator.
- Increased hairiness; this reduces heat loss by convection.
- Humans have been evolving into different 'races' for thousands of years. The classification of these races is difficult and there is some disagreement about their exact nature.

Review questions

Provide answer for the following questions

1. Explain why the human races are now less likely to evolve into separate species.

Answer:

- Human beings have evolved into different 'races' for thousands of years. The classification of these races is difficult as there is some disagreement about their exact nature. One classification is given below. In this classification, there are three main races with several subdivisions. This is based on a recent genetic analysis of the different races.

- ✓ **African** (Negroid), 100 million people from Africa and Melanesians of the South Pacific.
- ✓ **Eurasian** (Caucasoid), 1000 million people with variable skin colours ranging from white to dark brown. Under Eurasian classification, three subdivisions exist:
- ✓ **Nordic** – often tall, blonde and narrow-headed; includes people from Scandinavian and Baltic countries, Germany, France, Britain
- ✓ **Mediterranean** – usually lighter in body build, dark and narrow-headed; includes people from Southern France, Spain, Italy, Wales, Egypt, Jews, Arabs, Afghanistan, Pakistan, India.
- ✓ **Alpine** – usually broad-headed, square jaws, olive skin, brown hair; includes people from countries from the Mediterranean to Asia.
- ✓ **East Asian** (Mongoloid), most numerous of the present-day populations and split into three groups:
- ✓ Eastern Siberians, Eskimos and the Northern American Indians
- ✓ Japanese, Koreans and Chinese
- ✓ Indonesians and Malays

2. Describe how brain size evolved in hominid.

Answer:

- As early humans faced new environmental challenges and evolved with bigger bodies, they evolved larger and more complex brains. Large, complex brains can process and store a lot of information. That was a big advantage to the early humans who faced with unfamiliar habitats in their social interactions. Over the course of human evolution, brain size tripled. The modern human brain is the largest and most complex of any living primate.

3. Explain how modern human evolved.

Answer:

- The relationships among *Australopithecus*, *K. platyops*, *Paranthropus*, and the direct ancestors of *Homo* are unknown. Because of its early date and geographic location, *A. anamensis* may be the common ancestor of *A. afarensis*, *A. garhi*, *K. platyops*, and perhaps the Laetoli Pliocene hominins of eastern Africa, *A. bahrelghazali* of central Africa, and *A. africanus* of southern Africa. *A. afarensis* in turn may be ancestral to *P. aethiopicus*, which begot *P. boisei* in eastern Africa and *P. robustus* in southern Africa.

4.7 Mutations

- A mutation is any spontaneous change in the genetic material of an organism. There can be large structural changes involving the whole chromosomes or parts of chromosomes, or changes that involve only a single base. The changes involving only a single base are called point mutations.

4.7.1 Point mutation

- There are several types of point mutation, in which one of the bases in the DNA sequence of a gene is altered, usually by being copied wrongly when the DNA replicates. The different point mutations are:
    - Substitution
    - Addition
    - Deletions
- These mutations occur quite randomly when the DNA is replicating and each involves a change to just one base, but the change to the gene can be dramatic and the result can be that the protein the gene should code for is not made at all or a different protein is made.

Substitution

- Guanine replaces thymine in this substitution. The triplet ATT has been changed to ATG (no other triplet is affected). The original triplet, ATT, codes for the amino acid isoleucine. However, the new triplet, ATG, codes for methionine (see Figure 4.26). As a result, a different protein will be synthesized, which may or may not be significantly different from the original. One different amino acid in a protein does not always make a functional change.

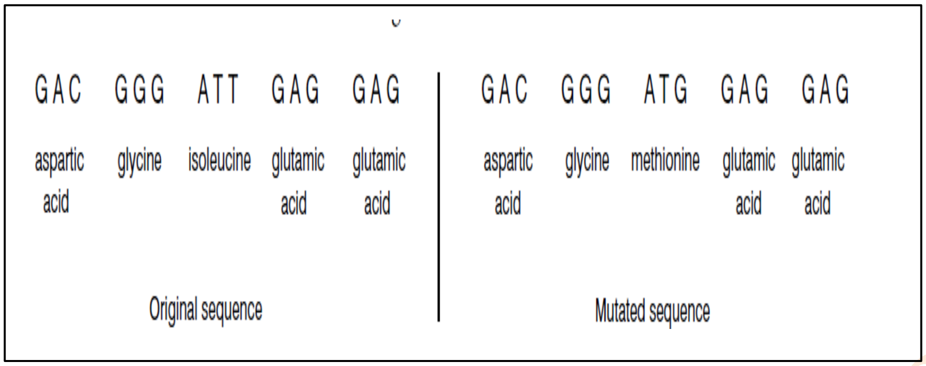


Figure 45 A substitution mutation

- If a substitution of just one base in the sixth triplet of the gene coding for one of the four polypeptides in the haemoglobin molecule alters the triplet from GAG to GTG.
- This results in the amino acid valine replacing glutamate in the polypeptide chain. The different haemoglobin molecule formed results in the condition known as **sickle-cell anaemia**

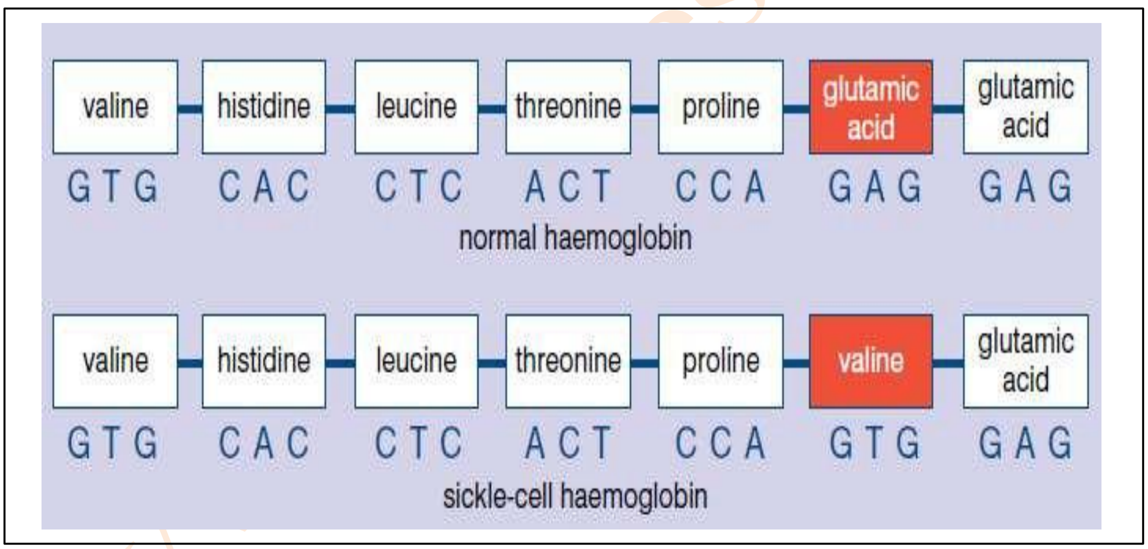


Figure 46: Sickle-cell anaemia

Addition and deletion

- In a **deletion mutation,** a base is 'missed out' during replication, whereas in additions, an extra base is added**.** Both deletion and additions are more significant mutations than substitutions. The reason for this is that they do not just alter the triplet in which the mutation occurs. Because there is one fewer or one extra base, the whole sequence after the point of the mutation is altered. We say that there has been a frame shift and these are frame shift mutations. A totally different mRNA is produced (if one is produced at all) and a non-functional protein or no protein at all. Sometimes, a whole triplet is missed out or inserted.

- This will result in either one extra or one fewer codon in the mRNA. In turn, this will lead to one extra or one fewer amino acid in the polypeptide chain.

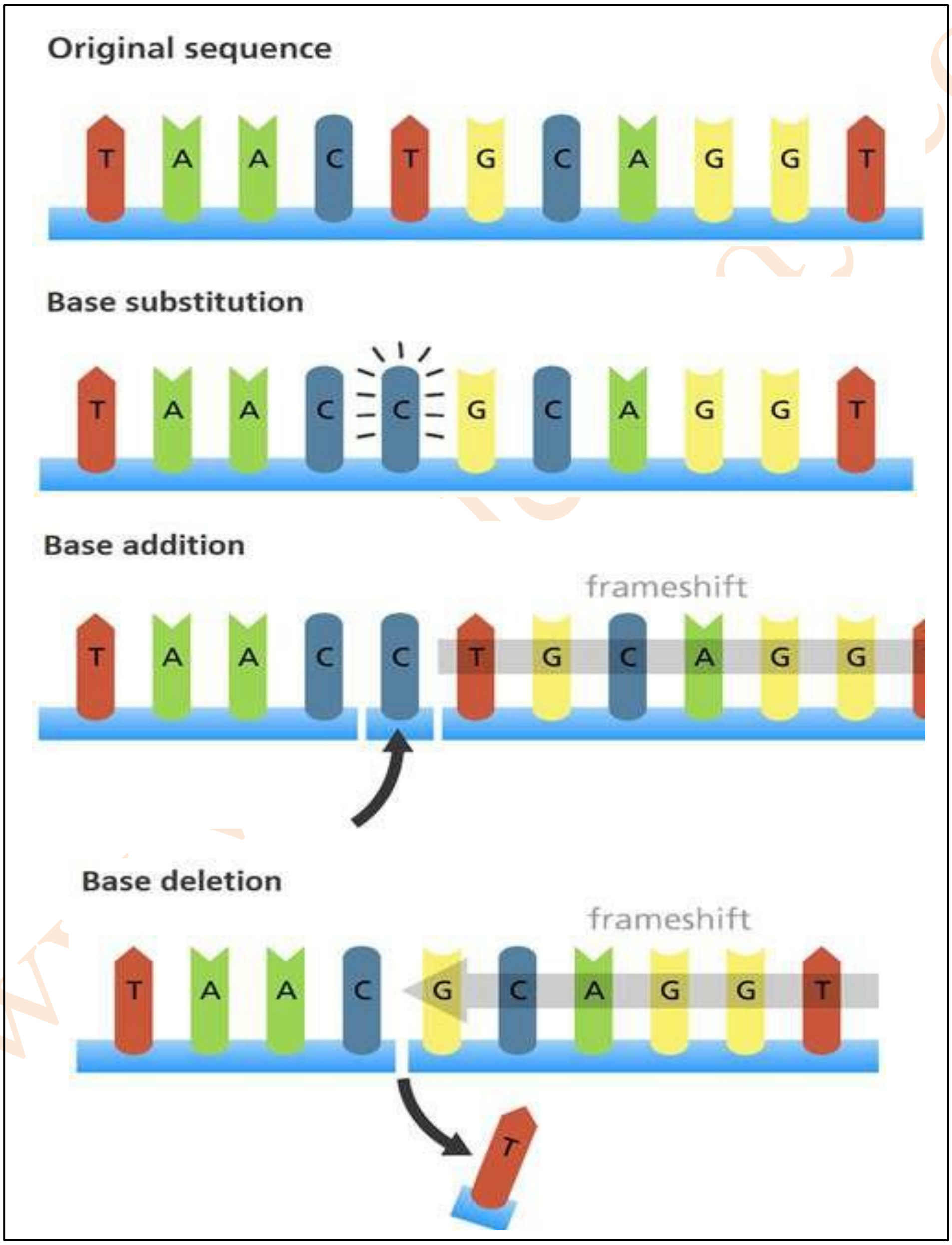


Figure .47 Types of point mutation

4.7.2 Chromosome mutations

- Chromosomal mutations occur when there is any change in the arrangement or structure of the chromosomes. They occur most often during meiosis at crossing over in prophase I. There are several different mutation types that result in a change in the structure of a chromosome such as duplication, deletion, inversion and translocation. They are much bigger events than point mutations and usually result in the death of a cell. They may also affect the whole organism. For example, if essential parts of the DNA are affected by chromosomal mutations, a foetus may be aborted. There are different types of chromosome mutations.

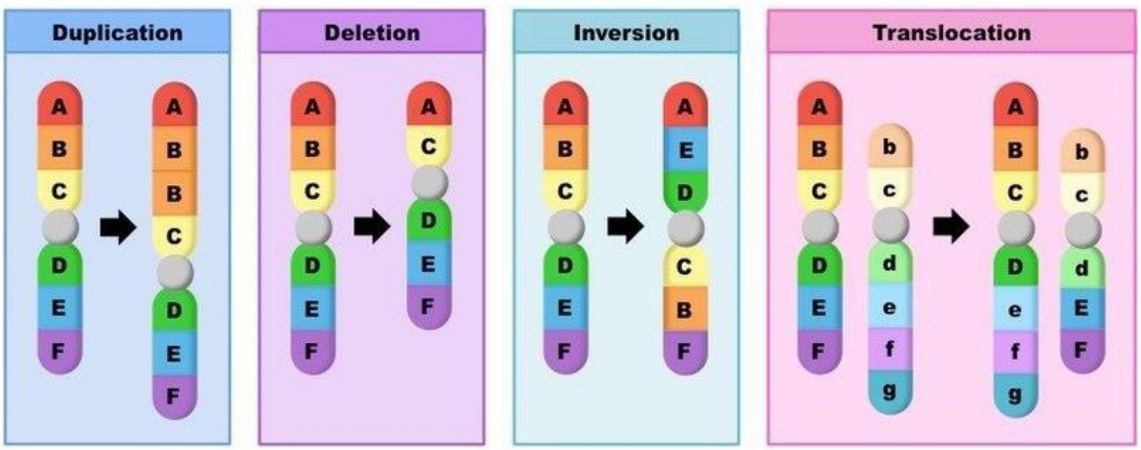


Figure 48: Types of Chromosomal mutations

Review questions

Provide answers for the following questions.

1. Explain in detail causes and consequences of mutation.

Answer:

- ✓ The rate of mutation can be increased by a number of factors including Carcinogenic chemicals, for example, those in tobacco smoke, High-energy radiation, for example, ultraviolet radiation, X-rays.
- ✓ Four possible consequences: It will be completely harmless, It will damage the cell, It will kill the cell, It will make the cell cancerous, which might kill the person.

2. Explain what occurs if a substitution occurs in the DNA of an organism.

Answer

- ✓ These mutations occur quite randomly during DNA replication by which each involves a change to just one base. However, the change to the gene can be dramatic and the result can be that the protein that the gene should code for is not made at all or a different protein is made.

3. Describe how sickle cell anaemia occurs.

Answer:

- ✓ Sickle cell anemia is caused by a mutation in the gene that encodes information to your body to make the iron-rich compound. This iron-rich compound makes blood red and enables red blood cells to carry oxygen from your lungs throughout your body (hemoglobin). In sickle cell anemia, the abnormal hemoglobin causes red blood cells to become rigid, sticky and deformed. For a child to be affected, both the mother and father must pass the defective form of the gene. If only one parent passes the sickle cell gene to the child that a child will have the sickle cell trait. With one normal hemoglobin gene and one defective form of the gene, people with the sickle cell trait make both normal hemoglobin and sickle cell hemoglobin. Their blood might contain some sickle cells, but they generally don't show symptoms. They are carriers of the disease indicating that they can pass the gene to their children.

4.8 Genetic Drift

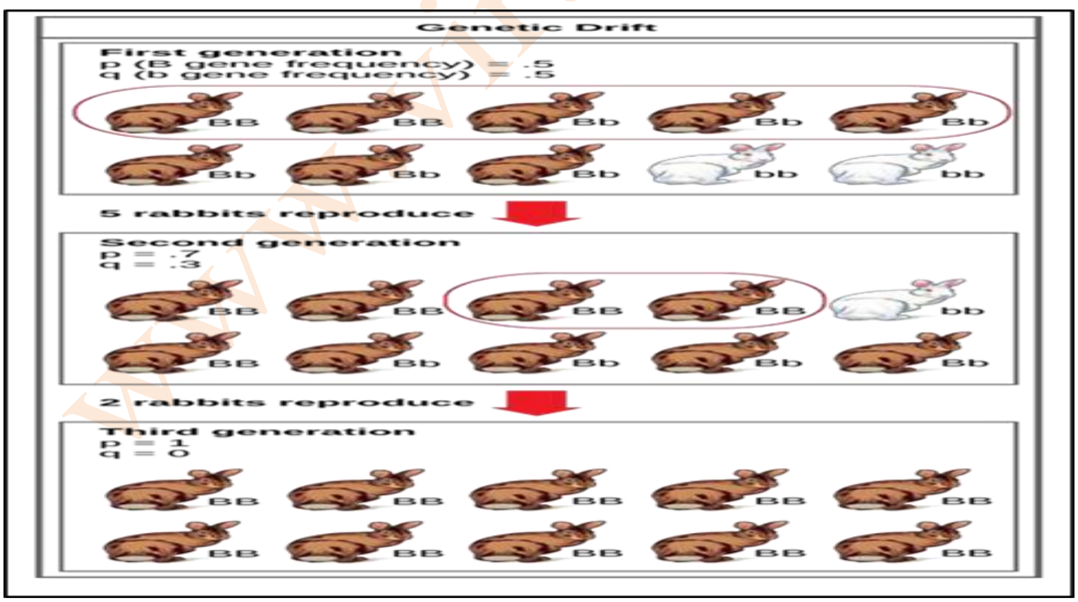
What is genetic drift?

- Allele frequencies can change due to chance alone. This is called genetic drift. Drift is a binomial sampling error of the gene pool. What this means is, the alleles that form the next generation's gene pool are a sample of the alleles from the current generation. When sampled from a population, the frequency of alleles differs slightly due to chance alone.
- Alleles can increase or decrease in frequency due to drift. The average expected change in allele frequency is zero, since increasing or decreasing in frequency is equally probable. A small percentage of alleles may continually change frequency in a single direction for several generations just as flipping a fair coin may, on occasion, result in a string of heads or tails. A very few new mutant alleles can drift to fixation in this manner.
- The variance in the rate of change of allele frequencies is greater in small populations than in large populations. Let's make the idea of drift more concrete by looking at an example. As shown in

Figure 4.39, we have a very small rabbit population that's made up of 8 brown individuals (genotype BB or Bb) and 2 white individuals (genotype *bb*). Initially, the frequencies of the *B* and *b* alleles are equal. What if, purely by chance, only the 5 circled individuals in the rabbit population reproduce? (Maybe the other rabbits died for reasons unrelated to their coat color, e.g., they happened to get caught in a hunter's snares.) In the surviving group, the frequency of the *B* allele is 0.7 and the frequency of the *b* allele is 0.3.

- The allele frequencies of the five lucky rabbits are perfectly represented in the second generation. Because the 5-rabbit "sample" in the previous generation had different allele frequencies than the population as a whole, the frequencies of B and b in the population have shifted to 0.7 and 0.3 respectively. From this second generation, what if only two of the *BB* offspring survive and reproduce to yield the third generation? In this series of events, by the third generation, the *b* allele is completely lost from the population.

However, the overall rate of genetic drift (measured in substitutions per generation is independent of population size. If the mutation rate is constant, large and small populations lose alleles to drift at the same rate. This is because large populations will have more alleles in the gene pool, but they will lose them more slowly. Smaller populations will have fewer alleles, but these will quickly cycle through. This assumes that mutation is constantly adding new alleles to the gene pool and selection is not operating on any of these alleles.



The bottleneck effect

- The bottleneck effect is an extreme example of genetic drift that happens when the size of a population is severely reduced. Events like natural disasters (earthquakes, floods, fires) can decimate a population, killing most individuals and leaving behind a small, random assortment of survivors.
- The allele frequencies prior to the natural disasters may be very different from those of the population after the event, and some alleles may be missing entirely. The smaller population will also be more susceptible to the effects of genetic drift for generations (until its numbers return to normal), potentially causing even more alleles to be lost.
- Imagine a bottle filled with marbles, which represent individuals in a population. If a bottleneck event occurs, a small, random assortments of individuals survives the event and pass through the bottleneck (and into the cup), while the vast majority of the population is killed off (remains in the bottle). The genetic composition of the random survivors (Figure 4.40) is now the genetic composition of the entire population. A population bottleneck yields a limited and random assortment of individuals. This small population will now be under the influence of genetic drift for several generations.

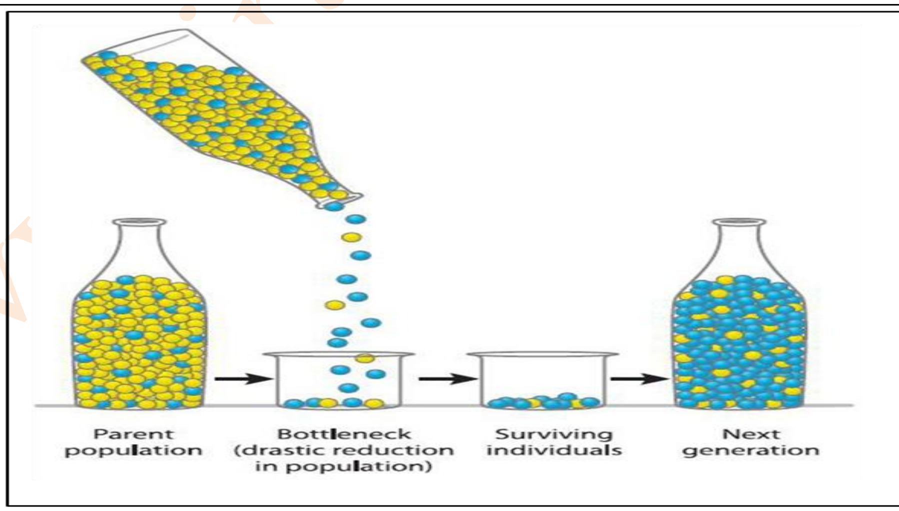


Figure .49: Bottleneck effect eliminates genes from a population

The founder effect

- The founder effect is another extreme example of genetic drift that occurs when a small group of individuals breaks off from a larger population to establish a colony. The new colony is isolated from the original population, and the founding individuals may not represent the full genetic diversity of the original population. That is, alleles in the founding population may be present at different frequencies than in the original population, and some alleles may be missing altogether. The small size of the new colonies means that they will experience strong genetic drift for generations. The founder effect is similar in concept to the bottleneck effect, but it occurs via a different mechanism (colonization rather than catastrophe).

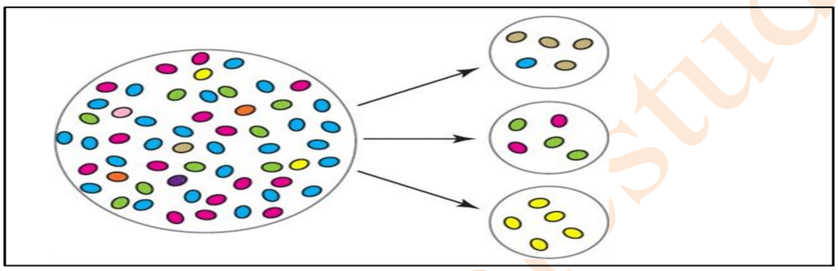


Figure4.:Foundereffecteliminatesgenesfromapopulation

Review questions

Provide answer for the following:

1. Genetic drift

✓ **Answer:** Allele frequencies can change due to chance alone. This is called genetic drift. Drift is a binomial sampling error of the gene pool. In other words, the alleles that form the next generation's gene pool are a sample of the alleles from the current generation. When a population is sampled, the frequency of alleles differs slightly due to chance alone.

2. Bottle neck effect.

✓ **Answer:** The **bottleneck effect** is an extreme example of genetic drift that happens when the size of a population is severely reduced. Events such as natural disasters (earthquakes, floods, fires) can decimate a population, killing most individuals and leaving a small, random assortment of survivors behind.

3. Founder effect.

✓ **Answer:** The **founder effect** is another extreme example of drift that occurs when a small group of individuals breaks off from a larger population to establish a colony. While the new colony is isolated from the original population, the founding individuals may not represent the full genetic diversity of the original population. Specifically, alleles in the founding population may be present at different frequencies than in the original population, and some alleles may be missing at all. The founder effect is similar in concept to the bottleneck effect, but it occurs via a different mechanism (colonization rather than catastrophe).

4.9 Gene flow

- **Gene flow (**migration) is any movement of individuals, and/or the genetic material they carry from one population to another. Gene flow includes lots of different kinds of events, such as pollen being blown to a new destination or people moving to new cities or countries. If gene versions are carried to a population where those gene versions previously did not exist, gene flow can be a very important source of genetic variation. The gene version for brown coloration moves from one population to another.

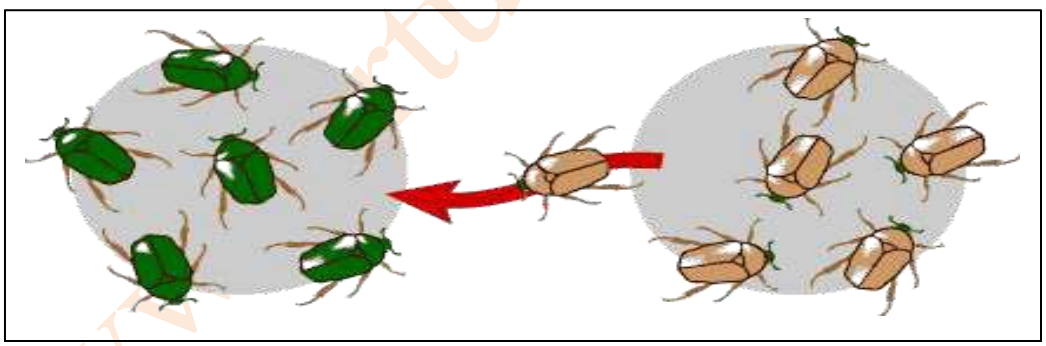


Figure 50 Gene flow (immigration)

- Immigration is when new organisms join a population, changing allele frequencies. Emigration is when members of a population leave, taking with them their genes.
- These phenomena change the overall balance of the gene pool of the populations.
- Gene transfer is the flow of alleles from one species to another. Gene transfer is especially common in bacteria.

Review questions

Provide answer for the following questions

1. Describe gene flow?

✓ **Answer:** Gene flow **(**migration) is any movement of individuals, and/or the genetic material they carry from one population to another.

2. Explain the role of immigration and emigration on gene flow and speciation.

✓ **Answer:** Immigration is when new organisms join a population, changing allele frequencies. Emigration is when members of a population leave, taking with them their genes.

4.10 Causes of species extinction

- Evidence suggests that anthropogenic effects and natural disaster played significant role for the direct and indirect causes of species extinction.

Unit summary

❖ Special creation theory: a 'supreme being' is believed to have created life or directs its creation and evolution.

❖ Spontaneous generation theory: life is believed to arise from non-living matter; this was finally disproved by the experiments of Francesco Redi and Louis Pasteur

❖ Eternity of life theory: life is believed to have existed forever and will continue to exist forever. Hence, no origin is required.

❖ Cosmozoan theory: either life forms or the organic molecules needed for the origin of life are believed to have been brought to Earth by meteorites and comets.

❖ Biochemical origin theory:life is believed to have originated as a result of biochemical reactions creating first the necessary organic molecules, which then became assimilated into 'pre-cells', which eventually evolved into cells.

❖ Miller's 'spark discharge' experiment showed that the organic molecules essential for life could be synthesized on Earth 4.5 billion years ago.

❖ The oldest photo-autotrophs are the cyanobacteria and they were largely responsible for the increase in free oxygen in the atmosphere.

❖ In 1809, Lamarck proposed a two-part theory to explain evolution based on:

- use and disuse
- inheritance of acquired characteristics

❖ In 1859 Darwin proposed the theory of natural selection based on:
- a struggle for existence
- natural variation in the offspring

❖ Particularly, you have learnt about Darwin's theory of natural selection, which stated that 'those members of a species which are best adapted to their environment will survive and reproduce in greater numbers than others less well adapted'.

❖ Apart from theory of natural selection, a detailed account of concepts regarding have been provided. Based on this, it has been stated that Neo-Darwinism takes into account our knowledge of genetics, biochemistry and ethology to modify Darwin's original theory to include the effect of selection on allele frequency and frequency of behavior patterns.

❖ On a similar vein, other insights on the origin of life have been provided. Evidence supporting the theory of evolution comes from many areas, including:
- palaeontology (the fossil record)
- comparative anatomy
- comparative embryology
- comparative biochemistry

- Another important point you have studied in this unit was about the use of fossils to determine the origin of life. In this case, fossils can be dated using:
  - Stratigraphy –analyzing the sequence and thickness of different layers (strata) of rocks
  - radioactive carbon (C14) dating – measuring the ratio of radioactive carbon to normal carbon – is suitable for fossils up to 60 000 years old

❖ This unit was also devoted to illustrating the following scientific concepts, facts and evidence related to evolution. These are:

❖ Homologous structures are evidence of a common origin and divergent evolution.

❖ Analogous structures are evidence of a different origin and convergent evolution.

❖ Similar patterns of embryological development in vertebrates suggest a common origin.

- The extent of differences in molecules common to many species (for example, DNA, cytochrome c, hemoglobin) is a measure of their relatedness.
- A species can be defined as 'a group of similar organisms with a similar biochemistry, physiology and evolutionary history that can interbreed to produce fertile offspring.
- The gene pool is the sum of all the alleles of all the genes in a population.
- The gene pool is constantly changing as a result of mutations introducing new genes into the population and disadvantageous alleles being lost through natural selection.
- In natural selection:
    - individuals with an advantageous allele survive to reproduce in greater numbers
    - the process repeats over many generations in which the frequency of the advantageous allele increases in each generation
- In directional selection, one extreme of a range of values for a feature has a survival advantage; the range of values for the population shifts towards the extreme with the selective advantage.
- In stabilizing selection, the two extremes are at a selective disadvantage compared to those showing the mean values for a particular feature; the range is compressed around the mean.
- In disruptive selection, both extremes have a selective advantage compared with the mean; two distinct types begin to emerge showing the extreme values of the original population.
- If two populations of the same species are isolated for sufficient time, they may become so different genetically as to evolve into separate species.
- Speciation involving geographical separation is called allopatric speciation.
- Speciation involving separation within one area which is a result of different breeding strategies is called sympatric speciation; the different strategies can involve:
- Divergent evolution involves adaptive radiation and is the evolution of one basic 'type' into several different 'types' as a result of different selection pressures. Examples include

- The divergent evolution of the pentadactyl limb into flippers, legs, wings, etc.
- The divergent evolution of the beaks (and other features) of Darwin's finches on the Galapagos Islands

❖ Convergent evolution is the evolution of similar 'types' with similar adaptations from several different original 'types'. Examples include:

- The elongated 'snouts' (and other features) of the different anteaters of the world
- The wings of birds, insects, pterodactyls, etc.

❖ Modern humans and other primates have evolved from a common primate ancestor that lived before the dinosaurs became extinct.

❖ Modern humans and chimpanzees have evolved from a common ancestor that lived about 6 million years ago.

❖ Two distinctive features of modern humans are:

- large brains
- true bipedalism

❖ The fossil Lucy was significant because it showed that bipedalism evolved before large brains.

❖ The fossil Ardi was significant because it showed that the common ancestor of humans and chimpanzees cannot have resembled a chimpanzee.

❖ Brain size has increased as hominids have evolved.

❖ Modern humans evolved in Africa, in and near Ethiopia, and have since migrated to all parts of the world.

❖ Humans evolved into different 'races' because natural selection favored different features in different environments.

Review questions

- Provide the correct answer for the following questions

1. List at least one point in favour and one point against the theories on the origin of life listed here under. You may have to imagine yourself as a 'person of the times' in some cases.
   a. Special creation
   b. Spontaneous generation

c. Eternity of life
d. Cosmozoan (panspermia)
e. Biochemical (abiogenesis)

2. (a) Explain what is meant by each of the following terms:
   i. Evolution
   ii. convergent evolution
   iii. divergent evolution

   (b) How does the fossil record provide evidence for evolution?

   (c). Explain how Neo-Darwinism has modified Darwin's original theory of natural selection.

3. (a) In each of the following examples of natural selection, identify: The selection pressure (feature of the environment that is selecting for some types and against others), and the type within the population that is best adapted.
   i. wildebeest hunted by lions:
   ii. Bacteria in a hospital where penicillin is widely used
   iii. Nettle plants with different-sized leaves in a shaded woodland area.

(b) Allopatric speciation and sympatric speciation are two processes by which new species can evolve. Explain:
   - one similarity between the two processes
   - one difference between the two processes

4. (a). Explain what is meant by the term 'species'.

   (b) It is possible to use DNA hybridisation to suggest relationships between species. Explain why

5. Explain the importance of each of the following in speciation:
   - Isolation of different populations
   - Mutation
   - Selection pressures
   - Reproductive isolation
6. Describe how the experiments of Redi and Pasteur were able to disprove the theory of spontaneous generation.

7. Describe
   (a) The Oparin/Haldane theory of abiogenesis (the biochemical origin of life).
   (b) Three pieces of evidence that support this theory.
8. Write a short essay on human evolution. Include the following aspects of human evolution in the essay:
   - The idea of a common ancestor with chimpanzees
   - Some of the early humans that have existed
   - The importance of bipedalism and large brain size
   - The significance of the Lucy, Ardi and Selam fossils.

Answer key

1. **a. Special creation**:

- The theory tried to explain formation of life on earth may have been taken place due to supernatural or divine forces. Special creation theory mainly focuses on spiritual matters which cannot be seen, touched or measured effectively by their very nature.

b. Spontaneous generation:

- Spontaneous generation is a hypothetical process by which living organisms develop from nonliving matter. The theory could not experimentally prove how living organisms developed from a nonliving matter.

c. Eternity of life:

- This theory state there is no beginning and no end to life on earth. However, evidence supports the formation of the earth before the existence of life on the earth.

d. Cosmozoan (panspermia):

- This theory assumes that life was present in the form of resistant spores and appeared on earth from another planet. However, no mechanism has been revealed about the transfer of spores from another planet or whether these spores could survive the journey in space. It states the absence of life forms on any planet except on the earth, but no detail was provided about the spores, its origin and mechanism of crossing interplanetary space and reaching the earth.

e. Biochemical (abiogenesis):

- This theory was supported by considerable experimental evidence. However, purines (adenine and guanine) were not synthesized under the same conditions as pyrimidines (thymine, uracil and cytosine). This is quite a serious problem for the theory.

2. a

i. **Evolution** - The theory of evolution describes how the various forms of life on earth (including humans) emerged and developed

ii. **Convergent evolution**- is the evolution of similar 'types' with similar adaptations from several different original 'types'

iii. **Divergent evolution**- the development of dissimilar traits or features (as of body structure or behavior) in closely related populations, species, or lineages of common ancestry that typically occupy dissimilar environments or ecological niches.

2. b Fossils are important evidence for evolution because they show that life on earth was once different from life that exists on earth today. Paleontologists can determine the age of fossils using methods such as radiometric dating and categorize them to determine the evolutionary relationships between organisms.

2. c Neo-Darwinism, the modern version of Charles Darwin's theory of evolution by natural selection, incorporates the laws of Mendelian genetics and emphasizes the role of natural selection as the main force of evolutionary change.

3. a If the bacteria is resistant to penicillin, the bacteria gains considerable advantage to flourish.

b. Both allopatric and sympatric speciation is a process that leads to new species but they are different in many ways.

Basis of comparison	Allopatric speciation	Sympatric speciation
Speed of Evolution	Speed of evolution of new species is slow.	Speed of the emergence of new species is fast with autopolyploidy and slow with allopolyploidy.

4. a. **A species** can be defined as 'a group of similar organisms with a similar biochemistry, physiology and evolutionary history that can interbreed to produce fertile offspring.

5. a. DNA hybridization: To measure the similarity of the DNA of one species with the DNA of another species.

- The technique measures the extent to which a strand of DNA from one species can hybridise with a strand of DNA from another species. In this technique, the double helix of the DNA molecule is heated to separate it into single strands and then the single-stranded DNA (ssDNA) from both species is mixed and the mixture cooled. Although the ssDNA from species A and species B will hybridise (bind) as it cools, it will not do so along all its length

6. Explain the importance of each of the following in speciation:

- Isolation of different populations: The inter specific sterility of species due to the accumulation of independent gene mutations for structural and functional characters.
- Mutation. A spontaneous change in the genetic material of an organism that leads to the formation of new species.
- Selection pressures: Reproductive isolation: the inability of living organisms to interbreed. It maintains distinctiveness of characters among species

7. In 1668, Francesco Redi, an Italian scientist, designed a scientific experiment to test the spontaneous creation of maggots by placing fresh meat in jars. While one jar was left open, the others were covered with a cloth. Days later, the open jar contained maggots, whereas the covered jars contained no maggots. He did note that maggots were found on the exterior surface of the cloth that covered the jar. Redi successfully demonstrated that the maggots came from fly eggs and thereby helped to disprove spontaneous generation.

- Louis Pasteur, the notable French scientist, showed that broth (or wine) only went sour if microorganisms were allowed to enter. Also no microorganisms appeared in the broth unless they were allowed to enter from the outside. Today, spontaneous generation is generally accepted to have been decisively dispelled during the 19th century by the experiments of Louis Pasteur.

8. The current ideas about how life may have evolved on earth as a result of biochemical reactions (sometimes called abiogenesis) owe much to two biologists working early (Oparin/Haldene) in the twentieth century.

- In 1953, Stanley Miller conducted his spark-discharge renowned experiment. In this investigation, he passed electric sparks repeatedly through a mixture of gases that were thought to represent the primitive atmosphere of the Earth. These gases were methane (CH_4), ammonia (NH_3), water (H_2O) and hydrogen (H_2). When he analyzed the liquid in the water trap, he found that it contained a number of simple organic molecules, out of which hydrogen cyanide (HCN) was one of them. He found that by leaving the equipment for longer periods of time, a larger variety and more complex organic molecules were formed including:
- Amino acids – essential to form proteins

- Pentose sugars – needed to form nucleic acids
- Hexose sugars – needed for respiration and to form starch and cellulose
- Hydrogen cyanide – But it has been rejected because the nitrogenous bases found in nucleotides can be synthesized in the laboratory using HCN as a starting point.

9. There is often a lot of very loose language used in describing human evolution. You will hear people say 'we evolved from monkeys' or 'we evolved from apes' or 'we evolved from chimpanzees'. None of these statements are accurate. There has been a 'line of evolution' for millions of years that has given rise to old world monkeys, new world monkeys, the great apes and the different species of humans that have lived. But, we are Homo sapiens and we are the latest of several humans to live on the planet.

- We have two features in particular that distinguish us from other primates. These are:
  - A very large brain, and
  - Bipedalism – the ability to truly walk on just two legs.
  - There was a lot of debate amongst biologists as to which of these came first and also about exactly how this 'evolutionary tree' (Figure 4.27) has given rise to the various groups although they may disagree
- Approximately 70,000,000 years ago, the dinosaurs disappeared completely. At that time, monkey-like animals appeared from more or less similar to the modern lemurs. Tail of these monkey-like animals disappeared about 40,000,000 years ago. Due to the enlargement of brain and improvement in their hands, ape-like animals evolved and then later they evolved into gibbon and orangutan. From gibbon and orangutan, gorilla and chimpanzee evolved about 25, 000,000years ago. About 20,000,000 years ago, the first human-like animals evolved who had erect posture and who was able to use their hands. Ramapithecus ape was recorded as the first human like animal. Afterwards, this ape grew up in size and became more intelligent. About 2, 000,000years ago, skilled human developed and about 1,500,000 years ago, human with erect posture and walking ability evolved. Neanderthal man was considered as the first wise-man. About 50thousand years ago, the Cro-Magnon man evolved and afterwards, this evolution had been faster than the earlier
- The relationships among *Australopithecus*, *K. platyops*, *Paranthropus*, and the direct ancestors of *Homo* are unknown. Because of its early date and geographic location, *A. anamensis* may be the common ancestor of *A. afarensis*, *A. garhi*, *K. platyops*, and perhaps the Laetoli Pliocene hominins

of eastern Africa, *A. bahrelghazali* of central Africa, and *A. africanus* of southern Africa. *A. afarensis* in turn may be ancestral to *P. aethiopicus*, which begot *P. boisei* in eastern Africa and *P. robustus* in southern Africa.

- The fossil Lucy was significant because it showed that bipedalism evolved before large brains.
- The fossil Ardi was significant because it showed that the common ancestor of humans and chimpanzees cannot have resembled a chimpanzee.

UNITE 5
HUMAN BODY SYSTEM

5.1 The Nervous System

- All living organisms need some level of awareness of their surroundings so that they can avoid danger, find food and, in some cases, find a mate. Whatever the level of awareness, it requires co- ordination and control within an organism to respond to changes in the surroundings. In large and complex organisms like a human being, it is also very important that the different systems within our body are coordinated and work together. We need to pick up all sorts of changes in the environment, and respond to them

- In human beings the nervous system is a highly complex system that provides rapid, coordinated responses to the situations we meet in our lives. It allows us to react to our surroundings and co-ordinate our behavior. Human nervous system has two main parts. These are the central nervous system (CNS), which is made up of **brain** and **spinal cord,** and the **peripheral nervous system** which consists of the nerves that branch out from the brain and spinal cord.

5.1.1 The Central Nervous System

- The Central Nervous System (CNS) consists of two main parts: – the **brain** and the **spinal cord**.

The Brain

- Human brain is a delicate mass of the nervous tissue with the consistency of thick yoghurt. It is enclosed in membranes and protected by the bones of a skull in a space known as the **cranium**. The nerves that come out of the brain are known as the **cranial nerves**. They go mainly to structures in the head, neck, eyes, tongue and jaws.

- Human brain is a very complex structure that carries out an amazing variety of functions. The different areas of the brain (Figure 5.2) carry out very different functions, from the basic reflexes that keep us breathing to the complex ideas needed to create a story or write and play music.
- The bulk of the brain is made up of **grey matter and white matter.** The **grey matter** (cell bodies and short relay neurons) in the brain **is** the darker outer portion whereas the **white matter** (mostly axons) is the lighter, inner section underneath the grey matter.
- As an embryo develops in the womb, the brain starts off as a tube in the head with three main areas. The **fore brain** develops into the olfactory lobes, which deal with smell, and the cerebral hemispheres that are involved in all the higher levels of thought. Some areas of the cerebrum (cerebral hemispheres) are involved in the co- ordination and interpretation of affector input from the sense organs. Other areas are involved in sending out effector impulses to control the actions of the body in response to the affector information.

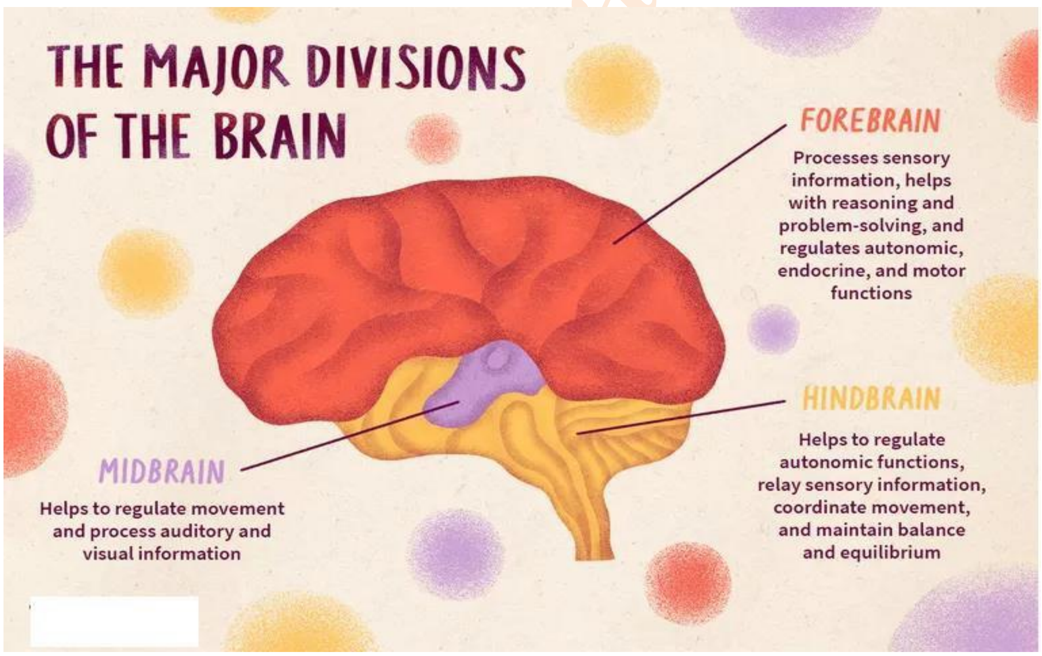


Figure 51: The three main areas of the human brain; the fore, mid and hind brain.

- The **mid brain** develops into the areas of the brain that deals with vision (the optic lobes) while the **hind brain** forms the areas of the brain that deals with balance and orientation (the cerebellum) and the most fundamental reflexes of life (the **medulla**) (Figure 5.1).

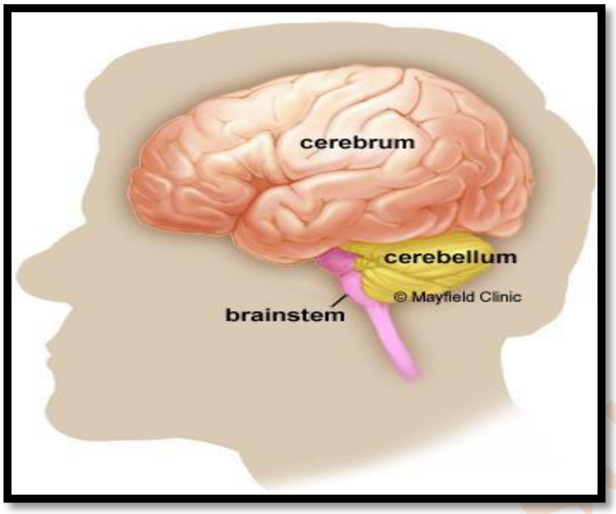


Figure 5.52 Main parts of the human brain

- The brain is an amazing three-pound organ that controls all functions of the body, interprets information from the outside world, and embodies the essence of the mind and soul. Intelligence, creativity, emotion, and memory are a few of the many things governed by the brain. Protected within the skull, the brain is composed of the **cerebrum**, **cerebellum**, and **brainstem (Medula)** (Figure 5.2).
- **Cerebrum:** is the largest part of the brain and is composed of **right** and **left** hemispheres. It performs higher functions like interpreting touch, vision and hearing, as well as speech, reasoning, emotions, learning, and fine control of movement.
- **Cerebellum:** is located under the cerebrum. Its function is to coordinate muscle movements, maintain **posture**, and **balance**.
- **Medula:** acts as a relay center connecting the cerebrum and cerebellum to the spinal cord. It performs many automatic functions such as **breathing**, **heart rate**, **body**

temperature, **wake** and **sleep cycles**, **digestion**, **sneezing**, **coughing**, **vomiting**, and **swallowing**.

- The brain receives information through our five senses: **sight**, **smell**, **touch**, **taste**, and **hearing** which many often do at one time. It assembles the messages in a way that has meaning for us, and can store that information in our memory. The brain controls our thoughts, memory and speech, movement of the arms and legs and the function of many organs within our body.

The spinal cord

- The spinal cord has a much simpler structure than the brain. It is a tubular structure composed of the nervous tissue that extends from the brainstem and continues distally before tapering at the lower thoracic/upper lumbar region as the conus medullaris (the terminal end of the spinal cord). The spinal cord runs out from the brain down the body. The spinal cord is encased and protected by the vertebrae making up the spine. The majority of nerves come out of the spinal cord are known as the **spinal nerves**. They stretch to the arms, legs, and trunk and to the rest of the body.
- In the spinal cord **the grey matter** is located in the middle whereas the **white matter** is found on the outside (Figure 5.4). At regular intervals along the spinal cord there are entrance points for **affector** nerves that bring information into the CNS and exit points for **effector** nerves carrying instructions from the CNS.

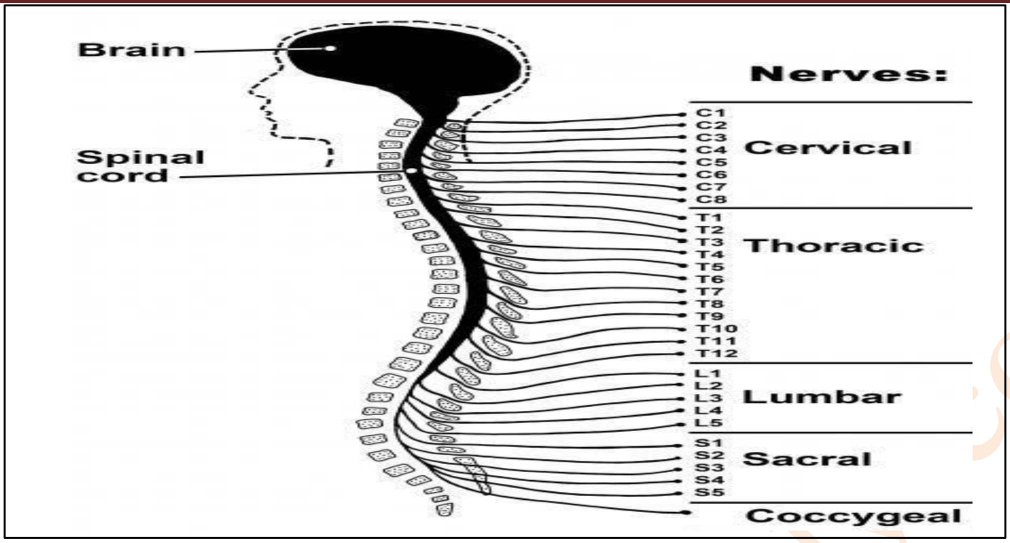


Figure .53. The spinal cord and spinal nerves

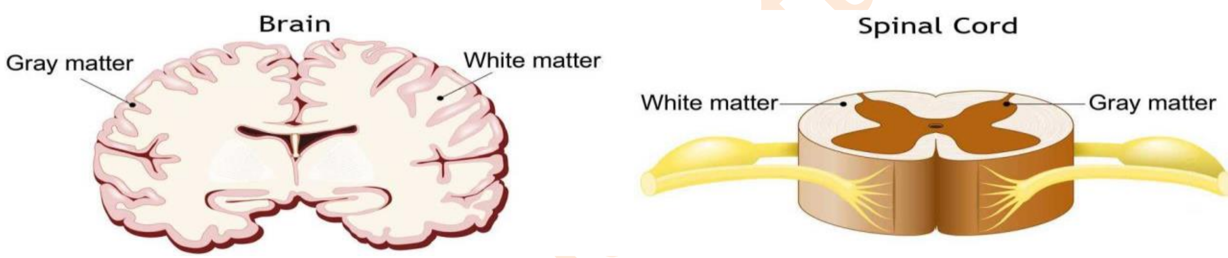


Figure .54 The cross-section of the CNS showing the position of grey and white matters.

- **Dura mater** – This is the thick outermost covering (meninges) of the brain and spinal cord. It is the layers of connective tissue that make up the meninges of the brain (dura, arachnoid, and pia). It is the outermost layer of the three meninges that surround and protect the brain and spinal cord.
- **Pia mater** – This is the innermost covering of the spinal cord. Intimately adhered to its surface, the pia mater stabilizes the spinal cord through lateral extensions of the pia called the denticulate ligaments, extending between the ventral and dorsal roots unto the dura mater.
- **The arachnoid mater** is interposed between Dura mater and Pia mater. It is delicate layer which is not attached to the inside of the dura but against it and surrounds the brain and spinal cord.

- Cerebrospinal fluid (CFS) - is the fluid that flows in and around the hollow spaces of the brain and spinal cord, and between two of the meninges (the thin layers of tissue that cover and protect the brain and spinal cord). Cerebrospinal fluid is made by tissue called the choroid plexus in the ventricles (hollow spaces) in the brain..

5.1.2 The Peripheral Nervous System

- The Peripheral Nervous System (PNS) is the division of the nervous system that contains all the nerves that lie outside of the central nervous system. The primary role of the PNS is to connect the CNS to the organs, limbs, and skin (Figure 5.5). These nerves extend from the central nervous system to the outermost areas of the body. The Peripheral Nervous System allows the brain and the spinal cord to receive and send information to other areas of the body which allows you to react to stimuli in your environment. The peripheral nervous system itself is divided into two parts: the somatic nervous system and the autonomic nervous system. Each of these components plays a critical role in how the peripheral nervous system operates.

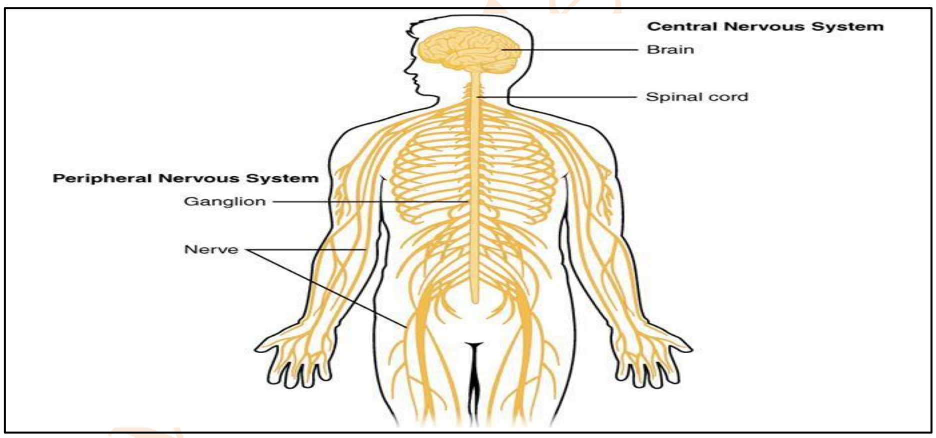


Figure 55 The human central and peripheral nervous systems.

5.1.3 The Somatic Nervous System

- The somatic system is the part of the PNS that is responsible for carrying out sensory and motor information to and from the central nervous system. The somatic nervous system derives its name from the Greek word *soma*, which means "body." The somatic system is responsible for transmitting sensory information as well as for voluntary movement.

5.1.4 The Autonomic Nervous System

- The autonomic system is part of your PNS that is responsible for regulating involuntary body functions, such as blood flow, heartbeat, digestion, and breathing. In other words, it is the autonomic system that controls aspects of the body that are usually not under voluntary control. This system allows these functions to take place without the need to consciously think about what is happening. The autonomic system is further divided into two branches:
- **Sympathetic system:** By regulating the 'flight-or-fight' response, the sympathetic system prepares the body to expend energy to respond to environmental threats. When action is needed, the sympathetic system triggers a response by accelerating heart rate and increasing breathing rate, boosting the blood flow to muscles, activating sweat secretion, and dilating the pupils.
- **Parasympathetic system:** This helps maintain the normal body functions and conserve physical resources. Once a threat is recognized, this system will slow the heart rate, slow breathing, reduce blood flow to muscles, and constrict the pupils. This allows us to return our bodies to a normal resting state.

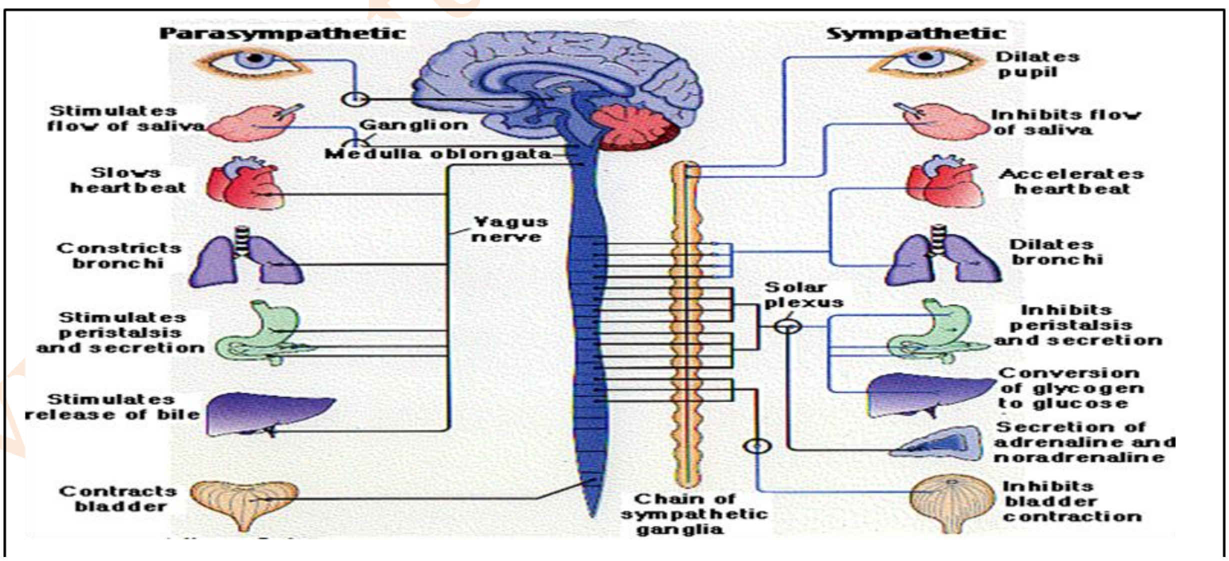


Figure 56. The Autonomic Nervous System

5.1.5 Neurons and their functions

- The basic unit of communication in the nervous system is the nerve cell (**neuron**). Each nerve cell consists of the **cell body**, which includes the nucleus, a **major branching fiber (axon)** and numerous **smaller branching fibers (dendrites).** Neurons vary in size, shape, and structure depending on their role and location. However, nearly all neurons have three essential parts: a cell body, an axon, and dendrites.

Cell body

- Also known as a soma, the cell body is the neuron's core. The cell body carries genetic information, maintains the neuron's structure, and provides energy to drive activities. Like other cell bodies, a neuron's soma contains a nucleus and specialized organelles. It's enclosed by a membrane which both protects and allows it to interact with its immediate surroundings.

Axon

- An axon is a long, tail-like structure which joins the cell body at a specialized junction called the axon hillock. Many axons are insulated with a fatty substance called myelin. **Myelin sheath** provides a layer of insulating material so the nerve impulse travels as fast as possible. Neurons generally have one main axon.
- **Node of Ranvier** is periodic gap in the myeli shath on the axon of certain neurons that serves to facilitate the rapid conduction of nerve impulses. These interruptions in the myelin covering were first discovered in 1878 by French histologist and pathologist, Louis-Antoine Ranvier, who described the nodes as constrictions.

Dendrites

- Dendrites are fibrous roots that branch out from the cell body. Like antennae, dendrites receive and process signals from the axons of other neurons. Neurons can have more than one set of dendrites, known as dendritic trees. The number of dendritic tree neurons have generally depends on their role. For instance, Purkinje cells are a special type of neuron found in the cerebellum. These cells have highly developed dendritic trees which allow them to receive thousands of signals.

- Node of Ranvier is periodic gap in the insulating myelin sheath on the axon of certain neurons that serves to facilitate the rapid conduction of nerve impulses. These interruptions in the myelin covering were first discovered in 1878 by French histologist and pathologist Louis-Antoine Ranvier, who described the nodes as constrictions.

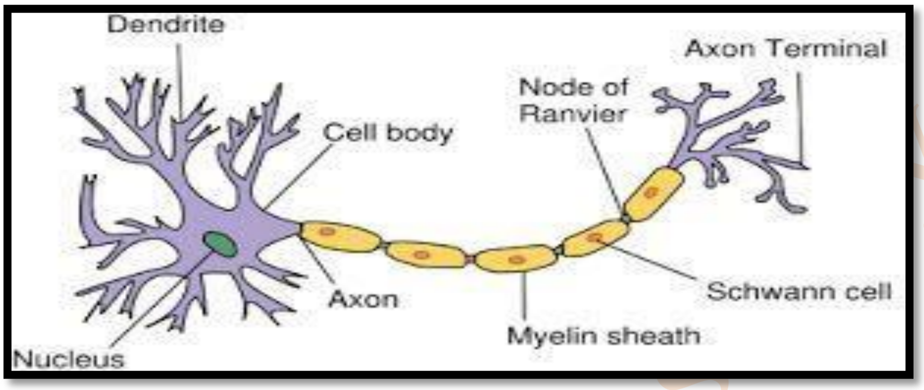


Figure.57 Structure of a neuron

5.2.1 Types of neurons

- Neurons vary in structure, function, and genetic makeup. Given the sheer number of neurons, there are thousands of different types, which are as many as thousands of species of living organisms on earth. In terms of function, scientists classify neurons into three broad types: **sensory**, **motor**, and **interneurons**.

Sensory (affector) (afferent) neurons

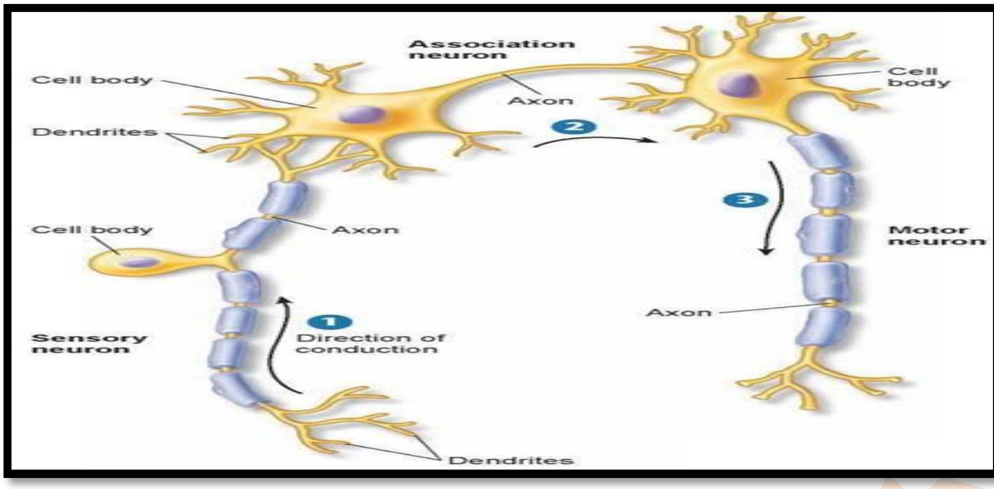
- Sensory neurons help you to taste, smell, hear, see, and feel things around you. Sensory neurons are triggered by the physical and chemical inputs from your environment. Sound, touch, heat, and light are physical inputs. Smell and taste are chemical inputs. For example, stepping on hot sand activates sensory neurons in the soles of your feet. Those neurons send a message to the brain, which makes you aware of the heat. Sensory neurons that carry messages from **sensory receptors** to the central nervous system typically have a **long dendrite and short axon.**

Motor (effector) (efferent) neurons

- Motor neurons play a role in movements that include voluntary and involuntary movements. These neurons allow the brain and the spinal cord to communicate with muscles, organs, and glands all over the body. Motor neurons have a **long axon and short dendrites** and transmit messages from the **central nervous system** to the **effectors** (muscles or glands).
- There are two types of motor neurons: lower and upper. Lower motor neurons carry signals from the spinal cord to the smooth muscles and the skeletal muscles. Upper motor neurons carry signals between the brain and the spinal cord.

Interneurons

- Interneurons are neural intermediaries found in the brain and the spinal cord. They are the most common type of neuron. They pass signals from sensory neurons and other interneurons to motor neurons and other interneurons. Often, they form complex circuits that help you to react to external stimuli.
- The nervous system takes in information through our senses. Once a stimulus is picked up by a sensory receptor, the information is passed along special nerve cells, **affector** or **afferent (sensory)** neurons, to the central nervous system (CNS). In the CNS **interneurons (associated neurons)** pass signals from sensory neurons to motor neurons and other interneurons. Once the information has been processed in the CNS, instructions are sent out to the body along more neurons called **effector** or **efferent (motor)** neurons. These stimulate the effector organ, usually muscles or a gland **(effecors)** as follows:
- **Sense organ → afferent neuron → central nervous system → efferent neurons → muscles**



- **Nerves** are bundles of neurons. Some nerves that carry only effector neurons are known as effector nerves. Some nerves that carry only affector neurons are known as affector nerves, whilst others that carry a mixture of effector and affector neurons and are called mixed nerves.

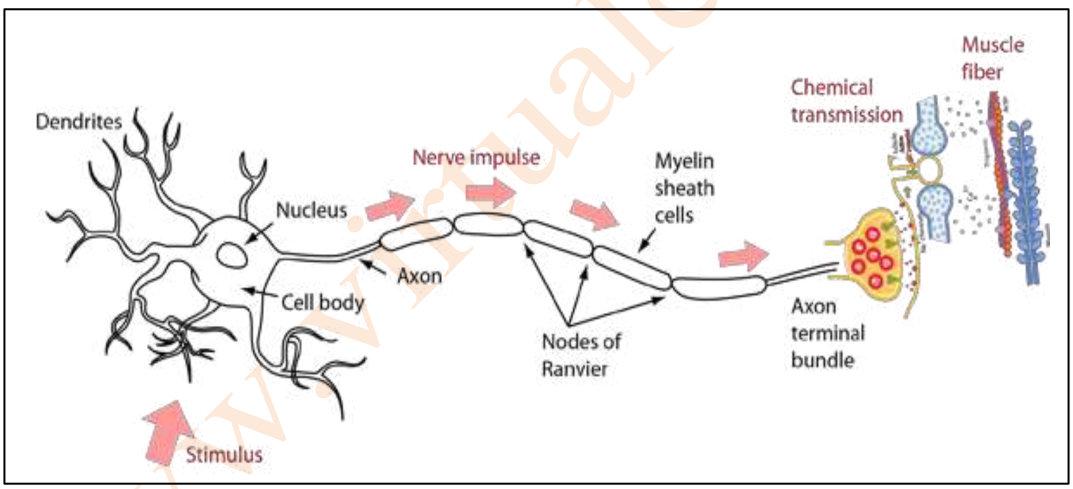


Figure 59 The afferent (affector) neuron and afferent (effector) neurons carry message to and from human central nervous system and are vital for the coordination of human body

Neural Junctions (Synapses)

- Whenever one neuron ends and another begins there is a gap known as a s**ynapse**. The electrical impulses that travel along the neurons have to cross these synapses, but an electrical impulse cannot leap the gap. Therefore, when an impulse arrives at the end of a neuron, chemicals are released.

- These chemical transmitters (**neurotransmitters**) cross the synapse and are picked up by special receptor cells in the end of the next neuron. In turn this starts up an electrical impulse, which then travels along the next neuron. This is how impulses pass from one neuron to another.

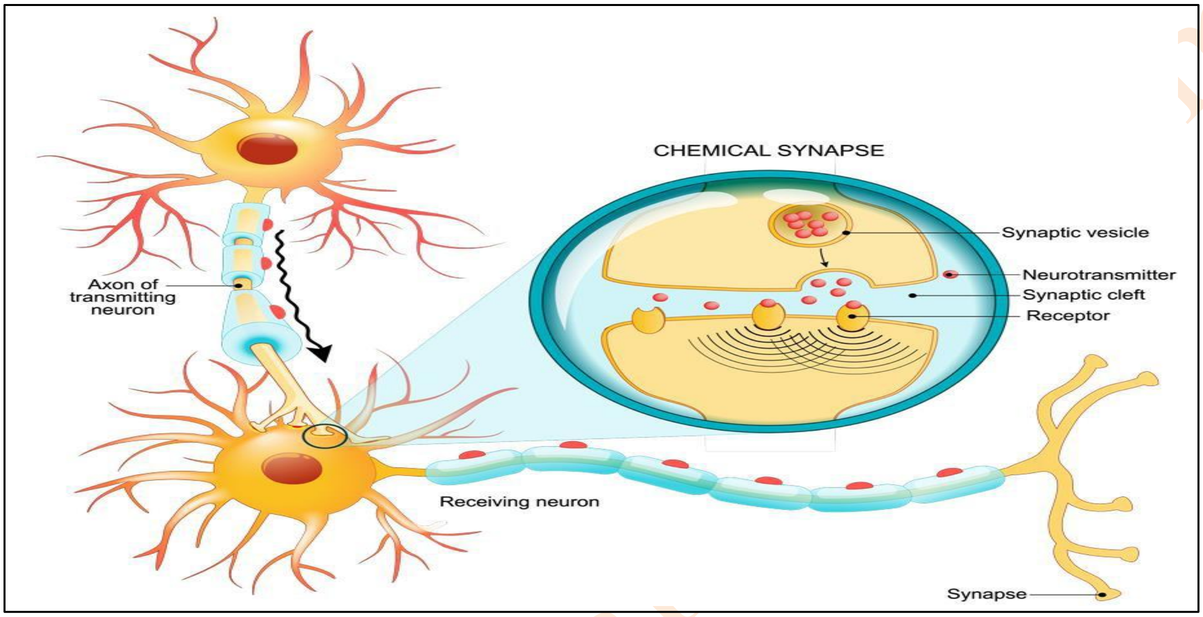


Figure.60 Neurons communicate with each other by imparting neurotransmitters via contact points, the so-called neuronal synapses.

Nerve impulse and transmission

- The nervous system relies on nerve impulses travelling along the neurons. Each nerve impulse is a minute electrical event that works as a result of charge differences across the membrane of the axon. The wave of positive charge inside the axon when the neuron is stimulated is known as the **action potential**.
- When a neuron is stimulated, the potential across the cell membrane changes. This is because when a neurotransmitter binds to its receptor, it can open channels that let particular ions go through the membrane. When a sodium channel is open, Na+ ions will flow through the membrane into the cell for two reasons:

1. The resting potential keeps the inside of the cell negatively charged, so positive ions are attracted in.
2. There is an attracting concentration gradient for sodium, because there are many more

Na+ ions outside the cell than inside it.

- The resulting influx of positive ions makes the inside of the cell less negative, reducing the resting potential. This is called **depolarizing** the cell. If the cell is depolarized from its resting potential of around minus 70 millivolts to its **threshold potential** of about minus 55 millivolts, an abrupt change occurs. This is called an **action potential**. The potential across the cell membrane radically flips from the normal state, to a transient state. Consequently, the inside is negative relative to the outside the inside becomes positive relative to the outside. The normal direction of polarization is rapidly restored once the stimulation stops. In fact, the neuron becomes **hyperpolarized** for a few milliseconds, which means that its inside becomes even more negatively charged than usual. During this time – the **refractory period** – the hyperpolarized neuron is less readily able to respond to further input. So a single, relatively small, stimulation pulse can produce a radical change in the neuron's electrical state.

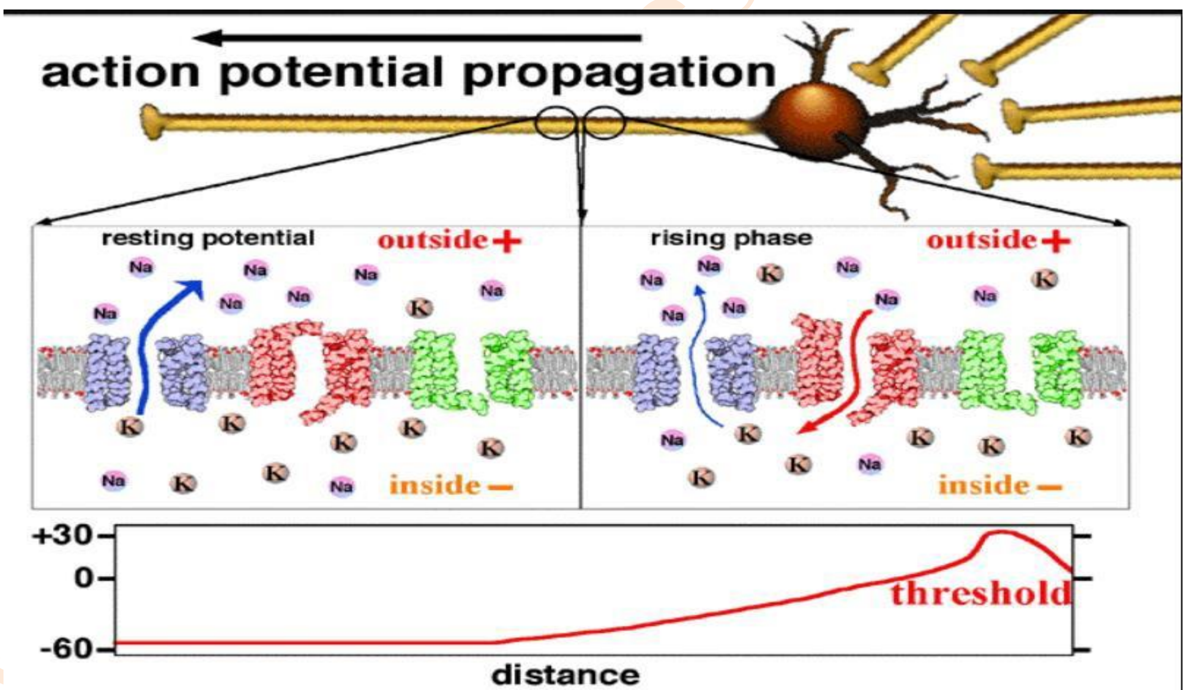


Figure .61 Action potential

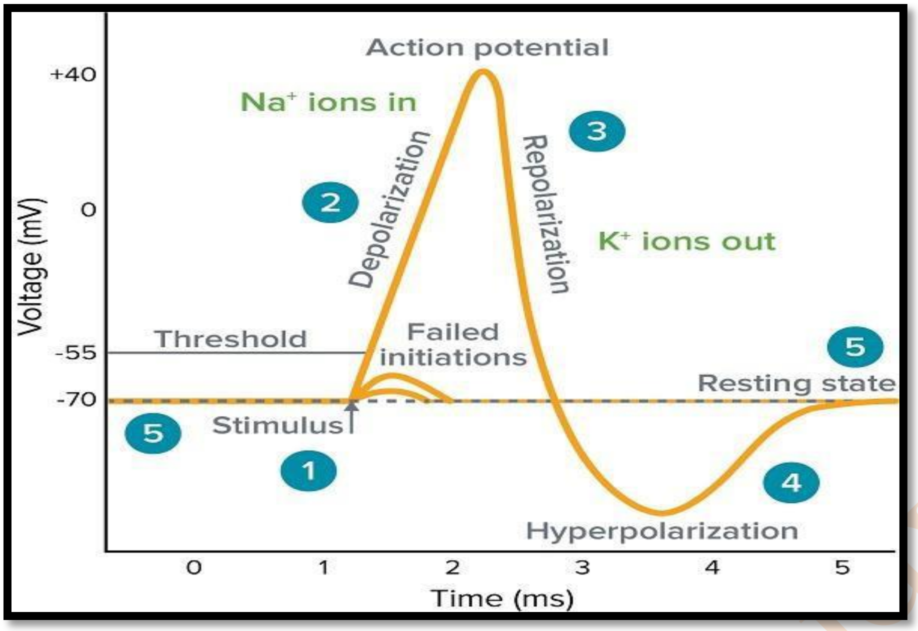


Figure.62 The action potential is the basis of all the electrical signals in the nervous system of the body.

Neurotransmitters

- Neurotransmitters are often referred to as **the body's chemical messengers**. They are the molecules used by the nervous system to transmit messages between neurons, or from neurons to muscles. Acetylcholine (ACh) is **an abundant neurotransmitter in the human body**. It is found in both the central nervous system (CNS) and the peripheral nervous system (PNS).
- An **excitatory transmitter** promotes the generation of an action potential in the receiving neuron, whereas an **inhibitory transmitter** prevents it. Whether a neurotransmitter is excitatory or inhibitory depends on the receptor it binds to. **Neuromodulators** are a bit different, as they are not restricted to the synaptic cleft between two neurons, and so can affect large numbers of neurons at once. Neuromodulators therefore regulate populations of neurons, while also operating over a slower time course than excitatory and inhibitory transmitters.

Review questions

1. What are the differences between a neuron and a nerve?
2. Figure out the constituents of central nervous system and peripheral nervous system.
3. How do synapses work?

Answer

- 1. Nerve is a group of neurons, whereas a neuron is an individual specialized cell. A nerve transmits information to the various parts of the body. But a neuron conducts electrochemical signaling or nerve impulses. Nerves are found in the peripheral nervous system. But neurons are found in the brain, spinal cord and the peripheral nerves. A nerve constitutes different types of axons, with each nerve covered by three layers (endoneurium, perineurium and epineurium). A neuron constitutes four parts (soma, nucleus, dendrite tree and axons.

- 2. Human nervous system has two main parts. These are the central nervous system (CNS), which is made up of **brain** and **spinal cord,** and the **peripheral nervous system** which consists of the nerves that branch out from the brain and spinal cord.
- 3. Synapses are very important for the co-ordination of information in the human central nervous system and information that is coming in from many different areas of human body. There are special synapses between effector neurons and the muscles they stimulate. These are known as **neuromuscular junctions** and they work in the same way as a normal synapse, except the chemical crossing in which the gap causes the muscles to contract.

5.1.7 Reflexes

Reflex action

- A reflex action is a sudden, automatic and uncontrolled response of parts of the body or the whole body to the external stimuli. They are usually involved in helping us to avoid danger or damage. We also have lots of reflexes that help us take care of our basic bodily functions by leaving the brain free for thinking about other things. Breathing is a good example.

The pupillary light reflex

- The pupil of an eye dilates or constricts depending on the light levels. This is another example of a protective reflex action. It protects the retina from damage from too much light, and enables a person to see in low light conditions. You blink the eyes if something comes towards your face to protect the eyes from physical damage.

- The key point about a reflex action is that the messages do not reach a conscious area of your brain before instructions are sent out to take action. Many reflexes involve the spinal cord, whereas others involve the brain. They involve three types of neuron affector neurons, relay neurons and effector neurons. Relay neurons (interneurons with short axons) connect the affector and effector neurons directly in the CNS, without input from other areas. The receptors, neurons and effectors involved are referred to as a reflex arc. The brain and spinal cord act together as acoordinators that process the information coming from sensory receptors and neurons and instruct effector neurons and effectors to react.

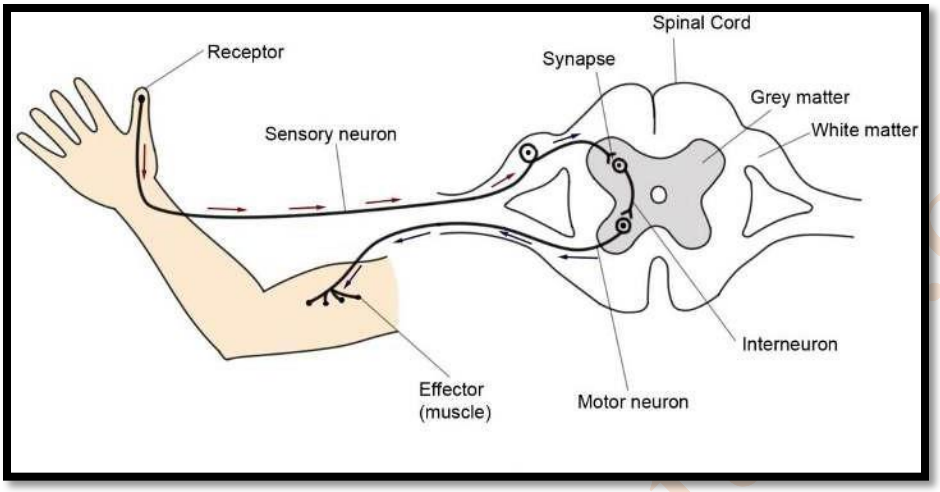


Figure 63 The reflex action. As shown in

- Impulses from a sensory receptor in the skin pass along an affector neuron to the central nervous system – the spinal cord. The neuron enters the spinal cord through the **dorsal root**. When an impulse from the affector neuron arrives in the synapse with a short relay neuron a transmitter is released, which causes an impulse to be sent along the relay neuron. When the impulse reaches the synapse between the relay neuron and an effector neuron returning to the arm again another transmitter chemical is released. This starts impulses travelling along the effector neuron to the organ (effector), which brings about change. The effector neuron leaves the spinal cord by the **ventral root**. In this example the impulses arrive in the muscles of the upper arm, causing them to contract and move your hand upwards sharply.

Review questions

Provide answers for the following questions

1. Explain why reflexes can happen so quickly?
2. Do you think that all reflexes are simple?
3. How are reflexes so important for keeping us safe and helping us to learn?

Answer

- 1. Most reflexes don't have to travel up to your brain to be processed, and hence they take place so quickly. A reflex action often involves a very simple nervous pathway called a reflex arc. A reflex arc starts off with receptors being excited. They then send signals along a sensory neuron to your spinal cord where the signals are passed on to a motor neuron. As a result, one of your muscles or glands is stimulated.
- 2. There are many different reflexes in the body. Some of them are complicated and involve multiple interneurons and synapses. When there are many synapses, the reflex is called polysynaptic ("poly" means many). These reflexes, just like the simple monosynaptic reflex, exist in living beings, especially in human beings, to keep us safe!
- 3. A reflex is an involuntary movement executed in response to a stimulus transmitted to the nerve center in the brain or spinal cord. Naturally, if a movement results, the brain will become aware of such movement and can regulate it somewhat, but the brain cannot control it. For example, when you trip and fall, reflexes automatically command your hands and arms to reach out and handle your fall, and your muscles will contract throughout your body to minimize injury. Reflexes perform many essential jobs for our central nervous system. They protect us from danger, help us to move our body and see. They are intended to help prevent injury to our bodies, but they are not always entirely effective in totally preventing injuries. An example of this is when you reflexively put your hands out to prevent a fall; you may injure your wrist in the process. Having good reflexes aids performance in sports, exercise, and everyday physical activities such as crossing the street, driving and working, whereas poor reflexes can be an underlying reason for faulty movement and injury. Reflexes and reaction time do have a surprisingly large bearing on our ability to avoid any undue injury.

5.1.9 Drug abuse

- Drugs are substances that change a person's mental or physical state. They can affect the way the brain works, how you feel and behave, your understanding and your senses. This makes people; especially young people develop unpredictable and dangerous behavior.

- In every society there are certain drugs which are used for medicine and there are others which are used for pleasure. Usually some of these substances are socially acceptable and others are illegal. In Ethiopia caffeine, nicotine, khat and alcohol are not prohibited legally. The status of a drug may be related to its effect on people, or it may be simply down to the history of its use. Most of the drugs being used for medicine affect our bodies. The drugs people use for pleasure tend to have a distinct effect on their minds. Drug (or substance) use is when someone is used to the extent that affects the brain and/or body function and mental activity.

- Legal drugs are used for the mild pleasure they bring, to be sociable and as a habit. **Drug (or substance) abuse** is when a person uses a substance to the point of excess and/or dependence. When drugs are taken in excess they cause a serious health risk and even death. Drug dependence is when a person use a drug again and again and become **addicted**. Addiction is marked by a change in behavior caused by the biochemical changes in the brain after continued substance abuse.

- **Substance use disorder (SUD)** or **drug addiction** is a disease that negatively affects a person's brain and behavior. A person can become obsessed with any legal or illegal drugs. Some people can get addicted to certain medications. This addiction gradually starts developing when the individual continues to consume the drug despite the impairment it causes. Nicotine, marijuana and alcohol are commonly misused drugs in today's world.
- Drug abuse, of both legal and illegal substances, is becoming more of a public health problem in Ethiopia. School surveys have shown that alcohol, khat, tobacco, cannabis (marijuana) and solvents are the substances most widely used in Ethiopia. Alcohol, khat and tobacco are legal drugs in Ethiopia but cannabis is illegal. Solvents like gasoline are legal but are not meant for humans to inhale. Drugs such as lysergic acid diethylamide (LSD), ecstasy, cocaine and heroin are illegal but rarely used in Ethiopia.
- Khat, alcohol and tobacco are linked to a wide range of health problems. The health issues linked to these legal drugs are mainly the result of their effect on the systems of the body.

5.1.10 Common substances (drugs) used in Ethiopia

- In Ethiopia, **alcohol and khat** are the most common substances of abuse, followed by cannabis and solvents. Hard drugs such as heroin and cocaine are rarely used

Smoking

- Smoking is not as common in Ethiopia as it is in many parts of the world. However, the documented evidence suggests that more and more young people are smoking across the world. The addictive drug in cigarette smoke is **nicotine**, which affects the brain and produces a sensation of calm, well-being and being able to cope with. However, it is very physically addictive. Unfortunately cigarette smoke also contains many very harmful chemicals, and these are linked to a number of very serious health problems.

Alcohol

- Alcohol is one of the drugs most commonly used by people of all ages in Ethiopia. Interestingly, however, we still drink far less than many other countries. For many people alcohol is part of their social life. They like to share a drink with friends and don't think of themselves as drug users. In small amounts, alcohol makes people feel relaxed and cheerful. It makes users less inhibited. Shy people may feel more confident when they've had an alcoholic drink, alcohol has a powerful effect on human body. It is very addictive and it is also very poisonous. Although some religions ban the use of alcohol many people all over the world drink in defiance of the ban. Perhaps this is because alcohol has been used for thousands of years.

Khat

- Catha edulis (Khat) is a plant grown commonly in the horn of Africa. The leaves of khat are chewed by people for it is stimulant. Its young buds and tender leaves are chewed to attain a state of euphoria and stimulation. Khat contains a drug that affects the brain. It can also be made into a tea. It is a mild stimulant that makes people feel happy and reduces their appetite. It is often used in social situations.
- In Ethiopia, khat use is growing fast among young people. It is not yet prohibited legally in the country. Khat contains a drug that affects the brain. The drug cathinone from the khat leaves is absorbed into the bloodstream through the membranes lining of the mouth and the stomach. It acts quickly, within 30 minutes of time, before it is broken down and removed by the liver. When addicted people cannot get the drug, feel depressed, tired and unable to concentrate.

Cannabis (marijuana)

- **Cannabis** is a plant that contains 400 known chemicals, 60 of which are the cannabinoids, unique to the plant. The most potent is delta-9-tetrahydrocannabinoid (THC). THC is known to affect the brain cells that are responsible for memory, emotion and motivation. Cannabis is usually smoked but it can also be eaten, whenit has a much stronger effect because your liver converts it into a much more powerful drug. It can make you feel a great sense of wellbeing and relaxation, happy and euphoric – and this is why people use it. It is a mild hallucinogenic drug.

- **Hallucinogens** are drugs that produce vivid waking dreams, where the user sees or hears things that are not really there, or has a distorted view of the world. However, many people find the effect of the drug a very unpleasant and disturbing experience. The effect of cannabis is very variable. It affects different people in different ways, and even the same person can react very differently depending on how it is used.
- Cannabis is illegal in Ethiopia. In spite of this, there is a long tradition of using it. It is currently used in a number of social contexts. There are many other illegal drugs, but they are not widely used in Ethiopia where in some places they are becoming more common.

Review questions

Provide answer for the following questions

1. Explain some of the disease arises due to the effects of chronic alcohol abuse.

- Answer:
- If you drink large amounts of alcohol such as a whole bottle of spirits, your liver simply cannot cope. You suffer from alcohol poisoning. This can quickly lead to unconsciousness, coma and death. Some people who drink heavily for many years become **alcoholics**. They are addicted to the drug. Their liver and brain suffer long-term damage and eventually the drink may kill them. They may develop **cirrhosis of the liver**. This disease destroys your liver tissue. They can also get liver cancer, which spreads quickly and can be fatal. The brain of some heavy drinkers can be so damaged (it becomes soft and pulpy) that it can't work any longer. This causes death. It is also an established fact that those addicted (dependent) to alcohol are more likely to develop **Korsakoff's syndrome** (chronic memory disorder) as a result of damage to the neurons.

2. Describe some of the problems related to the use of drugs such as kchat, cannabis and heroin

Answer

- Khat affects the health of the population directly and indirectly by the behaviour it causes. For many young people, khat is destroying their chances in life. Many people in Ethiopia need to work together to find the best way to deal with the problem of khat. It might seem impossible, but smoking widespread in the UK 50 years ago. Hundreds of thousands died from smoking-related diseases. Some people still smoke in the UK, but numbers has fallen dramatically and it is now against the law to smoke in public buildings. The numbers of people dying from smoking-related diseases has fallen steadily. This shows that it is possible to reduce the use of familiar local drugs. Khat use is linked to unprotected sex, which put young people at risk of pregnancy and HIV/AIDS infection. Young men who used khat were found to be more likely to use a sex worker, and more likely to have many different sexual partners. All of these behaviours increase their risk of becoming infected with HIV/AIDS and of passing that infection on to someone else. Using khat also makes people more likely to be injured in accidents, more likely to be involved in crime, less likely to have a job and more likely to have problems in their family lives.

5.2 Sense organs

5.2.1 Skin as a sense organ

- The skin is one of the largest organs in the human body in surface area and weight. It is a remarkably complex organ which carries out a number of important functions in human body. It gives you senses of touch, temperature and pain.

  - The skin: Contains a huge variety of sense organs (touch, temperature, pressure, pain).Forms a waterproof layer around the body tissues, which protects against the loss of water by evaporation and prevents gaining waterby osmosis while swimming in the river or wash.
  - It protects the body from the entry of bacteria and other pathogens.
  - It protects the body from damage by UV light.
  - It is an excretory organ (nitrogenous wastes are lost with the sweat).
  - It is vital in controlling the body temperature.

Basic components of the human skin

- The human skin is the largest organ of the body, with a total area of about 20 square feet. The skin protects us from microbes and elements, helps regulate body temperature, and permits the sensations of touch, heat, and cold. Skin has three main layers. These are **epidermis, dermis** and **hypodermis.**
- The epidermis, the outermost layer of skin, provides a waterproof barrier and creates our skin tone. The dermis, beneath the epidermis, contains tough connective tissue, hair follicles, and sweat glands. The deeper subcutaneous tissue (hypodermis) is made of fat and connective tissue.

- The lower layer, the hypodermis, contains fatty tissue which is both an energy store that acts as an insulation layer, protecting against heat loss. The middle layer or dermis contains the blood vessels, the sweat glands, the sensory receptors and the hair follicles. This layer is closely involved in temperature control in homeostasis and in your sense of touch. The upper layer or epidermis is made up of dead cells. Keratinocytes, melanocytes and langerhans cells are some of the important cells found in the epidermis. Keratinocytes- produce the protein known as keratin, the main component of the epidermis. Keratin makes up hair, nails, and the surface layer of the skin. Keratin is what forms the rigidity of your skin and helps with the barrier protection that your skin offers. Melanocytes produce skin pigment, which is known as melanin. Langerhans cells, which prevent things from getting into your skin. Epidermal layer of the skin stop water loss and also protect against the entry of pathogens.
- The dermis is a complex combination of blood vessels, hair follicles, and sebaceous (oil) glands. In the dermis, there are collagen and elastin proteins necessary for skin health because they offer support and elasticity (the skin's ability to go back to its original state after being stretched). Collagen is the most plentiful protein in the skin, making up 75-80% of the skin. Collagen and elastin are responsible for warding off wrinkles and fine lines. Over time, the environment and aging reduce the body's ability to produce collagen. It is the dermis which is particularly involved in the homeostatic mechanisms of the skin.
- The thickness of the epidermis and dermis may vary. Due to variation in the thickness the skin can be categorized as thick and thin. Thin skin covers most of the body and can vary in thinness, with the thinnest skin covering the eyelids. Thick skin is present on the soles of the feet and palms of the hands. In addition to differing thicknesses, the skin also differs in what is available in the layers. For example, thick skin has no hair follicles or sebaceous glands, whereas thin skin does.

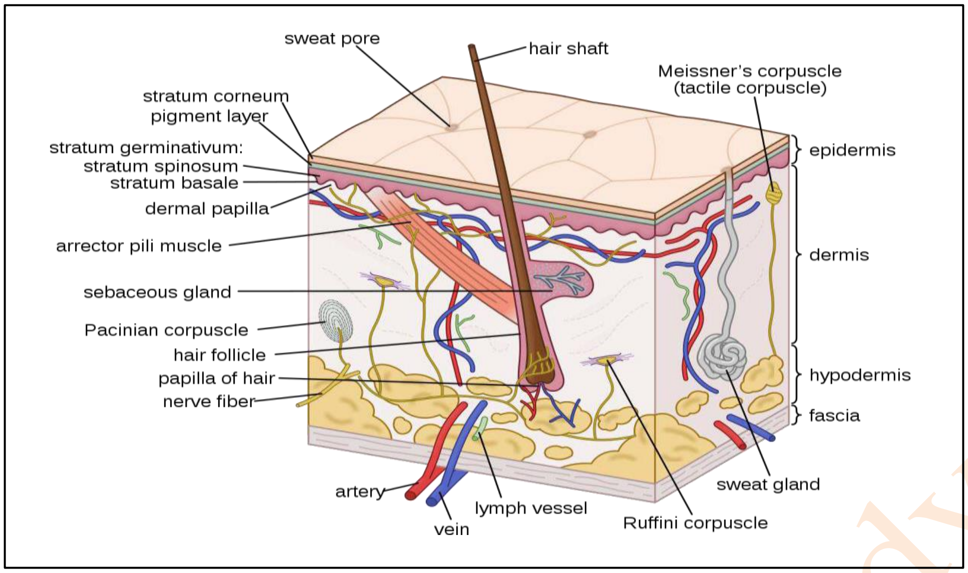


Figure 5.64 Part of the human skin

5.2.2 The Tongue as a sense organ

- The tongue is a muscular organ in the mouth. The tongue is covered with moist, pink tissue called mucosa. Tiny bumps called **papillae** give the tongue its rough texture. Thousands of taste buds cover the surfaces of the papillae. Taste buds are collections of nerve-like cells that connect to nerves running into the brain.
- The tongue is anchored to the mouth by webs of tough tissue and mucosa. The tether holding down the front of the tongue is called the frenum. In the back of the mouth, the tongue is anchored into the hyoid bone. The tongue is vital for chewing and swallowing food, as well as for speech.

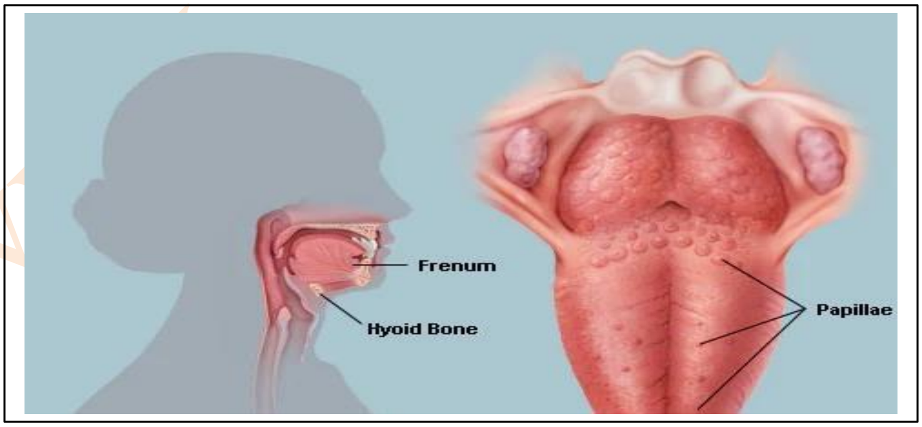


Figure 65: The human tongue

- The sensory receptors of the tongue and those found in the nostrils are sensitive to solutions of certain chemical substances. The sensory receptors of taste are located on the upper surface of the tongue, and to a lesser extent on the surface of the throat. The receptors for smell are located in the upper parts of the nasal passages. There are five basic taste sensations. The first four are sweet, sour, bitter and salt. We have known too much about these for many years. Scientists have also discovered a fifth taste called umami (a very savoury flavour found in foods such as meat, cheese, broth and mushroom). For many years it was thought that the receptors for the four known senses had their areas of greatest concentration on different parts of the tongue. It has now been clearly shown that in fact all of the five different taste organs are spread out all over the tongue, although some of them may seem to be in a greater concentration in certain places.

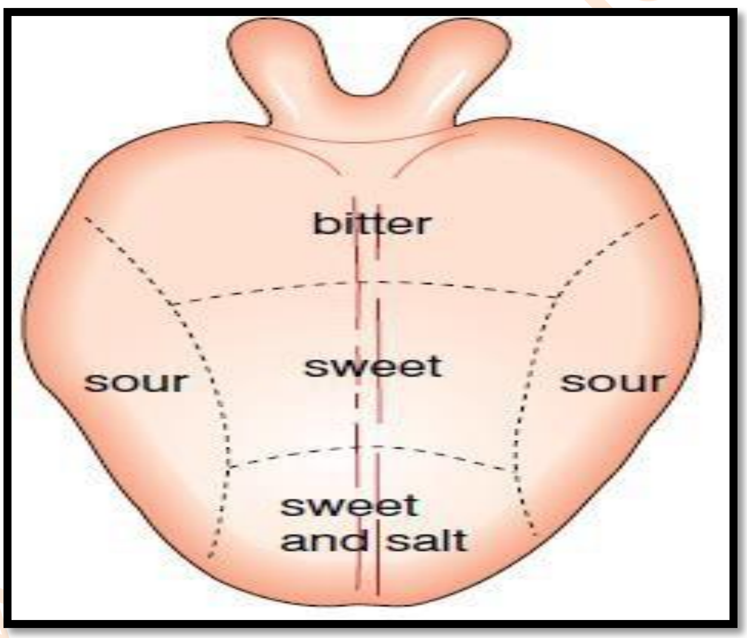


Figure 66 The main taste areas of the tongue that has been taught for many years.

5.2.3 The Nose

- The human nose is a sense organ of smell. Another word for smell is **olfaction**. The olfactory receptors in the nose help to identify food, mates, predators, and provides both sensual pleasure in the odor of flowers and perfume, as well as warnings of danger. For example, spoiled food, fire or chemical dangers. For both humans and animals, it is one of the important means by which the environment communicates with us. Another function of the nose is the conditioning of inhaled air, which the nose makes it more humid and warmer. Hairs inside the nose prevent large particles from entering the lungs.

Anatomy and Physiology

- The nasal passages not only allow the passage of air for respiration through the nose but also warm and filter the air.
- The nasal concha or turbinate bone is a long, narrow and curled bone shelf that protrudes into the breathing passage of the nose. In humans, the turbinates divide the nasal airway into four groove like air passages, and are responsible for forcing inhaled air to flow in a steady, regular pattern around the largest possible surface of cilia and climate controlling tissue.

How do you smell?

- Specialized receptor cells of the olfactory epithelium detect and recognize smells. The air passes through the nasal cavity and through a thick layer of mucus to the olfactory bulb. The olfactory bulb is situated in the forebrain. The smells are recognized here because each smell molecule fits into a nerve cell like a puzzle piece. The cells then send signals to the brain via the olfactory nerve. The brain then interprets those molecules as the sweet flowers, or the curdling milk that you have held up to your nose.

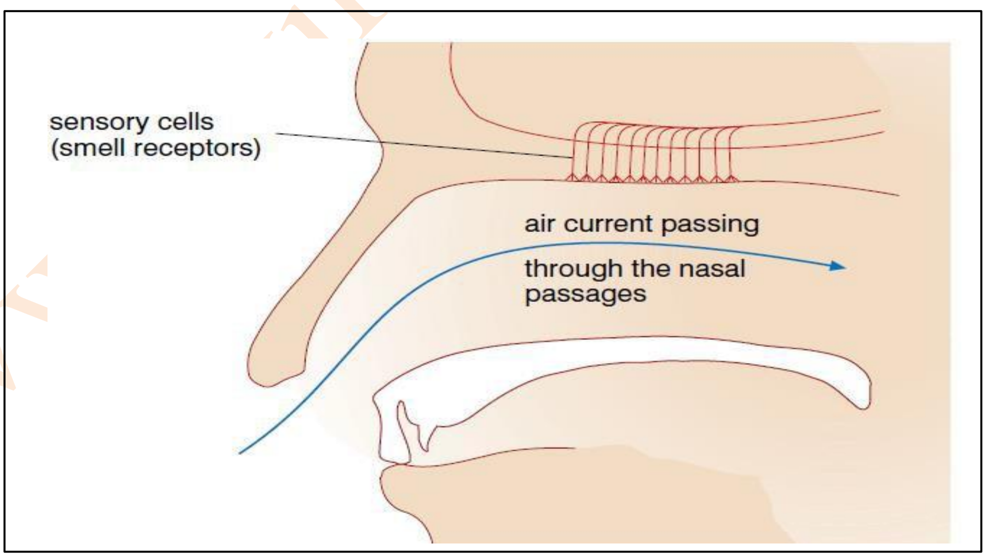


Figure 67 Internal structure of nose

- For human being to be able to taste and smell, chemicals must go into solution in the form of liquid coating the membranes of receptor cells before they can be detected. The major functional difference between the two kinds of receptors is that smell receptors are more specialized for detecting vapors coming to the organism from distant sources. Taste receptors are specialized for detection of chemicals present in the mouth itself. Furthermore, smell receptors are much more sensitive than taste receptors.

5.2.4The eye structure, function, and defects

- The eye transmits visual stimuli to the brain for interpretation and thereby functions as sensory organ of vision. The eyeball is located in the eye orbit, a round, bony hollow formed by several different bones of the skull. In the orbit, the eye is surrounded by a cushion of fat. The bony orbit and fat cushion protect the eyeball. To perform a thorough assessment of the eye, it is crucial to understand the external structures of the eye, the internal structures of the eye, the visual fields and pathways, and the visual reflexes.

External structures of the eye

- The parts of the eye that include the following are visible externally.
- The **eyebrows** protect the eyes by preventing perspiration from running down the forehead and into the eyes, causing irritation. They also help shade the eyes from direct sunlight.
- The **eyelids (upper and lower)** with their associated lashes are two movable structures composed of skin and two types of muscle: striated and smooth. Their purpose is to protect the eye from foreign bodies and limit the amount of light entering the eye.
- In addition, they serve to distribute tears that lubricate the surface of the eye (see Figure 5.21). The eyelids join at two points: the lateral (outer) canthus and medial (inner) canthus. The medial canthus contains the puncta, two small openings that allow drainage of tears into the lacrimal system, and the caruncle, a small, fleshy mass that contains sebaceous glands.

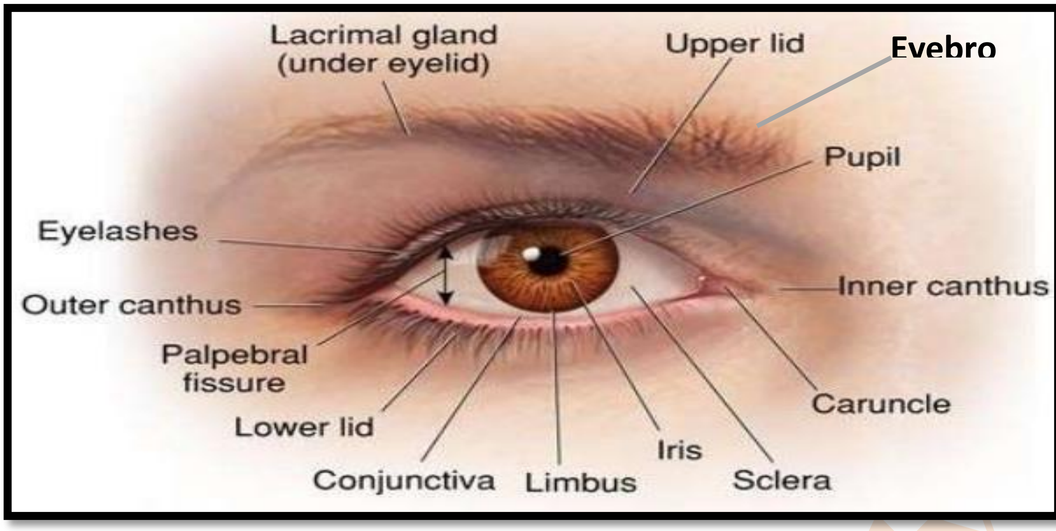


Figure .68 External structures of the eye

- The white space between open eyelids is called the palpebral fissure. When closed, the eyelids should touch. When open, the upper lid position should be between the upper margin of the iris and the upper margin of the pupil. **Eyelashes** are projections of stiff hair curving outward along the margins of the eyelids that filter dust and dirt from air entering the eye.

- The **conjunctiva is** a thin, transparent, continuous membrane that is divided into two portions: a palpebral and a bulbar portion. The palpebral conjunctiva lines the inside of the eyelids, and the bulbar conjunctiva covers most of the anterior eye, merging with the cornea at the limbus. This transparent membrane allows for inspection of underlying tissue and serves to protect the eye from foreign bodies.

- The **lacrimal apparatus** consists of glands and ducts that serve to lubricate the eye. The lacrimal gland, that is located in the upper outer corner of the orbital cavity just above the eye, produces tears. The **extraocular muscles** are the six muscles attached to the outer surface of each eyeball (Figure 5.18). These muscles control six different directions of eye movement. Four rectus muscles are responsible for straight movement, and two oblique muscles are responsible for diagonal movement.

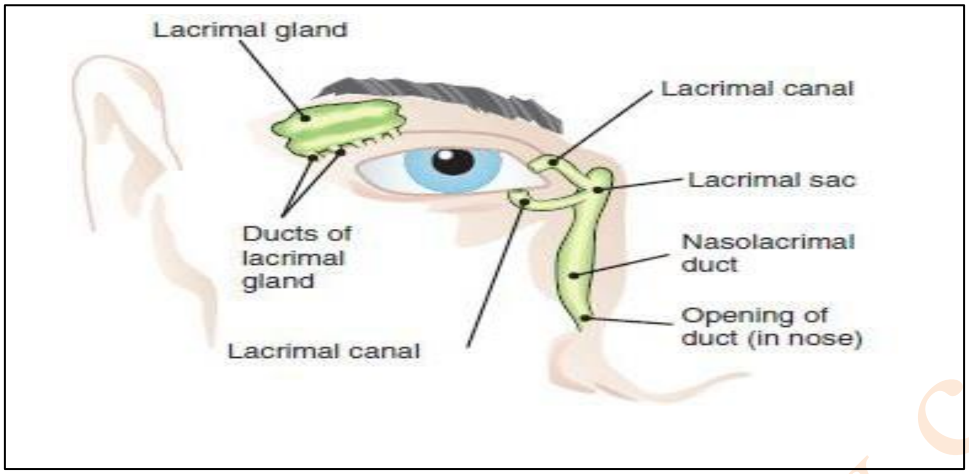


Figure 69 Lacrimal apparatus in the human eye

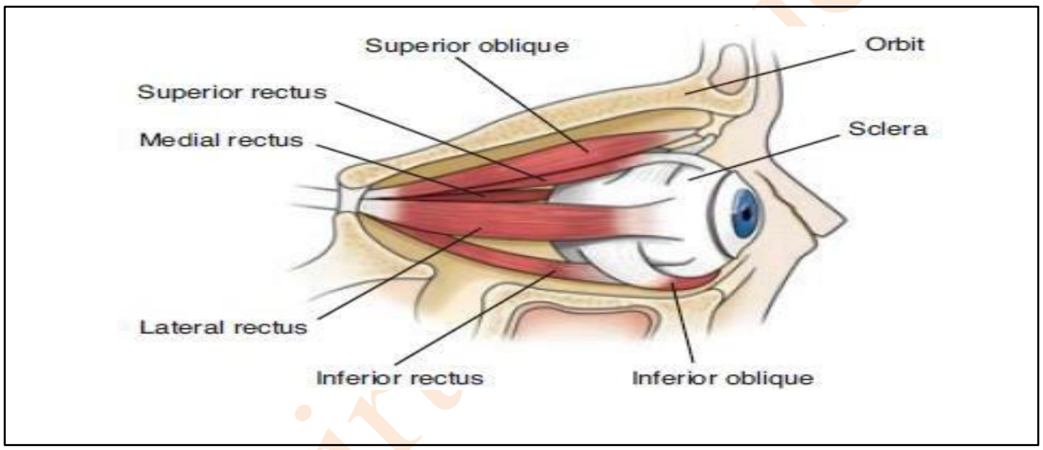


Figure 70 Extraocular muscles of the human eye.

Internal structure of the eye

- The eyeball is composed of three separate coats or layers (Figure 5.24). The external layer consists of the **sclera** and **cornea**.
- The **sclera** is a white visible portion. It is a dense, protective, white covering that physically supports the internal structures of the eye. It is continuous interiorly with the transparent cornea (the "window of the eye").

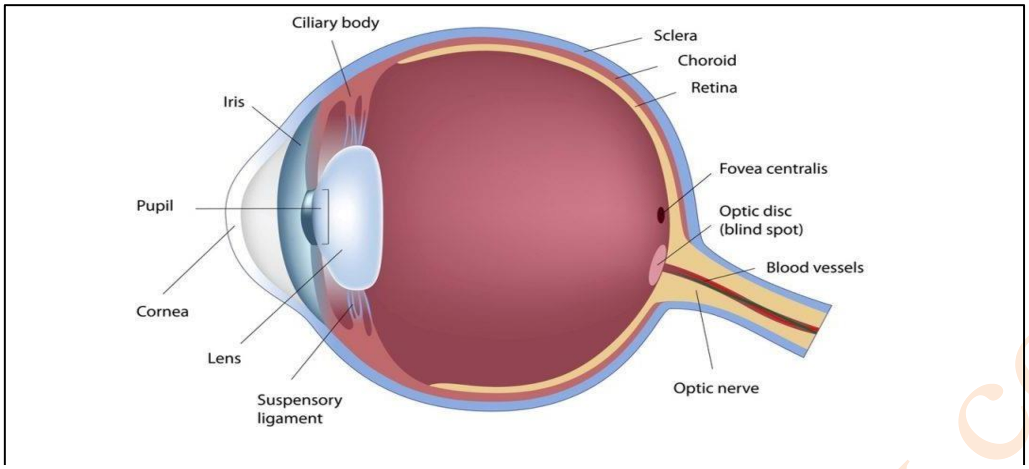


Figure.71 Anatomy of the human eye

- The **cornea** is the transparent, anterior or front part of our eye, which covers the pupil and the iris. The main function is to refract the light along with the lens. The cornea permits the entrance of light, which passes through the lens to the retina. It is well supplied with nerve endings, making it responsive to pain and touch.

- **Iris:** It is the pigmented, colored portion of the eye, visible externally. The main function of the iris is to control the diameter of the pupil according to the light source.
- **Pupil:** It is the small aperture located in the centre of the Iris. It allows light to enter and focus on the retina.

- The **lens** is a biconvex, transparent, avascular, encapsulated structure located immediately posterior to the iris. **Suspensory ligaments** attached to the **ciliary muscles** support the position of the lens. The lens functions to refract (bend) light rays onto the retina. Adjustments must be made in refraction depending on the distance of the object being viewed. The refractive ability of the lens can be changed by a change in the shape of the lens (which is controlled by the ciliary body). The lens bulges to focus on close objects and flattens to focus on far objects. The **choroid layer** contains the vascularity necessary to provide nourishment to the inner part of the eye and prevents light from reflecting internally.

- Anteriorly, it is continuous with the ciliary body and the iris. Once the light has travelled through the cornea it has to pass through the **pupil** in the center of the **iris**. The iris is the colored part of the eye, but it is not there simply to look pretty. The iris is made up of muscles that contract or relax to control the size of the pupil and to control the amount of light reaching the retina. The circular muscles run around the iris, whereas the radial muscles run across it like the spokes of a bicycle wheel. When the light is relatively dim, the radial muscles contract and the circular muscles relax and the pupil is pulled open wide (it **dilates**). When the pupil is dilated, lots of light can get into the eye that enables us to see even in relatively low light conditions. In bright light, however, the circular muscles of the iris contract and the radial muscles relax, which makes the pupil very small (it **constricts**). This reduces the amount of light that goes into the eye so that the delicate light-sensitive cells are not damaged by too much bright light (see Figure.25).

- The innermost layer, the **retina,** extends only to the ciliary body anteriorly. It receives visual stimuli and sends it to the brain. The retina consists of numerous layers of nerve cells, including the cells commonly called rods and cones. These specialized nerve cells are often referred to as "photoreceptors" because they are responsive to light. The rods are highly sensitive to light, regulate black and white vision, and function in dim light.
- The cones function in bright light and are sensitive to color. The optic disc is a cream-colored, circular area located on the retina toward the medial or nasal side of the eye. It is where the optic nerve enters the eyeball.

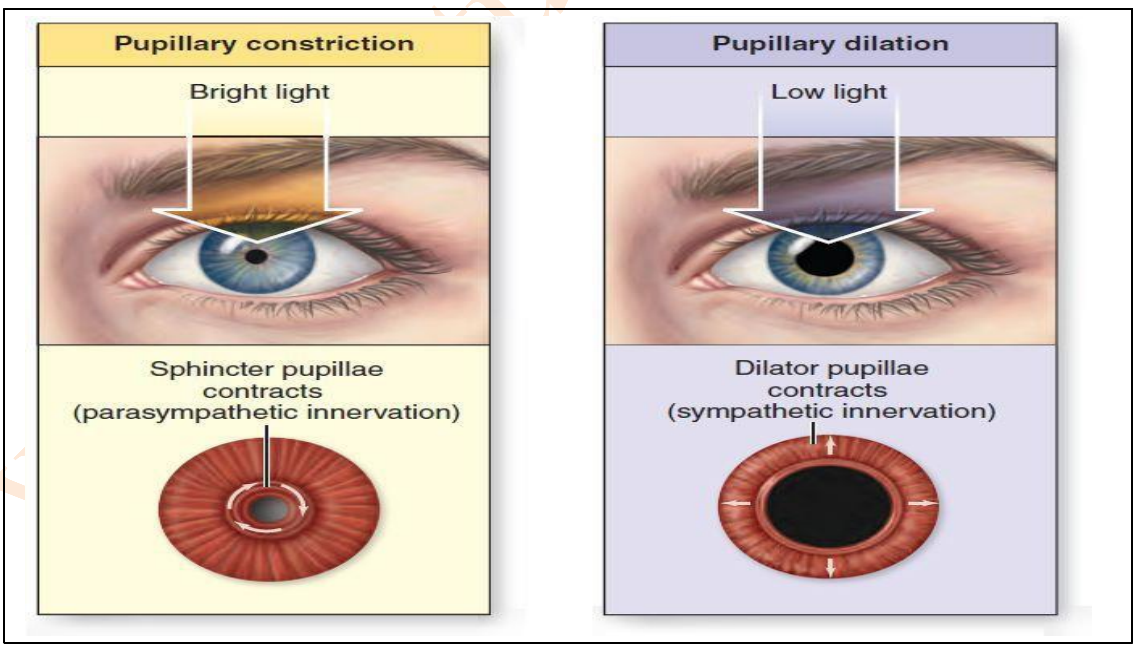


Figure.72 Figure showing the constriction and relaxation of pupil

- When an image is produced on the retina, the light-sensitive cells are stimulated. They send impulses to the brain along affector (sensory) neurons in the optic nerve. When the brain receives these messages it interprets the information and enable the person to see. At the point where your optic nerve leaves the eye there is no retina but there is a **blind spot**.

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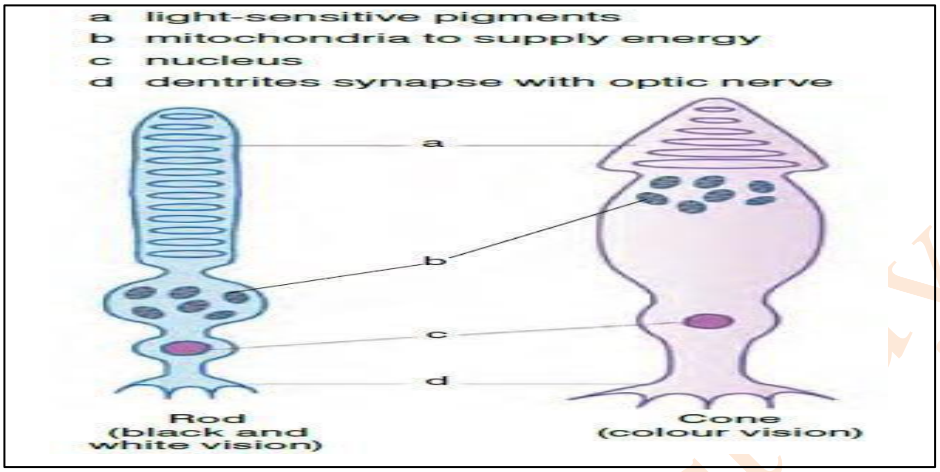

Figure 73 The rods and the cones in the retina of human

- A retinal depression known as the **fovea centralis** is located adjacent to the optic disc (blind spot) in the temporal section of the fundus. This area is surrounded by the macula, which appears darker than the rest of the fundus. The fovea centralis and macular area are highly concentrated with cones and form the area of highest visual resolution and color vision. The eyeball contains several chambers that serve to maintain structure, protect against injury, and transmit light rays. The **anterior chamber** is located between the cornea and iris, and the **posterior chamber** is the area between the iris and the lens.

- These chambers are filled with aqueous humour, a clear liquid substance produced by the ciliary body. **Aqueous humour** helps to cleanse and nourish the cornea and lens as well as maintain intraocular pressure. The aqueous humour filters out of the eye from the posterior to the anterior chamber then into the *canal of Schlemm* through a filtering site called the *trabecular meshwork.*
- Another chamber, the **vitreous chamber,** is located in the area behind the lens to the retina. It is the largest of the chambers and is filled with a clear and gelatinous vitreous humour.

The structure, function, and defects of the ear

- Ears are specialized organs for hearing. They are also concerned with the balance and position of the body. The ear is divided into three regions: **the outer ear, middle ear and inner ear**. The outer ear consists of a flap called a **pinna (auricle)**. Leading from the pinna is a tube, the **ear canal**. In a human being, this is about 2 cm long. The pinna helps to trap and funnel sound into the ear. This is particularly important in animals, which can move the pinna to pick up sounds with longer ears than humans. At the end of the ear canal that closes the tube is a sheet of very thin membrane called the **eardrum** or **tympanum**
- The pinna, ear canal and the eardrum form the outer part of the human ear. At the entrance of the ear canal are a number of small hairs. These filter out dust particles from the air entering the ear canal. The cells lining the ear canal produce waxy material which traps dust and germs, and lubricates the eardrum.
- Behind the eardrum is a cavity filled with air. This cavity contains three tiny bones and forms the middle ear. The three tiny bones– called the **malleus** (**hammer**), the **incus** (**anvil**) and the **stapes** (**stirrup**) (see Figure 5.28) are the smallest bones in the human body. They form joints with one another, with the malleus attached to the eardrum and the stapes to the oval window. The cavity of the middle ear is connected to the throat by a tube called the Eustachian tube. This is usually closed but when the pressure in the middle ear increases, the tube opens until the air pressure in the middle ear is equal to that in the throat and therefore to the atmosphere. At one end of the middle ear, opposite to the eardrum, there are two openings: one of them is oval in shape and hence it is called the oval window. The other is round and is called the round window. The openings are covered by very thin membranes.
- The inner ear consists of a cavity filled with a fluid, two sac-like structures called the sacculus and utriculus, three semicircular canals and a coiled tube called the cochlea. The sacculus,utriculuss and semicircular canals and the cochlea are filled with a liquid. The sacculus, utriculuss and semicircular canals are part of the balancing system. A cross section of the cochlea reveals that it is made up of three tubes in one (Figure 5.29). The floor of the middle tube is lined with sensory cells linked to affector neurons. These nerve fibers join to form the auditory nerve which leads to the brain.

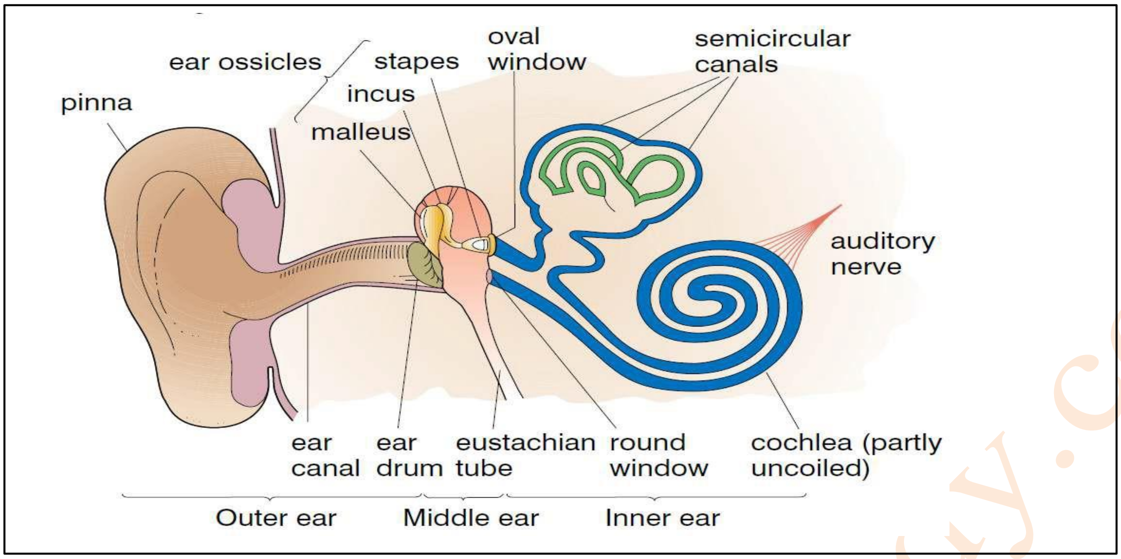

Figure 74 Structure of human ear

The mechanism of hearing

- The pinna collects sound waves and directs them to the eardrum through the ear canal. When sound waves hit the eardrum, it vibrates. This magnifies the vibrations which are then transmitted through the ear ossicles (the small bones) to the oval window. The three bony ossicles are called the malleus, incus, and stapes. These three ossicles connect the tympanic membrane to the inner ear allowing for the transmission of sound waves. The ear ossicles also amplify the vibrations (make them bigger).
- The vibrations of the stapes make the membrane at the vibrations of the fluid cause the hair-like sensory cells to move. These movements in turn cause production of nerve impulses in the affector nerve fibres. These impulses are transmitted to the brain for interpretation.
- The human ear is sensitive to vibrations ranging from those of a very low note of about 20 vibrations per second, to a very high note of about 30 000 vibrations per second. High notes are detected in the first part of the cochlea and low notes are recorded in the last part of the cochlea.

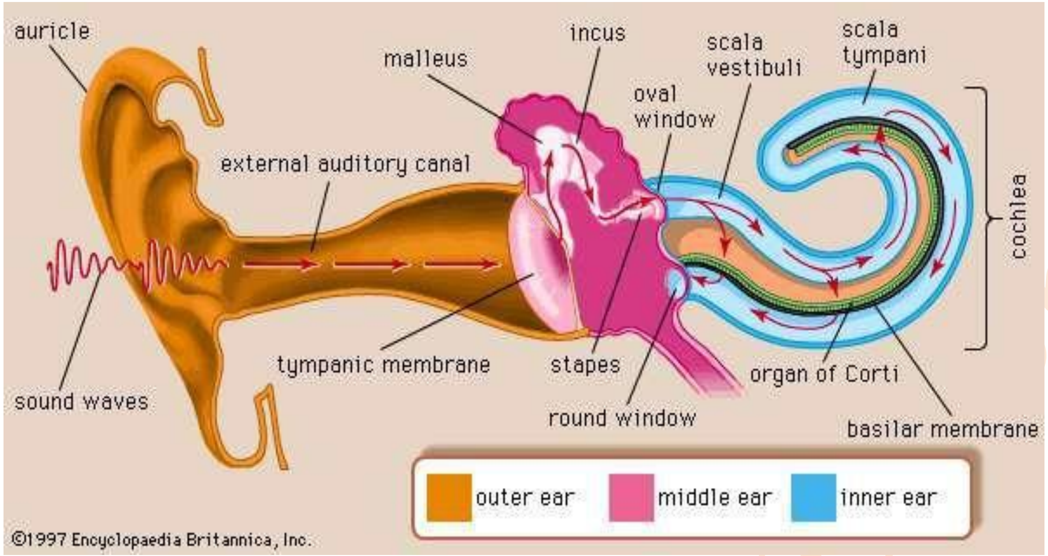

Figure.75 hearing processes

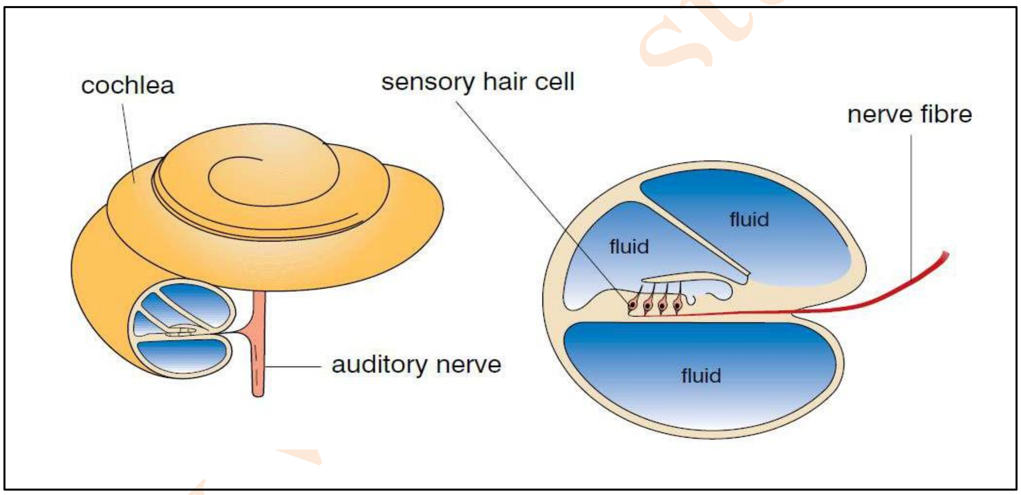

Figure .76 The cross section of a cochlea

The sense of balance and movement

- The semicircular canals in the inner ear are concerned with the detection of motion. The swellings on each of the semicircular canals (the ampullae) contain sensory cells attached to the sensory nerve endings. The **sensory cells** have hairs which are enclosed in a core of jelly substance called a cupula (Figure26). Whenever the body or the head moves, the semicircular canals move with the head. The fluid in the semicircular canals also starts to move but it lags behind in its motion, so it apparently moves in the opposite direction. The moving fluid causes the cupula to tilt, thus pressing the hairs of the sensory cells. The pressing of the sensory hairs creates nerve impulses in the sensory nerve endings. The nerve impulses are transmitted to the brain. The brain then interprets the direction and speed of the motion of the body or head.

- The semicircular canals are all at right angles to each other, so each one is sensitive to movement in a different plane. One canal responds to nodding, one to shaking and one to head tilting. Fast spinning of the body followed by instant interruption causes dizziness. This is because the fluid in the semicircular canals keeps on moving after the spinning has stopped.

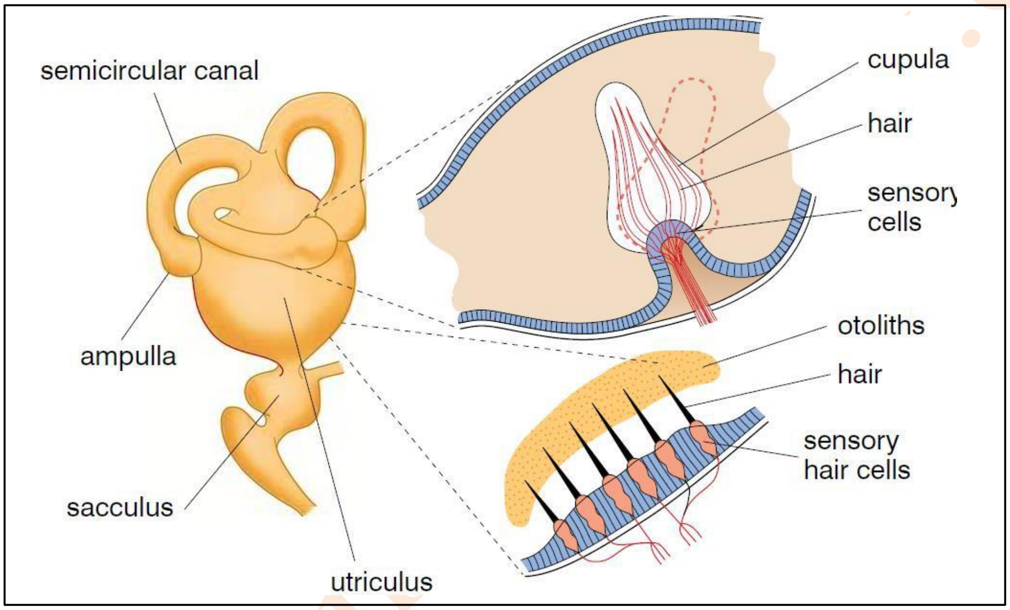

Figure.77 The balance organs of the ear

Review questions

Provide answers for the following questions

1. Explain some of the eye disorders with their possible corrections.

Answer:

- **Short sight**: A short-sighted person can focus clearly on things that are close to them but has much more difficulty with objects in the distance, which appear blurred. This may be as a result of a lens that is effectively 'too strong'. It is too curved even when the ciliary muscles are fully relaxed and so the light from distant objects is focused in front of the retina, making the image that actually lands on the retina spread out again and blurry. Another cause of short sightedness is when the lens is normal but the eyeball is particularly long and again this means light is focused in front of the retina. This problem can be corrected using concave (diverging) lenses that spread the light out more before it gets into your eye. This means that the thicker lens can bring the rays of light into perfect focus on the retina, or there is room in the long eyeball for the light rays to be focused on the correct point.

- **Long sight**: A long-sighted person can focus clearly on things that are at a distance but has much more difficulty with objects close to them, which appear blurred. This may be as a result of a lens that is effectively 'too weak'. It is too flat even when the ciliary muscles are fully contracted and so the light from close objects is focused behind the retina. Consequently, the image that actually lands on the retina spreads out and becomes blurry. Another cause of long sightedness is that when the lens is normal although the eyeball is particularly short and again this means light is focused behind the retina. This problem can be corrected using convex (converging) lenses that bring the light rays together more before they reach your eye. Now the thinner lens can bring the rays of light into perfect focus on the retina – or the short eyeball becomes the right length for the light rays to be focused on the correct point.
- **Astigmatism**: Astigmatism is another fairly common eye defect. The shape of the eye is irregular, more egg-shaped than round, so the cornea is curved asymmetrically and this affects the way light is focused on your retina. In some people, it is the lens rather than the eyeball itself that is an unusual shape, but the end result is the same. Astigmatism can also be corrected by using lenses, but the situation is more complex than for long and short sight.

2. Briefly explain how you can use your ears to hear a sound.

Answer

- Hearing depends on a series of complex steps that change sound waves in the air into electrical signals. Our auditory nerve then carries these signals to the brain.
- Sound waves enter the outer ear and travel through a narrow passageway called the ear canal, which leads to the eardrum.
- The eardrum vibrates from the incoming sound waves and sends these vibrations to three tiny bones in the middle ear. These bones are called the malleus, incus, and stapes.

- The bones in the middle ear amplify, or increase the sound vibrations and send them to the cochlea, a snail-shaped structure filled with fluid, in the inner ear. An elastic partition runs from the beginning to the end of the cochlea, splitting it into an upper and lower part.
- This partition is called the basilar membrane because it serves as the base, on which key hearing structures are situated. Once the vibrations cause the fluid inside the cochlea to ripple, a traveling wave forms along the basilar membrane.
- Hair cells, sensory cells situated on top of the basilar membrane ride the wave. Hair cells near the wide end of the snail-shaped cochlea detect higher-pitched sounds, such as an infant crying. Those closer to the center detect lower pitched sounds, such as a large dog barking.
- As the hair cells move up and down, microscopic hair-like projections (known as stereocilia) that perch on the top of the hair cells bump against an overlying structure and bend. Bending causes pore-like channels, which are at the tips of the stereocilia, to open up. When that happens, chemicals rush into the cells, creating an electrical signal.
- The auditory nerve carries this electrical signal to the brain, which turns it into a sound that we recognize and understand.

3. Describe the role of some of the pigments that are found in your skin.

Answer:

- The colour of skin is influenced by a number of pigments, including melanin, carotene, and hemoglobin. Melanin is produced by cells called melanocytes, which are found scattered throughout the stratum basale of the epidermis. The melanin is transferred into the keratinocytes via a cellular organelle called a melanosome**.** The relative coloration of the skin depends on the amount of melanin produced by melanocytes in the stratum basale and taken up by keratinocytes.
- Melanin occurs in two primary forms. Eumelanin exists as black and brown, whereas pheomelanin provides a red color. Dark-skinned individuals produce more melanin than those with pale skin. Exposure to the ultraviolet (UV) rays of the sun causes melanin to be manufactured and built up in keratinocytes, as the sun exposure stimulates keratinocytes to secrete chemicals that stimulate melanocytes. The accumulation of melanin in keratinocytes results in the darkening of the skin. This increased melanin accumulation protects the DNA of epidermal cells from UV ray damage and the breakdown of folic acid, a nutrient necessary for our health and well-being. In contrast, too much melanin can interfere with the production of vitamin D, an important nutrient involved in

calcium absorption. Thus, the amount of melanin present in our skin is dependent on the balance between available sunlight and folic acid destruction, and protection from UV radiation and vitamin D production.

5.3 The endocrine system

5.3.1 The endocrine glands

- The endocrine system interacts with the nervous system to coordinate and integrate body activities by means of **hormones**. Endocrine tissues and organs secrete **hormone** into the body fluids (mainly blood and lymph) directly using diffusion. Hormones act as chemical messages that are produced in one part of the body, but they have an effect somewhere entirely different. Glands are structures which produce hormones and other useful substances.
- The **endocrine glands** that produce hormones have no ducts, so they are sometimes known as ductless glands. They secrete hormones directly into the blood, and the chemicals are carried from glands to the body parts throughout the bloodstream.
- Most hormones only affect certain tissues or organs – their target organ and the hormone is picked up from the blood by receptors in the cell membranes. They can act very rapidly, but often their effects are slower and longer lasting than the results of nervous control.

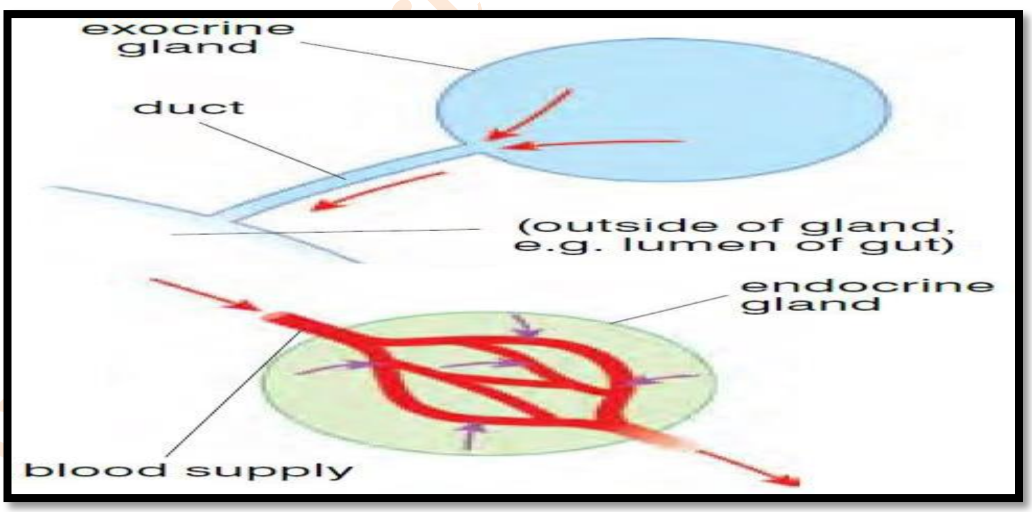

Figure 78 Figure showing differences between exocrine gland and endocrine gland

Action of protein hormones

- A protein hormone is transported in the blood or lymph, without a transporter. When the hormone arrives at the target cell, it binds with a specific receptor embedded in the cell membrane of target cell. The binding activates a series of chemical reactions ("cascade reactions") in the cytoplasm of target cell. The product of these reactions is a substance known as the "secondary messenger" (usually cyclic adenosine monophosphate or cAMP), which acts on behalf of the protein hormone, causes a potent effect in the target cell (usually within the cytoplasm). Since protein hormones never diffuse to the DNA of target cells, no new proteins or enzymes are made at the end.

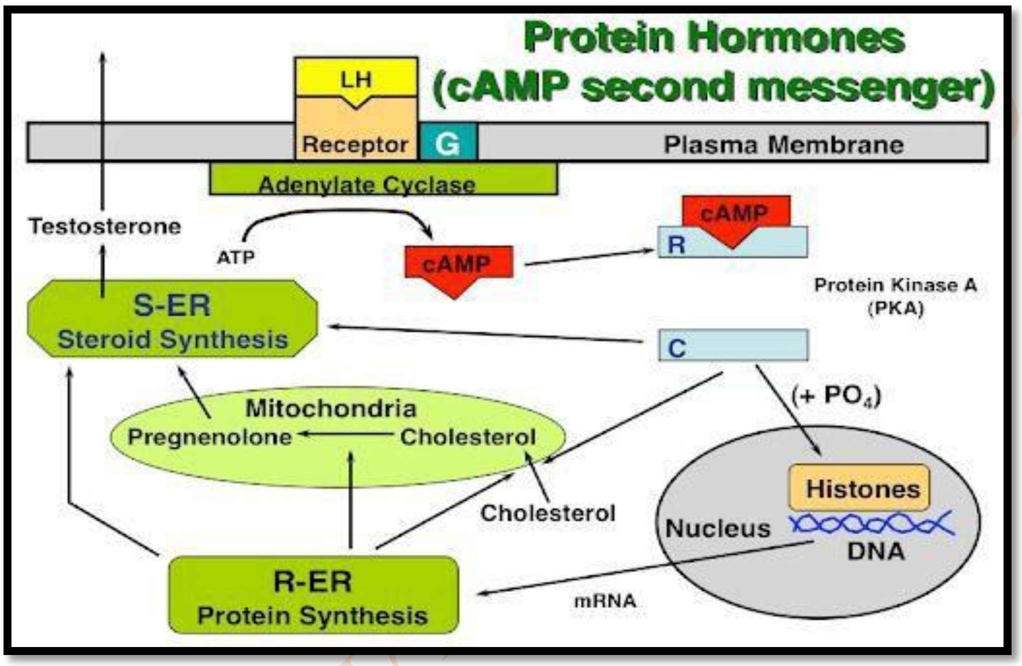

Figure .79 Mechanism of Protein Hormone action.

Actions of steroid hormones

- Steroid hormones bind to a protein transporter during the transport in blood of lymph. When they have arrived at the target cells, the protein transporter (being fat-insoluble) is repelled by the cell membrane, whereas, the steroid hormone (being fat-soluble) diffuses into the cytoplasm of target cell. Steroid hormone also diffuses across the nuclear envelope and enters into the nucleus of target cell. They can bind to a specific receptor located on a particular gene of target cell's DNA.

- This binding alters the genetic information within that gene, resulting in a new messenger RNA (mRNA) to be produced after transcription. This new mRNA sill be translated into a new protein (or enzyme) in the cytoplasm of target cell. The new protein or enzyme causes a specific effect to occur within the target cells.

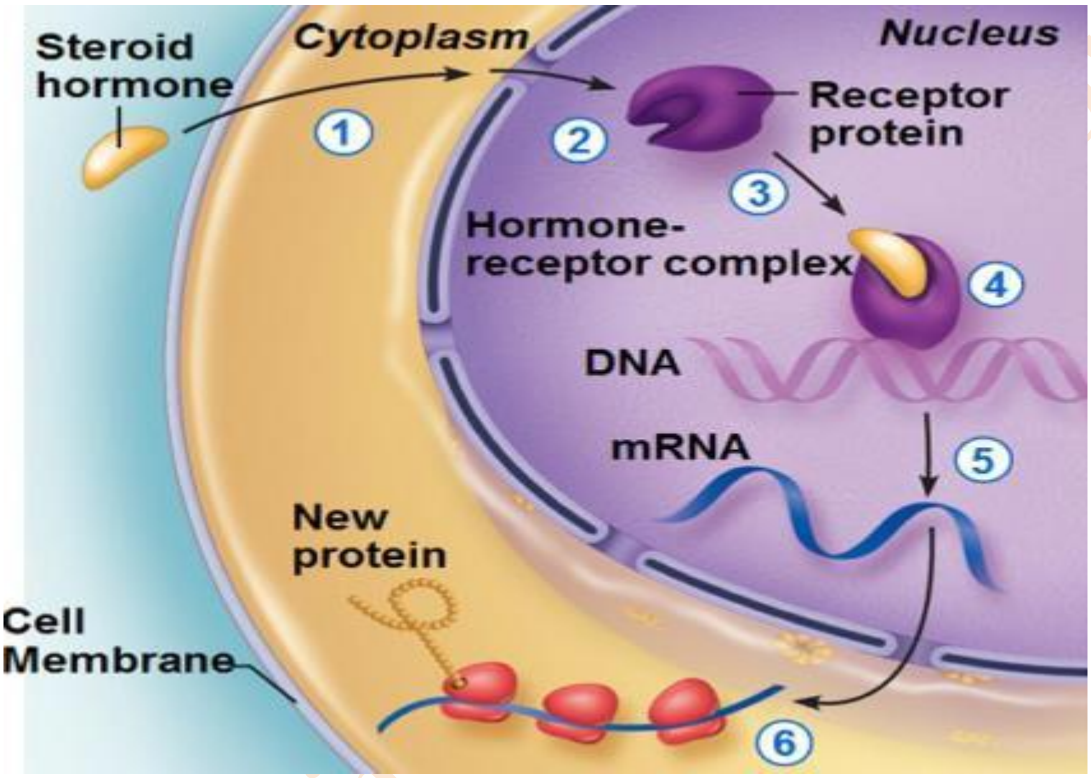

Figure 80 Mechanism of the interaction between a steroid hormone and its receptor

The major endocrine glands

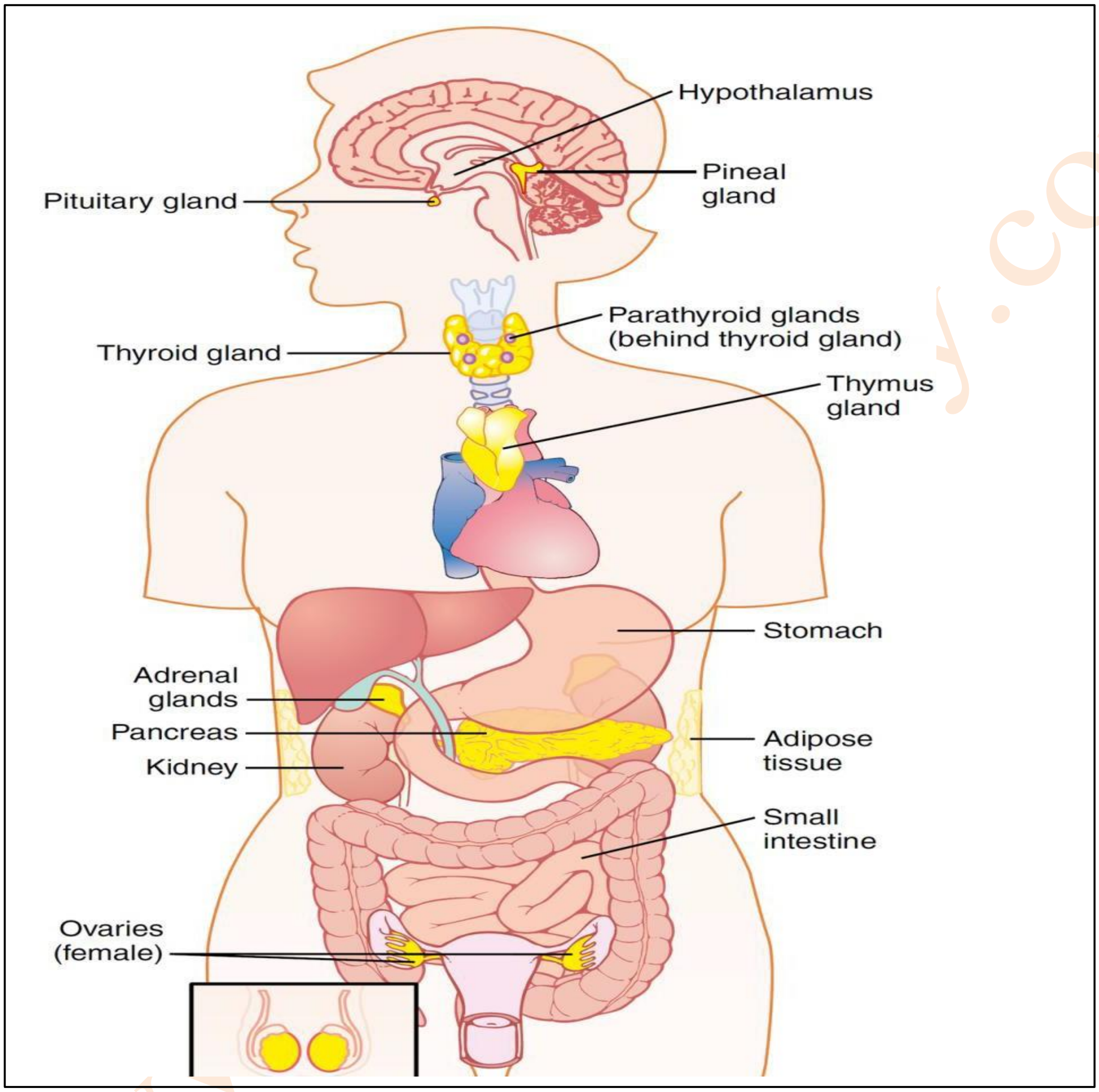

Figure.81 The location of endocrine glands in human body

5.3.1 Hypothalamus

- The hypothalamus connects the nervous system to the endocrine system. It receives and processes signals from other brain regions and pathways where the hypothalamus translates them into hormones that are the chemical messengers of the endocrine system. These hormones flow to the pituitary gland, by the infundibulum.

Some hormones are stored in the pituitary stores for later release; others spur it to secrete its own hormones. The hormones are released by the pituitary gland whereas the hypothalamus controls the other endocrine glands and regulate all the major internal functions.

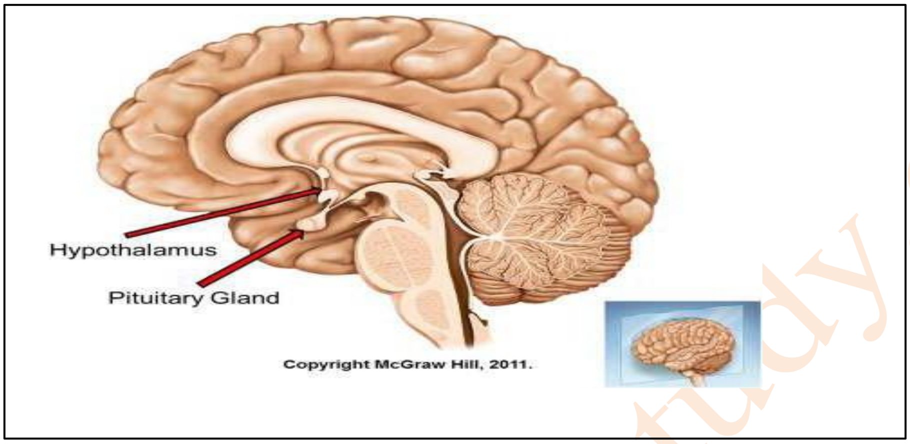

Figure .82 Hypothalamus and pituitary gland

5.3.2 The pituitary gland

- The pituitary gland, found in the brain and about the size of a pea, is sometimes described as the controller of the endocrine orchestra (master gland). The hormones made in this tiny gland control the secretion of many other hormones. Because of its position in the brain, it is also involved in the co-ordination between the nervous and hormonal systems of control. It is divided into **anterior lobe** (**adenohypophysis**) and **posterior lobe** (**neurohypophysis**). Anterior lobe is about 3 times larger than the posterior lobe.
- **Anterior pituitary** is under hormonal control by the hypothalamus where blood vessels transport "releasing hormones" to the anterior lobe. Anterior pituitary contains 5 types of glandular cells that produce different types of hormones.
- **Posterior pituitary** is under nervous control by the hypothalamus where nerve fibers innervate the posterior lobe for its release of hormones (posterior pituitary does not produce hormones; it only release hormones made by the hypothalamus).

5.3.3 Thyroid gland

- The thyroid gland is a small, butterfly-shaped gland located inferior to the larynx (voice box) and attached to the trachea. It is divided into two lateral lobes. Thyroid follicles utilize iodine and synthesize **thyroglobulin (TGB)** to be stored in the colloids. Upon stimulation of TSH, TGB is converted into two hormones: **Triiodothyronine (T3)** and **Thyroxine (T4)** to promote normal metabolism. Hypo secretion causes hypothyroidism (goiter, cretinism and myxedema) and hyper secretion causes hyperthyroidism that result in Graves' disease. Thyroid gland also secretes Calcitonin to lower blood calcium and phosphate levels and regulate digestive hormones. Both hypo secretion and hyper secretion would affect the normal balances of calcium and phosphate.

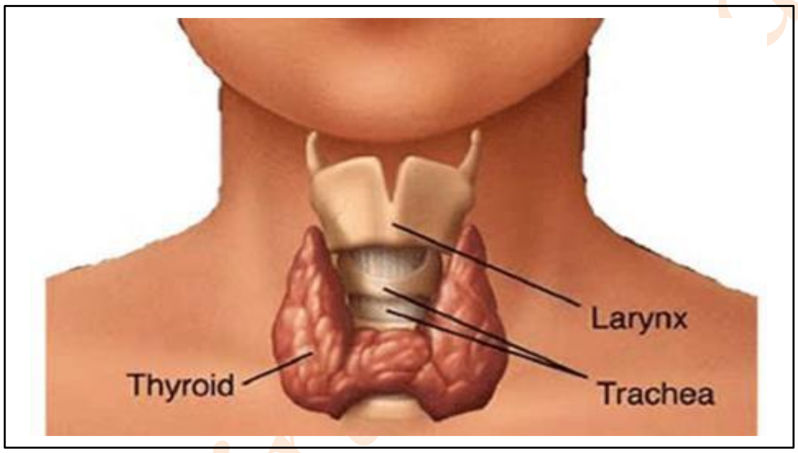

Figure.83 The thyroid gland

5.3.4 Parathyroid glands

- Four oval-shaped glands are embedded in the posterior surface of the thyroid gland. Each parathyroid gland is normally about the size of a grain of rice (about 3-5 millimeters in diameter and 30 - 60 milligrams in weight). Parathyroid glands release **parathyroid hormone (PTH)** which controls the calcium levels in the blood stream. Other areas of the body, especially the bones, kidneys and small intestine, respond to PTH by increasing the calcium levels in the blood. Calcium is very important for our bodies, especially for muscle and nerve function. Hypo secretion causes tetany, and hyper secretion causes osteitis fibrosa cystica.

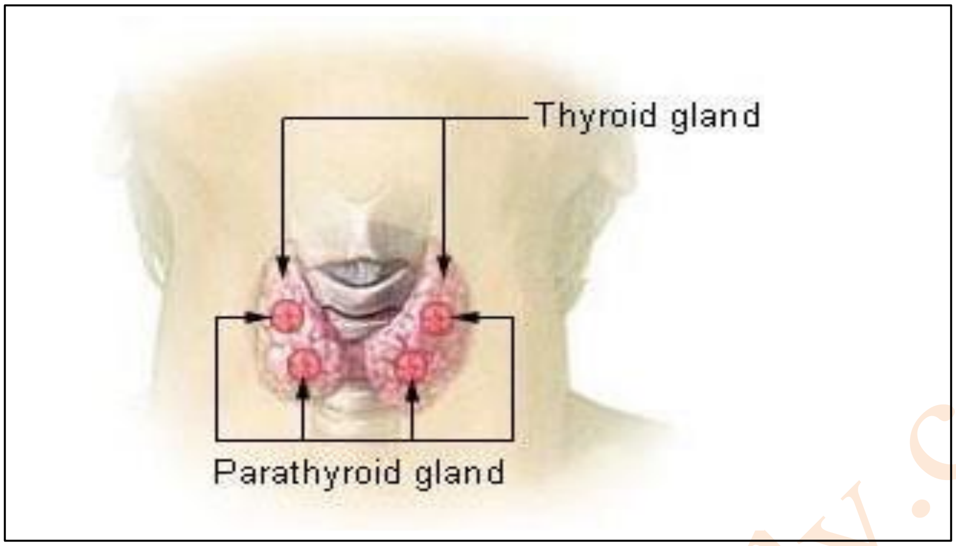

Figure.84 Parathyroid gland

5.3.5 Adrenal gland

- Adrenal glands, also known as suprarenal glands, are small, triangular-shaped glands located on the top of both kidneys. Adrenal glands are composed of two parts. The cortex and the medulla-which are responsible for the production of different hormones.
- **Adrenal Cortex:** is the outer portion of the adrenal gland which is attached to the superior surface of the kidney. It is divided into 3 regions, from outside to inside: **Zona glomerulosa**, **Zona fasciculate** and **Zona reticularis**. Adrenal cortex secretes over 30 steroid-based substances and several steroid hormones, all crucial for normal homeostasis.

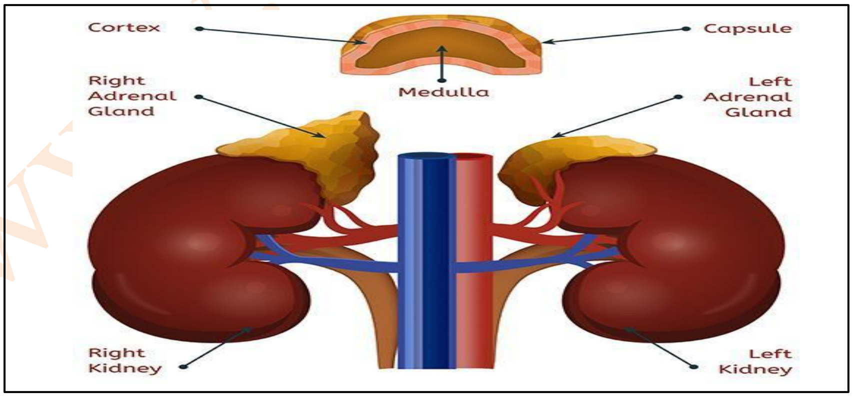

Figure.85 Adrenal gland

- **Adrenal Medulla**: This is the inner portion of the adrenal gland. It is made of modified nerve tissue that is under direct regulation of sympathetic nerves of the autonomic nervous system. Contains glandular cells called chromaffin cells which secrete 2 closely related hormones- **Epinephrine (adrenaline)** and **Norepinephrine (noradrenaline).**
- Adrenaline is a well-known hormone produced by your adrenal glands. It is the hormone of 'fight or flight'. If you are stressed, angry, excited or frightened your adrenal glands will secrete lots of adrenalin. Carried rapidly round in your blood, adrenalin affects many different organs from the pupils of your eyes (it dilates them) to the beating of your heart (it speeds it up). Adrenalin basically prepares your body for action, so that you can run fast to escape or fight successfully if you need to.

5.3.6 Pancreas

- Pancreas is a small pink organ found below the stomach. It is both exocrine and endocrine in physiology. In its exocrine aspect, 99% of its mass is composed of cells called acini which secrete digestive enzymes and fluids into the small intestine through the pancreatic ducts. In its endocrine aspect, 1% of its mass is little groups of cells called **islets of langerhans (or pancreatic islets)** secrete hormones to regulate blood glucose level. In each pancreatic islet, **alpha cells (α cells)** secrete **glucagons** to raise blood glucose level, **beta cells (β cells)** secrete **insulin** to lower blood glucose level. Hypo secretion causes **diabetes mellitus** and hyper secretion causes **hyperinsulinism**. **Delta cells (δ cells)** secrete **somatization** or **growth hormone inhibiting hormone (GHIH)** which helps regulate carbohydrate metabolism by inhibiting the secretion of glucagon.

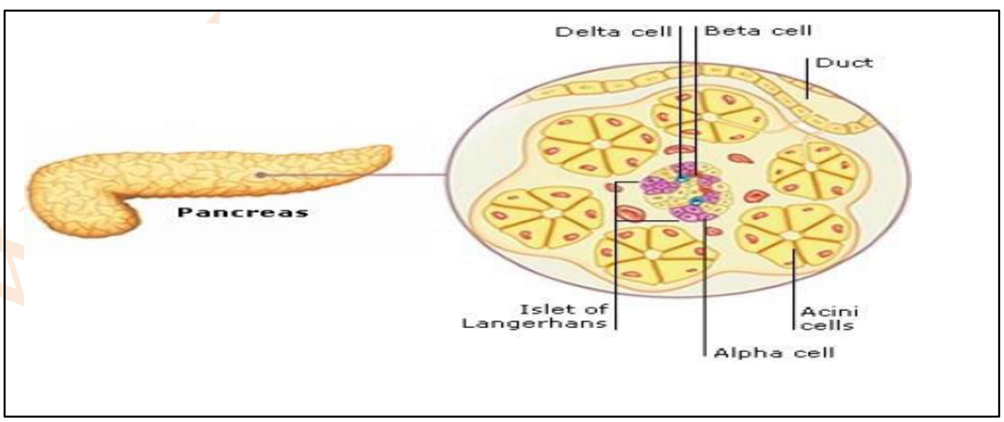

Figure.86 Islets of Langerhans in pancreas

5.3.7 The gonads: Ovary and testis

- The gonads are the endocrine glands which produce some of the sex hormones. These are the testes in boys and ovaries in girls who become active at the time of puberty. When the big physical changes take place, boys and girls look very different which the body takes its adult form. The changes come about in response to hormones released by the brain and by the gonads themselves.

The role of the ovaries

- The female gonads are the ovaries, two walnut-sized organs found low in the abdomen in either side of the uterus. Ovaries produce eggs and hormones. Girls often go into puberty slightly earlier than boys. Between the ages of 8–14 most girls begin the changes which will take their bodies into sexual maturity. As with boys, the time and speed of puberty varies greatly from one person to another. Although it is different for everyone, and everyone ends up a slightly different shape and size – the basic changes which take place are the same.

- Puberty in girls is controlled by hormones from the pituitary gland in the brain and from the gonads themselves – in this case the ovaries. FSH from the brain stimulates the ovaries to become active and start producing the female sex hormone **oestrogen**. As the levels of oestrogen rise and the body responds, all kinds of changes are triggered and the female secondary sexual characteristics develop.

The role of the testes

- Testis is the male sex organ that also serves as an endocrine gland. It contains interstital cells (or leydig's cells) that secrete **testosterone** to develop male secondary sexual characteristics. Puberty in boys usually begins somewhere between the ages of 9 and 15 years old. It may happen very rapidly, or it may take place much more slowly over a number of years. Two people do not experience puberty in exactly the same way.
- The chemical changes which trigger puberty are unseen, which is another important example of hormonal co-ordination and control. The pituitary gland in the brain starts to produce increasing amounts of **FSH**. This in turn stimulates the male gonads or testes to begin developing and producing the male sex hormone **testosterone**. The rising levels of testosterone trigger the many changes which affect the body during puberty, causing the development of the secondary sexual characteristics.

5.3.8 Pineal gland

- Pineal gland is pine cone shaped located deep in the cerebrum. It secrets **melatonin** to regulate circadian rhythms which are necessary to keep track of day or night cycles, sleep/wake rhythm, menstrual and ovarian cycles.

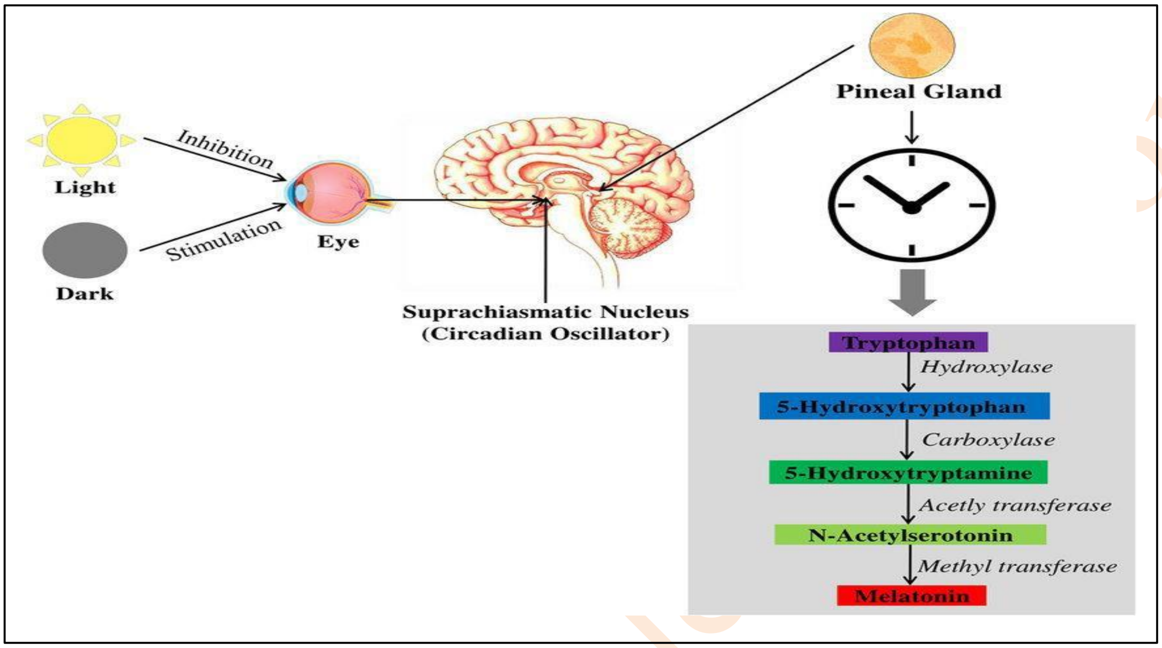

Figure.87 Pineal gland

5.3.9 Thymus gland

- A thymus gland is a diminishing gland (over time) located between the lungs. It secretes a group of hormones, such as **thymosin**, to affect the production and maturation of lymphocytes in body defenses.

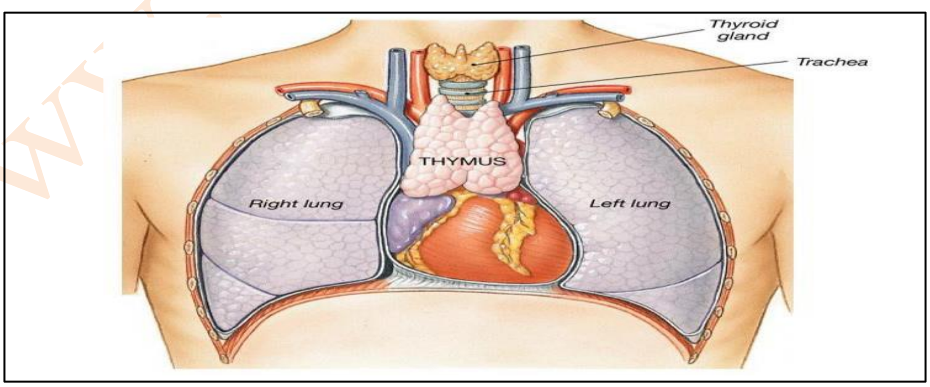

Figure .88 Thymus gland

5.3.10 Exocrine glands

- Many glands in the body are **exocrine glands**. These glands are glands that secrete substances onto an epithelial surface by way of a duct. This means that they have a special tube or duct that carries the secretion from the gland where it is made to the place where it is needed. Exocrine glands, such as salivary glands, and sebaceous glands, secrete chemical substances through ducts into an open space. Sweat glands, salivary glands, ceruminous, lacrimal, sebaceous, prostate and mucous as well as mammary glands are all examples of **exocrine glands**.

- The liver and pancreas are both exocrine and endocrine glands; they are exocrine glands because they secrete products such as bile and pancreatic juice into the gastrointestinal tract through a series of ducts, and endocrine because they secrete other substances directly into the bloodstream.

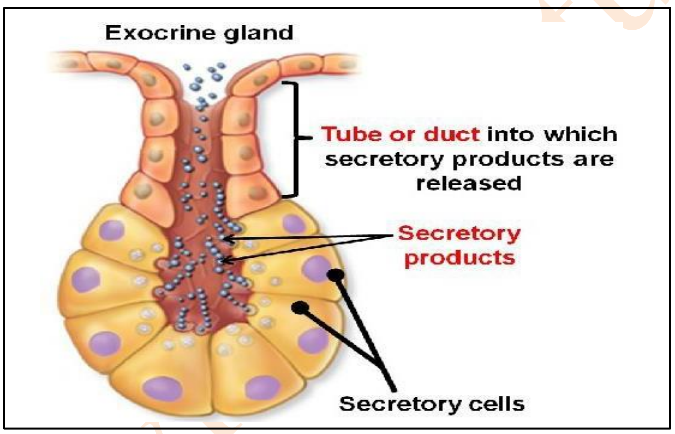

Figure.89 Anatomy of an Exocrine (duct) gland

Review questions

Provide the correct answer for the following questions

1. Compare and contrast endocrine and exocrine glands.

Answer:

- Both endocrine and exocrine glands secrete hormones for different purposes. Endocrine glands secrete hormones and transport via blood vessels due to its ductless whereas exocrine glands secrete hormones and transport via there ducts.

2. Describe several main differences of communication methods used by the endocrine system and the nervous system.

Answer

- The body coordinates its functions through the two major types of communication: neural and endocrine. Neural communication includes both electrical and chemical signaling between neurons and the target cells. Endocrine communication involves chemical signaling via the release of hormones which travel through the bloodstream, where they elicit a response in the target cells. Endocrine glands are ductless glands that secrete hormones. Many organs of the body with other functions—such as the heart, stomach, and kidneys—also have endocrine activity.

3. Compare and contrast the anatomical relationship of the anterior and posterior lobes of the pituitary gland and the hypothalamus.

Answer

- The hypothalamus–pituitary complex is located in the diencephalon of the brain. The hypothalamus and the pituitary gland are connected by a structure called the infundibulum, which contains vasculature and nerve axons. The pituitary gland is divided into two distinct structures with different embryonic origins. The posterior lobe houses the axon terminals of hypothalamic neurons. It stores and releases two hypothalamic hormones: oxytocin and antidiuretic hormone (ADH) into the bloodstream. The anterior lobe is connected to the hypothalamus by vasculature in the infundibulum and produces and secretes six hormones. Their secretion is regulated, however, by releasing and inhibiting hormones from the hypothalamus. The six anterior pituitary hormones are: growth hormone (GH), thyroid-stimulating hormone (TSH), adrenocorticotropic hormone (ACTH), follicle-stimulating hormone (FSH), luteinizing hormone (LH), and prolactin (PRL).

5.4 Homeostasis in the human body

The structure and function of the human kidney

- The kidneys are a pair of bean-shaped organs just above the waist. They are important organs with many functions in your body, including, producing hormones, absorbing minerals, and filtering blood and producing urine. Internally, the kidney has three regions: an outer cortex, a medulla in the middle, and the renal pelvis, which is the expanded end of the ureter. The renal cortex contains the nephrons, which is the functional unit of the kidney. The renal pelvis he urine and leads to the ureter on the outside of the kidney. The ureters are urine- bearing tubes that exit the kidney and empty into the urinary bladder.

- Blood flows into the kidney along the renal artery. The blood is filtered, so fluid containing water, salt, urea, glucose and many other substances is forced out into the kidney tubules. Then everything the body needs is taken back (reabsorbed), including all of the sugar and the mineral ions needed by the body.
- The amount of water reabsorbed depends on the needs of the body. The waste product urea and excess ions and unwanted water of the body are released as urine. Each kidney has a very rich blood supply and is made up of millions of tiny microscopic tubules (nephrons) where all the filtering and reabsorption takes place.

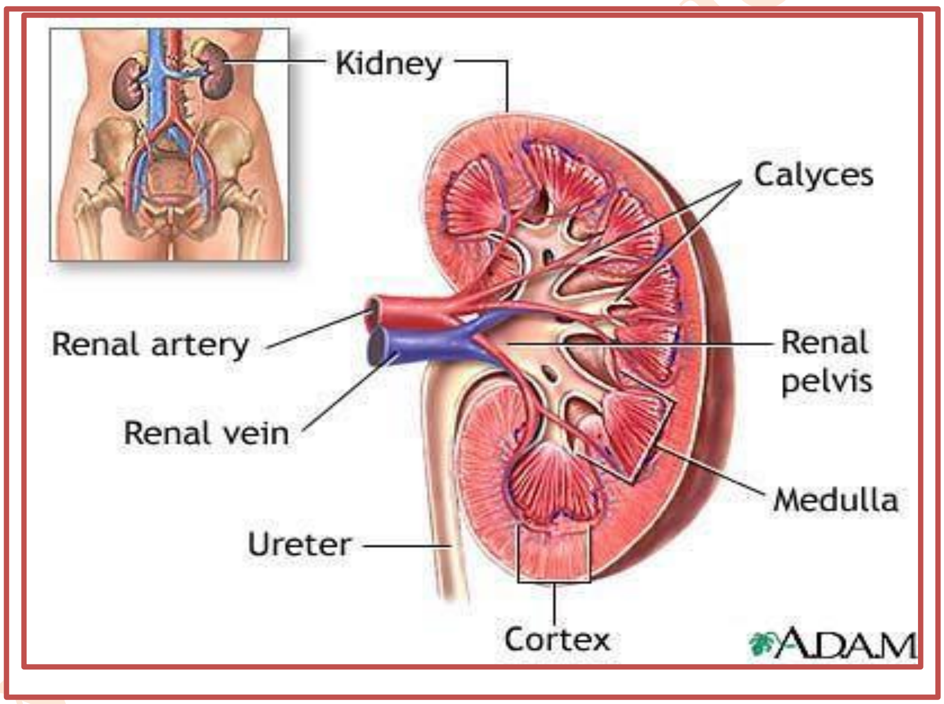

Figure .90 The anatomy of human kidneys

- The roles of the different areas of a single kidney tubule in the production of urine are described below:
- **Bowman's capsule** is the site of the ultrafiltration of the blood. The blood vessel feeding into the capsule is wider than the vessel leaving the capsule, which means the blood in the capillaries is under a lot of pressure. Several layers of cells, the wall of the blood

capillaries and the wall of the capsule act as a filter and the blood cells and the large blood proteins cannot leave the blood vessels as they are too big to fit through the gaps. However, water, salt, glucose, urea and many other substances are forced out into the start of the tubule. In fact, the concentration of substances in the liquid in the capsule is the same as that in the blood itself. This process is known as ultrafiltration – filtration on a very small scale.

- **Glomerulus:** This is the knot of blood vessels in the Bowman's capsule where the pressure builds up so that ultrafiltration occurs. The volume of the blood leaving the glomerulus is about 15% less than the blood coming in which is a measure of the liquid which has moved into the capsule as a result of ultrafiltration.

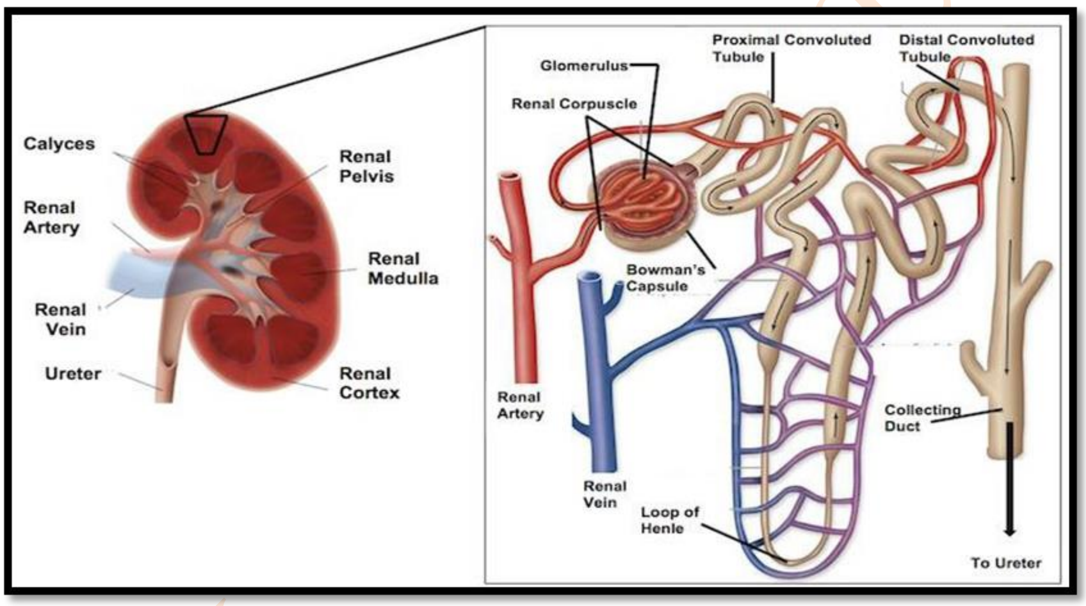

Figure .91 The kidney filters the blood and removes waste materials.

• **First coiled (convoluted) tubule:** This is the liquid which enters this first tubule is known as the glomerular filtrate. The first tubule is where much of the reabsorption takes place. All of the glucose is actively taken back into the blood along with around 67% of the sodium ions and around 80% of the water. It has many microvilli to increase the surface area for absorption.

• **Loop of Henlé:** is part of a kidney where the urine is concentrated and more water is conserved.

• **Second coiled (convoluted) tubule:** is part of a kidney where the main water balancing is done. If the body is short of water, more is reabsorbed into the blood in this tubule under the influence of the anti-diuretic hormone or ADH. (Diuresis means passing urine, so anti-diuresis means preventing or reducing urine flow.) Also ammonium ions and some drugs (if they have been taken into the body) are secreted from the blood into this tubule to get rid of them. By the end of this second coiled tubule all of the salt which is needed by your body has been reabsorbed, leaving the excess in the filtrate along with most of the urea.

• **Collecting duct:** is also part of a kidney where the liquid (essentially urine) is collected. It contains about 1% of the original water, with no glucose at all. The level of salt in the urine will depend on the amount of salt in your diet and the water content of the urine. There is also a much higher concentration of urea (about 60 times more) in the urine than in the blood. But, if your body badly needs more water, more may be reabsorbed along the collecting duct again under the influence of ADH – until the urine passes into the pyramid of the kidney and on into your bladder.

- Urine is formed constantly in your kidneys as it drips down to collect in your bladder. The bladder is a muscular sac which can hold between 600 and 800 cm3 urine, although we usually empty it when it contains only 150–300 cm3.
- The amount of water lost from the kidney in the urine is controlled by a sensitive feedback mechanism involving the hormone ADH. If the water content of the blood is too low (so the salt concentration of blood increases) special sense organs known as osmoreceptors in the brain detect this. They stimulate the pituitary gland in the brain to release ADH into the blood. This hormone affects the second coiled tubules of the kidneys, making them more permeable so more water is reabsorbed back into the blood.
- Less water is left in the kidney tubules and so more concentrated urine is formed. At the same time the amount of water in the blood increases so that the concentration of salts in the blood returns to normal.
- If the water content of the blood is too high, the pituitary gland releases much less ADH into the blood. The kidney then reabsorbs less water back into the blood, and thereby producing a large volume of dilute urine. Water is effectively lost from the blood and concentration of salts returns to normal.

- This system of osmoregulation is an example of negative feedback. As the water concentration of the blood falls, the level of ADH produced rises. Then as the water concentration of the blood rises again, the level of ADH released falls. On an average day the kidneys will produce around 180 l (that's about 50 gallons) of liquid filtered out of the blood in the glomerulus (glomerular filtrate) – but only about 1.5 l (just over 2.5 pints) of urine. So more than 99% of the liquid filtered out of the blood is eventually returned to it.

Thermoregulation

- It is vitally important that wherever we go and whatever we do our body temperature is maintained at the temperature (around 37 °C) at which our enzymes work best. It is not the temperature at the surface of an organism which matters as the skin temperature can vary enormously without causing harm. It is the temperature deep inside the body, known as the internal or core body temperature, which must be kept stable. Human beings are good examples of homeotherms. The body temperature is controlled by a number of physiological mechanisms which work together to allow gain or lose heat you need to.

Osmoregulation

- If the concentration of the body fluids changes, water will move into or out of the cells by osmosis and they could be damaged or destroyed. Yet some days you may drink several liters of water of liquid and other days much less. How is the balance maintained?

- We gain water when we drink and eat. We lose water constantly from the lungs when we breathe out, when water evaporates into the air in the lungs and is breathed out. This water loss is constant.

- Whenever we exercise or get hot we sweat and lose more water. The water balance is maintained by the kidneys. They remove any excess water which leaves the body as urine. If we are short of water we produce very little urine and most water is saved for use in the body. If we have too much water then our kidneys produce lots of urine to get rid of the excess. The ion concentration of the body – particularly ordinary salt – is also important. We take in mineral ions with our food. Some are lost via our skin when we sweat. Again the kidney is most important organ to keep an ion balance. Excess mineral ions are removed by the kidneys and lost in the urine. The balance of water and salts in the body is very important because of the osmotic impact of the cells. If the balance is wrong controlling this balance is known as **osmoregulation**. The kidneys as discussed above are vitally important in two aspects of homeostasis, both in excretion and in osmoregulation.

Chemical regulation

- Human liver plays a vital role in maintaining a constant internal environment. It is the largest individual organ in the body that makes up around 5% of the body mass. The liver cells are very active in carrying out a wide range of functions, many of which help to maintain a constant internal environment. The liver has a very special blood supply in addition to the usual artery and vein (hepatic artery and vein) there is another blood vessel which comes to the liver directly from the gut. This is the hepatic portal vein and it brings the products of digestion to the liver to be dealt with.

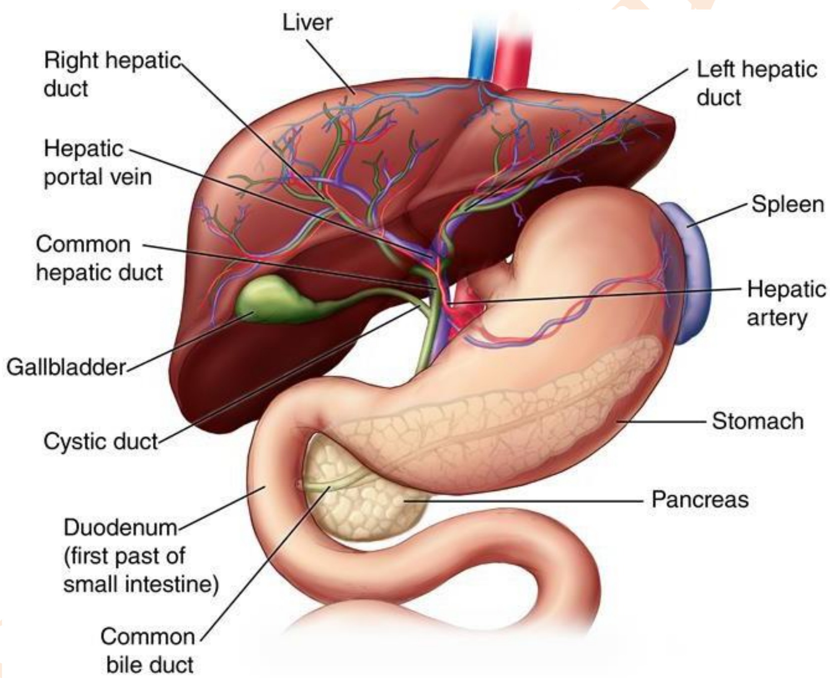

Figure .92 The liver is one of the most active organs in the body

- A large number of reactions take place in the liver. Many of them are involved in homeostasis in one way or another. It plays a part in all of the following functions:
- It controls the sugar levels in the body (through stored glycogen in the liver itself.
- It controls and balances the fats that you eat and the cholesterol levels in the blood.

- It is an important organ where protein metabolism takes place. The liver breaks down excess amino acids and forms urea. If you eat more carbohydrate or fat than you need in the diet the body simply stores the excess energy as fat. If you eat too much protein, it isn't so easy. The body cannot store the excess amino acids or simply convert protein to fat. Instead the amino acids which make up the protein are broken down in the liver. The amino (nitrogen containing) part of the amino acid molecule is removed and converted into ammonia and then urea in the liver. The rest of the amino acid can be used in cellular respiration or converted to fat for storage. The process of removing the amino group from excess amino acids is known as **deamination.** This it is a very important function of the liver.
- It carries out the breakdown of worn-out red blood cells – in particular the red pigment hemoglobin.
- It is vital organ for the formation of bile which is made in the liver and stored in the gall bladder before it is released into the gut to emulsify fats and help in their digestion.
- It controls toxins. The liver breaks down most of the poisons you take into the body, including alcohol. This is why the liver is so often damaged when people drink heavily.
- It is used to control temperature. Around 500 different reactions take place in the liver at any time. For many years it has been believed that as a result of all these reactions the liver generates a lot of heat which is then spread around the body by the bloodstream.
- The regulation of tissue oxygenation is another typical example for chemical regulation in the body. The respiratory chemoreceptors work by sensing the pH levels of their environment through the concentration of hydrogen ions. Because most carbon dioxide is converted to carbonic acid (and bicarbonate) in the bloodstream, chemoreceptors are able to use blood pH as a way to measure the carbon dioxide levels of the bloodstream.

- The main chemoreceptors involved in respiratory feedback are:

1. **Central chemoreceptors**: These are located on the ventrolateral surface of medulla oblongata and detect changes in the pH of spinal fluid. They can be desensitized over time from chronic hypoxia (oxygen deficiency) and increased carbon dioxide.
2. **Peripheral chemoreceptors**: These include the aortic body, which detects changes in blood

oxygen and carbon dioxide, but not in the pH, and the carotid body which detects all three. They do not desensitize, but they have less impact on the respiratory rate compared to the central chemoreceptors.

- The need for different levels of respiration varies with the physiologic state of the organism (e.g., sleep, excitement, exercise). The respiratory system must try to maintain constant levels of O_2, CO_2 and H^+ in the arterial blood which then ensures relatively constant levels of these important substances in the interstitial fluid. For O_2, one needs an adequate supply to meet cellular metabolic requirements. For CO_2 and H^+, one needs to maintain the acid–base status of the body's cells. The respiratory system provides a rapid, but usually incomplete, compensation for acid–base disturbances through altered partial pressure of CO_2. (PCO_2). Changes in the levels of O_2, CO_2 and H^+ in the blood cause compensatory changes in the level of ventilation

Review questions

<u>Choose the correct answer for the following questions.</u>

1. The two types of main components of macromolecules in myelin are;
   a. carbohydrates and lipids
   b. proteins and nucleic acids
   c. lipids and proteins
   d. carbohydrates and nucleic acids
2. If a thermo receptor is sensitive to temperature sensations, what would a chemoreceptor be sensitive to?
   a. Light
   b. Sound
3. What ion enters a neuron causing depolarization of the cell membrane?
   a. Sodium b. Chloride
   c. Potassium d. phosphate
4. The gonads produce what class of hormones?
   a. amine hormones
   b. peptide hormones
   c. steroid hormones

d. catecholamines

5. Which of the following response is not part of the fight-or-flight response?
   a. pupil dilation
   b. increased oxygen supply to the lungs
   c. suppressed digestion
   d. reduced mental activity
6. Which one of the following correctly traces the transmission of sound from the external environment to the nerves that carry the signal to the brain to be interpreted?
   a. Cochlea, tympanic membrane, ossicles, pinna, external auditory meatus.
   b. Pinna, external auditory meatus, tympanic membrane, ossicles, cochlea
   c. Tympanic membrane, Cochlea, ossicles, pinna, external auditory meatus
   d. External auditory meatus, Pinna, tympanic membrane, ossicles, cochlea
7. Which structure detects rotational acceleration of the head and body?
   a. Ossicles
   b. Cochlea
   c. Tympanic membrane
   d. Semicircular canals
8. Which section of the ear contains the malleus, incus, and stapes bones?
   a. Outer ear
   b. Middle ear
9. Which of the following is not an example of homeostasis?
   a. A control of the blood sugar levels
   b. control of the body temperature
   c. control of the water content of the blood
   d. control of the length of the limbs
10. Which of the following areas is NOT part of the nephron (kidney tubule)?
   a. Bowman's capsule
   b. urinary bladder
   c. loop of Henle
   d. first coiled tubule

Provide correct answer for the following questions

1. Explain the role of neurotransmitters.

2. Describe the role of negative feedback in the function of the parathyroid gland.

3. What are the three regions of the adrenal cortex and what hormones do they produce?

4. List down the hormones produced by anterior pituitary gland.

5. Describe the role of negative feedback in the function of the thyroid gland

Answer for multiple choice

3. **C 2. A 3. C 4. C 5. D 6. B 7. A 8. C 9. D 10. B**

Answer for give short answer

6. **Explain the role of neurotransmitters**.

Answer :

- Neurotransmitters are often referred to as the body's chemical messengers. They are molecules used by the nervous system to transmit messages between neurons, or from neurons to muscles. Communication between two neurons happens in the synaptic cleft (the small gap between the synapses of neurons). Here, electrical signals that have travelled along the axon are briefly converted into chemical ones through the release of neurotransmitters, causing a specific response in the receiving neuron

7. **Describe the role of negative feedback in the function of the parathyroid gland.**

Answer :

- The parathyroid glands produce and secrete parathyroid hormone (PTH), a peptide hormone, in response to low blood calcium levels.
- PTH secretion causes the release of calcium from the bones by stimulating osteoclasts, which secrete enzymes. These enzymes degrade bone and release calcium into the interstitial fluid.
- PTH also inhibits osteoblasts, the cells involved in bone deposition, thereby sparing blood calcium. PTH causes increased reabsorption of calcium (and magnesium) in the kidney tubules from the urine filtrate. In addition, PTH initiates the production of the steroid hormone calcitriol (also known as 1,25-dihydroxyvitamin D), which is the active form of vitamin D3, in the kidneys. Calcitriol then stimulates increased absorption of dietary calcium by the intestines. A negative feedback loop regulates the levels of PTH, with rising blood calcium levels inhibiting further release of PTH.

8. **What are the three regions of the adrenal cortex and what hormones do they produce?**

- **Answer :**
- **Zona Glomerulosa**: The outermost layeror the zona glomerulosa is the main site for production of mineralocorticoids, mainly aldosterone, that are largely responsible for the long-term regulation of blood pressure.
- **Zona fasciculata** is the layer situated between the glomerulosa and reticularis. This layer is responsible for producing glucocorticoids, such as 11-deoxycorticosterone, corticosterone, and cortisol in humans.
- **Zona reticularis** is the innermost cortical layer where it produces androgens, mainly dehydroepiandrosterone (DHEA), DHEA sulfate (DHEA-S), and androstenedione (the precursor to testosterone) in human beings.

9. **List down the hormones produced by anterior pituitary gland**.

- **Answer :**
- **ACTH**: Adrenocorticotrophic hormone. Stimulates the production of cortisol, a “stress hormone” that maintains blood pressure and blood sugar levels.
- **FSH:** Follicle-stimulating hormone. Promotes sperm production and stimulates the ovaries to produce estrogen.
- **LH:** Luteinizing hormone. Stimulates ovulation in women and testosterone production in men.
- **GH**: Growth hormone helps to maintain healthy muscles and bones and manage fat distribution.
- **PRL:** Prolactin stimulates breast to produce milk after childbirth. It also affects hormones that control the ovaries and testes, which can affect menstrual periods, sexual functions and fertility.
- **TSH**: Thyroid-stimulating hormone stimulates the thyroid gland, which regulates metabolism, energy and the nervous system.

10. Describe the role of negative feedback in the function of the thyroid gland

Answer :

- Feedback loops are used extensively to regulate the secretion of hormones in the hypothalamicpituitary axis. An important example of a negative feedback loop is the control of thyroid in hormone secretion. The thyroid hormones thyroxine and triiodothyronine ("T4 and T3") are synthesized and secreted by thyroid glands and affect metabolism throughout the body.
- The basic mechanisms for control in this system are:
- Neurons in the hypothalamus secrete thyroid releasing hormone (TRH), which stimulates cells in the anterior pituitary to secrete thyroid-stimulating hormone (TSH).
- TSH binds to receptors on epithelial cells in the thyroid gland, stimulating synthesis and secretion of thyroid hormones, which affect probably all cells in the body.
- When blood concentrations of thyroid hormones increase above a certain threshold, TRH secreting neurons in the hypothalamus are inhibited and stop secreting TRH.
- Inhibition of TRH secretion leads to shut-off of TSH secretion, which leads to shut-off of thyroid hormone secretion. As thyroid hormone levels decay below the threshold, negative feedback is relieved, TRH secretion starts again, leading to the TSH secretion.

UNITE 6

CLIMATE CHANGE

6.1 Climate Change: Causes and effects

- Climate change is the global phenomenon of climate transformation characterized by the changes in the usual climate of the planet (temperature, precipitation, and wind) that are especially caused by human activities. Climate change is a systematic change in the long-term state of the atmosphere over multiple decades or longer.

What Causes Climate change?

- Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change. Humans are increasingly influencing the climate and the earth's temperature by burning fossil fuels, cutting down forests and farming livestock that increases the concentration of atmospheric CO_2 by more than 40%, with over half the increase occurring since 1970 (Figure 6.1).. This adds enormous amounts of greenhouse gases to the atmosphere, increasing the greenhouse effect and global warming. At its most basic, climate change is caused by a change in the earth's energy balance how much of the energy from the sun that enters the earth (and its atmosphere) is released back into space. The earth is gaining energy as we reduce the amount of solar energy that is reflected out to space.

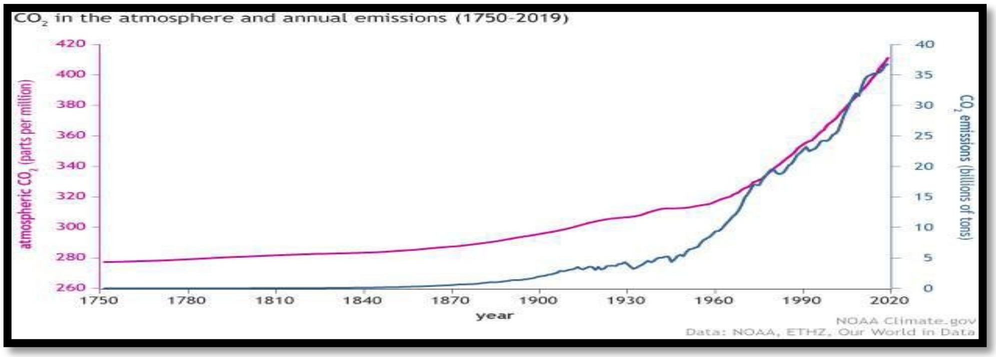

Figure .93 The history of atmospheric Carbon dioxide concentrations since the start of the Industrial Revolution.

6.1.1 Greenhouse gases

- Greenhouse gases are released into the atmosphere at various scopes (Figure 6.2) that have an influence on the earth's energy balance by trapping heat in the atmosphere, which makes the Earth warmer. Scientists have known for centuries that gases of various sources. In Earth's atmosphere like carbon dioxide and methane act as a greenhouse, preventing a certain amount of heat radiation from escaping back to space.

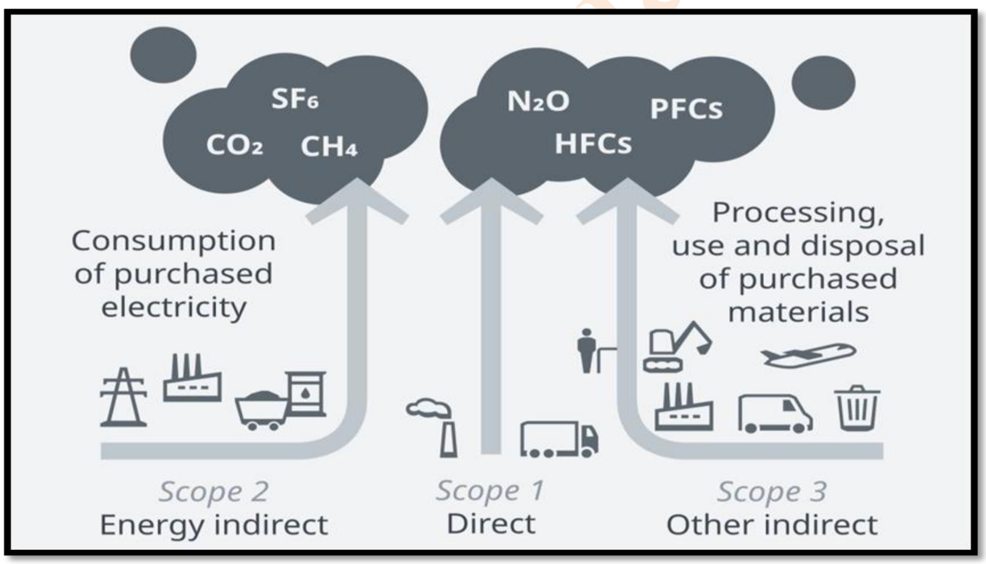

Figure .94. Source–Path relationship of Greenhouse gases

- Since the Industrial Revolution, human activities have added very large quantities of greenhouse gases (GHG) into Earth's atmosphere. These GHG act like a blanket windshield to trap the sun's energy and heat, rather than letting it reflect back into space. When the concentration of GHG is too high, too much heat is trapped, and the earth's temperature rises outside the range of natural variability. There are many GHG, each with a different ability to trap heat and a different half-life in the atmosphere. GHG are sometimes called "climate active pollutants" because most have additional notable effects on human health.

Carbon dioxide (CO_2)

Carbon dioxide (CO_2) is the GHG responsible for greatest amount of warming to date. The majority of CO_2 is released from the incomplete combustion of fossil fuels-coal, oil, and gas used for electricity production, transportation and industrial processes.

- Carbon dioxide absorbs and radiates heat warmed by sunlight, and thermal infrared energy (heat). Unlike oxygen or nitrogen which makes up most of our atmosphere, GHG absorb that heat and release it gradually over time. Without this natural greenhouse effect, the e earth's average annual temperature would be below freezing instead of close to 60°F. But, increases in greenhouse gases have tipped the earth's energy budget out of balance by trapping additional heat and raising Earth's average temperature.
- Carbon dioxide is one of the most important elements of the earth's long-lived greenhouse gases. It absorbs less heat per molecule than methane or nitrous oxide, but it's more abundant and stays in the atmosphere much longer. Increases in atmospheric carbon dioxide are responsible for about two-thirds of the total energy imbalance that is causing the earth's temperature to rise (Figure 6.3).

Figure .95 Ethiopia's annual CO2 emission

- In nature, CO_2 is exchanged continually between the atmosphere, plants, and animals through photosynthesis, respiration, and decomposition, and between the atmosphere and ocean through gas exchange. A very small amount of CO_2 roughly 1% emitted from fossil fuel combustion, is also from volcanic eruptions. This is balanced by an equivalent amount that is removed by chemical weathering of rocks. The CO_2 level in 2019 was more than 40% higher than it was in the 19th century. Most of this CO_2 increase has taken place since 1970 when the global energy consumption accelerated.

- The rise in CO_2 is largely from combustion of fossil fuels. Deforestation and other land use changes have also released carbon from the biosphere (living world) where it normally resides for decades to centuries. The additional CO_2 emitted from fossil fuel burning and deforestation has disturbed the balance of the carbon cycle because the natural processes that could restore the balance are too slow compared to the rates at which human activities are adding CO2 to the atmosphere. As a result, a substantial fraction of the CO2 emitted from human activities accumulates in the atmosphere, where some of it will remain for decades or centuries but for thousands of years. Comparison with the CO2 levels measured in air extracted from ice cores indicates that the current concentrations are substantially higher than they have been in at least 800,000 years.

6.1.2 Effects of climate change

- Climate change destabilizes the earth's temperature equilibrium and has far-reaching effects on human beings and the environment. During the course of global warming the energy balance and thus the temperature of the earth change posing a significant impact on humans and the environment. And, it is likely that global warming will increase the probability of extreme weather events.
- The direct consequences of man-made climate change include:
  - rising maximum temperatures
  - rising sea levels
  - higher ocean temperatures
  - an increase in heavy precipitation and shrinking of glaciers
  - thawing of permafrost

- The indirect consequences of climate change which affect humans and our environment include:
  - an increase in hunger and water crises, especially in developing countries
  - health risks due to the rising air temperatures and heat waves
  - economic crisis
  - increasing spread of pests and pathogens
  - loss of biodiversity due to limited adaptability of flora and fauna
  - ocean acidification due to increased HCO_3 concentrations in the water as a consequence of increased CO_2 concentrations

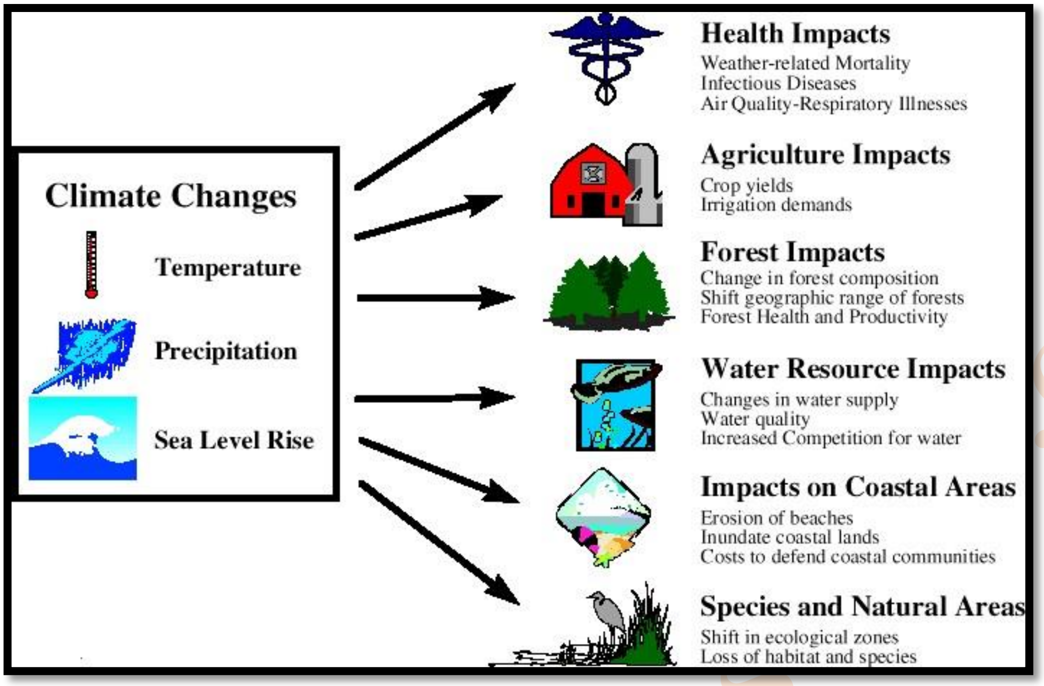

Figure .96. Potential climate change impacts

Effects of climate change on biodiversity

- Biodiversity provides immense direct benefits to humanswith at least 40% of the world's economy being derived from biological resources. Maintaining biodiversity provides greater food security, opportunities for economic development, and provides a foundation for new pharmaceuticals and other medical advances. However, climate change is affecting the habitats (Figure 6.4) of several species, which they must either adapt or migrate to areas with more favorable conditions. Climate change is likely to become the dominantly direct driver of biodiversity loss by the end of the century. Projected changes in climate combined with land use change and the spread of exotic or alien species are likely to limit the capability of some species to migrate and therefore will accelerate their loss.

Effects of climate change on Agriculture

- Agricultural biodiversity refers to all components of biological diversity of relevance to food and agriculture. It includes plants genetic resources, crops, wild plants harvested and managed for food, trees on farms, pastures, rangeland species, medicinal plants and ornamental plants of aesthetic value. Animal genetic resources include domesticated animals, wild animals hunted for food, wild and farmed fish and other aquatic organisms, insect pollinators and microbial and fungal genetic resources. Climate change can disrupt food availability, reduce access to food, and affect food quality. For example, projected increases in temperatures, changes in precipitation patterns, changes in extreme weather events, and reductions in water availability may all result in reduced agricultural productivity (Figure 5)

Figure 97 : Effect of climate on a agricultural activity

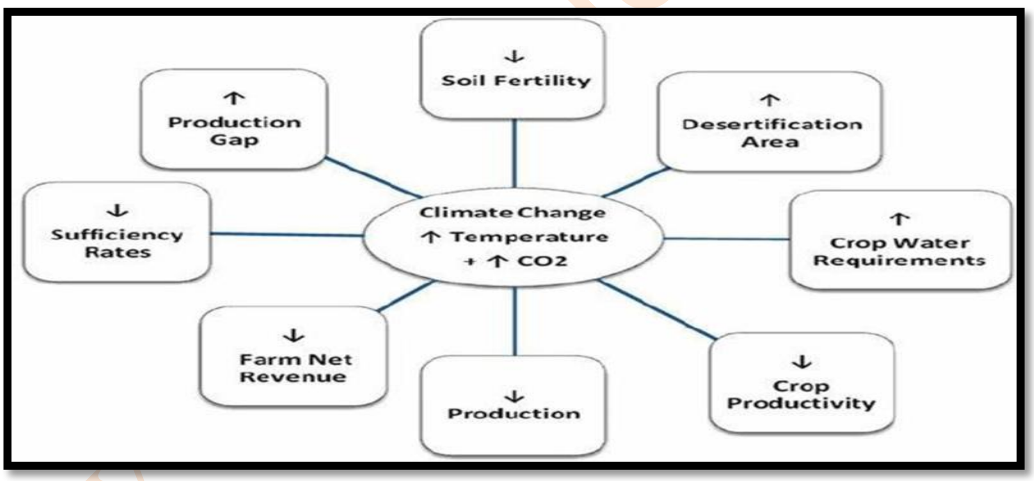

Figure .7 Climate change and its potential impacts on Agriculture.

Effect of climate change on forest productivity

- Climate change could alter the frequency and intensity of forest disturbances such as pest outbreaks, invasive species, wildfires, and storms. These disturbances can reduce forest productivity and change the distribution of tree species. In some cases, forests can recover from a disturbance. In other cases, existing species may shift their range or die out. In these cases, the new species of vegetation that colonize the area create a new type of forest. Insect outbreaks often defoliate, weaken, and kill trees. Warm temperatures and drought conditions during the early summer triggered wild fire, which can consume millions of acres of forest (Figure .8).

Figure 8 Forest fire in Chilaalo Oromia **Regional** State,Ethiopia

6.1.3 Climate change and natural disasters

- Climate hazards are natural events in weather cycles. We have always had hurricanes, droughts and wildfires, high winds and flooding (Figures7). Surprisingly however, we are currently witnessing a scale of destruction and devastation that is new and terrifying. With the increasing global surface temperatures, the possibility of more droughts and increased intensity of storms will likely to occur. As more water vapor is evaporated into the atmosphere, it becomes fuel for more powerful storms to develop.

Figure98DuststormsinEasternEthiopi

Melting ice and rising seas

- When water warms up it expands. At the same time global warming causes polar ice sheets and glaciers to melt. The combination of these changes is causing sea levels to rise resulting in flooding and erosion of coastal and low lying areas.

Extreme weather, shifting rainfall

- Heavy rain and other extreme weather events are becoming more frequent. This can lead not only to floods and decreasing water quality but also to decreasing availability of water resources in some regions (Figure.7).

Figure .99 Failed crops as a result of climate change, Ethiopia

Risks of climate change for human health

- Climate change is already having an impact on health: There has been an increase in the number of heat-related deaths in some regions of the earth and a decrease in cold-related deaths in other parts of the world. We are already observing changes in the spread of some water-borne illnesses and disease vectors.

Safety rules/ precautions during natural disaster

- Disaster risk management is a comprehensive approach involving the identification of threats through implementation of the proposed mitigation measures (Figure 6.8). Natural disasters are catastrophic events that often occur without warning and disrupt the ecosystem causing damage to personal lives, property, transportation, and livelihood. While it is never possible to prevent a disaster, the damage can be minimized through timely preparation. As such, every natural disaster has its own set of precautions to be taken, which must be followed to save precious lives.

Figure .100 Elements of Comprehensive risk management

- Here under are a few precautions to be taken during natural disasters.

Earthquakes

- The shifting of tectonic plates under the earth's crust causes earthquakes, which are responsible for mass destruction. When faced with an earthquake, these tips can be of use:

If you are indoors

- Take cover under a sturdy table or other pieces of furniture, and hold on until the shaking stops.
- Stay away from glass, windows, outside doors and walls, and anything that could fall, such as lighting fixtures or furniture.
- Stay inside until the shaking stops, and it is safe to go outside. Most injuries occur to people trying to move a different location inside the building or try to leave.
- Do not use the elevators.

If you are outdoors,

- Stay away from buildings, streetlights, and utility wires.
- Stand in open ground until the shaking stops. It's dangerous to stay directly outside

buildings, at exits, and alongside exterior walls. Ground movement during an earthquake is seldom the direct cause of death or injury. Most earthquake-related casualties result from collapsing walls, flying glass, and falling objects.

- **Tsunamis**

- Tsunamis are a series of enormous ocean waves caused by earthquakes, underwater landslides, or volcanic eruptions. Tsunami waves range from tens to hundreds of feet tall and can travel twenty to thirty miles per hour. When faced with this phenomenon, these tips are to be followed:
  - Turn on your radio/TV to learn and follow the precautionary instructions during a tsunami warning, primarily when you reside near a coastal area.
  - Move inland to higher ground immediately and stay there.
  - Check for a noticeable recession in water away from the shoreline as this is nature's tsunami warning and should be heeded. It would help if you moved away immediately.
  - Stay away from flooded and damaged areas until officials say it is safe to return.
  - Keep yourself away from debris in the water; it may pose a safety hazard to boats and people.

- **Cyclones**

- Cyclones are tropical storms, caused by atmospheric disturbances around a low- pressure area. Cyclones are accompanied by strong winds, moving at a speed of sixty- two Kmph or more.

- **When faced with a hurricane, keep these tips in mind:**
  - Be alert to the changing weather conditions.
  - Listen to radio/TV for the latest information.
  - Look for approaching storms.
  - Look for the following warning signs: – Dark, often greenish sky – Large hailstones, a large, dark, low-lying cloud (particularly if rotating), roars, similar to a freight train. If you see approaching storms or any of the danger signs, be prepared to take shelter

immediately. If you are under a tornado warning, seek shelter immediately.

- NOTE: In places where you have designated cyclone shelters, take refuge there.

Floods

- Floods are among the earth's most common and dangerous natural hazards formed due to a flow of water on areas of land that are usually dry. Excessive rains can damage nearby dams where tsunamis are some of its causes. When faced with flooding, these tips are to be followed:
- Do not attempt to walk, swim, or drive through the floods. Floodwater contains debris and contamination and can also be deadly due to fallen electrical lines in the water.
- Stay clear of bridges over fast-moving water.
- Keep an eye out for evacuation alerts.
- Move to higher ground. If your vehicle is trapped in flood and water starts filling inside the car, seek refuge on the roof.

Mitigation Measures

- There are three main climate change mitigation approaches. The first route is conventional mitigation effort that employs decarbonization to reduce CO_2 emissions. The techniques include renewable energy, fuel switching, efficiency gains, nuclear power, and carbon capture storage and utilization (Figure 6.11). The second route focuses on capturing and sequestering of CO_2 from the atmosphere through ocean fertilization, ocean alkalinity enhancement, soil carbon sequestration, afforestation and reforestation, wetland construction and restoration (Figure 6.12). The third route is the principle of altering the earth's radiation balance through the management of solar and terrestrialradiatio

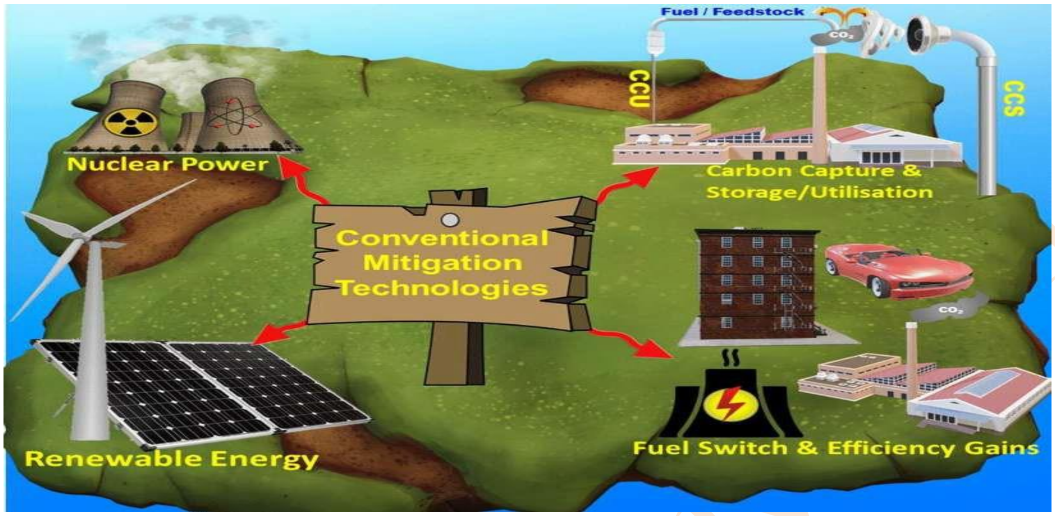

Figure.101: Conventional mitigation effort that employ decarbonization

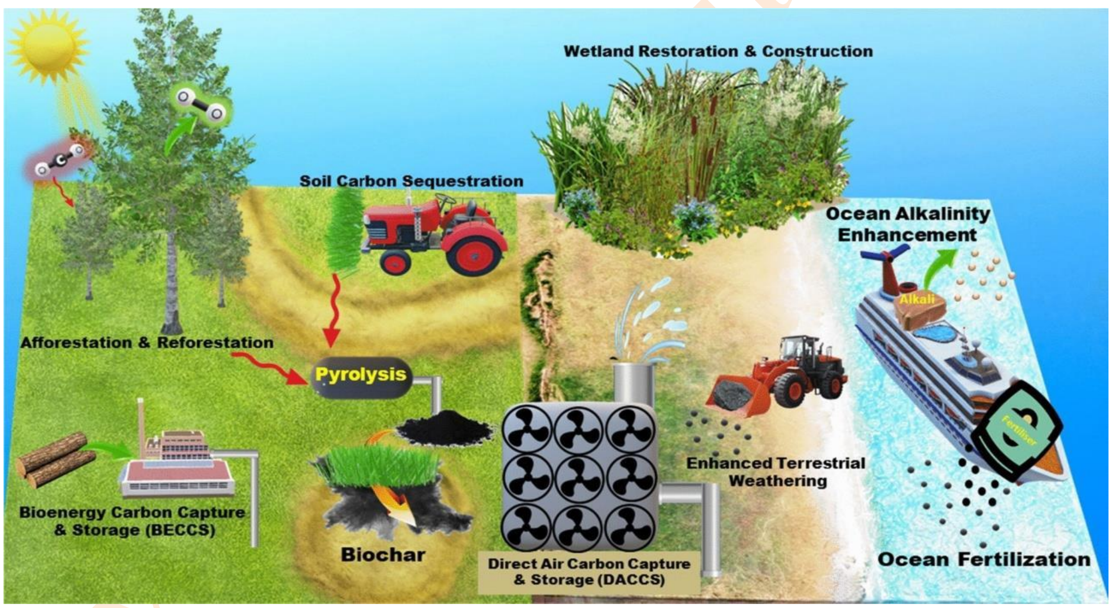

Figure 102 A mitigation measure that involves carbon sequestration

6.2 International conventions

- Climate change is a long-term, global problem. Long-term problems generally require stable but flexible policy implementation over time. Various international conventions have continuously evolved to address the increasingly complex and changing environmental priorities of the world (Figure.10).

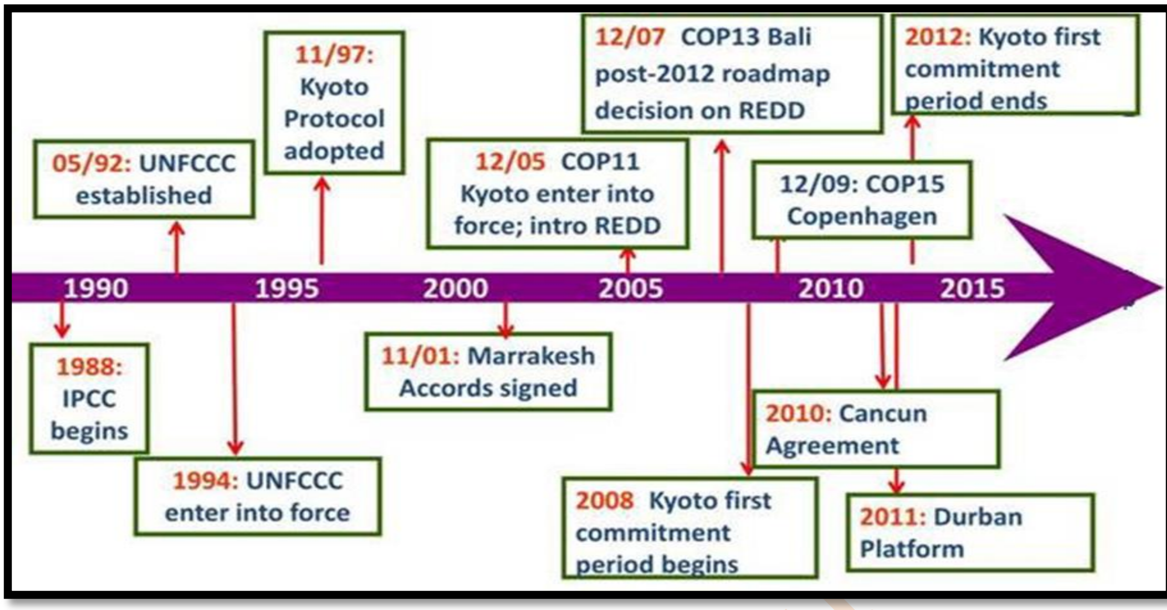

Figure .103. Climate Policy Timeline

- In 2009 in Copenhagen (COP15), for the first time it was decided that each country would propose a national contribution (INDC, Intended Nationally Determined Contributions). All the 195 UNFCCC countries pledged to reduce their greenhouse gas emissions by 2025-2030. It aimed "to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty" and contained three key provisions:
- Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above preindustrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;
- Increasing the ability to adapt to the adverse impacts of climate change and foster climate resilience and low greenhouse gas emissions development, in a manner that does not threaten food production;
- Making finance flows consistent with a pathway towards low greenhouse gas emissions and climate-resilient development.

6.2.1 The United Nations Framework Convention

- The United Nations Framework Convention on Climate Change (UNFCCC), agreed in 1992, is the main international treaty to combat "dangerous human interference with the climate system", in part by stabilizing greenhouse gas concentrations in the atmosphere. Its objective is to prevent dangerous man-made interference with the global climate system. The UNFCCC is an international environmental treaty. Ethiopia and all its member countries are among the 197 Parties of the Convention.

6.2.2 Kyoto Protocol on Climate Change

- The Kyoto Protocol was **adopted on 11 December 1997** The Kyoto Protocol operationalizes the UNFCCC by committing industrialized countries and economies in transition to limit and reduce GHG emissions in accordance with agreed individual targets. That means **the Kyoto Protocol** is an international agreement that called for industrialized nations to reduce their greenhouse gas emissions significantly. Other accords, like the Doha Amendment and the Paris Climate Agreement, have also tried to curb the global-warming crisis.
- First agreed in 1997, it took eight years for participating countries to ratify the Kyoto Protocol. The deal was simple. Industrialized countries would be legally obliged to cut their greenhouse gas emissions 5% on 1990 levels by 2008-2012. Developing countries – including China, India, Brazil and South Africa – would face no restriction on their emissions but were encouraged to adopt policies to promote greener growth. To help countries meet targets, Kyoto also offered a range of market mechanisms that could help rich countries offset emissions by investing in low carbon projects in poorer parts of the world. It was hailed as an "environmentally strong and economically sound" deal by US President Bill Clinton, speaking just after agreement had been reached in 1997. "It reflects a commitment from our generation to act in the interests of future generations," he said.

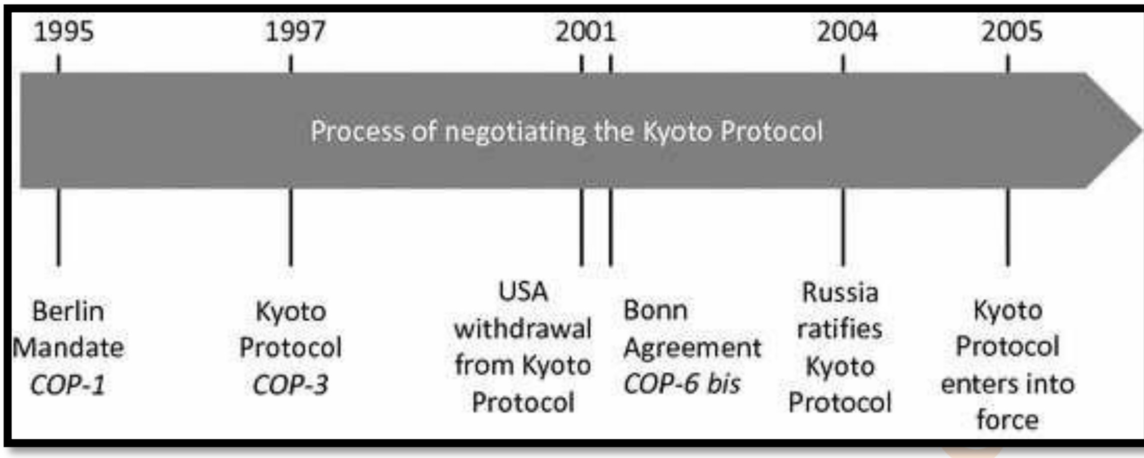

Figure 104 The Negotiation process leading to the Kyoto Protocol

End of review Exercises

Answer the following questions

1. What is climate change? Explain how it differs from global warming?
2. How does climate change affect human health?
3. How is agricultural productivity related to climate change?
4. Describe some of the climate change conventions
5. What is climate change mitigation?

Answer of review exercises

1. **What is climate change? Explain how it differs from global warming?**

- **Answer:**
  - Climate change is a systematic change in the long-term state of the atmosphere over multiple decades or longer. Global warming refers only to the Earth's rising surface temperature, whereas climate change includes warming and the "side effects" of warming such as melting glaciers, heavier rainstorms, or more frequent drought.

2. **How does climate change affect human health?**

Answer:

- In some cases, there can be health benefits, but in the clear majority of observed and predicted cases, the health impacts of climate change are negative. Climate change can lead to increased infectious diseases such as malaria and dengue fever, and can have significant impacts on mental health

3. **How is agricultural productivity related to climate change?**

- **Answer:**
- Climate change can disrupt food availability, reduce access to food and affect food quality. For example, key global projections showed increasing in temperatures, changing in precipitation patterns, changing in extreme weather events, and reductions in water availability, which may all result in reduced agricultural productivity.

4. **Describe some of the climate change conventions**

- **Answer:**
- The United Nations Climate Change Conferences are yearly conferences held in the framework of the United Nations Framework Convention on Climate Change (UNFCCC). They serve as the formal meeting of the UNFCCC Parties (Conference of the Parties, COP) to assess the progress in dealing with climate change., and beginning in the mid-1990s, it has served to negotiate the Kyoto Protocol to establish legally binding obligations for developed countries to reduce their greenhouse gas emissions. Since 2005, the "Conference of the Parties Serving as the Meeting of Parties to the Kyoto Protocol" (CMP) accepted parties that are not parties to the Protocol to join to the Convention, but. To participate in the Protocol-related meetings as observers. Since 2011, the meetings have also been used to negotiate the Paris Agreement as part of the Durban platform activities until its conclusion in 2015, which created a general path towards climate action.

5. **What is climate change mitigation?**

- **Answer:**

- Climate change mitigation means the practices of avoiding and reducing emissions of heat trapping greenhouse gases into the atmosphere to prevent the planet from warming to more extreme temperatures.

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