BIOLOGY FOR TTCs

STUDENT'S BOOK

YEAR TWO

OPTION: Sciences and Mathematics Education (SME)

FOREWORD

Dear Student- teacher,

Rwanda Basic Education Board is honoured to present to you this Biology Textbook for Year Two of Science and Mathematics Education (**SME**) Option which serves as a guide to competence-based teaching and learning to ensure consistency and coherence in the learning of Biology subject. The Rwandan educational philosophy is to ensure that you achieve full potential at every level of education which will prepare you to be well integrated in society and exploit employment opportunities.

The government of Rwanda emphasizes the importance of aligning teaching and learning materials with the syllabus to facilitate your learning process. Many factors influence what you learn, how well you learn and the competences you acquire. Those factors include the instructional materials available among others. Special attention was paid to the activities that facilitate the learning process in which you can develop your ideas and make new discoveries during concrete activities carried out individually or with peers.

In competence-based curriculum, learning is considered as a process of active building and developing knowledge and meanings by the learner where concepts are mainly introduced by an activity, a situation or a scenario that helps the learner to construct knowledge, develop skills and acquire positive attitudes and values. For effective use of this textbook, your role is to:

- Work on given activities including laboratory experiments which lead to the development of skills;
- Share relevant information with other learners through presentations, discussions, group work and other active learning techniques such as role play, case studies, investigation and research in the library, from the internet or from your community;
- Participate and take responsibility for your own learning;
- Draw conclusions based on the findings from the learning activities.

I wish to sincerely extend my appreciation to the people who contributed towards the development of this book, particularly REB staff who organized the whole process from its inception. Special gratitude goes to teachers, illustrators and designers who diligently worked to successful completion of this book.

Dr. MBARUSHIMANA Nelson

Director General of Rwanda Basic Education Board

ACKNOWLEDGEMENT

I wish to express my appreciation to all the people who played a major role in development of this Biology book for Year Two of TTC, Science and Mathematics Education (**SME**) Option. It would not have been successful without active participation of different education stakeholders.

I owe gratitude to different Universities and schools in Rwanda that allowed their staff to work with REB in the in-house textbooks production project. I wish to extend my sincere gratitude to lecturers, teachers, tutors, illustrators, designers and all other individuals whose efforts in one way or the other contributed to the success of writing of this textbook.

Finally, my word of gratitude goes to the Rwanda Basic Education Board staff particularly those from the Curriculum, Teaching and Learning Resources Department who were involved in the whole process of in-house textbook writing.

Joan MURUNGI,

Head of Curriculum, Teaching and Learning Resources Department

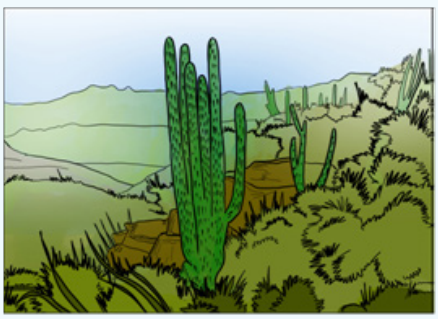
TABLE OF CONTENT

UNIT 1

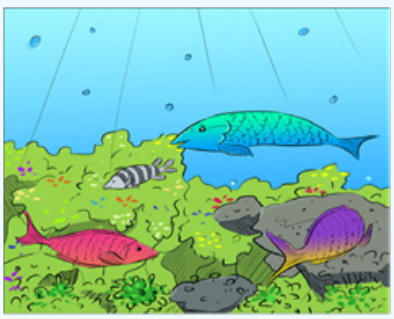
CONCEPT OF ECOSYSTEM

Key unit competence: Explain components of an ecosystem and how energy flows in an ecosystem.

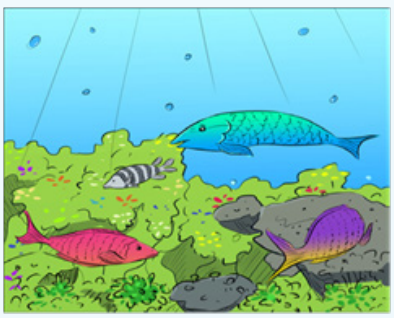
Introductory activity 1



A



B



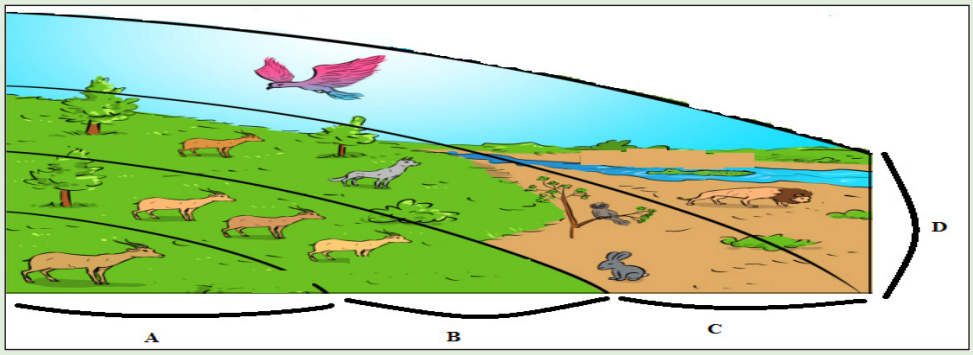
C

1. Make observation of picture A, B and C, state abiotic components and biotic components observed.
2. Describe how giraffe in picture C obtains energy
3. What would happen if plant species are removed from picture C?

1.1 Description of an ecosystem

Activity 1.1

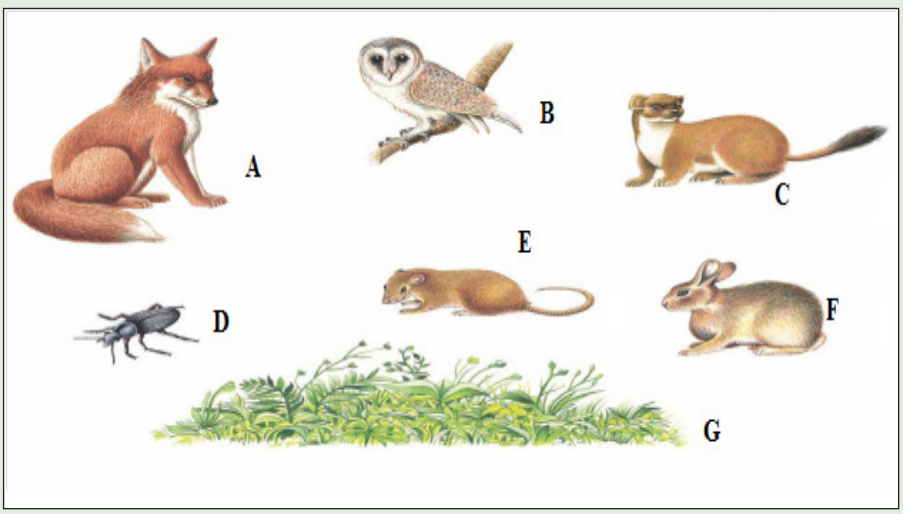
1. Observe carefully the diagram below, and answer the questions that follow



a. Referring to the diagram , Make a table showing the observable differences between A,B, C and D

b. Referring to the diagram, give the living and non living things found in D and specify their habitats

2. Analyze carefully the diagram below and answer the questions that follow:



Make a classification of living organisms by the letters A, B, C, D, E, F and G based on the principle of being eaten by

1.1.1 Definition of ecosystem

Different concepts define levels in ecology. From the low to high level, the concepts include:

a. Species

Species such as bees in figure 1.1 is defined as a group of organisms that can breed to produce fertile offspring.

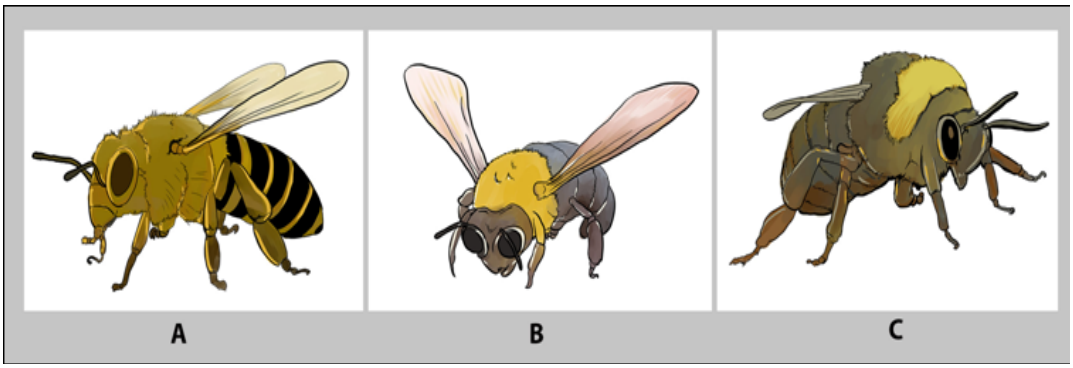


Figure 1.1: Species of bees

b. Population

A population is a group of organism of the same species which live in the same habitat at the same time where they can freely interbreed. Elephants such as those indicated in figure 1.2 constitute a population.

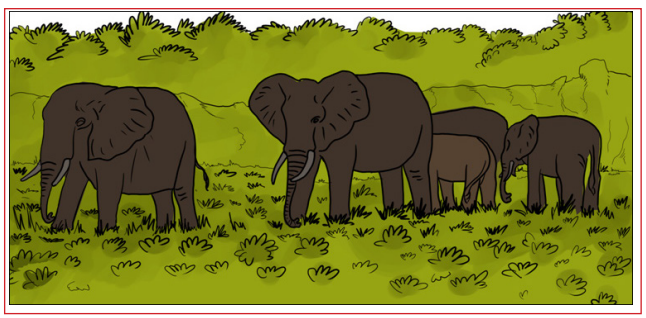


Figure 1.2: Population of elephants

c. Community

In ecology, a community consists of all populations of different species living and interacting at a certain level in the same ecosystem. Animals indicated in the figure 1.3 interact and share the same ecosystem

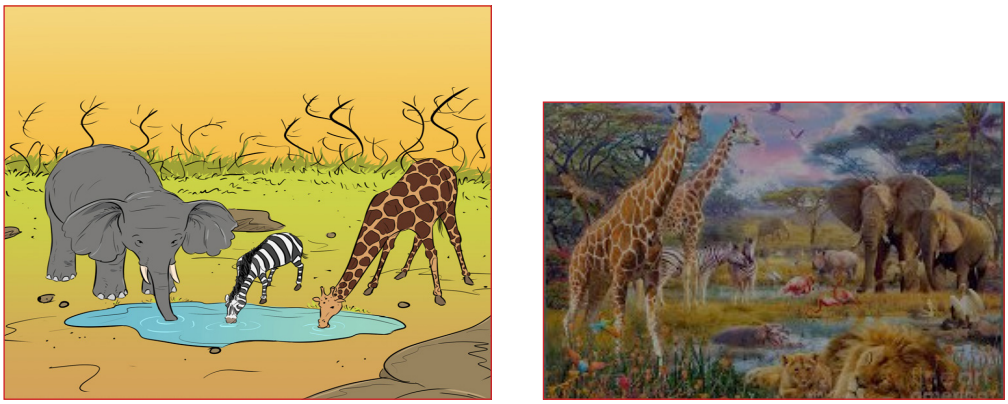


Figure 1.3: Ecological community

d. Niche

A niche refers to the role played by a species in its ecosystem. It includes all the ways that the species interacts with the biotic and abiotic factors of the environment. Two important aspects of a species' niche are the food it eats and how the food is obtained. Birds (figure 1.4) live in the same ecosystem, but they have different adaptations for food. For example, the longest slender beak of the nectarivore allows it to sip the nectar from flowers; the short study beak of the granivore allows it to crush hard and tough grains.

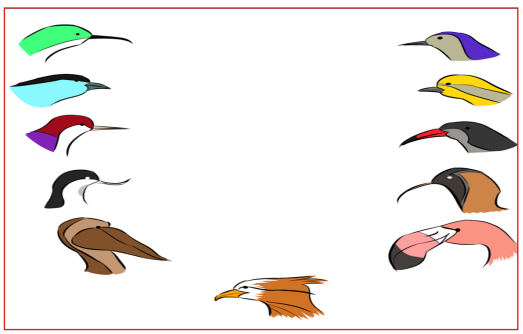


Figure 1.4: Adaptations of birds' beak for food in an ecosystem

The habitat is the physical environment in which a species lives and to which it is adapted. A habitat's features are mainly determined by abiotic factors such as temperature and rainfall, which in turn have an influence on the traits of the organisms that live in that habitat. A habitat is also influenced by biotic factors as it may contain many different species. However, in the same habitat, two different species cannot occupy the same niche in the same place for very long. This is known as the competitive exclusion principle. If two species were to occupy the same niche, they would compete with one another for the same food and other environmental resources leading to the extinction of the weaker species.

e. Ecosystem

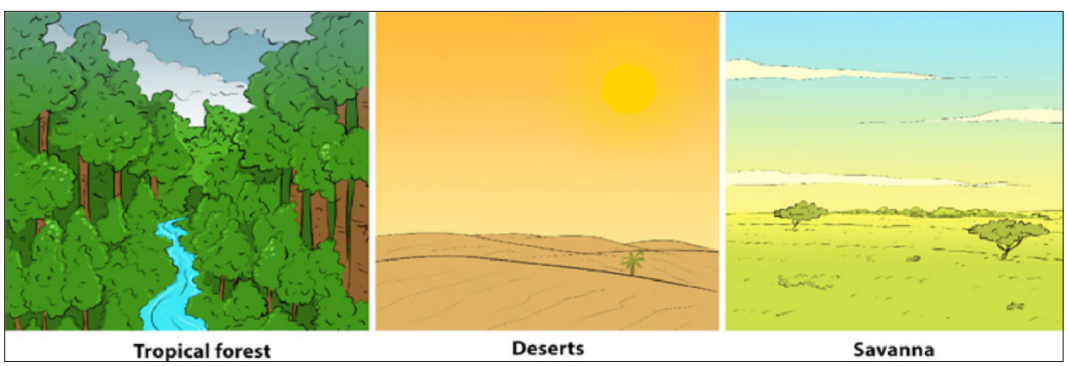
An ecosystem is a natural unit consisting of all the living organisms in an area functioning together with all the non-living physical factors to bring about a stable or self sustaining unit. The concept of an ecosystem can apply to units of different sizes. For example, a large body of fresh water could be considered an ecosystem, and so could a small piece of dead wood. Both contain a community of species that interact with one another and with the abiotic components of their environment.

Figure 1.5: Examples of ecosystems

f. Biomes

A biome is a broad regional type of an ecosystem characterized by distinctive climate and soil conditions and a distinctive kind of biological community adapted to those conditions. Biomes are of various types including terrestrial and aquatic biomes.

Terrestrial biomes consist of all the land areas on Earth where organisms live. The distinguishing features of terrestrial biomes are determined mainly by climate. The dominant terrestrial biomes include; tundra, temperate forests, grasslands, temperate, tropical deserts, tropical forests and grasslands (Figure 1.6).



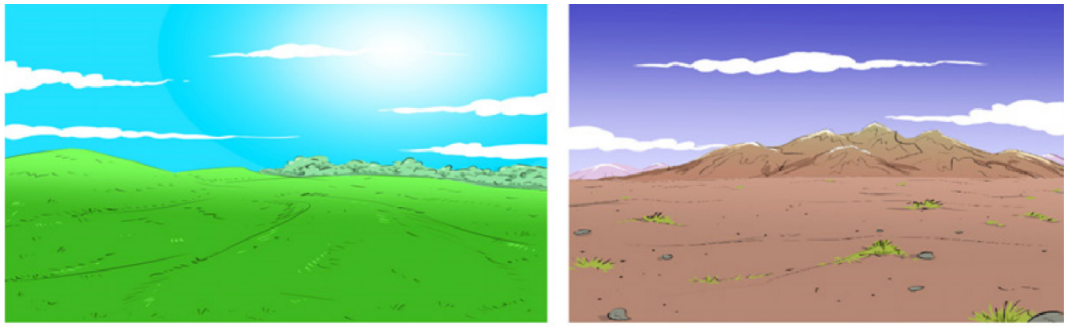


Figure 1.6: Different types of biomes

Aquatic biomes occupy the largest part of biosphere. These are divided into two, i.e. marine and freshwater. The marine biomes e.g. oceans which is the biggest of the two (Figure 1.7 below) have a very high salt concentration and have fauna adapted to them. The fresh water biomes such as lakes and rivers have a low salt concentration of less than 1%.

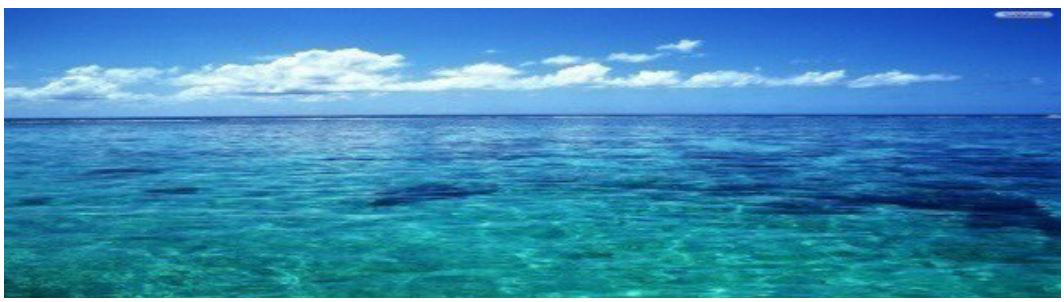


Figure 1.7: Example of aquatic biome

g. Biosphere

The biosphere is the portion of Earth inhabited by life and which represents the sum of all communities and ecosystems.

1.1.2 Components of an ecosystem

In an ecosystem, living organisms have feeding relationships. In terms of sources of food, organisms are classified as; producers, consumers, or decomposers.

- Producers are organisms that can manufacture their own food. They include; green algae, green plants and other autotrophs that are able to make their own food through photosynthesis or chemosynthesis
- Consumers are organisms that obtain food from other organisms because they cannot make their own food. Based on their level of feeding, consumers are classified as primary consumers when they feed directly

on plants. Primary consumers include herbivorous or omnivorous animals. Consumers are also classified as secondary consumers, when they feed directly on primary consumers. Secondary consumers include carnivorous animals. Tertiary consumers are consumers that feed directly on secondary consumers and are top carnivorous or omnivorous animals.

- Decomposers are organisms that break down the tissues of dead organisms into simpler substances, for example bacteria and fungi that break down dead plants and animals into compounds of carbon and nitrogen. These compounds are released into the soil to be used by plants and animals for growth.

In a food chain, producers such as plants produce their own energy without consuming other life forms. They gain their energy from conducting photosynthesis via sunlight. Consumers exist on the next level of the food chain and they are three main types of consumers namely herbivores, carnivores and omnivores.

Consumers get the energy by feeding on plants or by eating other carnivores or herbivores.

In an ecosystem, life is influenced by biotic and abiotic factors.

a. Abiotic factors

Sunlight: Sunlight plays an important role in the species composition and development of vegetation. Sunight is abundantly received on the surface of the earth from solar energy and it is used by primary producers to do photosynthesis. Sunlight intensity shows special variations due to the factors like atmospheric water layer, particles dispersed in the air, etc. Furthermore, the vegetation of an area may also affect the light intensity. In deep shade under trees, or under water, light becomes limiting factor below which photosynthesis is not sufficient for effective growth.

Temperature: Temperature is a measurement of the degree of heat. Like light, heat is a form of energy. The radiant energy received from the sun is converted into heat energy. Heat is measured in calories. The temperature at which physiological processes are at their maximum efficiency is called optimum temperature.

The minimum, optimum and maximum temperatures are called cardinal temperatures. The cardinal temperature varies from species to species and in the same individual from part to part. The distributions of plants, animals are also influenced by temperature.

Water: Water is an indispensable part of land contributing to soil productivity, and the well beings of organisms. All physiological processes take place in the medium of water. For example, cellular protoplasm is made up mostly of water contributing to the maintenance of cells and hence the entire living organism survives.

Rainfall: The rainfall provides water to plants and animals, and determines the types of vegetation in a given region. For example, the evergreen forests are found in tropical regions. Changes in rainfall influence the vegetation types in different parts of the earth, and in turn, vegetation causes changes in the types of forests, animals and birds. The quantity of water that a soil holds or that infiltrates into the soil depends upon the properties of soil and type and density of vegetation covering it. In a bare area, the rain drops beat the compact surface of the soil and loosen the soil particles which are washed away.

Wind: Air in motion is called wind. It modifies the water relation and light conditions of a particular region, and brings about a number of physical, anatomical and physiological changes of plants. Such changes are breakage and uprooting of plants, deformation, erosion and deposition of different organic particles. The wind accelerates transpiration, removes solid moisture and at high velocities causes soil erosion, which contributes to the removal of the surface soil, rich in organic matter and fine mineral particles.

Humidity: Humidity is greatly influenced by intensity of solar radiation, temperature, altitude, wind, and water status of soil. Low temperature causes higher relative humidity by decreasing the capacity of air for moisture. Processes as transpiration, absorption of water are influenced by atmospheric humidity.

Atmospheric Gases: Some principal gases like nitrogen, oxygen, carbon-dioxide, helium, hydrogen, methane, and ozone are found in atmosphere. In addition to these gases, there is water vapor. Industrial gases, dust, smoke particles, microorganisms are present in the atmosphere. These gases have different influences on the environment and hence on the living things.

Soil is often considered an abiotic factor since it is mostly made up of small particles of rock (sand and clay) mixed with decomposed plants and animals. Plants use their roots to get water and nutrients from the soil. Soils are different from place to place this can be a big factor in which plants and animals live in a certain area.

There are other examples of abiotic factors such as, **salinity, pressure, light, wind a**nd **pH**

Biotic Factors

The biotic factors constitute the living organisms of the environment and their direct or indirect interactions. The population occurring together in an area interacts with each other in several ways including predation, competition for mating and for different natural resources including; food, water and oxygen. The biotic factors include producers, consumers and decomposers

1. **Producers**. All plants, such as grass and trees, green algae are producers. These organisms absorb the sun's energy and convert the energy into food for themselves, allowing them to grow larger, make flowers and seeds, etc.
2. **Consumers**. These organisms, mostly animals, zooplankton eat producers and/or other animals. They may also eat decomposers. Two examples of consumers are cows (eat plants) and lions (eat animals). Consumers that only eat plants (herbivores) are often known as primary consumers.
3. **Decomposers**. These organisms break down dead material (such as a fallen tree) into soil and return nutrients to the soil so they can be re-used by producers to create food. An example of a decomposer is a bacterium

1.1.3 Types of ecosystem

They are two major classifications of ecosystems: natural ecosystem and artificial ecosystem. Natural ecosystems are those ecosystems that are capable of operating and maintaining themselves without any major interference by man.

Natural ecosystems are furthermore classified into terrestrial ecosystems including; forest, grassland and desert, and in Aquatic ecosystems including freshwater ecosystem such as; ponds, lakes, rivers and marine ecosystems such as ocean, sea or estuary.

Artificial Ecosystem are those ecosystems maintained by the intervention of humans. They are manipulated by man for different purposes including; croplands, artificial lakes and reservoirs, townships and cities.

Figure 1.8: Artificial ecosystem

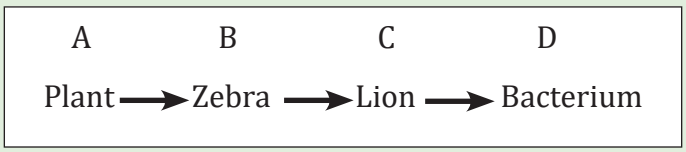
Application activity 1.1

1. Carry out a fieldwork in school environment or outside the school. Identify three aquatic and three terrestrial ecosystems found in Rwanda
2. Make a brief description of an ecosystem

1.2 Energy flow in ecosystems

Activity 1.2

Observe carefully the diagram below and answer the questions that follow.



1. Discuss how the energy flows in the above food chain of living things.
2. Indicate which living organisms above are consumers, decomposers in the figure.
3. Discuss the role played by organism represented by the letter C.
4. What would happen if A is removed from the food chain?

Energy enters in an ecosystem in the form of sunlight or chemical compounds. Some organisms including plants and green algae use sunlight energy to make their own food.

Other organisms get energy through food by eating producers or consumers or by decomposing producers and consumers.

1.2.1 Food chains and food webs

Food chains and food webs are diagrams that represent feeding relationships. They show who eats who. In this way, they model how energy and matter move through ecosystems.

a. Food chains

A food chain represents a single pathway through which energy and matter flow through an ecosystem. Food chains are generally simpler than what really happens in nature. Most organisms consume and are consumed by more than one species.

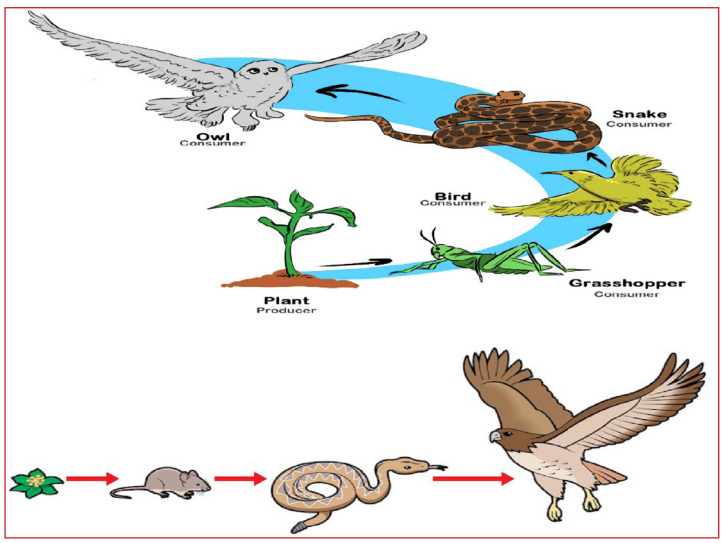


Figure 1.9: Illustration of a food chain (Source shutterstock.com)

b. Food webs

A food web represents multiple pathways through which energy and matter flow through an ecosystem. It includes many intersecting food chains. It demonstrates that most organisms eat, and are eaten, by more than one species.

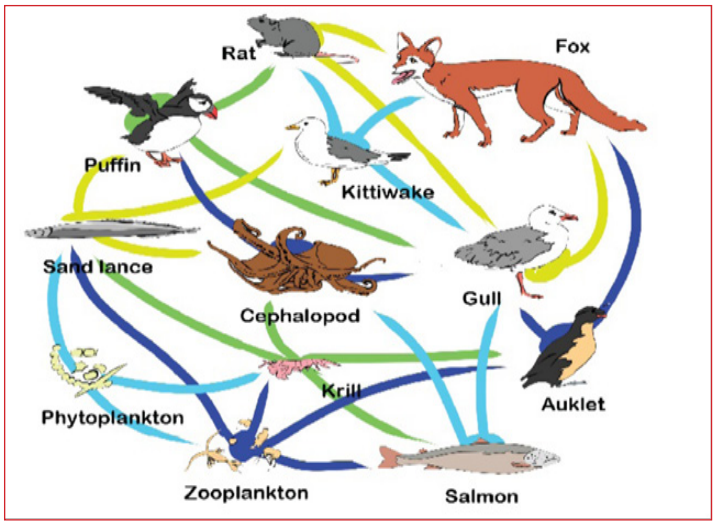


Figure 1.10: Illustration of the food web

c. Trophic levels

The feeding positions in a food chain or web are called trophic levels. The different trophic levels are defined in the table below (Table 1.1). All food chains and food webs have at least two or three trophic levels, the maximum being of four trophic levels. Many consumers feed at more than one trophic levels. Humans, for example, are primary consumers when they eat plants, secondary consumers when they eat meat from primary consumers, and are tertiary consumers when they eat meat of secondary consumers.

Table: 1.1. Description of producers, primary, secondary and tertiary trophic levels

Trophic level	Where it gets food	Example
1st Trophic level: Producer	Makes its own food	Plants make food
2nd Trophic level: primary consumer	Consumes producers	Mice eat plant seeds
3rd Trophic level: Secondary consumer	Consumes primary consumers	Snakes eat mice
4th Trophic level: Tertiary consumer	Consumes secondary consumers	Hawks eat snakes

1.2.2 Ecological pyramids

Ecological pyramid is a graphical representation in the form of a pyramid showing the feeding relationships of groups of organisms. It is often represented in a way that the producers are at the bottom level and then proceeds through the various trophic levels in which the highest is on top. There are 3 types of ecological pyramids: pyramid of numbers, pyramid of biomass and pyramid of energy.

a. Pyramid of numbers

Pyramid of numbers is a graph representing the total number of individuals present at each trophic level. This type of pyramid can have two different forms depending on the number of organisms: upright and inverted. In an upright pyramid of numbers, the number of organisms generally decreases from the bottom to top. This generally occurs in grassland and pond ecosystems where plants occupy the base of the pyramid. An inverted pyramid of numbers, on the other hand, is just the opposite of the upright one. It is usually observed in tree ecosystems with the trees as the producers and the insects as consumers.

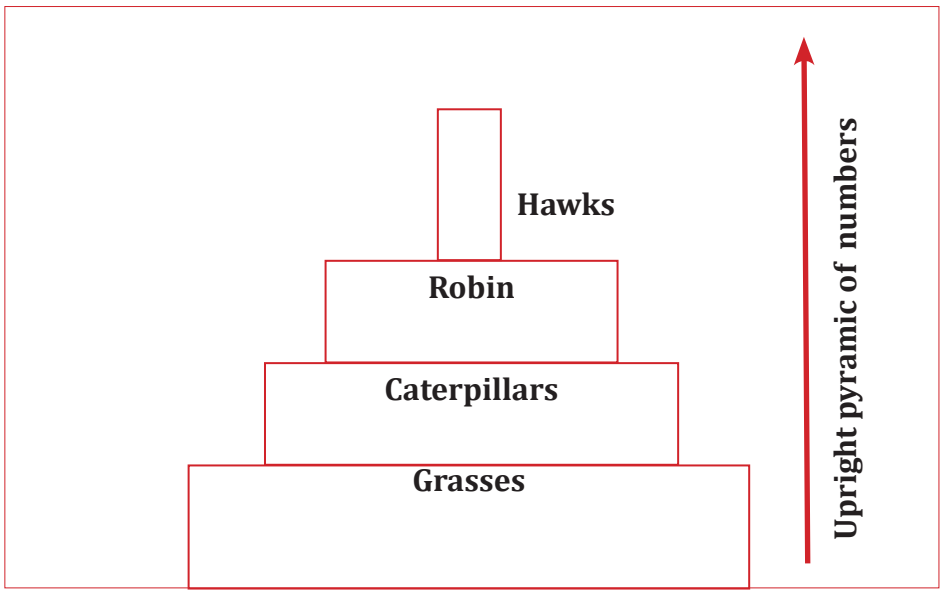


Figure 1.11: illustration of the upright pyramid of numbers and the inverted pyramid of numbers

b. Pyramid of biomass

Biomass is defined as the amount of biomass per unit area product of the living material present in an organism and the total number of organisms present in a specific trophic level. In less complicated terms, it refers to the food available for the succeeding trophic level.

A pyramid of biomass is a depiction of the amount of food available and how much energy is being passed on at each trophic level. Most the biomass that animals consume is used to provide the energy, converted to new tissues, or just remain undigested.

Most of the time, pyramids of biomass are in a true pyramidal shape with biomass in the lower trophic levels are greater than the trophic levels above them. Like the pyramid of numbers, the pyramid of biomass can either have two forms: upright and inverted. Usually, terrestrial ecosystems are characterized by an upright pyramid of biomass having larger base for primary producers with the smaller trophic levels for consumers located at the top (figure located left). Aquatic ecosystems are the complete opposite as they will assume the inverted structure of the pyramid. This is because the phytoplankton producers with generally smaller biomass are located at the base while the consumers having larger biomass are located at the top of the pyramid (figure located right)

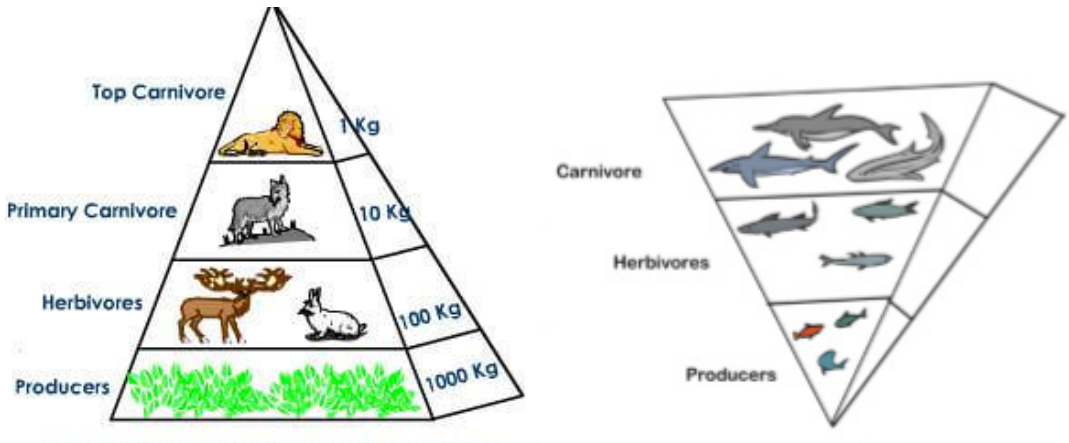


Figure 1.12: Illustration of upright pyramid of biomass (left) and the inverted pyramid of biomass (right)

In other words, the phytoplankton has a short turnover time, which means they have a small standing crop compared to their production. The turnover time is calculated by the following formula:

$$\text{Turnover time} = \frac{\text{Standing crop } (g/m^2)}{\text{Production } (g/m^2 day)}$$

1.2.3 Pyramid of energy

The pyramid of energy shows the overall energy in the ecosystem and how much energy is required by organisms as it flows up the higher trophic levels. This pyramid shows that energy is transferred from lower trophic levels with

more amount of energy (producers) to higher ones (consumers) and converted in the biomass. Therefore, it can be concluded that organisms found at the highest trophic levels of shorter food chains bear greater amount of energy than the ones found in longer ones. Unlike the first two ecological pyramids, the pyramid of energy is always illustrated in an upright position, with the largest energy carriers at the base.

The pyramid shows the total energy stored in organisms at each trophic level in an ecosystem.

Starting with primary consumers, each trophic level in the food chain has only 10 percent of the energy of the level below it (Figure 1.13). The energy available at a given trophic level is measured in Kilojoules per square metre per year ($kJm^{-2}Y^{-1}$).

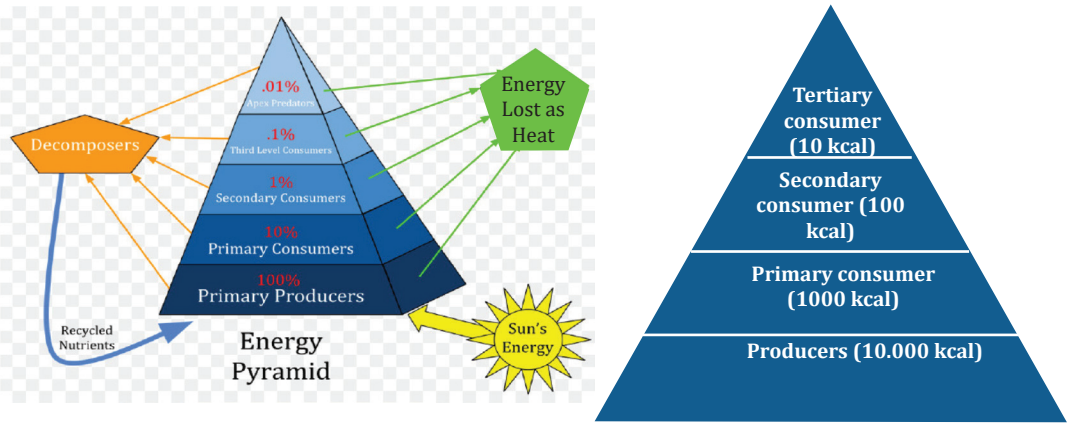


Figure 1.13: Illustration of the pyramid of energy

1.2.4 Limitations of ecological pyramids

While the three ecological pyramids are highly specific to the aspect of ecosystem they want to describe, all of them still tend to overlook important aspects. Some of these limitations are the following:

- These types of pyramids only are applicable in simple food chains and not for the food webs and they also do not consider the possible presence of the same species at different trophic levels.
- None of the three ecological pyramids provide any idea related to variations in seasons and climates.
- Other organisms like microorganisms and fungi are not given specific role in the pyramids despite their vital roles in ecosystems.

1.2.5. Biogeochemical Cycles

The chemical element or water moves through ecosystems. In the term biogeochemical, bio- refers to biotic components and geo- to geological and other abiotic components. During biogeochemical cycle, chemicals cycle through both biotic and abiotic components of ecosystems. For example, an element might move from the atmosphere to the water of the ocean, goes to ocean organisms, and then back to the atmosphere to repeat the cycle.

Elements or water may be held for various lengths of time by different components of a biogeochemical cycle. Components that hold elements or water for a relatively short period of time are called exchange pools. For example, the atmosphere is an exchange pool for water. It holds water for several days. This is a very short time compared with the thousands of years the deep ocean can hold water. The ocean is an example of a reservoir for water. A reservoir is a component of a geochemical cyclethat hold elements or water for a relatively longer period of time.

a. Water Cycle

Earth's water is constantly in motion. Although the water on Earth is billions of years old, individual water molecules are always moving through the water cycle. The water cycle describes the continuous movement of water molecules on above and below Earth's surface. Like other biogeochemical cycles, there is no beginning or end to the water cycle. It just keeps repeating. During the cycle, water occurs in its three different states: gas (water vapour), liquid (water), and solid (ice). Processes involved in changes of state in the water cycle include; evaporation, sublimation, and transpiration.

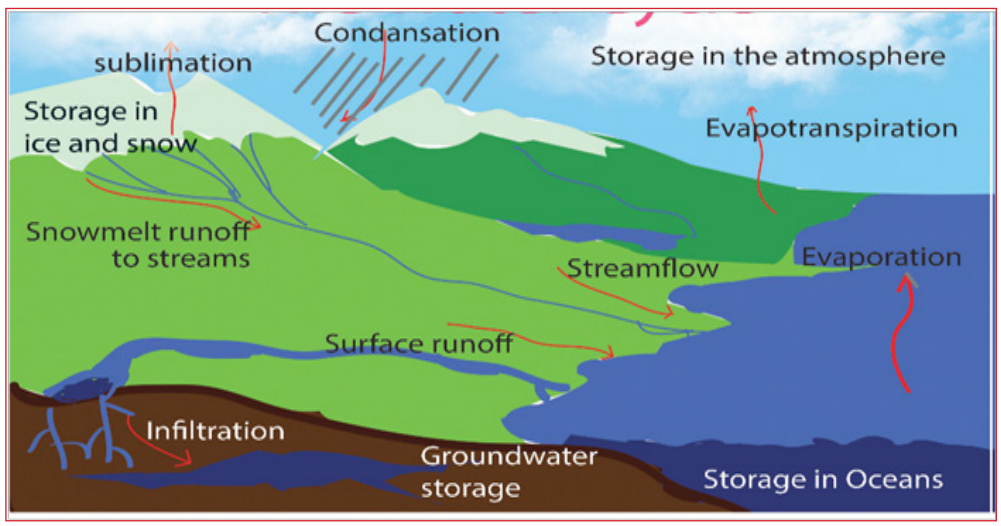


Figure 1.14: Illustration of the water cycle

b. Carbon Cycle

Carbon is essential to all life as it is the main constituent of living organisms. It serves as the backbone component for all organic polymers, including; carbohydrates, proteins, and lipids. Carbon compounds such as carbon dioxide (CO_2) and methane (CH_4) circulate in the atmosphere and influence global climates. Carbon circulates between living and non-living components of the ecosystem primarily through the processes of photosynthesis and respiration. Plants and other photosynthetic organisms obtain CO_2 from their environment and use it to build biological materials. Plants, animals, and decomposers (bacteria and fungi) return CO_2 to the atmosphere through respiration. CO_2 trapped in rock or fossil fuels can be returned to the atmosphere via volcanic eruptions, or fossil fuel combustion. The movement of carbon through biotic components of the environment is known as the fast carbon cycle.

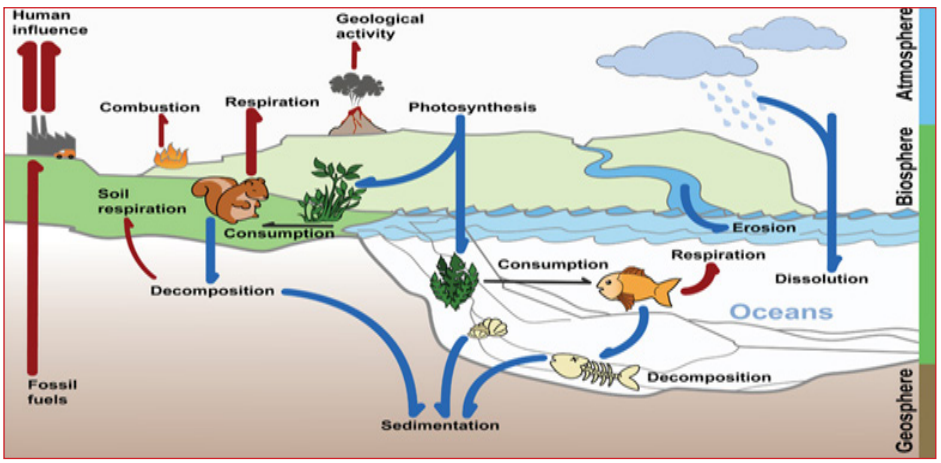


Figure 1.15: Carbon cycle

c. Nitrogen Cycle

The atmosphere is the largest reservoir of nitrogen on Earth. It consists of 78% nitrogen gas (N_2). Similar to carbon, nitrogen is a necessary component of biological molecules. Atmospheric nitrogen (N_2) is converted to ammonia (NH_3) by nitrogen-fixing bacteria in aquatic and soil environments. These organisms use nitrogen to synthesize the biological molecules they need to survive. Some nitrogen-fixing bacteria live in soil, others live in the root nodules of legumes such as; peas and beans. In aquatic ecosystems, some cyanobacteria are nitrogen fixing.

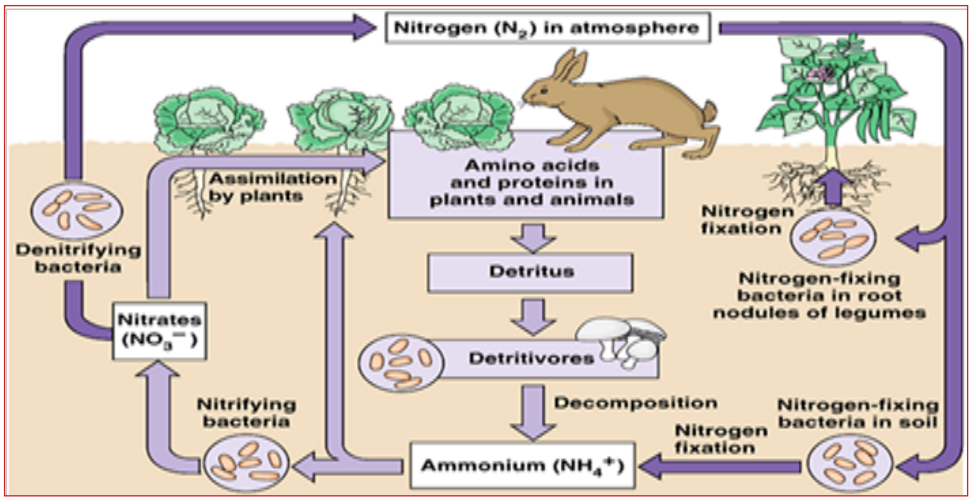
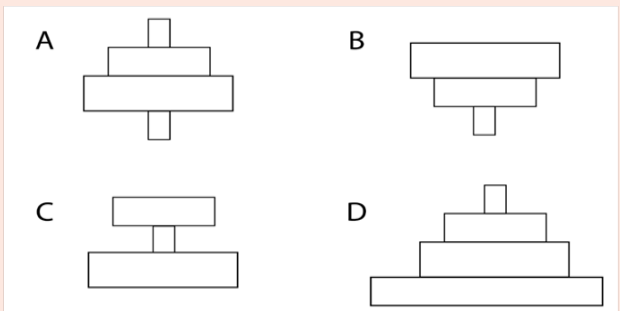


Figure 1.16: Illustration of the nitrogen cycle (Adapted from Pearson Education, 2003)

NH_3 is subsequently converted to nitrite (NO^-_2) and nitrate (NO_3^-) by bacteria known as nitrifying bacteria. Plants obtain nitrogen by absorbing ammonium salts (NH_4^+) and nitrate (NO_3^-) through their roots. Nitrate and ammonium are used to produce organic compounds, while Nitrogen in its organic form is obtained by animals when they consume plants or animals. Decomposers return NH_3 to the soil by decomposing solid waste and dead or decaying matter, and Nitrifying bacteria convert NH_3 to nitrite and nitrate. Finally, denitrifying bacteria convert nitrite and nitrate to N_2, released back into the atmosphere.

Application activity 1.2

1. a. Explain how herbivores affect their grassland environment
   b. What would happen if herbivores were removed from Akagera National Park?
   c. What would happen to Akagera National Park if overgrazing occurs?
2. The diagrams A, B, C and D indicate different cases of pyramid of numbers. Using your knowledge on pyramids, analyses and interpret each diagram



1.3 Ecological succession

Activity 1.3

Use books and search for information related to ecological succession. Describe how new species should appear on bare rocks.

Communities are not usually static, and the numbers and types of species that live in them generally change through time. This is called ecological succession. Important cases of succession are primary and secondary succession.

1.3.1 Primary succession

Primary succession occurs in an area that has never been colonized such as bare rock. This type of environment may come about when lava flows from a volcano and hardens into rock, a glacier retreats and leaves behind bare rock or when a landslide uncovers an area of bare rock.

The first species to colonize a disturbed area are called pioneer species including bacteria and lichens that can live on bare rock. These species change the environment and make the way for other species to come into the area. Along with wind and water, they help weather the rock and form soil. Once soil begins to form, plants can move in from pioneer species to intermediate stages and to climax communities (Figure 1.17). At first, the plants include herbs, grasses and other species that can grow in thin, poor soil. As more plants grow and die, organic matter is added to the soil. Soil is improved and gets the capacity to hold water. The improved soil allows shrubs and trees to move into the area.

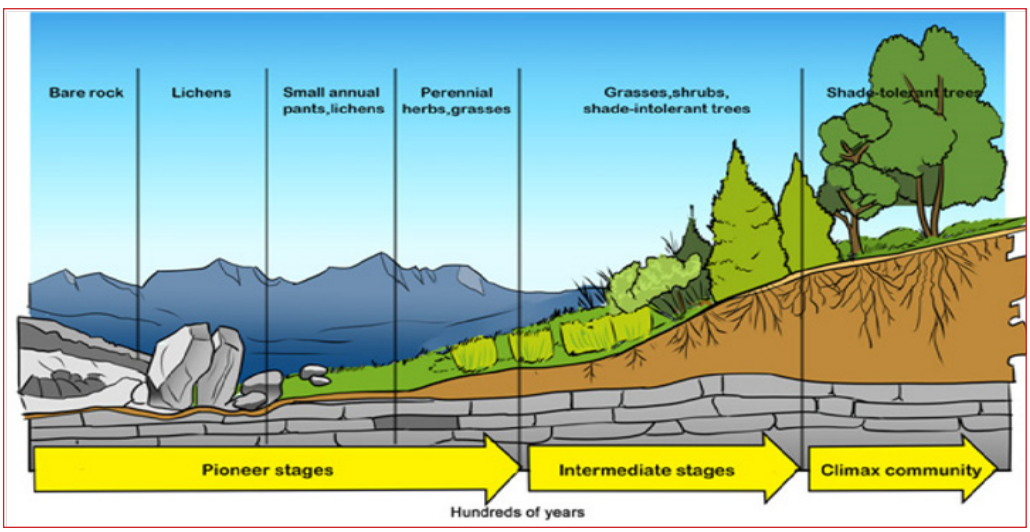


Figure 1.17: Primary succession

1.3.2 Secondary succession

Secondary succession occurs in a formerly inhabited area that was disturbed. The disturbance could be a fire, flood, or human action such as farming. This type of succession is faster because the soil is already in place.

In this case, the pioneer species are plants such as grasses, birch trees, and fireweed. Organic matter from the pioneer species improves the soil and lets other plants move into the area.

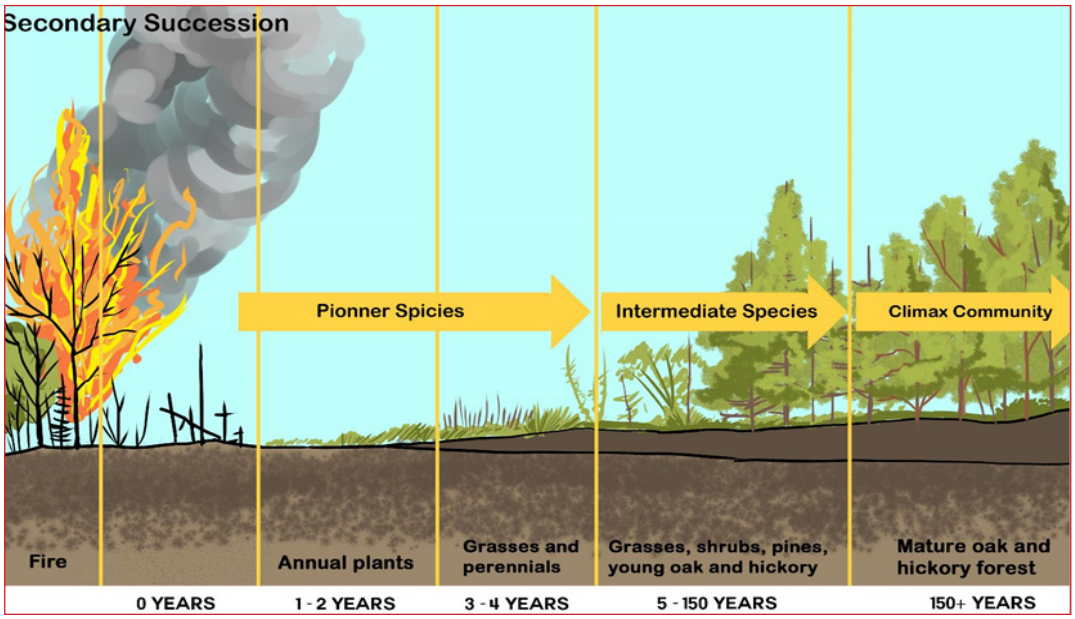


Figure 1.18: Secondary succession

Similarities and differences between primary and secondary succession are summarized in the following table:

Table: 1.2 Comparison between primary succession and secondary succession

Primary succession	Secondary succession
Begins with no life	Follows a disturbance that leaves the soil intact
No soilSoil is present	Lichens and mosses are the first colonizers
Seeds and roots already present	Biomass low Biomass higher
New area e.g. Volcanic island	Old area e.g. following a forest fire

Application activity 1.3

How would you apply what you learned to explain why new species should appear in an area that have been disturbed by fire

1.4 Bioaccumulation and bio magnification

Activity 1.4

Use the school library and search additional information on the internet. Discuss between bioaccumulation and bio magnification

1.4.1 Bioaccumulation

Bioaccumulation refers to the accumulation of toxic chemical substances such as pesticides, or other chemicals in the tissue of a particular organism. Bioaccumulation occurs when an organism absorbs a substance at a rate faster than that at which the substance is lost by catabolism and excretion.

1.4.2 Bio magnification

Bio magnification is a process by which chemical substances become more concentrated at each trophic level. Bioaccumulors of toxic substances such as heavy metals and polychlorinated biphenyls that slowly increases up in concentration in living organisms including bacteria, algae, fungi, and plants. Bioaccumulants enter a body through contaminated air, water, and/or food, and keep on accumulating because they are very either slowly metabolized, not all metabolized, or are excreted very slowly

1.4.3 Example of the causes of bio magnification

Some toxic chemicals were deliberately put in the environment to kill insect pests. One of these pesticides is Dichloro Diphenyl Trichloroethane (DDT), which was used to control mosquitoes and other insect pests. It was commonly sprayed on plants and eventually entered water supplies. There it was absorbed by microscopic organisms, which in turn were eaten by small fish and the small fish eaten by larger fish from where it could have transferred to other animals, where it accumulates in the fat tissue of animals at the top of the food chain. This food chain shows typical concentrations of DDT found in a food chain (in parts per million, ppm):

water	⟶	zooplankton	⟶	small fish	⟶	Large fish	⟶	Birds
		0.040 ppm		0.5 ppm		2 ppm		25 ppm

Another biological magnification of Polychlorinated Biphenols (PCBs) was found in the food web of great lakes, where the concentration of PCBs in herring gull eggs, at the top of the food web, is nearly 5,000 times that in phytoplankton at the base of the food web.

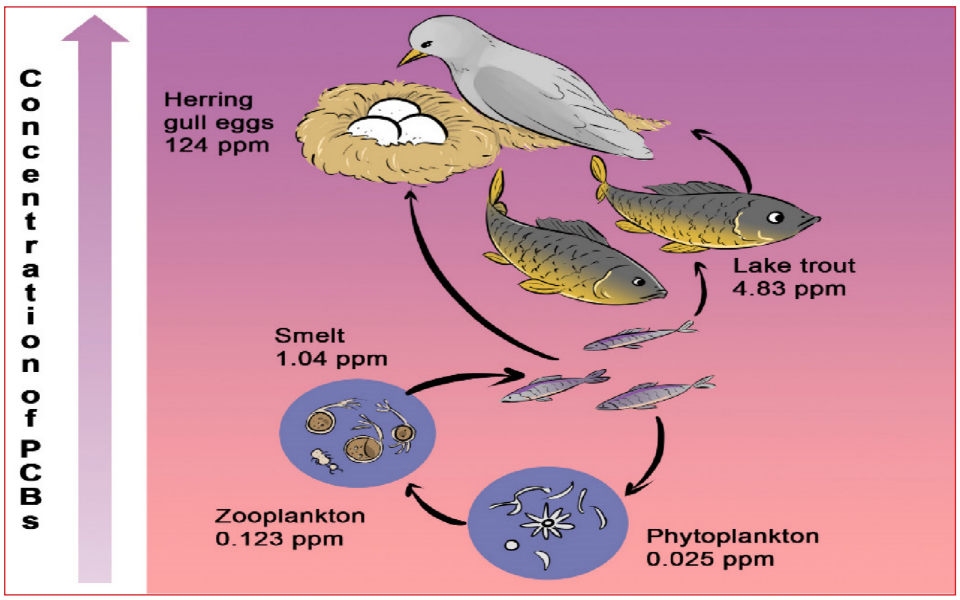


Figure 1.19: Biological magnification of PCBs in a great lakes food web.

1.4.4 Consequences of bio magnification

The first sign of the problem was a decline in the number of predator birds. Studies showed that the eggs of these birds were easily cracked. In fact, the weight of the mother sitting on the eggs cracked them. It was finally discovered that DDT was building up in the tissue of the birds and interfering with the calcium needed for the shell to be hard.

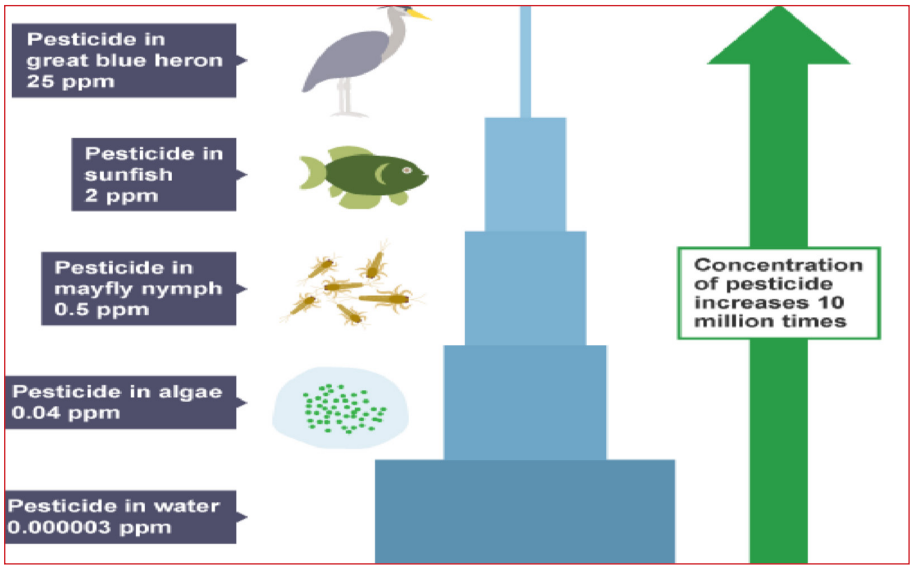


Figure 1.20: Biomagnification of pesticides in food chain

1.4.5 Prevention and reduction of bioaccumulation of toxic substances

The following are some of the ways to prevent and to reduce bioaccumulation of toxic substances:

- Do not put harmful substances into water system or storm drains.
- Reduce the use of toxic chemical pesticides.
- Eat certified organic foods when possible.
- Avoid fishing or spending time in contaminated areas.

Application activity 1.4

In the face of biological magnification of toxins such as DDT, construct the levels of food chains where it is healthier to feed on

1.5 Efficiency of ecological production

Activity 1.5

Use the books from the school library and search further information from the internet. Discuss the roles of efficiency of ecological production and make a brief description of the ecosystem primary production, total primary production, and net primary production.

1.5.1 Efficiency of primary production

The amount of light energy converted to chemical energy in the form of organic compounds by autotrophs during a given period of time is called ecosystem primary production (R). Most primary producers use light energy to synthesize energy rich-organic molecules, which are subsequently broken down to generate adenosine triphosphate (ATP). The total primary production in an ecosystem's gross production (GPP) is the amount of light energy that is converted to chemical energy by photosynthesis per unit time.

Note that not all of this production is stored as organic material in the primary producers because they use some of the molecules as fuel in their own cellular respiration. The net primary production (NPP) equals the gross primary production minus the energy used by the primary producers for respiration(R), as it is summarized in the following formula, i.e NPP = GPP – R.

In many ecosystems, NPP is about one-half of GPP.

To an ecologist, net primary production is the key measurement because it represents the storage of chemical energy that will be available to consumers in the ecosystem

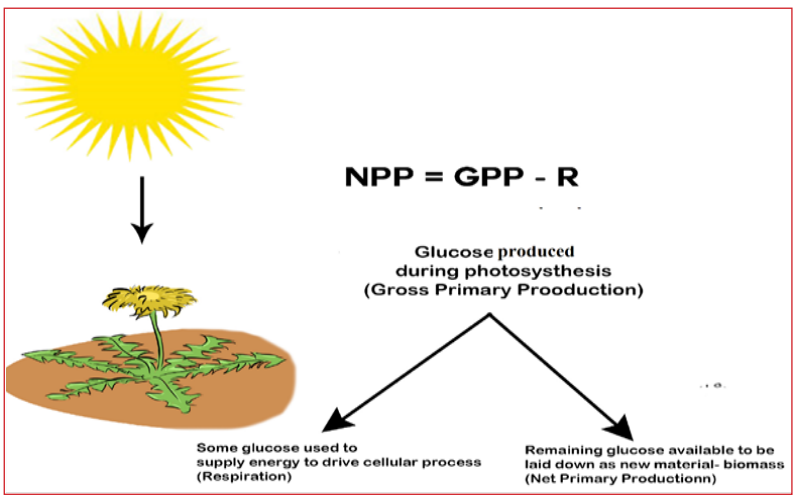


Figure 1.21: Illustration of the net primary productivity

1.5.2 Efficiency of secondary production

The amount of chemical energy in consumer's food that is converted to their own biomass during a given period of time is called the secondary production of the ecosystem. Consider the transfer of organic matter from primary producers to herbivores, the primary consumers. In most ecosystems, herbivores eat only

a small fraction materials produced by plants. Moreover, they cannot digest all the eaten plant materials. Thus, much of primary production is not used for consumers. In this case, the secondary production is calculated by:

Net Secondary Production (NSP) = Gross Secondary Production (GSP) – Respiration (R)

NSP = GSP-R

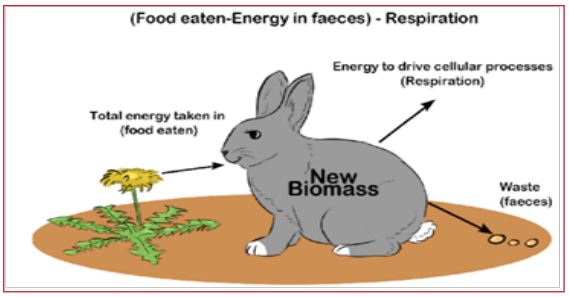


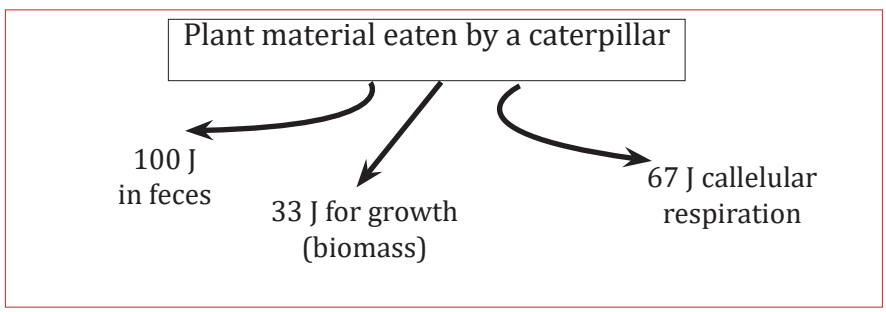
Figure 1.22: Net secondary production

1.5.3 Ecological production efficiency

Production efficiency is the percentage of energy stored in assimilated food that is not used for respiration. It is calculated as follows:

$$\text{Production efficiency} = \frac{\text{Net secondary production X 100\%}}{\text{Assimilation of primary production}}$$

Production efficiency is expressed in percentage (%).As an example, when a caterpillar feeds on a plant leaf, only about 33 J of out 200 J, or one-sixth of the energy in the leaf is used for secondary production or growth. The caterpillar uses some of the remaining energy for cellular respiration and passes the rest in faeces. The energy contained in faeces remains in the ecosystem temporarily, but most of it is lost as heat after the faeces are consumed by detritivores. The energy used for caterpillar's respiration is also lost from the ecosystem as heat.



$$\text{The production efficiency} = \frac{33X100}{200} = 16.5\%$$

Application activity 1.5

1. As part of a new reality show on television, a group of overweight people are trying to safely lose in one month as much weight as possible. In addition to eating less, what could they do to decrease their production efficiency for the food they eat?
2. Tobacco leaves contain nicotine, a poisonous compound that is energetically expensive for the plant to make. What advantage might the plant gain by using some of its resources to produce nicotine?
3. If an insect eats plant seeds containing 100J of energy, energy from which 30 J is used for respiration while 50J remains in faeces.
   a. Calculate the net secondary production.
   b. Estimate the production efficiency

Skills lab 1

Being exposed to hands on and minds on activities like fieldworks either in school environment or in parks in order to observe the different species, populations, and communities related to the unit ecosystem. The various skills such as identification of species, communication have been developed.

1. All animal species found in your school and village
2. Identify and describe the plant species found in your school and village
3. Identify some areas in your school or village that should be contaminated by bioaccumulants.

Discuss your findings and write a report and present

End unit assessment 1

Section A: Multiple choice questions

Choose the letter that best answers the question or completes the statement

1. All of life on Earth exists in a region known as
   a. Ecosystem
   b. Biome
   c. Biosphere
   d. Ecology
2. Groups of different species that live together in a defined area make up
   a. Population
   b. Community
   c. Ecosystem
   d. Biosphere
3. The series of steps in which a large fish eats a small fish that has eaten algae is a) Food web b) Food chain c) Pyramid of numbers d) Biomass pyramid. The total mass of living tissue at each trophic level can be shown in
   a. Energy pyramid
   b. Pyramid of numbers
   c. Biomass pyramid
   d. Biogeochemical cycle
4. The total mass of living tissue at each trophic level can be shown in
   a. Energy pyramid
   b. Pyramid of numbers
   c. Biomass pyramid
   d. Biogeochemical cycle
5. An ecosystem is not considered to be self-sustaining if
   a. There is interaction between biotic and abiotic factors
   b. Some of its living organisms incorporate energy into organic compounds
   c. Cycling of materials occurs between organisms and their environment
   d. It lacks a constant supply of energy
6. By what process do:
   a. Decomposers convert organic matter into ammonia
   b. Bacteria convert gaseous nitrogen into ammonia
   c. Nitrosomonas convert ammonia into nitrites
   d. Pseudomonas convert nitrates into gaseous nitrogen

Section B: Short Answer Type Questions

7. What is the meaning of the term ecology?
8. Name the different levels of organization within the biosphere, from smallest to largest
9. How is sunlight important to most ecosystems?
10. Why is the transfer of energy and matter in a food chain only about 10 percent efficient?

Section C: Long Answer Type Questions

11. Describe the three different types of ecological pyramids.
12. Why do the rectangles in a pyramid of energy get smaller at each higher trophic level?
13. Discuss the reasons why the secondary succession is usually much faster than primary succession?
14. The table below shows mean values for primary productivity for four ecosystems: temperate deciduous forest, tropical forest, temperate grassland, and intensively cultivated land in a temperate region

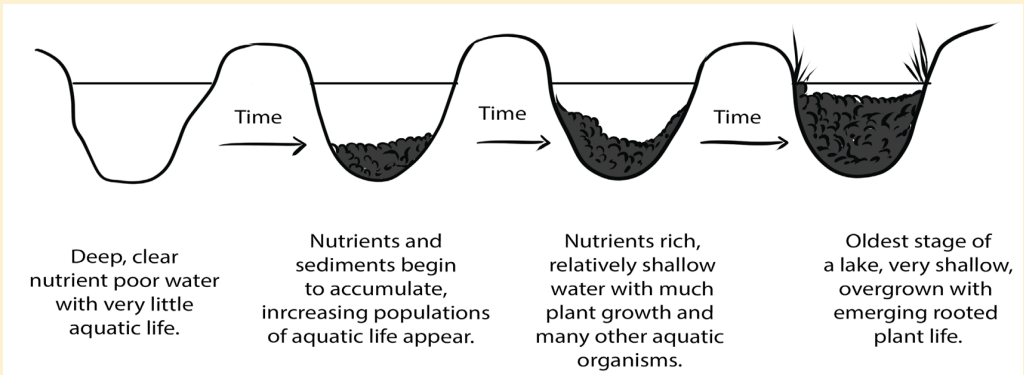
Ecosystem	Primary productivity Kjm-2 yr-1
Temperate deciduous forest	26000
Tropical forest	40000
Temperate grassland	15000
Intensively cultivated land in a temperate	3000

a. Suggest two reasons to account for the higher primary productivity of a tropical forest compared with a temperate forest.

b. Suggest explanations for the difference in primary productivity between temperate grassland and intensively cultivated land.

c. Describe how you would estimate the fresh biomass of the producers in a grassland ecosystem.

15. The diagram shows a number of stages in an ecological succession in a lake.



d. Use information from this diagram above and explain what is meant by an ecological succession.

e. Give two general features this succession has in common with other ecological successions.

f. A number of small rivers normally flow into the lake. These rivers flow through forested areas. Explain how deforestation may affect the process of succession in the lake.

16. Use the skills learnt in classroom and give answers to the following questions:

a. What is an ecosystem?

b. What is the required information to fully describe the make-up of an ecosystem?

c. Discuss the flow of energy through ecosystems and make a description of the various ways in which human activity can influence the energy flow at all levels in terrestrial ecosystems

17. As part of a science project, Ganza Gentil is trying to estimate total primary production of plants in a prairie ecosystem for a period of one year. Once per quarter, Ganza cuts a plot of grass with a lawnmower, do a collection and weighs the cuttings with the main purpose to estimate plant production. What is missing for Ganza to estimate the total primary production?

18. Describe the biogeochemical cycles

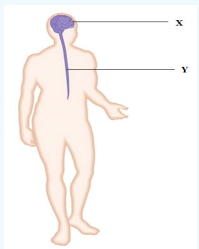
UNIT 2

NERVOUS AND HORMONAL COORDINATION

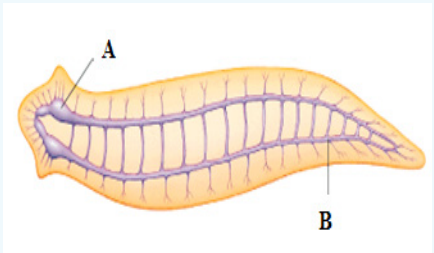
Key unit competence: Describe the structure of neurons, explain the mechanisms of impulse transmission and functions of endocrine glands in the body.

Introductory activity 2

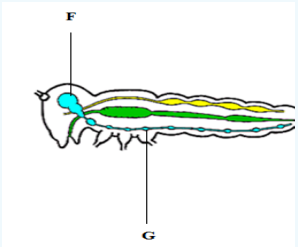
The diagrams 1 shows the human nervous system, diagram 2 shows a planarian nervous system (a planarian is an invertebrate belonging to flat worms and diagram 3 shows an insect nervous system. Observe carefully the diagrams and answer the questions that follow basing on the diagram



1



2



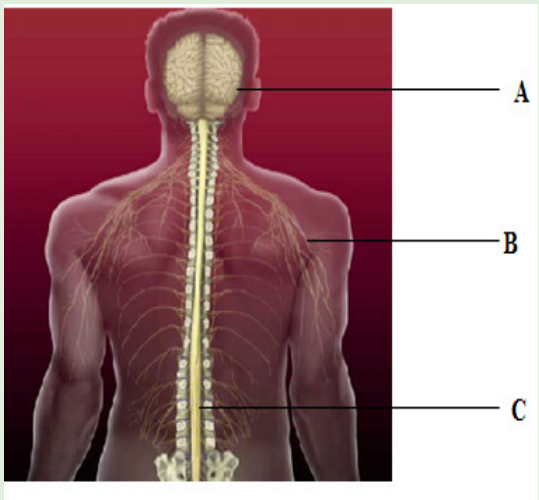
3

1. Identify the parts indicated by X,Y,A, B,F
2. Make a comparison between human ,planarian and insect nervous systems. Do you think that the nervous system of 1,2,3 have common characteristics
3. Identify the main components of human, planarian and insect nervous system

2.1 Human nervous system

Activity 2.1

Human body is made up of many systems. The following diagram illustrates one of the systems of body. Observe carefully this diagram and use the school library in order to answer these questions



1. Which human body system does this diagram represent
2. Identify the names of A,B and C
3. How would you show your understanding of A and C, then B

Coordination: It is the process in which body coordinate, ordinate and control different activities.

The nervous system is a system for gathering, transmitting and interpretation of information. It plays the main functions such as:

i. Sensory input: Sensory receptors present in skin and organs respond to external and internal stimuli by generating nerve impulseswhich are transmitted to the brain and spinal cord.

ii. Integration: The brain and spinal cord sum up the information from all over the body and send out nerve impulses

iii. Motor output: The nerve impulses from the brain and spinal cord are transmitted go to the effectors, which are muscles and glands.

The Nervous system is divided into two main divisions: The central nervous system (CNS) and the peripheral nervous system (PNS) The central nervous system (CNS) consist of the brain and spinal cord, which are located in the midline of the body.

The peripheral nervous system (PNS), which is further divided into the somatic division and the autonomic division, includes all the cranial and spinal nerves.

2.1.1 Some key word definitions

- Irritability or sensitivity. This is the ability of living organisms to detect and respond to a stimulus
- A stimulus: This is any change in the external or internal environment which provokes a response
- Receptors: These are specialized cells that detect a stimulus.
- Effectors: are organs that respond to the stimuli and bring about a response such as glands and muscles.
- A nervous system: This is a system for gathering transmitting and interpretation of information of information.
- The response may be to both the external and internal environments.
- Neurone or nerve cell: It is the basic functional unit of the nervous system. Neurones are cells specialized to generate and transmit nerve impulses (action potentials) are cells which transmit nerve impulses (action potentials).

2.1.2 Division of nervous system

The nervous system of a mammal comprises of the central nervous system (CNS) consisting of the brain and the spinal cord, and the peripheral nervous system (PNS) consisting of the cranial nerves from the brain, the spinal nerves from the spinal cord and the sensory organs (Figure 2.1).

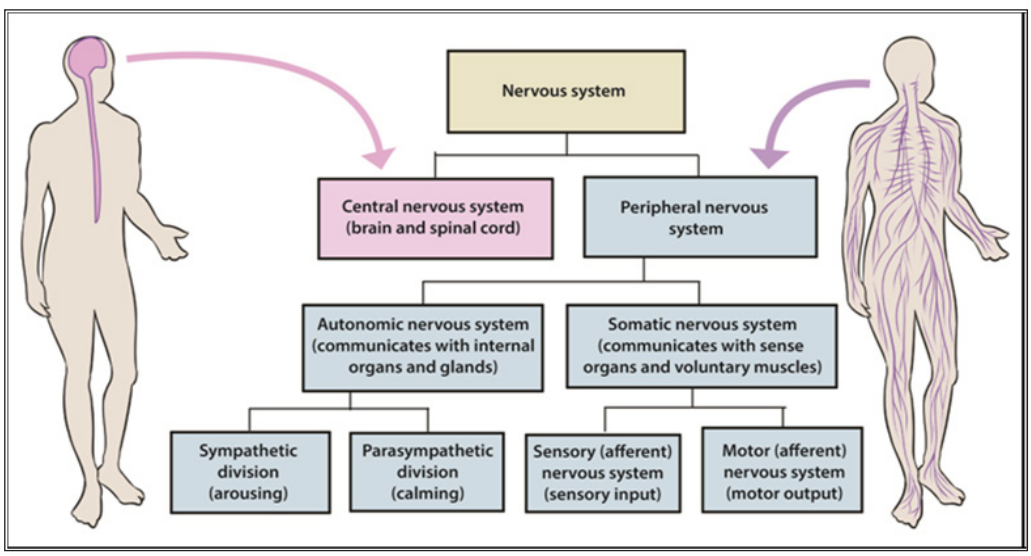


Figure 2.1: Organization of the human nervous system

1. Human brain

The brain is the enlarged end of the spinal cord. It is enclosed in the skull which protects it against mechanical damage. It is divided into three main parts namely: the fore brain, the mid brain, the hind brain.

a. Forebrain

This consist of: cerebrum, thalamus, hypothalamus and pituitary gland

- **Cerebrum:**

This is the largest part of the brain made up of two hemispheres called the right and the left cerebral hemispheres. The left cerebral hemisphere controls those activities of the right side of the body while the right cerebral hemisphere controls those of the left side of the body.

The functions of the cerebral hemisphere

- It is the centre of the judgment, memory, reasoning and imagination.
- It receives the impulses from the sensory organs: sight, taste, sound and touch.
- It controls all the body's voluntary activities, e.g. walking, eating, singing,

- **Thalamus:**

This is a relay centre. It relays sensory information towards higher centre. It is the centre for the perception of pain and pleasure.

- **Hypothalamus**

It performs many functions such as; regulates and monitors the temperature of blood, monitors and regulates the water content of blood, a co-ordinating centre for activities of the internal organs, e.g. rate of heart beat, blood pressure. It is a centre of for feelings such as; hunger, thirst, sex drive, satisfaction, sleep, speech, etc. As an endocrine gland, it produces hormones i.e. anti-diuretic hormone (ADH) and oxytocin

- **Pituitary gland:**

It produces hormones such as: Follicle-stimulating hormone (FSH), Thyroid stimulating hormone (TSH), Adreno-cortico trophic hormone (ACTH), Prolactin hormone and Luteinizing hormone (LH). It also serves as a master gland i.e controls activities of other endocrine glands.

b. Mid brain

This acts as an association centre between the fore and the hind brain. It is a relay centre for audio and visual information. It is also responsible for movement of the head and the trunk.

The **hind brain** receives the impulse from the ear, the skin and the semi-circular canals. It consists of: The cerebellum and the medulla oblongata

The cerebellum: It lies behind the optic lobes. It receives impulses simultaneously from the eyes and the ears. It regulates and co-ordinate muscular movement, especially those concerned with maintaining body equilibrium and controls all the unconscious activities of the body.

The medulla oblongata: This controls all the involuntary movements of the body especially those concerned with respiration, digestion, heartbeat, breathing rate and sneezing.

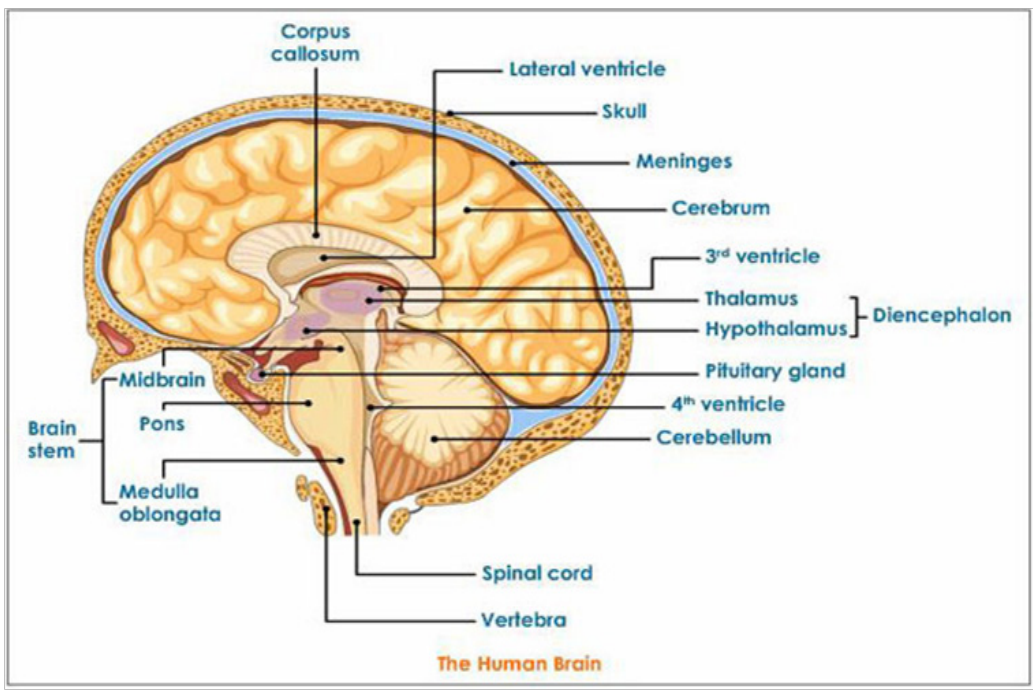


Figure 2.2: Main parts of the brain

2. Spinal cord

The spinal cord is a dorso -ventrally flattened cylinder of nervous tissue running from the base of the brain down the lumbar region. It is protected by the vertebrate of the backbone and the meninges.

Functions of spinal cord include:

- It is a coordinating centre for simple reflex such as the knee-jerk response and the autonomic reflexes such as contraction of the bladder.
- Providing a means of communication between peripheral nerves and the brain.

- It sends messages to the effectors

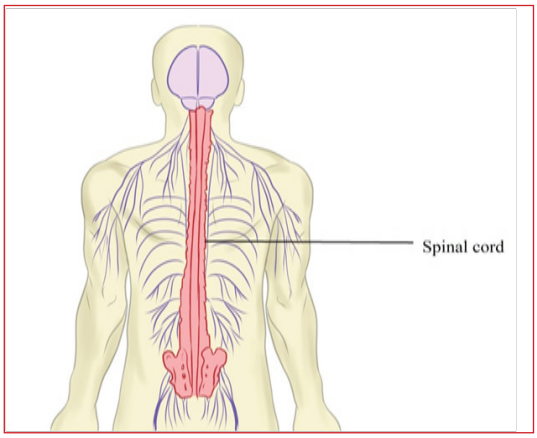


Figure 2.3: Position and external structure of spinal cord

A transverse section of the spiral cord shows an H-shaped central core of grey matter. Grey matter is composed of nerve cell bodies, dendrites and synapses surrounding a central canal which contains cerebrospinal fluid. White matter: around the grey matter, is an outer layer containing nerve fibres whose fatty myelin sheaths give it its characteristics colour.

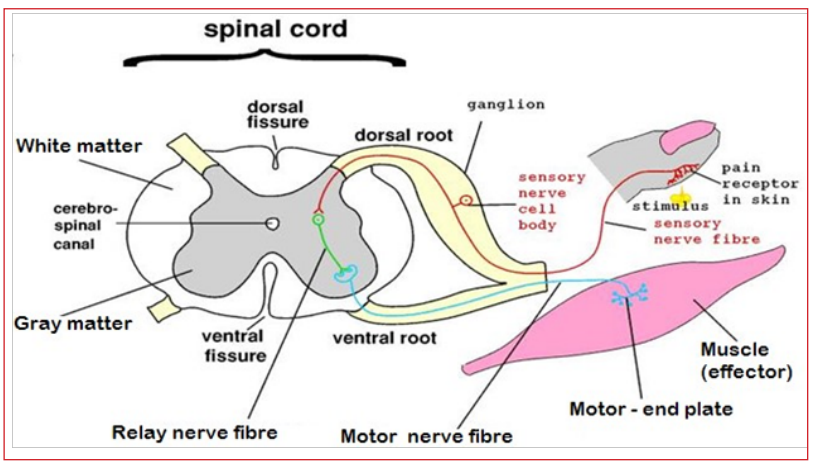


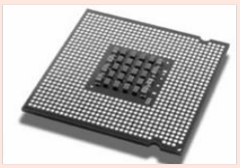
Figure 2.4: Transverse section of the spinal cord

The spinal cord acts as a coordinating centre for simple reflex such as knee jerk response and autonomic reflexes. The spinal cord acts as means of communication between spinal nerves and the brain. It sends impulses to the brain through sensory neurons from the body and returns the motor impulses to the effectors which are muscles and glands.

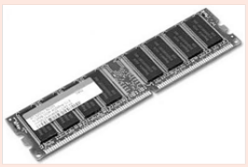
Application activity 2.1

1. The diagrams A, B and C show a laptop, processor and RAM (Random Accessory Memory) respectively. How would you link what you learned to answer the following questions?

A



B



C

1. Which organ of the nervous system that correspond to A,B and C
2. Identify the parts of the nervous system that plays the same role as C.

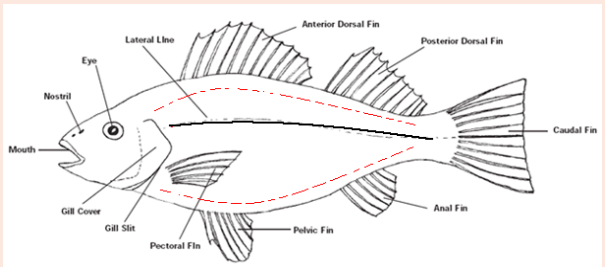
2. Identifying of fish nervous system component

Materials needed

- (Dead fish.)
- Dissecting kit
- Dissecting board
- Cotton wool
- Pins

Procedure

- Place the fish on the dissection board. Dissect along, as shown in dotted lines below



- Open the abdominal cavity

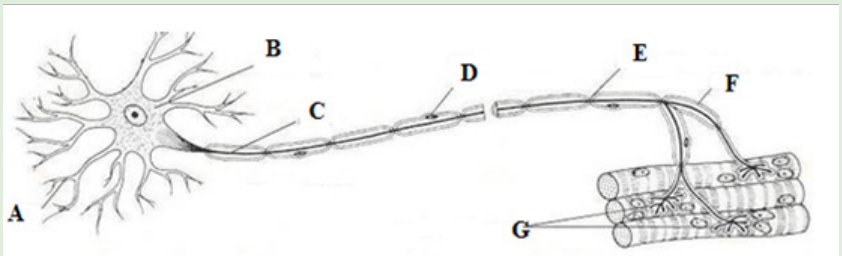
1. Locate the organs (brain and spinal cord) associated with Nervous systems
2. Draw and label the brain you are observing

2.2 Structure, types and functions of neurons

Activity 2.2

Research activity

a. Observe and label the following illustration



b. Using the school library or search engine, search on the structure of neuron, give the types and function of the above illustration

c. Make a table comparing different types of neurons

Neuron also called nerve cell is the basic functional unit of the nervous system. Neurons are cells specialized to generate and transmit nerve impulses (action potentials) are cells which transmit nerve impulses (action potentials).

2.2.1 Types of neurons

Nerve cells may be grouped according to the number of processes they possess so that their types include:

- Unipolar neurons (sensory neuron): those with one process only, found mainly in invertebrates.
- Bipolar neurons (relay neuron): those with two separate processes such as neurons in the retina of the vertebrate eye.
- Multipolar neurons (motorr neuron): those with more than two processes such as most of the vertebrate neurons.

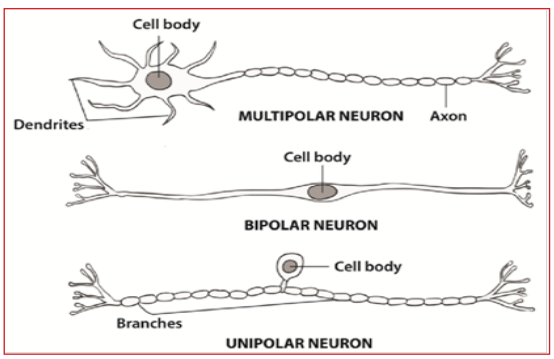


Figure 2.5: Multipolar, bipolar, unipolarneurons

2.2.2 Classification of neurons by their functions

In vertebrates, it is also common to group neurons according to their functions. They include:

- Sensory or afferent neurons: transmit impulses from the receptors to the Central nervous system. In addition to sensory or afferent neurons.
- Motor or efferent neurons: that transmits impulses from the central nervous system to effectors motor organs such as muscles or glands that carry out the response. Most motor neurones are stimulated by impulses conducted by interneurons. However, there are some others that are stimulated directly by sensory neurons.
- Interneurons also known as intermediate or association, or relay or interneuron. They connect the pathways of sensory and motor impulses, and are found mainly in the central nervous system.

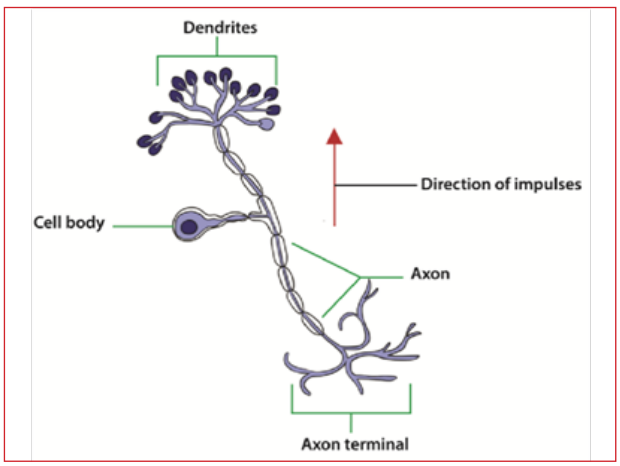


Figure 2.6: Sensory neuron

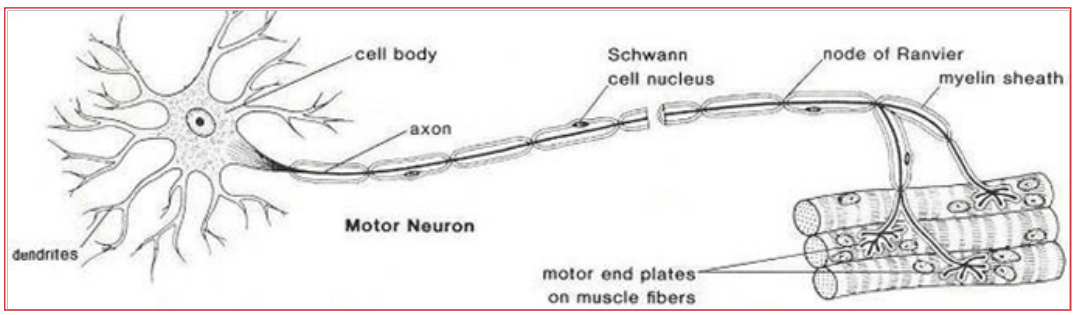


Figure 2.7: Motor neuron (image from google)

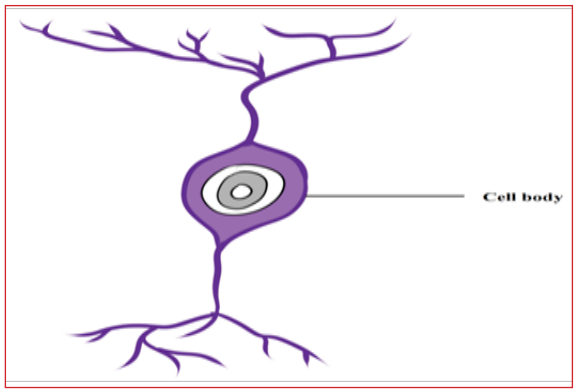


Figure 2.8: Intermediate neuron

2.2.3 Parts of a neuron and their functions

Each motor neuron possesses a cell body and cytoplasm with many mitochondria, endoplasmic reticulum, Golgi apparatus and ribosomes.

The Nissl granules which consist of endoplasmic reticulum and ribosomes function in protein synthesis. The table below (Table 2.1) shows all parts of neuron and their functions.

Table 2.1: Parts of a neuron and their functions

Structure	Functions
Cell body	The cell body has a number of processes called Dendron. The fine terminal branches are called dendrites. These dendrites receive and transmit nerve impulses. nerve impulses toward the cell. It Coordinates the nerve cell activities and makes protein for the growth of the nerve cell,
Axon	Transmits impulses away from the cell body. It contains axoplasm surrounded by the axon membrane known as axomembrane
Synaptic knobs	These contain many mitochondria, endoplasmic reticulum and synaptic vesicles filled with neurotransmitters

Myelin sheath	In a myelinated fibre, the myelin sheath has three functions It acts as an electrical insulator and prevents movement of ions through it e.g. Na+ /K+ ions It speeds up the transmission of nerve impulse (action potential) along the axon. The action potential can leap from one node of Ranvier to the next by salutatory conduction.It guides regeneration of PNS axons
Schwann cells	Secrete the myelin sheath, The Schwann cells are located at regular intervals with their cell membranes wrapped around the axon
Node of Ranvier	Propagates nerve impulses and speeds up their transmission
Terminal dendrite	Transmits nerve impulses to effector organs.

2.2.4 Reflex Actions

A reflex action is a quick and involuntary response of the central nervous system to a stimulus. Examples are: The quick withdrawal of the hand from a hot object, knee jerk, eye blinking. When the spinal cord alone is involved, the reflex action is called spinal reflex and when the brain alone is involved, it is a cranial reflex e.g. blinking of eyes.

Reflex actions are described as involuntary actions and the same stimuli produce the same responses every time. Reflexes are useful because they make autonomic involuntary adjustments to changes in the external environment, such as the iris pupil reflex and the balance during locomotion. They also control the internal environment, such as breathing rate and blood pressure, and prevent damage to body as in cuts and burns. These help to maintain constant conditions, in other word they are involved in homeostasis.

Reflex arc is a pathway followed by a nerve impulse during a reflex action.

The components of reflex arc are:

- Stimulus
- Receptors
- The sensory receptor that detects the stimulus
- The sensory (or afferent) neurone along which the sensory impulse is transmitted;

- The relay neurone in the central nervous system to which the sensory impulse is passed on.
- The motor (or efferent) neurone along which the motor impulse is transmitted; and
- The effector (Muscle or gland) which the motor impulse triggers to bring about an appropriate response.
- CNS (Brain or spinal cord)

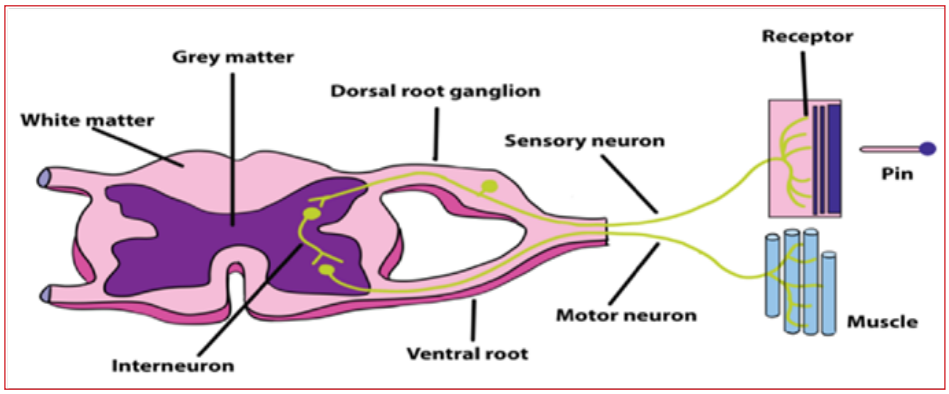


Figure 2.9: Diagram showing reflex arc

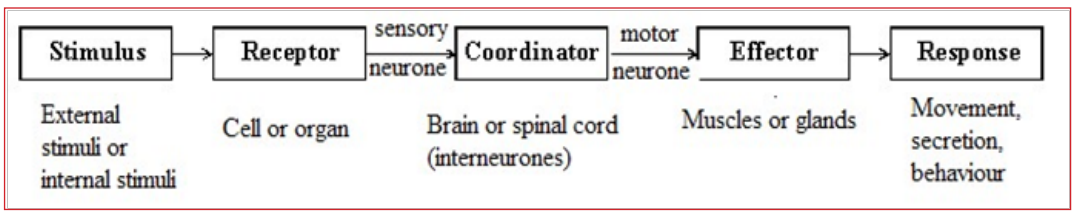


Figure 2.10: Sequence of change in a spinal reflexarc

The sequences of changes that occur during a spinal reflex are:

- A sensory receptor receives a stimulus and impulse is generated in it
- The impulse is transmitted along a sensory neuron towards the spinal cord via the dorsal root
- Once the impulse reaches the grey matter inside the spinal cord, it is passed on to the relay neuron across a synapse
- The relay neuron then transfers the impulse to a motor neuron across another synapse.
- The motor neuron conveys the impulse to an effector such as a muscle where a response takes place.

The pathway that is followed by an impulse along the sensory neurons relay and motor neurone, during a reflex action is called reflex arc.

Application activity 2.2

1. Some people suffer from paralysis; the diagram below shows a paralysed human hand and arm. Suggest the causes of this paralysis referring to how neurons function

(Source: http://www.healthpost.in/news/Mind-controlled-device-may-help-stroke-patients-move-paralysed-hands-325

2.3 Nature, structure and function of synapse in the nervous system

Activity 2.3

Discuss the nature, structure and function of synapse in the nervous system

All cells in animal body tissues are electrically polarized in other words; they maintain a voltage difference across the cell's plasma membrane, known as the membrane potential. This electrical polarization results from a complex interplay between protein structures embedded in the membrane called ion pumps and ion channels. Each excitable patch of membrane has two important levels of membrane potential: the resting potential, which is the value the membrane potential maintains as long as nothing passes along the cell, and a higher value called the threshold potential.

2.3.1 Resting potential in a neuron

A neuron is said to be in the resting state when it is not conducting an impulse. The membrane potential of an unstimulated excitable cell is called the resting potential. A resting potential is the difference in charge (electrical potential difference) which exists between the inside and the outside of the cell membrane. In excitable cells, the resting potential is about -70 millivolts (mV) and the threshold potential is around -55 mV. The negative sign indicates the interior of the cell is negative with respect to the exterior environment.

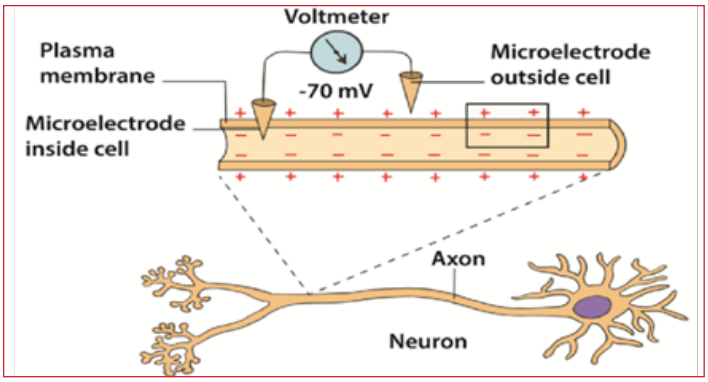


Figure 2.11: Resting potential in a neuron

The resting potential difference across the neuron membrane is maintained by:

- The sodium–potassium pump (Na^+ /K^+). This is always working. Three sodium ions (Na^+) are actively transported out of the cell for every two potassium ions (K^+) pump into the cell. Energy supplied by ATP is used for the transport of ions against their electrochemical gradients.
- The axon membrane: It is more permeable to potassium ions than the sodium ions. This is due to the presence of more potassium ion non-gated, voltageindependent channels and few sodium ion non-gated channels. More K^+ ions can diffuse out back again faster than Na^+ ions which can diffuse back in. The resting membrane potential is mainly determined by sodium-potassium pump, facilitated diffusion and electrochemical gradient of K^+ ions across the membrane.

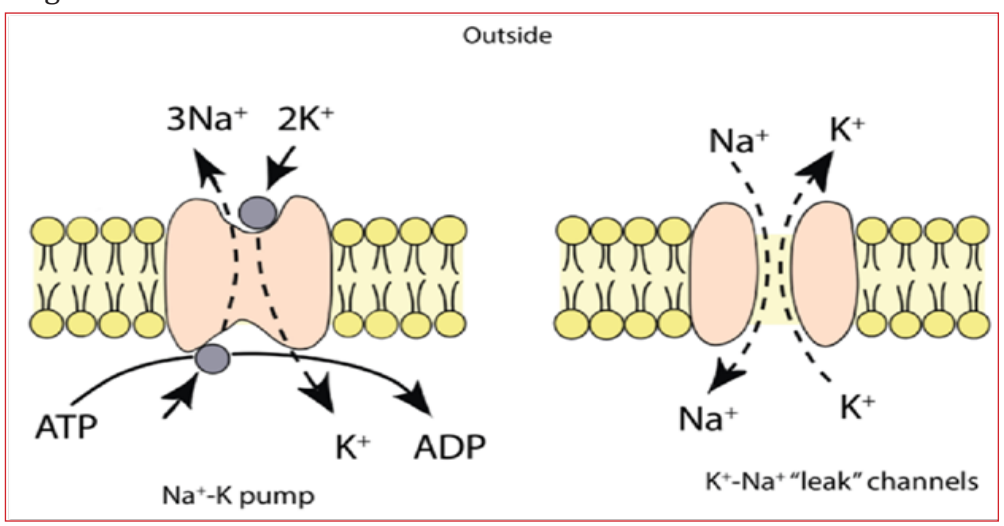


Figure 2.12: Sodium- potassium pump

2.3.2 Action potential

Action potential is the technical term for impulse. An action potential is rapid temporary reversal in the electrical potential difference of an excitable cell e.g. a neuron or a muscle cell. It is caused by changes in the permeability of the membrane following the application of a threshold stimulus. The action potential has a depolarization phase and a repolarization phase. There may be a short hyperpolarized phase after the repolarization phase. The time taken for an action potential is 2 to 3 milliseconds.

2.3.3 Depolarization

When a stimulus such as electric current reaches a resting neuron, some sodium voltage gated channels in the stimulated region of the axon membrane open. Sodium ions (Na^+) move into the axon by facilitated diffusion down an electrochemical gradient. The initial influx of sodium ions is slow. The axon membrane becomes slightly depolarized and the sodium voltage gates are sensitive to voltage changes. More gates open allowing more Na^+ ions to diffuse into the cell leading to further depolarization.

When the potential difference across the membrane reaches a threshold value (-50mV), many more sodium voltage gated channels open.

This is an example of positive feedback. The rapid diffusion of Na^+ ions leads to a sudden increase in the cell's potential difference which becomes positive (+ 40mV). This reversal in the potential difference is known as depolarization and lasts for about 1 millisecond

2.3.4 Repolarization

The reversal in polarity to + 40 mV causes the voltage gated sodium channel to close. At the same time the voltage gated potassium channels open. The potassium ions K^+ diffuse out of the cell down their electrochemical gradient to the tissue fluid outside. The axon membrane is repolarized. The action potential alters from + 40 mV to -70mV.

2.3.5 Hyperpolarization

The potassium voltage-gated channels are slow to close. An excess of K^+ ions leave the axon. The inside of the membrane becomes more negative. The voltage falls slightly below -70mV and causes hyperpolarization. However, within a few milliseconds, the potassium voltage-gated channels close. The resting potential of -70mV is reestablished by the Na^+ /K^+ pump and different rates of facilitated diffusion of K^+ and Na^+ ions through the non-gated ion channels.

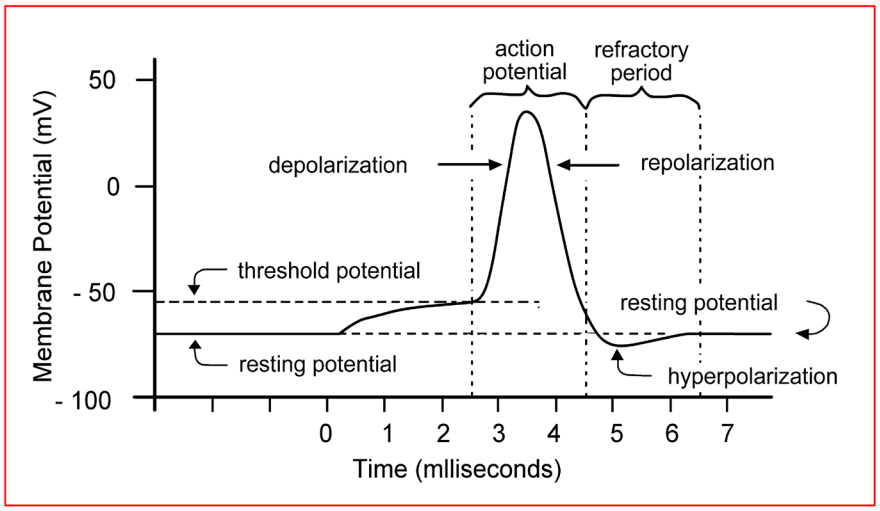


Figure 2.13: Action potential

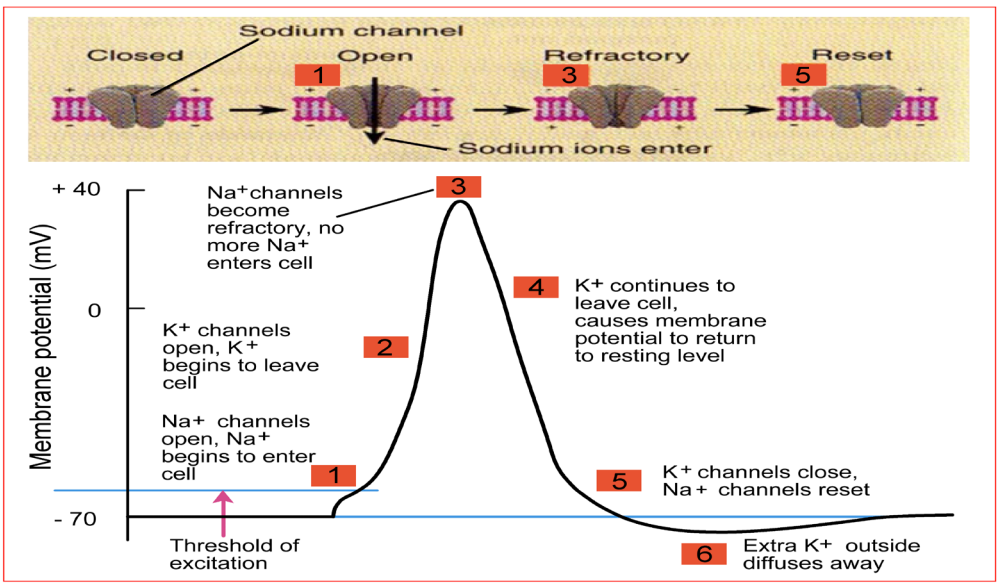


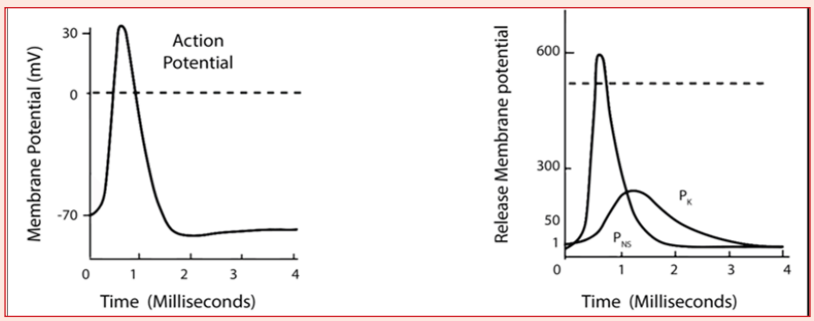
Figure 2.14: Sodium –potassium pump (Na^+/K^+) and action potential

2.3.6 Frequency of action potentials

Information in axons is coded in the frequency of the action potentials. A weak stimulus above threshold produces fewer action potentials. A stronger stimulus produces a greater frequency of action potentials. As the intensity of stimulation increases, more action occurs.

Application activity 2.3

The graphs below show the changes that occur during an action potential in a membrane potential and the relative membrane permeability to sodium and potassium ions in a neurone. Observe well to answer the following questions:



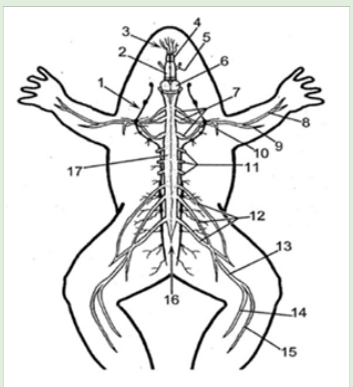
a. Describe the movement of ions during an action potential

b. Explain what is the effect of an action potential generation if there is a lowering of sodium ions in the extracellular fluid

2.4 Transmission of a nerve impulse

Activity 2.4: Research activity

The diagram below shows different nerves of a frog after dissection. Use school library and search additional information on internet and watch the movies on youtube related to frog dissection.



1. Redraw this diagram and label it from 1 to 17
2. Identify the main difference between the part numbered 13 from other parts
3. Identify the main function of 13
4. What would happen to a frog when 13 is damaged

2.4.1 Mechanism of transmission of nerve impulses along an axon

- The neurons, like other cells, are positively charged outside and negatively charged inside. The membrane of the axon is said to be polarized. The potential difference (voltage) across their membranes is of – 70mV and is called resting membrane potential (RMP).
- A stimulus (heat, pain, bite, sound ...) creates an action potential (AP) or an impulse that is transmitted along an axon by electro-chemical change.
- During an action potential, the membrane potential falls until the inside becomes positively charged with respect to the exterior. The membrane at this point is said to be depolarized. It takes few milliseconds to happen. In fact, the potential changes from – 75 mV to + 40 mV at the point of stimulation. That is an electrical change that runs along the axon.
- As the impulse is transmitted along the axon, the Na^+/K^+ pumps of the axolemma are re-established. Sodium channels open first, allowing a large number of Na^+ ions to flow in.
- The axoplasm becomes progressively more positive with respect to the outside of the axolemma. Then, almost instantly, the permeability of the membrane to Na^+ ions ceases, and the net flow of Na^+ ions stop. At the same time K^+ ion channels start to open and K^+ ions flow out from axoplasm where they are in high concentration. The counter-flow is of $3Na^+$ ions against $2K^+$ ions.
- The axoplasm now starts to become less positive again. This begins the process of re-establishing the resting potential difference of the membrane. That is an electro-chemical change.

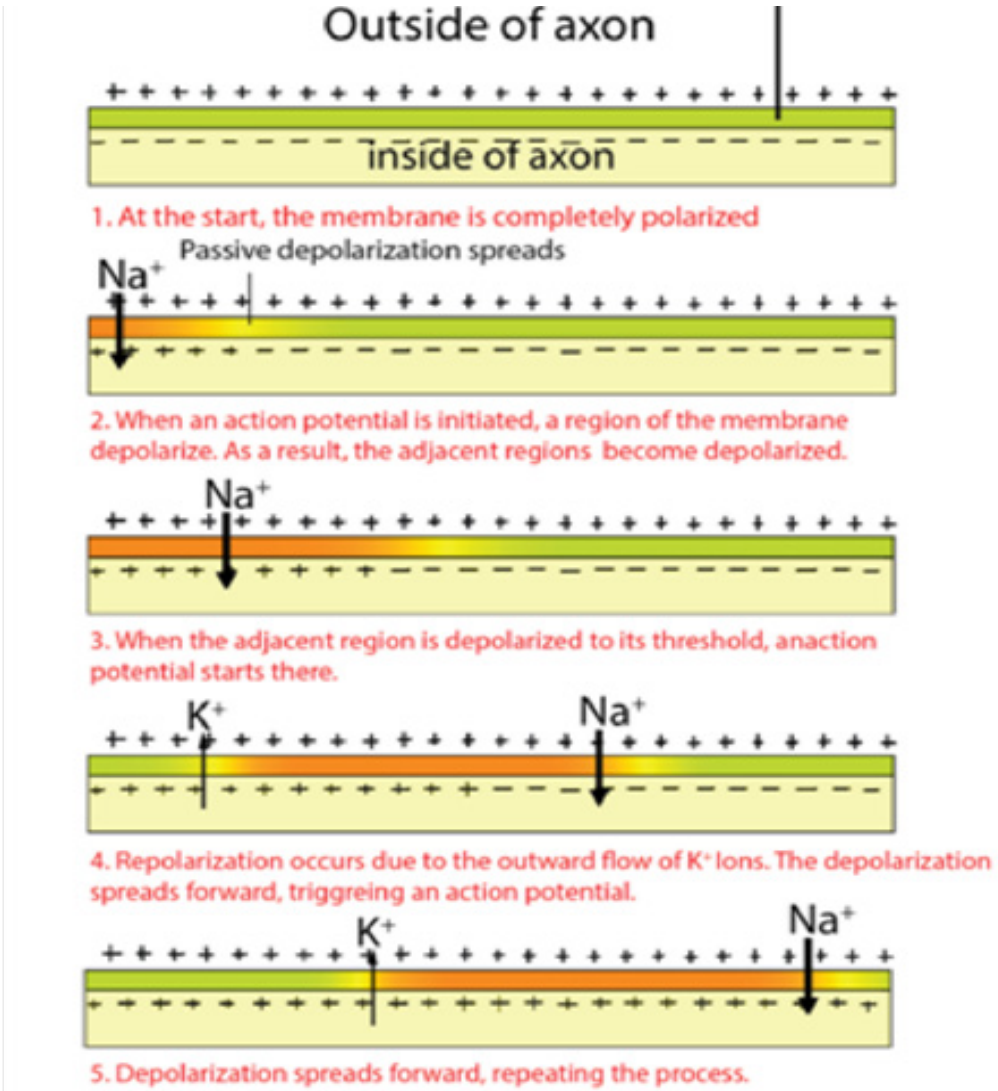


Figure 2.15: Nerve impulse transmission along axon

a. Factors that affect transmission of nerve impulses along the axon membrane

Along the axon membrane, the transmissions of nerve impulses are affected as follows:

- The diameter of the axon: the greater the diameter the faster the speed of transmission of nerve impulses.
- The myelin sheath: myelinated neurones conduct impulses faster than non- myelinated neurones.
- The presence of nodes of Ranvier speeds up the movement of impulses in myelinated neurones.

b. Structure of a synapse

Information from one neuron flows to another neuron across a synapse. The synapse is a small gap separating two adjacent neurons. The synapse consists of:

- A presynaptic ending that contains neurotransmitters, mitochondria and other cell organelles,
- A postsynaptic ending that contains receptor sites for neurotransmitters and,
- A synaptic cleft or space between the presynaptic and postsynaptic endings. It is about 20 nm wide.

The swollen tip of the axon of the presynaptic neuron, called synaptic knob or synaptic bulb contains many membranes bounded synaptic vesicles, mitochondria and microfilaments.

The synaptic vesicles contain neurotransmitter molecules such as acetylcholine or noradrenaline

An example of synapse is the cholinergic synapse which is a synapse which uses acetylcholine (Ach) as neurotransmitter. Calcium and vesicles are involved in the release of neurotransmitter across the synaptic cleft in the mechanism of synaptic transmission to generate an excitatory post-synaptic potential.

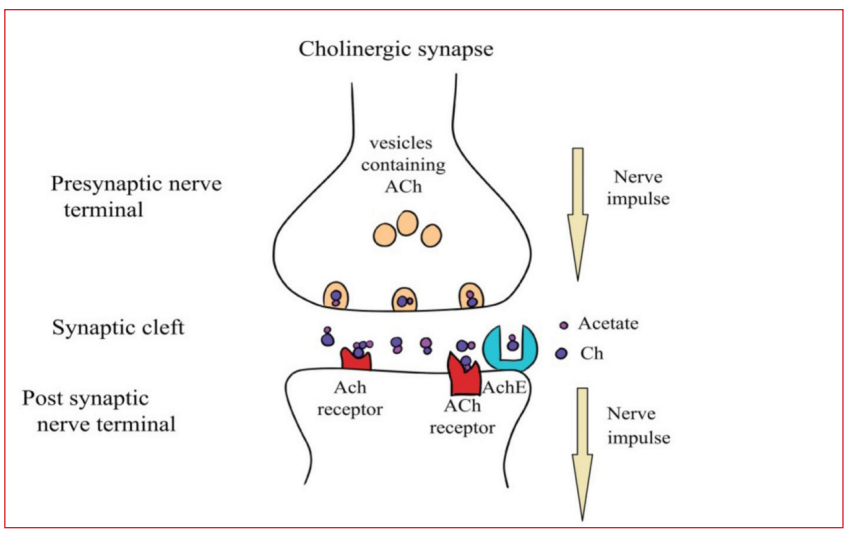


Figure 2.16: Cholinergic synapse

c. Neurotransmitter

A neurotransmitter is a relatively small chemical found in the synaptic vesicle. It helps to transmit an impulse across a synapse or neuromuscular junction.

There are about 50 different types of neurotransmitters in the human body. Examples are acetylcholine released by cholinergic neurons, noradrenaline (norepinephrine) released by adrenergic neurons, dopamine and serotonin including amino acids glutamate and glycine.

2.4.2 Mechanism of nerve impulse transmission across a synapse

- The arrival of an impulse on the synaptic knob causes the opening of Ca^{+2} ion channels on the presynaptic membrane, and Ca^{+2} ions flow in the presynaptic region from the synaptic cleft.
- The Ca^{+2} ions induce a few presynaptic vesicles to fuse with presynaptic membrane and to secrete their neurotransmitters (e.g. acetylcholine) by exocytosis into the synaptic cleft
- The neurotransmitter then binds with the receptor protein on the postsynaptic membrane. This causes the opening of Na^{+} channels on the postsynaptic neuron which in turn becomes depolarized.
- This causes a depolarization of the post-synaptic cell membrane, which may initiate an action potential, if the threshold is reached
- The action of the neurotransmitter does not persist because an enzyme cholinesterase catalyses the hydrolysis of acetylcholine into choline and acetate.

  The breakdown products (choline) are absorbed by the pre-synaptic neuron by endocytosis and used to re-synthesize more neurotransmitter, using energy from the mitochondria.

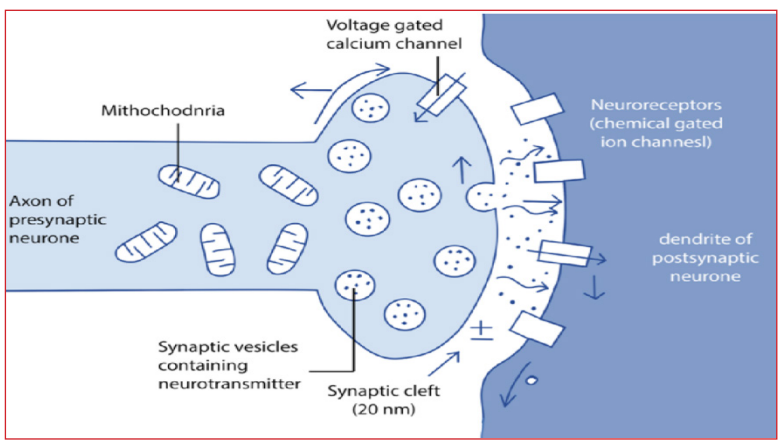


Figure 2.17: Nerve impulse transmission across synapse

2.4.3 Properties of a nerve impulse

a. All or nothing law

An action potential can only be generated after the threshold value is exceeded. After the threshold is reached, the size of the action potential produced remains constant and is independent of the intensity of the stimulus. This is the all or nothing response. All action potentials are of the same amplitude.

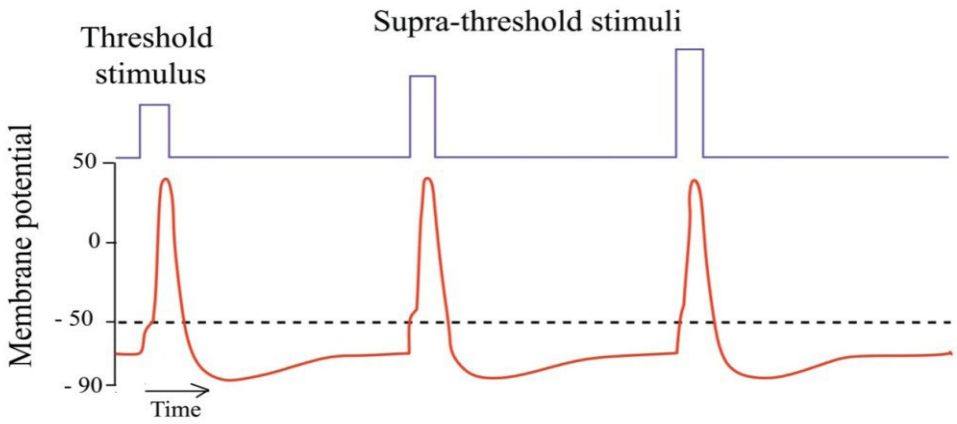


Figure 2.18: Illustration of all or nothing law

b. Refractory period

This is a brief period when an axon is unable to transmit an impulse following transmission of the same. It lasts about 5-10 milliseconds. It is divided into two; absolute and relative periods.

During the absolute refractory period which lasts about 1ms, the axon membrane is unable to respond to another stimulus, no matter how strong it is. An action potential cannot be produced. This is because there is conformational change in voltage-gated sodium channels which are still in a closed, inactive state. This also prevents the action potential from moving backwards.

Following the absolute refractory period, there is a relative refractory period which lasts around 5ms. During this period, the resting potential is gradually restored by Na^+/K^+ pump and the relative permeability of membrane to facilitated diffusion of ions is also restored. A new action potential can then be produced if the stimulus is greater than the usual one. The refractory period therefore allows impulses to move only in one direction and limits the frequency at which successive impulses can pass along axon.

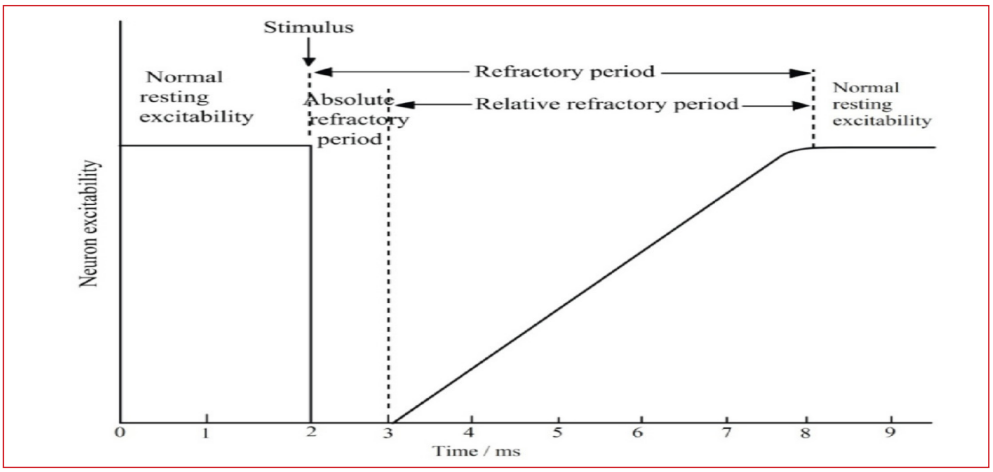


Figure 2.19: Neuron excitability before and after a nerve impulse

c. Saltatory conduction

It is movement or jump of nerve impulses from one node of Ranvier to another along the axon membrane of neurone.

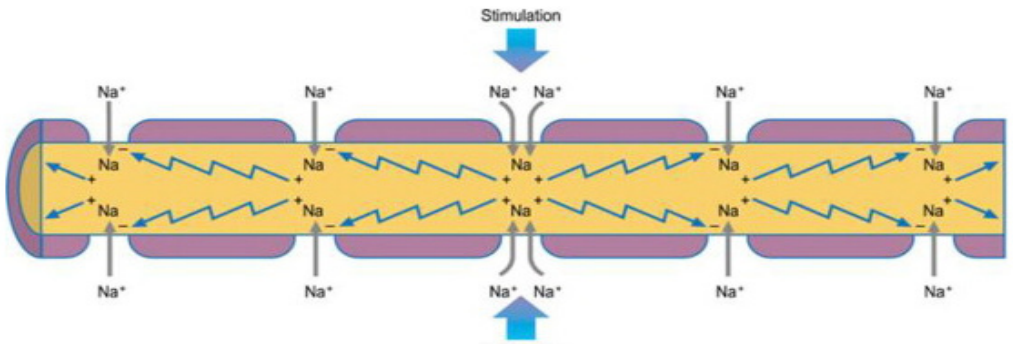
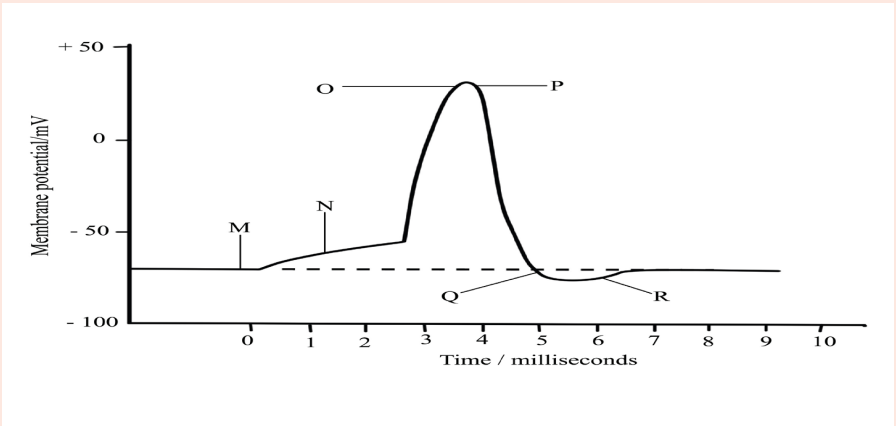


Figure 2. 20: Saltatory conduction. Source: Adapted from (https://www.sciencedirect.com/topics/veterinary-science-and-veterinary-medicine/saltatory-conduction)

Activity 2.4

1. Suppose a cell's membrane potential shifts from -70 mV to -50 mV. What changes in the cell's permeability to K^+ or Na^+ could cause such a shift?
2. The diagram below shows the changes in potential difference across an axon membrane as a nerve impulse passes



a. Explain what happens at M, N, O, P, Q and R as shown in the graph
b. Name two factors that can determine the speed of transmission of a nerve impulse and how each affects the speed
c. Explain why the initiation of an action potential is considered a positive feedback mechanism

2.5 Structure and function of the endocrine system in humans

Activity 2.5

Make a research using internet, watching movies, using different books from the school library and a charts showing different endocrine glands, make short notes on structure location and function of the endocrine system in humans

Endocrine glands secrete their products called hormones into the interstitial fluid surrounding the secretory cells rather than into ducts. From the interstitial fluid, hormones diffuse into blood capillaries and blood carries them to target cells throughout the body. Because most hormones are required in very small amounts, the circulating levels of hormones are typically low.

The word endocrine means internal secretion and endocrine glands are therefore glands of internal secretion. Since they shed their secretion into the bloodstream, they have no ducts and are hence known as ductless glands. Once in the bloodstream, the hormones are carried around the body, bringing about responses in various places. Structures that respond to them are called target organs. A hormone is a chemical messenger having the following properties:

- It travels in the blood
- It has its effect at a site different from the site where it is produced. The site where it has effect is called the target, while itself is called messenger
- It fits precisely into receptor molecules in the target like a key in a lock. It is therefore specific for a particular target;
- It is a small soluble molecule;
- It is effective in low concentrations.

The ability of a target cell to respond to a hormone depends on the presence of receptors, within the cell or on its plasma membrane, to which the hormone can bind. Hormone receptors are dynamic structures. Changes in number and sensitivity of hormone receptors may occur in response to high or low levels of stimulating hormones.

The endocrine glands include the pituitary, thyroid, parathyroid, adrenal, and pineal glands (Figure 10.1). Taken together, all endocrine glands and hormone-secreting cells constitute the endocrine system. The science of the structure and function of the endocrine glands and the diagnosis and treatment of disorders of the endocrine system is endocrinology (endo: within; crino: to secrete; -logy: study of).

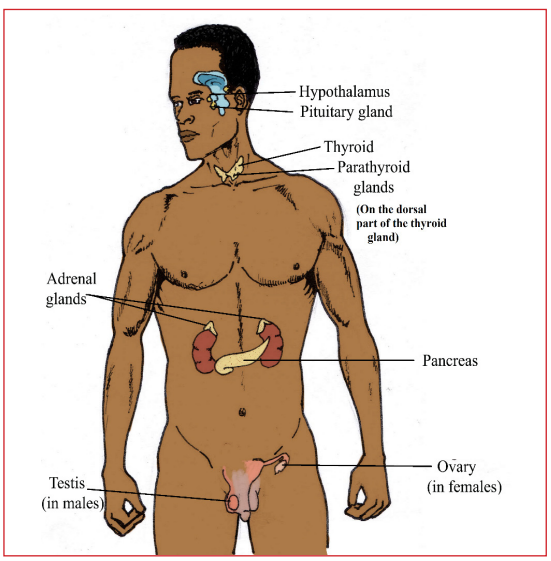


Figure 2.21: Major endocrine glands

a. Pituitary gland

The pituitary gland also called hypophysis or master gland hangs from the base of the brain by a stalk and is enclosed by bone. It consists of a hormone-producing glandular portion called anterior pituitary and a neural portion called posterior pituitary, which is an extension of the hypothalamus. The hypothalamus regulates the hormonal output of the anterior pituitary and synthesizes two hormones that it exports to the posterior pituitary for storage and later release. Four of the six hormones produced by the pituitary gland are tropic hormones that regulate the function of other endocrine organs. Growth hormone (GH) or Somatotropic hormone is a hormone that stimulates growth of all body tissues but especially skeletal muscle and bone. GH mobilizes the use of fats, stimulates protein synthesis, and inhibits glucose uptake and metabolism.

- Thyroid-stimulating hormone (TSH) stimulates the normal development and activity of the thyroid gland. Thyrotropin-releasing hormone (TRH) stimulates its release; negative feedback of thyroid hormone inhibits it.
- Adrenocorticotropic hormone (ACTH) stimulates the adrenal cortex to release its hormones. ACTH release is triggered by corticotropin-releasing hormone (CRH) and inhibited by rising glucocorticoid levels.
- The gonadotropins: follicle-stimulating hormone (FSH) and luteinizing hormone (LH) regulate the functions of the gonads in both sexes.
- Prolactin (PRL) promotes the production of milk in human's females. Its secretion is triggered by prolactin-releasing hormone (PRH) and inhibited by prolactin-inhibiting hormone (PIH).

The neurohypophysis stores and releases two hormones produced by the hypothalamus:

- Oxytocin stimulates powerful contractions of the uterus, which trigger labor and delivery of an infant, and milk ejection in nursing women. Its release is mediated reflexively by the hypothalamus and represents a positive feedback mechanism.
- Antidiuretic hormone (ADH) stimulates the kidney tubules to reabsorb and conserve water, resulting in small volumes of highly concentrated urine and decreased plasma osmolality.

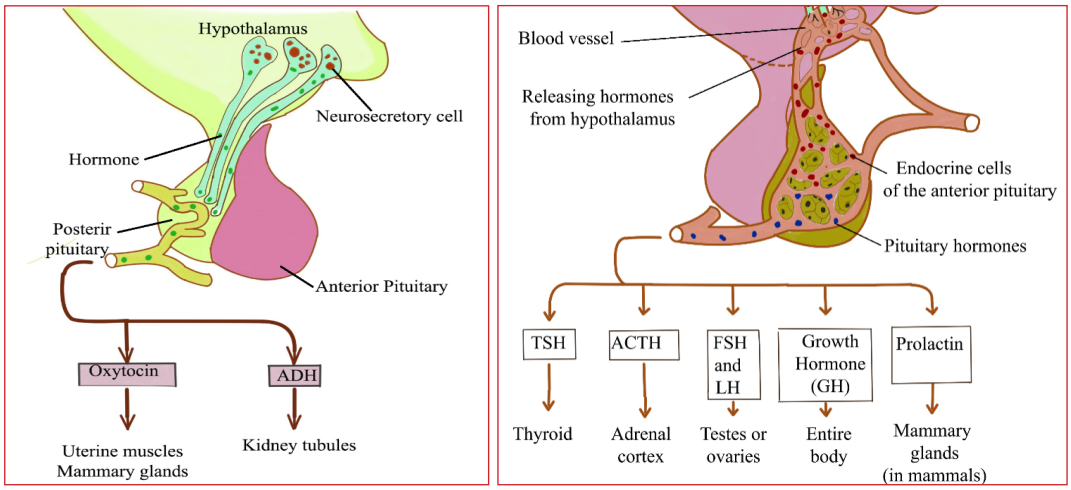


Figure 2.22: Pituitary and hypothalamic secretions

b. Hypothalamus

The hypothalamus plays an important role in integrating the vertebrate endocrine and nervous systems. The region of the lower brain receives information from nerves throughout the body and from other parts of the brain thus initiates endocrine signals appropriate to environmental conditions. A set of neurosecretory cells in the hypothalamus exerts control over the anterior pituitary by secreting two kinds of hormones into the blood: Releasing hormones which make the anterior pituitary to secrete its hormones and inhibiting hormones that make the anterior pituitary stop secreting hormones. Every anterior pituitary hormone is controlled at least by one releasing hormone and some have both a releasing and an inhibiting hormone.

Unlike the anterior pituitary, the posterior pituitary or neurohypophysis is an extension of the brain. It develops from a bulge of the hypothalamus that grows downward the mouth fold that forms the anterior pituitary. The posterior pituitary remains attached to the hypothalamus. It stores and releases two hormones that are made by a set of neurosecretory cells in the hypothalamus.

c. Thyroid gland

The thyroid gland is located in the anterior throat. Thyroid follicles store colloid containing thyroglobulin, a glycoprotein from which thyroid hormone is derived. Thyroid hormone (TH) includes thyroxine (T4) and triiodothyronine (T3), which increase the rate of cellular metabolism. Consequently, oxygen use and heat production rise. Calcitonin, produced by the parafollicular cells of the thyroid gland in response to rising blood calcium levels, decreases blood calcium levels by inhibiting bone matrix resorption and enhancing calcium deposit in bone.

d. Parathyroid glands

The parathyroid glands are located on the dorsal aspect of the thyroid gland and secrete parathyroid hormone (PTH), which causes an increase in blood calcium levels by targeting bone, the intestine, and the kidneys. PTH is the antagonist of calcitonin. PTH release is triggered by decreasing blood calcium levels and is inhibited by increasing blood calcium levels.

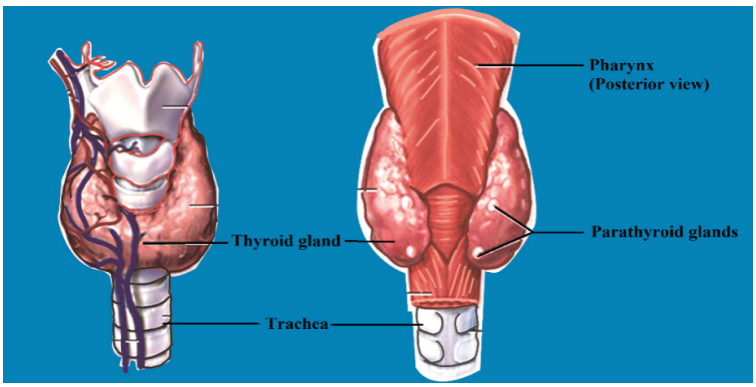


Figure 2.23: Location of the thyroid and the parathyroid glands

e. Pancreas

The pancreas is an organ located in the abdomen close to the stomach and is both an exocrine and an endocrine gland. The endocrine portion (islets of langerhans) releases insulin and glucagon and smaller amounts of other hormones such as somatostatine to the blood. Glucagon is released by alpha (α) cells when glucose levels in blood are low. Glucagon stimulates the liver to release glucose to the blood. Insulin is released by beta (β) cells when blood levels of glucose (and amino acids) are rising. It increases the rate of glucose uptake and metabolism by most body cells.

f. Gonads

The ovaries of the female which are located in the pelvic cavity, release two main hormones. Secretion of estrogens by the ovarian follicles begins at puberty under the influence of FSH. Estrogens stimulate maturation of the female reproductive system and development of the secondary sex characteristics. Progesterone is released in response to high blood levels of LH. It works with estrogens in establishing the human menstrual cycle. The testes of the male begin to produce testosterone at puberty in response to LH. Testosterone stimulates the maturation of the male reproductive organs, development of secondary sex characteristics, and the production of sperm by the testes.

g. Adrenal Glands / Suprarenal Glands

Each adrenal gland weighs about 5 g and sits on the superior pole of the respective kidney, like a cap. The glands are included in the fatty capsule of the kidney and are noteworthy for their rich supply of nerves and vessels. A fresh adrenal gland section shows a bright yellow cortex, making up about 80% of the organ, and a more reddish-grey medulla. The endocrine activities of the adrenal cortex and the adrenal medulla differ both in development and function.

1. Adrenal cortex

Adrenal cortex makes mineralocorticoids (such as aldosterone and cortisol). Cortisol raises blood glucose level whereas aldosterone stimulates the reabsorption of Na^+ and excretion of K^+ in kidney.

2. Adrenal Medulla

The adrenal medulla makes two hormones epinephrine (adrenaline) (80 %) and norepinephrine (noradrenaline) (20 %). Epinephrine and norepinephrine are released into the bloodstream during stress and they act on the whole organism by preparing it for increased energy use. Both hormones, for instance, activate the liberation of fatty acids from fat depots and liberate glucose from glycogen storage in the liver (producing a rise in the blood sugar level).

They raise the blood pressure and stroke volume of the heart and may lead to vasoconstriction in certain defined areas.

h. Other hormone-producing structures

Many body organs not normally considered endocrine organs contain isolated cell clusters that secrete different hormones. Examples include the gastrointestinal tract organs (gastrin, secretin, and others), the placenta (hormones of pregnancy such as estrogen, progesterone, and others) and the kidneys (erythropoietin and renin).

Table 2.2: Major human endocrine glands, their functions and the control of their secretions

Gland	Hormone	Target organ	Functions
Hypothalamus	Releasing and inhibiting hormones, posterior pituitary hormones produced here	Anterior pituitary	Control of anterior pituitary hormones
Posterior lobe of pituitary gland	Oxytocin	Uterus and mammary glands	Contraction of uterus during childbirth and ejection of milk from mammary gland
	ADH	Kidneys	Promotes retention of water by the kidney
Anterior pituitary	Growth hormone	Soft tissue, bones	Stimulates growth especially of bones of limbs and metabolic functions
	Prolactin	Mammary glands	stimulates milk production and secretion
	FSH	Gonads	In male, testosterone production In female, secretion of oestrogens and progesterone, ovulation and maintenance of corpus luteum.

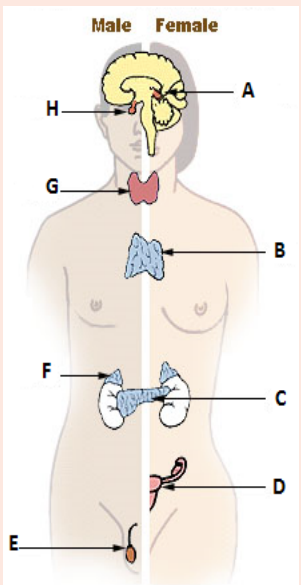
	LH	Gonads	In male, testosterone production In female, secretion of oestrogens and progesterone, ovulation and maintenance of corpus luteum.
	TSH	Thyroid gland	Synthesis and secretion of thyroid hormones, growth of thyroid glands
	ACTH	Adrenal cortex	Stimulates the adrenal cortex to secrete its hormones
Thyroid gland	Triiodothyronine (T_3) and thyroxine (T_4) Calcitonin	All tissues	Regulation of basal metabolic rate; Growth and development Decreases blood calcium level.
Parathyroid glands	Parathyroid hormone	Bones, Kidneys and intestine	Raises blood calcium level
Pancreas	Insulin	Liver, muscles, adipose tissues	Lowers blood glucose level
	Glucagon	Liver, muscles, adipose tissues	Raises blood glucose level
Adrenal cortex	Glucocorticoids and mineralocorticoids	Kidneys and all tissues	Raises blood glucose level and promotes reabsorbption of Na^+ and excretion of K^+ in kidney
Adrenal medulla	Epinephrine and norepinephrine	Cardiac and other muscles	Raise blood glucose level, increase metabolic activities, constrict blood vessels

Testes	Androgens	Gonads,	Sperm formation; promote development and maintenance of male secondary sex characteristics.
Ovaries	Estrogens and progesterone	gonads	Stimulates uterine lining growth; promotes development and maintenance of female secondary characteristics.
Stomach	Gastrin	stomach	Secretion of gastric juices
Duodenum	Secretin	Pancreas	Secretion of pancreatic juice; inhibits gastric gastric secretion
	Cholecystokinin	Pancreas and gallbladder	Emptying of gallbladder and release of pancreatic juice into duodenum.
Corpus luteum	Progestrone and estrogen	Different tissues	Growth and development of uterus Fetal development
Placenta	Chorionic gonadotrophin	Uterus	Maintenance of corpus luteum
Thymus	Thymosin	thymus	Stimulates T lymphocytes

Application activity 2.5

The diagram below shows the main endocrine glands

1. Name the parts from A to H
2. Describe the roles of hormones produced by C
3. What would happen if the hormones produced by G are secreted in low quantity

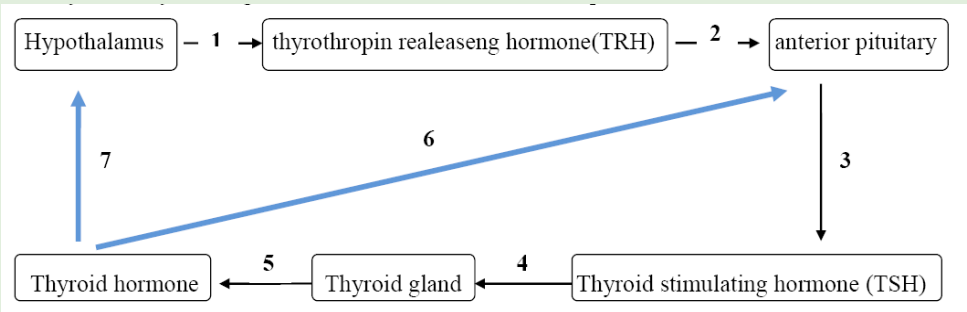


(Source:https://www.wikipremed.com/mcat_course_psychology.php?module=1&section=12)

2.6 Principles of the negative feedback mechanism of hormonal action

ACTIVITY 2.6

Study carefully the diagram below and answer the related questions



a. In the above diagram find arrow(s) that specify the following message:

"High concentration of hormone can inhibit the gland from releasing the same hormone in order to keep the concentration relatively stable".

b. What should happen if the event 6 and 7 were not there?

c. Explain what will happen when the quantity of thyroid hormone increases or decrease?

d. Suggest the name of the mechanism that intervene in hormonal control?

Feedback mechanisms are necessary in the maintenance of homeostatic mechanisms. All homeostatic control mechanisms have at least three interdependent components for the variable being regulated that work together. The receptor is the sensing component that monitors and responds to changes in the environment. When the receptor senses a stimulus, it sends information to a control center, the component that sets the range at which a variable is maintained. The control center determines an appropriate response to the stimulus. In most homeostatic mechanisms, the control center is the brain. The control center then sends signals to an effector, which can be muscles, organs or other structures that receive signals from the control center. After receiving the signal, a change occurs to correct the deviation by either enhancing it with positive feedback or depressing it with negative feedback.

The homeostatic mechanisms in mammals require information to be transferred between different parts of the body.

There are two coordination systems in mammals that control this: the nervous system and the endocrine system.

- In the nervous system, information in the form of electrical impulses is transmitted along nerve cells (neurons).
- The endocrine system uses chemical messengers called hormones that travel in the blood, in a form of long-distance cell signalling.

Positive feedback mechanisms are designed to accelerate or enhance the output created by a stimulus that has already been activated. Unlike negative feedback mechanisms that initiate to maintain or regulate physiological functions within a set and narrow range, the positive feedback mechanisms are designed to push levels out of normal levels. To achieve this purpose, a series of events initiates a cascading process that builds to increase the effect of the stimulus. This process can be beneficial but is rarely used by the body due to risks of the acceleration's becoming uncontrollable.

One positive feedback example event in the body is the accumulation blood platelets, which, in turn, causes blood clotting in response to a break or tear in the lining of blood vessels. Another example is the release of oxytocin to intensify the contractions of the uterus that take place during childbirth.

Another example of a positive feedback mechanism is the production of milk by a mother for her baby. As the baby suckles, nerve messages from the mammary glands cause the mother's pituitary gland to secrete a hormone called prolactin. The more the baby suckles, the more prolactin is released, which stimulates further milk production by the mother's mammary glands. In this case, a negative feedback mechanism would not be helpful because the more the baby nursed, the less milk would be produced.

Table 2.3: Negative and positive feedback compared

Negative feedback	Positive feedback
Shuts off the original stimulus, or reduces its intensity	Increases the original stimulus to push the variable farther.
In this feedback loop, the values remain within a range	Values go out of range
Common in the body Very uncommon	Very uncommon

This feedback loop is initiated by a stimulus that disturbs the homeostasis of a body system	Positive feedback is also initiated by a stimulus.
Examples: body temperature, sugar metabolism	Examples: lactation, labor contractions, blood clotting

Activity 2.7

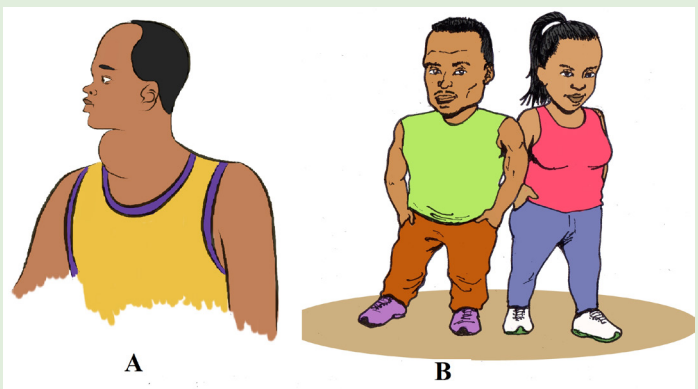
There are some events or steps that occur in human body when blood glucose increases above normal level or decreases below normal level. Describe 7 steps/events:

a. When glucose level in blood increases above normal level
b. When glucose level in blood decreases below normal level

2.7 Effects of hormonal imbalances

Activity 2.7

Observe carefully the photos below and suggest the type of disorders the following people may be suffering:



The disorders of the endocrine system often involve either the hyposecretion (hypo means too little or under), inadequate release of a hormone, or the hypersecretion (hyper means too much or above), excessive release of a hormone. In other cases, the problem is faulty hormone receptors, an inadequate number of receptors, or defects in second-messenger systems. Because hormones are distributed in the blood to target tissues throughout the body, problems associated with endocrine dysfunction may also be widespread.

2.7.1 Pituitary gland disorders

a. Pituitary dwarfism, gigantism, and acromegaly

Several disorders of the anterior pituitary involve human growth hormone. Hyposecretion of human growth hormone during the growth years slows bone growth, and the epiphyseal plates close before normal height is reached. This condition is called pituitary dwarfism. Other organs of the body also fail to grow, and the body proportions are childlike. Treatment requires administration of human growth hormone during childhood, before the epiphyseal plates close.

Hypersecretion of human growth hormone during childhood causes gigantism, an abnormal increase in the length of long bones. The person grows to be very tall, but body proportions are about normal. Hypersecretion of human growth hormone during adulthood is called acromegaly.

b. Diabetes insipidus

The most common abnormality associated with dysfunction of the posterior pituitary is diabetes insipidus.

This disorder is due to defects in antidiuretic hormone (ADH) receptors or an inability of the pituitary gland to secrete ADH. A common symptom of diabetes insipidus is excretion of large volumes of urine resulting in dehydration and thirst. Bed-wetting is common in afflicted children. Because so much water is lost in the urine, a person with diabetes insipidus may die of dehydration if deprived of water for only one day. Treatment of diabetes insipidus involves the injection of ADH.

2.7.2 Thyroid gland disorders

Thyroid gland disorders affect all major body systems and are among the most common endocrine disorders. Congenital hypothyroidism or the hyposecretion of thyroid hormones that is present at birth has devastating consequences if not treated quickly. Previously termed cretinism, it causes severe mental retardation and stunted bone growth. At birth, the baby typically is normal because lipid-soluble maternal thyroid hormones crossed the placenta during pregnancy and allowed normal development.

Hypothyroidism during the adult years produces a disorder called myxoedema. An indication of this disorder is oedema (accumulation of interstitial fluid) that causes the facial tissues to swell and look puffy. A person with myxoedema has a slow heart rate, low body temperature, sensitivity to cold, dry hair and skin, muscular weakness, general lethargy, and a tendency to gain weight easily. Because the brain has already reached maturity, mental retardation does not occur, but the person may be less alert.

The most common form of hyperthyroidism is Graves' disease which is an autoimmune disorder in which the person produces antibodies that mimic the action of thyroid-stimulating hormone (TSH). The antibodies continually stimulate the thyroid gland to grow and produce thyroid hormones. A primary sign is an enlarged thyroid, which may be two to three times its normal size. Graves' patients often have a peculiar oedema behind the eyes, called exophthalmos, which causes the eyes to protrude. Treatment may include surgical removal of part or all of the thyroid gland (thyroidectomy), the use of radioactive iodine to selectively destroy thyroid tissue, and the use of antithyroid drugs to block synthesis of thyroid hormones. A goitre is simply an enlarged thyroid gland. It may be associated with hyperthyroidism, hypothyroidism or by the lack of iodine.

2.7.3 Parathyroid gland disorders

Parathyroid gland disorders cause the hypoparathyroidism due to the too little parathyroid hormone leading to a deficiency of blood Ca^{2+}, causing neurons and muscle fibres to depolarize and produce action potentials spontaneously. This leads to twitches, spasms, and tetany (maintained contraction) of skeletal muscle.

The main cause of hypoparathyroidism is accidental damage to the parathyroid glands or to their blood supply during thyroidectomy surgery.

Hyperparathyroidism or an elevated level of parathyroid hormone, most often is due to a tumour of one of the parathyroid glands. An elevated level of PTH causes excessive resorption of bone matrix, raising the blood levels of calcium and phosphate ions and causing bones to become soft and easily fractured. High blood calcium level promotes formation of kidney stones. Fatigue, personality changes, and lethargy are also seen in patients with high levels of parathyroid hormone.

2.7.4 Adrenal gland disorders

a. Cushing's syndrome

Hypersecretion of cortisol by the adrenal cortex causes an endocrine disorder known as Cushing's syndrome. The condition is characterized by breakdown of muscle proteins and redistribution of body fat, resulting in thin arms and legs accompanied by a rounded moon face and buffalo hump on the back. Facial skin is flushed, and the skin covering the abdomen develops stretch marks. The person also bruises easily, and wound healing is very slow. The elevated level of cortisol causes hyperglycaemia, osteoporosis, weakness, hypertension,

increased susceptibility to infection, decreased resistance to stress, and mood swings.

b. Addison's disease

Hyposecretion of glucocorticoids and aldosterone causes Addison's disease (chronic adrenocortical insufficiency). The majority of cases are autoimmune disorders in which antibodies cause adrenal cortex destruction or block binding of ACTH to its receptors. Pathogens, such as the bacterium that causes tuberculosis, also may trigger adrenal cortex destruction. Symptoms, which typically do not appear until 90% of the adrenal cortex has been destroyed, include mental lethargy, anorexia, nausea and vomiting, weight loss, hypoglycemia, and muscular weakness. Loss of aldosterone leads to the elevated potassium and decreased sodium in the blood, low blood pressure, dehydration, decreased cardiac output and even cardiac arrest.

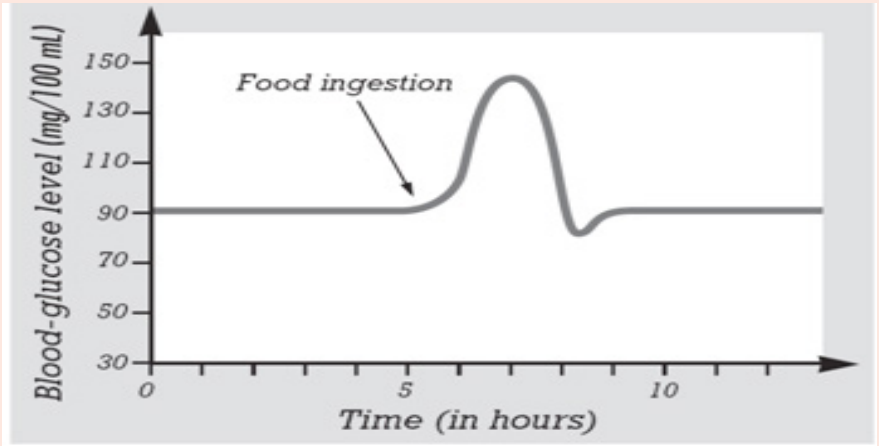
2.7.5 Pancreas disorders

The most common endocrine disorder is diabetes mellitus caused by an inability to produce or use insulin. According to the diabetes atlas of 2018, the prevalence of diabetes in Rwanda is about 3.16% of the population with 1,918 diabetes related deaths per year. On the world health day in 2016, the world health organization (WHO) addressed a call for action on diabetes, drawing attention to the need to step up prevention and treatment of this disease. The first WHO Global report on diabetes demonstrates that the number of adults living with diabetes has almost quadrupled since 1980 to 422 million adults. This dramatic rise is largely due to the rise in type 2 diabetes and factors driving it include overweight and obesity. In 2012 alone diabetes caused 1.5 million deaths. Its complications can lead to heart attack, stroke, blindness, kidney failure and lower limb amputation.

Because insulin is unavailable to aid transport of glucose into body cells, blood glucose level is high and glucose is found in the urine, the process known as glucosuria. The cardinal signs of diabetes mellitus are polyuria (excessive urine production due to an inability of the kidneys to reabsorb water), polydipsia (excessive thirst) and polyphagia (excessive eating).

Activity 2.8

The graph below blood–glucose level. Analyse it carefully and answer the following questions. What will happen after one eat food?



2.8 Comparison of hormonal and nervous systems

Activity 2.8

Make table comparing nervous system and endocrine system

The nervous and endocrine systems act together to coordinate functions of all our body systems. Remember that the nervous system acts through nerve impulses conducted along axons of neurons. At synapses, nerve impulses trigger the release of mediator molecules called neurotransmitters, while the endocrine system controls body activities by releasing mediators, called hormones. However, the means of control of the two systems are very different.

A basic similarity between the endocrine system and the nervous system is that both provide means of communication within the body of an organism. Both involve transmission of a message which is triggered by a stimulus and produces a response. Several chemicals function as both neurotransmitters and hormones including norepinephrine. Some hormones such as oxytocin are secreted by neuroendocrine cells; neurons that release their secretions into the blood. The target organs of a hormone are equivalent to nerve's effectors.

The main differences between the two systems concern the nature of the message. In the endocrine system, the message takes the form of a chemical substance transmitted through the blood stream. In the nervous system it is a discrete-all or none action potential transmitted along a nerve fiber. All other differences arise from this fundamental one. They can be listed as follows:

- Because of the comparatively high speed at which impulses are transmitted along nerves, nerves responses are generally transmitted more rapidly than hormonal ones.
- Since it is conveyed by the bloodstream, there is nothing to stop a hormone being carried to every part of the body. Nervous impulses however are transmitted by particular neurons to specific destinations.
- As a result, hormones are often widespread, sometimes involving the participation of numerous target organs. In contrast, nervous responses may be much localized, involving perhaps the contractions of only one muscle.
- Hormonal responses frequently continue over a long period of time. Obvious examples of such long-term responses are growth and metabolism.

A comparison between nervous and endocrine system is summarized in the table 2.4

Table 2.4: Comparison between nervous and endocrine system

Nervous system	Endocrine system
Involves nervous impulses (electrical) and neurotransmitters (chemical)	Involves hormones (chemical substance)
Impulses transmitted by neurons	Hormones transported by blood
Quick response	Usually a slow response
Response short-lived	Response may be short-lived or long term
May be voluntary or involuntary	Always involuntary
Usually localized	May affect more than one target organ
Stops quickly when stimulus stops	May continue responding long after stimulus stops

Skills lab 2

Objective : Determine the blood glucose level: Test for glucose level in blood by using a glucometer

Requirements: Blood, sterile needle, cotton wool, ethanol, glucometer

Procedure:

1. Insert a disposable test strip into its place in the glucometer.
2. Wash your finger with alcohol using cotton wool.
3. Use a needle; get some drops of blood from one volunteer participant.
4. Place the drop of blood on a disposable test strip.
5. Read and calculate the blood glucose level.

Discuss what will happen when the amount of sugar in blood increases or decreases to the normal range of sugar level in blood.

End unit assessment 2

Section A: Multiple choice questions: Choose the best answer

1. What happens when a neuron's membrane depolarizes?

a. There is a net diffusion of Na^+ out of the cell.
b. The equilibrium potential of K^+ becomes more positive.
c. The neuron's membrane voltage becomes more positive.
d. The neuron becomes less likely to generate an actionpotential.
e. The inside of the cell becomes more negative relative to the outside.

2. Why action potentials are usually conducted in only one direction along an axon?

a. The nodes of Ranvier can conduct potentials in only one direction.
b. The brief refractory period prevents reopening of voltage gated Na+ channels.
c. The axon hillock has a higher membrane potential than the terminals of the axon.
d. Ions can flow along the axon in only one direction.
e. Voltage-gated channels for both Na^+ and K^+ open in only one direction.

3. During the repolarisation phase of an action potential, the permeability of the axon membrane to:

a. Na^+ increases

b. K^+ increases

c. Ca^+ increases

d. Organic anions increases

4. What are the chemical messengers of the endocrine system called?

a. Neurons

b. Hormones

c. Blood cells

d. Carbohydrates

5. Endocrine glands

a. Function only after puberty

b. Function only before puberty

c. Release products through ducts

d. Release products into bloodstream

6. X and Y are hormones. X stimulates the secretion of Y, which exerts negative feedback on the cells that secrete X. Suppose the level of Y decreases. What should happen immediately afterwards?

a. Less X is secreted

b. More X is secreted

c. Secretion of Y stops

d. Secretion of X stops

7. Which one of the following hormones is secreted by the neurosecretory cells in mammals?

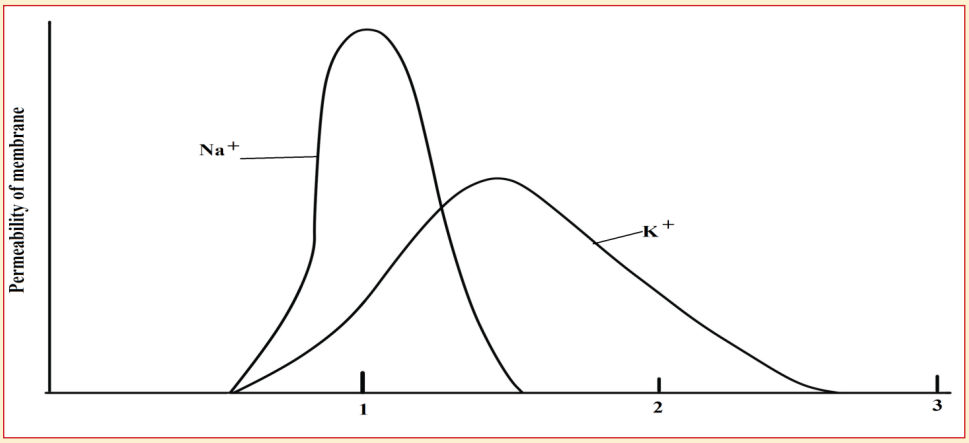
a. Adrenaline

b. Antidiuretic hormone

c. Insulin

d. Thyroxin

8. The graph shows the changes in the permeability of an axon to Na^+ and K^+ ions during an action potential

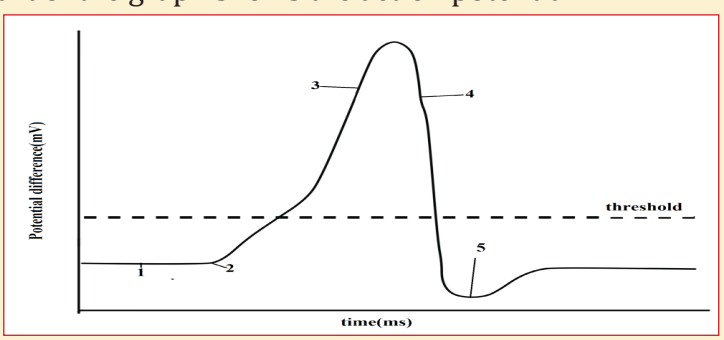


Which of the following shows the correct movement of these ions in the axon?

a. Na^+ ions enter the axon, K^+ ions leave the axon
b. Na^+ ions leave the axon, K^+ ions enter the axon
c. Both Na^+ and K^+ ions enter the axon
d. Both Na^+ and K^+ leave the axon

8. The graph shows the potential difference across an axon membrane. Which part of the graph shows the action potential?

9. The graph shows the potential difference across an axon membrane. Which part of the graph shows the action potential?



a. 3, 4 and 5
b. 2,3, 4 and 5
c. 1,2, 3 and 4
d. 1,2,3, 4 and 5

Section B: Short answer type questions

10. Name the hormone involved in the functions described below and the name of the gland which produces it:

a. Controls reabsorption of Na^+ in the kidney.

b. Increases the permeability of convoluted distal tubule and collecting duct.

c. Increases heart rate.

d. Increases blood glucose level.

e. Decreases blood glucose level.

f. Repair and growth of the endometrium.

g. Stimulates the anterior pituitary gland to release FSH.

h. Stimulates contraction of the uterus.

i. Stimulates the mammary glands to secrete milk.

11. A number of metabolic diseases in mammals arise as a result of abnormal endocrine function. Complete the table below concerned with this:

Name of abnormality	Caused by lack of (hormone)	From (gland)
Dwarfism		
	Insulin	
Water diabetes		
		Thyroid of baby

12. The list describes the main stages in the process by which information is transmitted across cholinergic synapses.

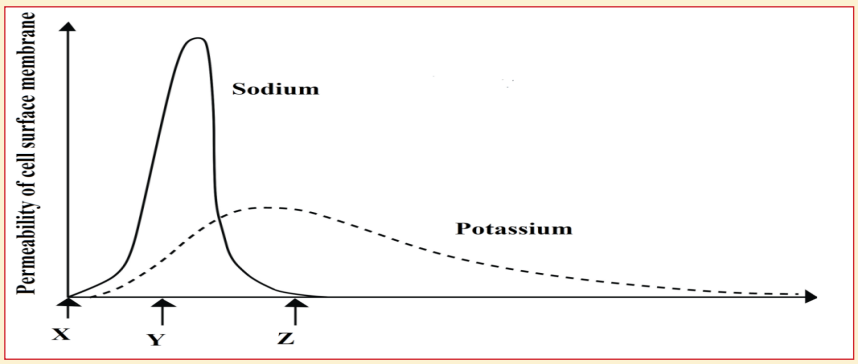
- An action potential arrives at synaptic knob of presynaptic neurone. This causes…. the ions to enter the synaptic knob.
- Vesicles move to the…….. membrane.
- A neurotransmitter called……..is released into the synaptic cleft
- This moves across the cleft by a process known as…….. the neurotransmitter combines with a…….. on the postsynaptic membrane.
- Influx of…….. ions cause local depolarisation and an action potential is set up in the postsynaptic neurone

a. Copy the list. Using the correct scientific terms, add the words that have been omitted.

b. Explain what happens to the neurotransmitter after it has passed information across a cholinergic synapse

c. Some nerves, especially those of the sympathetic nervous system, produce noradrenaline in their synaptic vesicles. Name this type of synapse

13. The graph shows the changes in permeability of the cell surface membrane of an axon to sodium and potassium ions during an action potential.



a. Explain how the events which take place between X and Y on the graph can lead to a change in the potential differences across the membrane

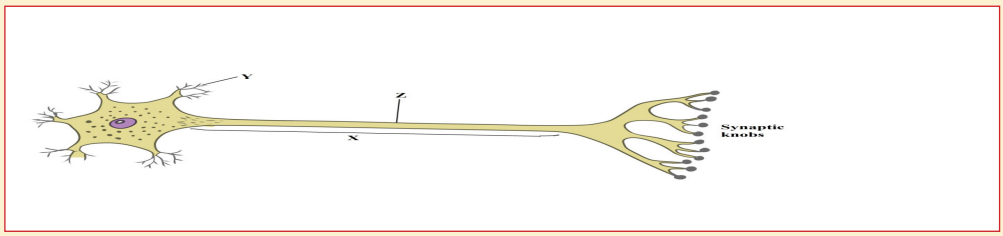
b. What happens to the potential difference across the membrane between times Y and Z?

c. Explain why a nerve impulse travels faster in myelinated neurone than in a non-myelinated one

14. During the control of blood sugar in a mammal two antagonistic hormones are employed. Fill in the table about them

	Raises blood sugar	Lowers blood sugar
Hormone's name		
Hormone's source		
Means of stimulating gland to secrete		
Main gland stimulated by the hormone		

15. The diagram below shows a nerve cell or neuron



a. Name the type of neurone shown.

b. Name the structures labelled X and Y

c. A nerve impulse can be initiated by stimulation with a microelectrode. What would be the effect of stimulation at point Z?

d. The synaptic knobs release a chemical transmitter, acetylcholine. Nerve gases prevent the breakdown of this chemical. From this information suggest

i. One early symptom of nerve gas poisoning

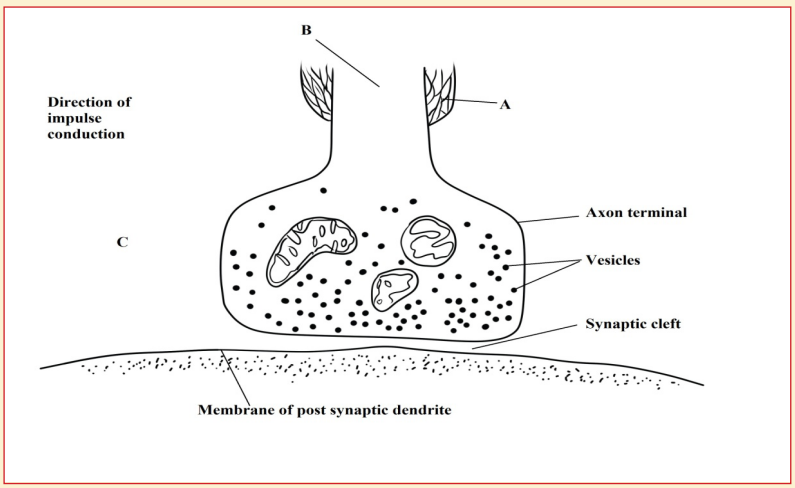
ii. One reason for this observed symptom

16. Complete the following table by stating which region of the brain controls each of the functions listed

Function	Region of brain	Lowers blood sugar
Osmoregulation		
Control of posture		
Modification of heart rate		
Main gland stimulated by the hormone		

17. The diagram below represents the structures visible at a synapse with the aid of electron microscopy.

a. Identify the structures labelled A and B



a. Name the chemical found in the numerous vesicles that occur in the synaptic knob

b. Identify the structure labelled C and suggests a reason for its presence in the synaptic knob

c. A powerful hydrolytic enzyme is found in the synaptic cleft. What is its function in normal synaptic transmission?

Section C: Long answer type questions

18. Describe what happens when an action potential arrives at a synaptic knob of an excitatory synapse
19. What is the difference between diabetes mellitus and diabetes insipidus? What are the characteristic signs of diabetes insipidus?
20. Use the following to describe a negative feedback mechanism: TSH, TRH, decreased metabolic rate, thyroxine and T3.
21. Compare the nervous system from hormonal system

UNIT 3

NUCLEIC ACIDS, DNA REPLICATION AND PROTEIN SYNTHESIS

Key unit competence: Explain nucleic acids, DNA replication, and the process of protein synthesis in eukaryotes.

Introductory activity 3

1. Three men A, B and C are at police station for being investigated as rapists. They are accused of forcing a woman to have sex with her and finally the woman gets pregnant and she is just given birth to a baby girl. All of those three men do not accept to be real father of a baby girl, the police brings men A,B and C to the forensic laboratory , the DNA samples of three men are collected and analyzed together with the one of the child and the mother in order to find out the potential father. The table below indicates the results obtained

A	B	C	Women	Baby	Observation
Negative (-)	Positive (+)	Negative (-)	Positive (+)	Positive (+)	

a. Basing on the results of table who should be the real father of baby girl between A, B and C

b. Explain why man named in a, is a real father of baby girl?

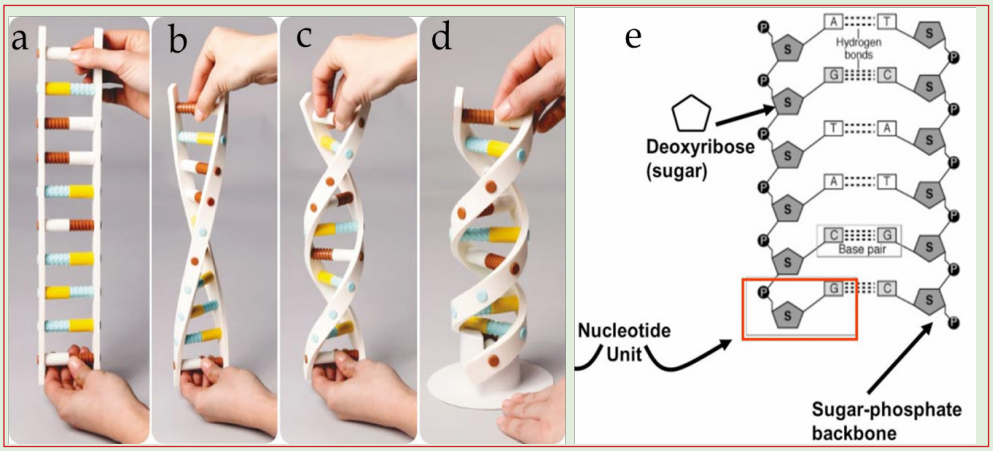
3.1 Structure of nucleic acids

Activity 3.1

Detecting components of DNA /RNA structure

Observe the diagrams below **(a, b, c, d and d)**

Do you see the resemblance? Which parts of the DNA molecule are like the steps and the spiral of the following figures? Use the tools indicated (like thread, toothpick and balls with different colurs) and construct the structure of DNA



Source: http://eatparade.eu, https://cahsbiology.weebly.com/dna---structure.html

DNA stands for deoxyribonucleic acid and RNA for ribonucleic acid. The nucleic acids such as DNA and RNA, like proteins and polysaccharides, are macromolecules. They are also polymers made up of many similar, smaller molecules joined into a long chain. The smaller molecules from which DNA and RNA molecules are made are nucleotides. DNA and RNA are therefore polynucleotides. They are often referred to simply as nucleic acids.

3.1.1 Nucleotide

Nucleotides are made up of three smaller components. These are:

- a nitrogen-containing base
- a pentose sugar
- a phosphate group.

There are just five different nitrogen-containing bases found in DNA and RNA. In a DNA molecule, there are four: adenine, thymine, guanine and cytosine

while in an RNA molecule also contains four bases, but instead of having the base thymine RNA has base called uracil rather than thymine.. These bases are often referred to by their first letters: A, T, C, G and U.

The pentose (5-carbon) sugar either ribose in RNA or deoxyribose in DNA molecules. As their names suggest, deoxyribose is ribose that has one fewer oxygen atoms in its molecule from which DNA and RNA molecules can be built up.

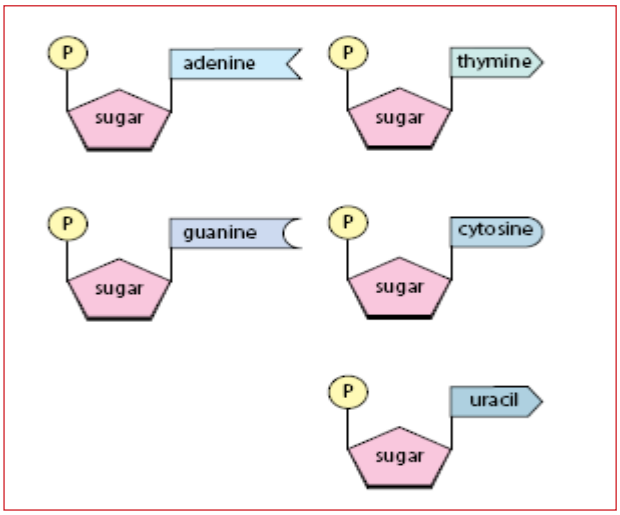


Figure 3.1 Nucleotides. A nucleotide is made of a nitrogen containing base, a pentose sugar and a phosphate group P

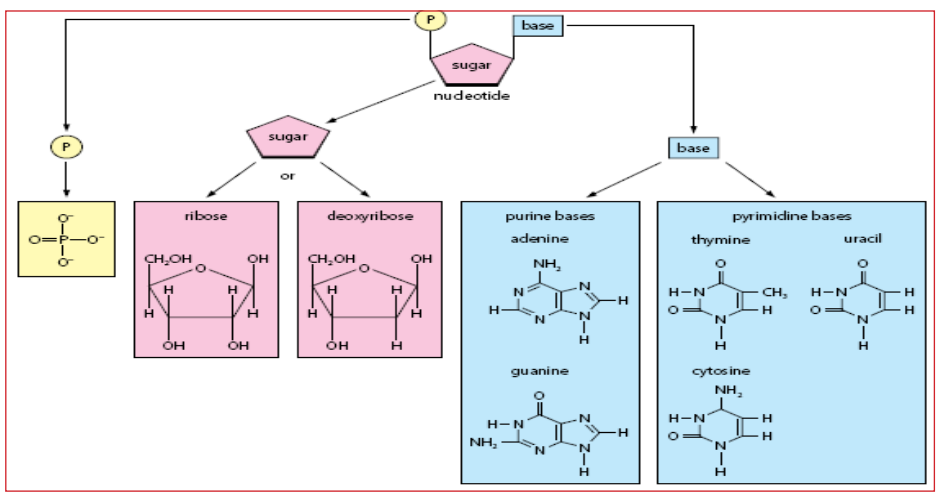


Figure 3.2: Components of nucleotides

In DNA and RNA, bases are covalently bonded to the 1' carbon of the pentose sugar. The purine and pyrimidines bases attached to pentose sugar from

different positions of their nitrogen bases. Purine bases use the **9th position of nitrogen** to attach with 1' carbon of pentose sugar, while pyrimidine bases use the **1st position of nitrogen** to attach with 1' carbon of pentose sugar. In both DNA and RNA, the phosphate group (PO_4^{2-}) attaches to the 5' **carbon** of pentose sugar. Thus, by attaching phosphate group to a nucleoside yields a **nucleoside phosphate** or **nucleotide**.

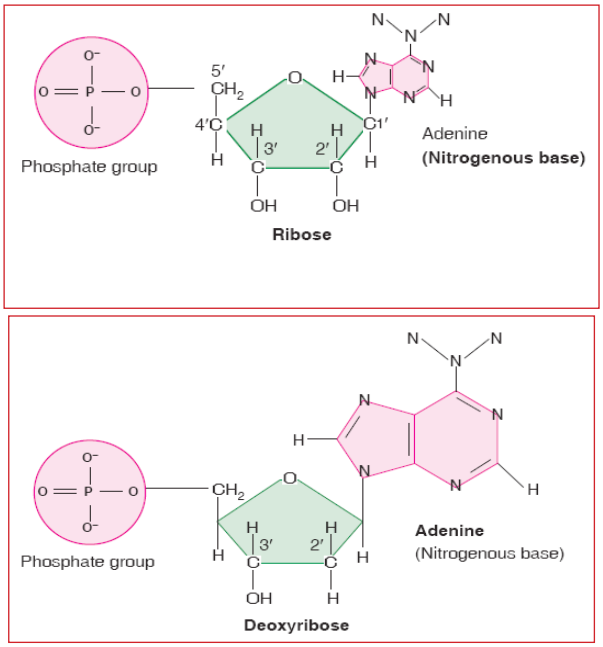


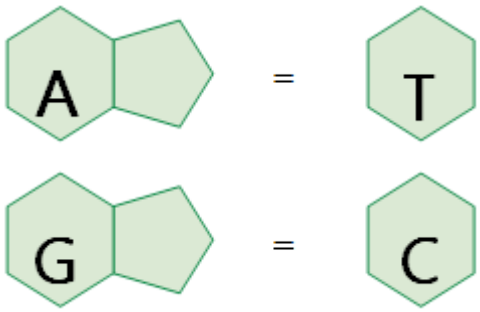
Figure 3.3: Deoxyribose and ribose

3.1.2 Chargaff's rules: Rules of base pairing

Erwin Chargaff's rules state that DNA of any cell in organism should have a 1:1 ratio of pyrimidine and purine bases, where the amount of adenine (A) is equal to that of thymine (T) and the amount of guanine (G) is equal to that of cytosine (C). This equivalence of purine and pyrimidine bases is known as **Chargaff's rules**. This pattern is found in both strands of DNA.

Table 3.1: Difference between purine and pyrimidine

Purine	Pyrimidine
Adenine (A)	Thymine (T) (found in DNA)
Guanine (G)	Cytosine (C)
	Uracil (U) (found in RNA)



Purines= Pyrimidines

The specific base pairing of A-T bases and G-C bases is called **complementary base pairs**.

For example, if one strand of DNA sequence is 5'-ATATCCGGAT-3', then the opposite strand of DNA sequence will be **3'-TATAGGCCTA-5'**. Thus, by using the rules of base pairing, once we have the sequence of at least DNA strand, we can find out the opposite base sequence of that DNA. In the structure of DNA, the strong electronegative atom is the Oxygen (O) and Nitrogen (N), while H atom has positive charge. In the structure of DNA (Figure 3.5), thymine and adenine have two **hydrogen bonds**; while guanine and cytosine have **three hydrogen bonds**. Hydrogen bonds or interactions play very important role in binding the bases of the opposite strands in the DNA. Though RNA is not the genetic material in most of the cases, both single-stranded and double-stranded RNAs are the genomes of certain viruses. RNA double-stranded molecules show structural similarity to that of double-stranded DNA molecules. The similarities are:

a. Both have **anti-parallel strands**.
b. Both have **sugar-phosphate backbones** on the outside of helical molecule.

In both the cases, in the middle of the helix, a complementary base pairing is formed by **hydrogen bonds**.

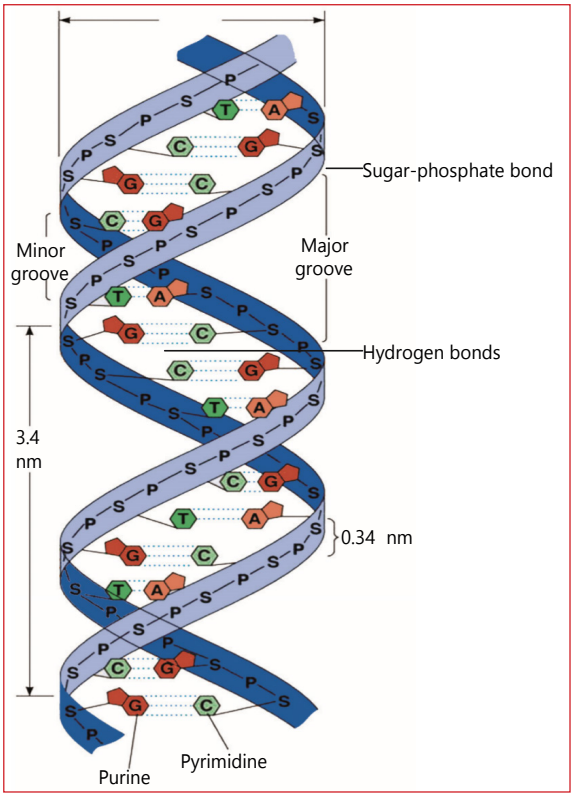


Figure 3.4: Double helical structure of DNA

3.1.3 WATSON and CRICK hypothesis of the nature of DNA

In 1953, James D. Watson, an American molecular biologist, and Francis H.C. Crick, a British molecular biologist, proposed a model for the physical and chemical structure of the DNA molecule. Today, their model is known as double helix model of DNA or simply the Structure of DNA.

The main features of Watson and Crick double helix model (Figure 3.6) of DNA are:

a. Two polynucleotide chains **wind around each other** in a right-hand double helix (Figure 3.12).

b. The two polynucleotide chains run side-by-side in **an antiparallel** fashion. This means that one strand of DNA will orient itself in a 5' -3' direction, whereas, the other strand will orient itself alongside the first one in a 3'-5' direction. In this way, the two strands are oriented in opposite directions (Figure 3.13).

c. On one hand, the **sugar-phosphate backbones** lie outside of the double helix. On the other hand, the bases orient themselves toward the central

axis of the double helix structure. The bases of one strand are bonded with the bases of the other strand of double helix by **hydrogen bonds.** These bonds are weak chemical bonds. Since **hydrogen bonds** are relatively weak bonds, the two strands can be easily separated by heating the DNA. The bonding of these bases in the double helical structure follows the Chargaff's base pairing rules. For example—Adenine (A) will form a hydrogen bond with Thymine (T). Similarly, Guanine (G) will form a hydrogen bond with Cytosine (C). This specific base paring is called **complementary base** pairing (Figure 3.6).

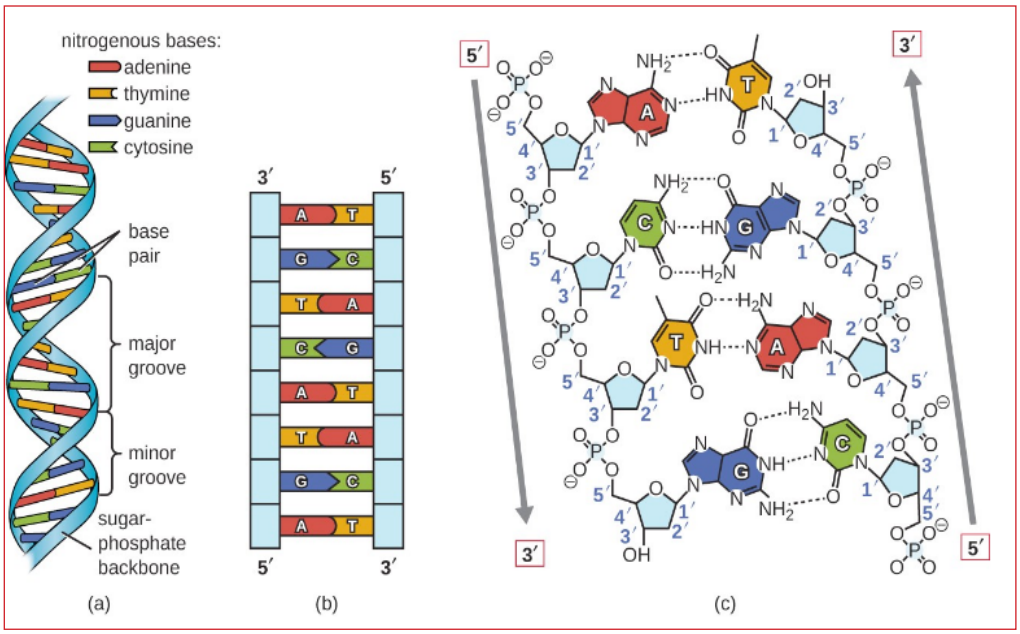


Figure 3.5 : Double hilux model for DNA (https://courses.lumenlearning.com/microbiology/chapter/structure-and-function-of-dna)

Watson and Crick proposed the double helix model for DNA. (a) The sugar-phosphate backbones are on the outside of the double helix and purines and pyrimidines form the DNA helix ladder. (b) The two DNA strands are antiparallel to each other. (c) The direction of each of each strand is identified by numbering the carbons (1 through 5) in each sugar molecule. The 5' end is the one where carbon 5 is not bound to another nucleotide; the 3' end is the one where carbon 3 is not bound to another nucleotide Source: 3.1.4.

3.1.4 Types and functions of RNA

The three most well-known and most commonly studied are messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA), which are present in all organisms. These and other types of RNAs primarily carry out biochemical

reactions, similar to enzymes. Some, however, also have complex regulatory functions in cells. Owing to their involvement in many regulatory processes, to their abundance, and to their diverse functions, RNAs play important roles in both normal cellular processes and diseases.

DNA vs. RNA – A Comparison

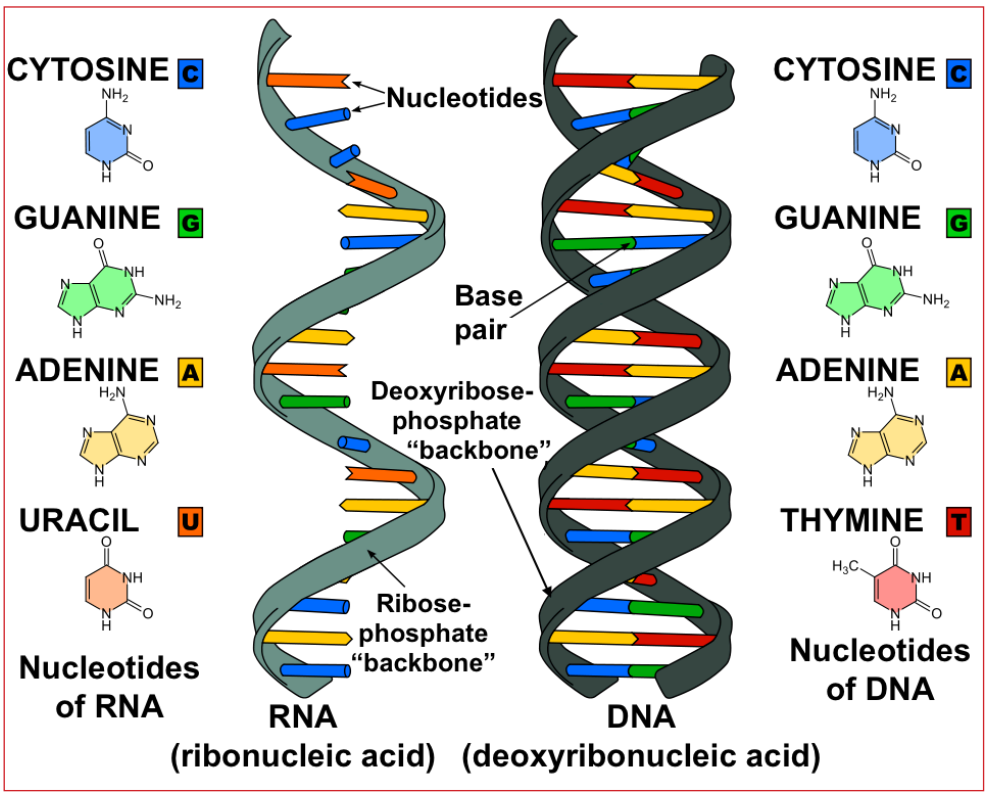


Figure 3.6: Comparison of the helix and base structure of RNA and DNA

Comparison	DNA	RNA
Full Name	Deoxyribonucleic Acid	Ribonucleic Acid
Function	DNA replicates and stores genetic information. It is a blueprint for all genetic information contained within an organism	RNA converts the genetic information contained within DNA to a format used to build proteins, and then moves it to ribosomal protein factories.

Structure	DNA consists of two strands, arranged in a double helix. These strands are made up of subunits called nucleotides. Each nucleotide contains a phosphate, a 5-carbon sugar molecule and a nitrogenous base.	RNA only has one strand, but like DNA, is made up of nucleotides. RNA strands are shorter than DNA strands. RNA sometimes forms a secondary double helix structure, but only intermittently.
Length	DNA is a much longer polymer than RNA. A chromosome, for example, is a single, long DNA molecule, which would be several centimetres in length when unravelled.	RNA molecules are variable in length, but much shorter than long DNA polymers. A large RNA molecule might only be a few thousand base pairs long.
Sugar	The sugar in DNA is deoxyribose, which contains one less hydroxyl group than RNA's ribose.	RNA contains ribose sugar molecules, without the hydroxyl modifications of deoxyribose.
Bases	The bases in DNA are Adenine ('A'), Thymine ('T'), Guanine ('G') and Cytosine ('C').	RNA shares Adenine ('A'), Guanine ('G') and Cytosine ('C') with DNA, but contains Uracil ('U') rather than Thymine.
Base Pairs	Adenine and Thymine pair (A-T) Cytosine and Guanine pair (C-G)	Adenine and Uracil pair (A-U) Cytosine and Guanine pair (C-G)
Location	DNA is found in the nucleus, with a small amount of DNA also present in mitochondria.	RNA forms in the nucleolus, and then moves to specialised regions of the cytoplasm depending on the type of RNA formed.

Reactivity	Due to its deoxyribose sugar, which contains one less oxygen-containing hydroxyl group, DNA is a more stable molecule than RNA, which is useful for a molecule which has the task of keeping genetic information safe.	RNA, containing a ribose sugar, is more reactive than DNA and is not stable in alkaline conditions. RNA's larger helical grooves mean it is more easily subject to attack by enzymes.
Ultraviolet (UV) Sensitivity	DNA is vulnerable to damage by ultraviolet light.	RNA is more resistant to damage from UV light than DNA.

Major differences between DNA and RNA

The three major structural differences of RNA from that of DNA are:

a. RNA contains ribose sugar instead of 2'-deoxyribose. It means that ribose has a **hydroxyl group** (**OH**) at the 2' position, whereas, deoxyribose has hydrogen (H) at 2' position in pentose sugar.

1. RNA has Uracil (U), whereas DNA has thymine (T).
2. Unlike DNA, which consists of two polynucleotide chains, in most cases, RNA is found in a **single polynucleotide chain.**

Table 3.2: Differences between DNA and RNA

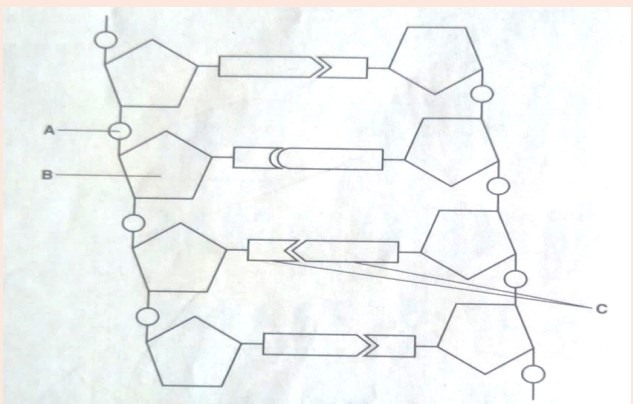
S.No	DNA	RNA
1.	Double stranded	Single stranded (normally) with some excepti on such as *riovirus*
2.	Deoxyribose sugar	Ribose sugar
3.	The base composition is: Adenine Thymine Guanine Cytosine	The base composition is: Adenine Thymine Guanine Uracil

4.	The main function is to transfer genetic information from one generation to another generation.	The main function is to direct synthesis of proteins in the body.
5.	Purine and Pyrimidine bases are equal in number.	No proportionality in the numbers of purine and pyrimidine bases.
6.	Hydrogen bonds are formed in between the complimentary bases of the two opposite strands. (A-T, G-C).	Hydrogen bonds are formed only when the RNA is in the secondary or coiled structure.
7.	It is spirally twisted to form a regular helix.	It gets coiled to form secondary helix or pseudohelix.
8.	It is long lived.	Most of them are short lived though there are some exceptions.
9.	It usually occurs inside the nucleus and in some organelles such as mitochondria and chloroplast in plants.	Very little occurs inside the nucleus. Majority of it is found in cytoplasm.

Application activity 3.1

The diagram below represents a complex organic substance found in living cells. Observe carefully this diagram and answer the questions that follow

1. Name that complex organic substance
2. Name A, B and C
3. Create a diagram showing another complex organic substance found in living cells

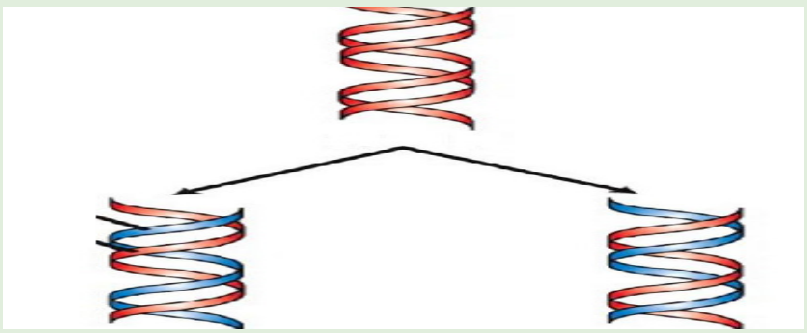


3.2 Mechanism of DNA replication

Activity 3.2

The diagram below shows how DNA replicates,

a) Explain the mechanism of DNA replication basing on this diagram.



b) Using a school library, search additional information on the internet and make short summary on DNA replication.

3.2.1 Different models of DNA replication

DNA is often described as a double helix. This refers to the three-dimensional shape that DNA moleculesform. The hydrogen bonds linking the bases, and therefore holding the two strands together can be broken relatively easily. This happens during DNA replication (DNA copying) and also during protein synthesis (protein manufacture). As we shall see, the breaking of the hydrogen bonds is a very important feature of the DNA molecule that enables it to perform its role in the cell. RNA molecules, unlike DNA, remain as single strands of polynucleotide and can form very different three-dimensional structures. We will look at this later in the chapter when we consider protein synthesis.

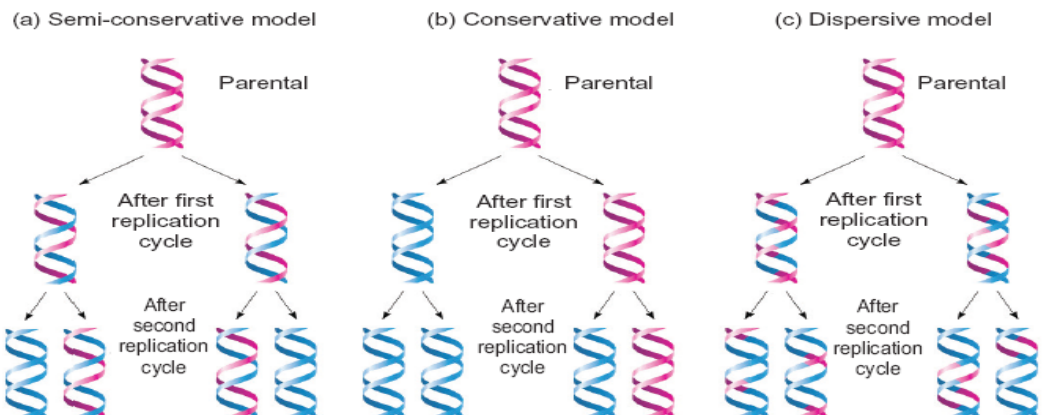


Figure 3.7: Different models of DNA replication

1. Semi-conservative model

In 1953, **Watson and Crick** proposed their classic paper postulating a double helix for DNA. A month later, they published another paper suggesting how such base-paired structures in DNA might duplicate itself. The essence of Watson and Crick suggestion is that if DNA molecule was untwisted and the two strands get separated, **each strand could act as a template** for the synthesis of a new complementary strand of DNA. And this new complementary strand could then be bound to the parental strand of DNA. This model replication is known as the **semiconservative model**. It is because half of the parent strand of DNA is retained by newly formed daughter DNA strand. Experimental evidence of semi-conservative DNA replication

In 1958, Matthew Meselson and Franklin Stahl–used two isotopic forms of nitrogen, ^{14}N (*light*) and ^{15}N (*heavy*), to distinguish newly synthesized strands of DNA from old strands.

- Initially, Meselson and Stahl grew *E. coli* (bacteria) for many generations in a medium containing ^{15}N-labelled ammonium chloride ($^{15}NH_4Cl$) to incorporate this heavy isotope of nitrogen into their DNA molecule. As expected, the DNA strands in the bacteria had **^{15}N-^{15}N (heavy) DNA** (Figure 3.7).
- In the **second stage**, they transferred the ^{15}N-labelled bacteria to a medium containing nitrogen in the normal ^{14}N form (light). Then the bacteria were allowed to reproduce for several generations. Since, the bacteria were grown in the normal ^{14}N form, the entire newly synthesized DNA after the transfer was **now labelled with ^{14}N**.
- Samples of *E. coli* were taken at various time periods as the bacteria continued to reproduce in the medium. The DNAs from these bacteria were extracted and analyzed to determine its density. They determined the density of extracted DNAs by using **equilibrium density gradient centrifugation technique**. This technique uses **Cesium Chloride (CsCl)**, a heavy metal salt that forms solutions of very high density. Thus, they analyzed the extracted DNA by simply mixing it with a solution of cesium chloride and then centrifuged at high speed.

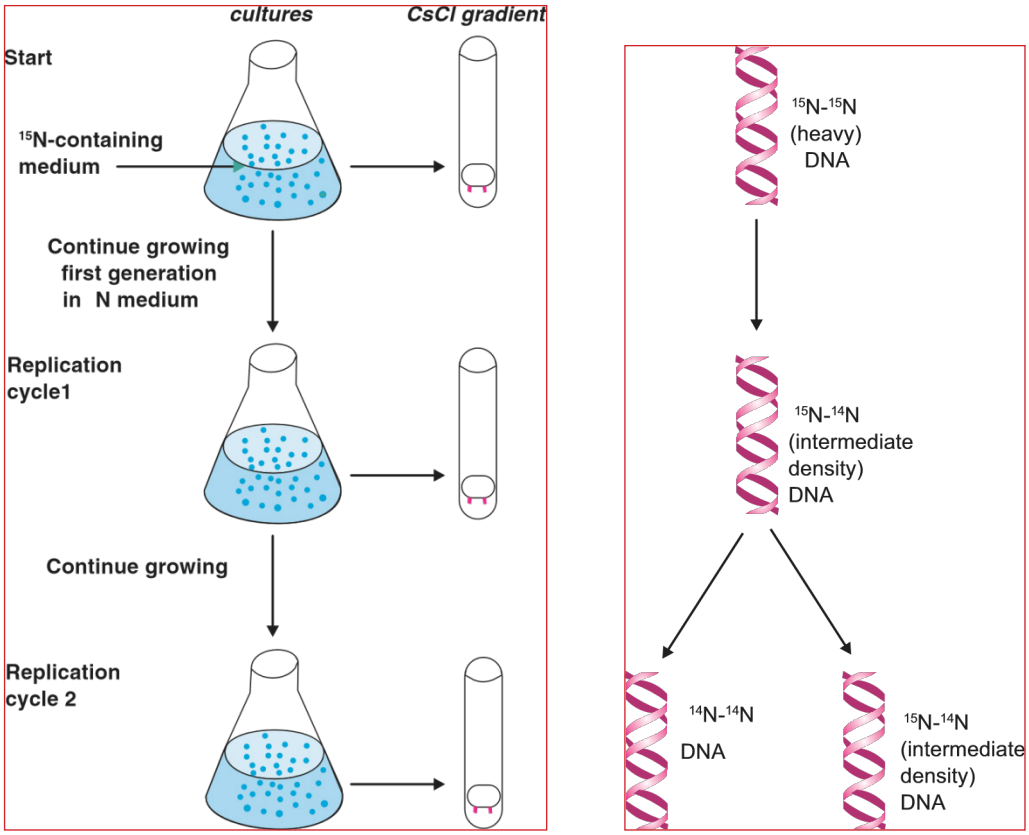


Figure 3.8: Meselson-Stahl experiment

In $^{15}NH_4Cl$ compound, the normal isotope of nitrogen, ^{14}N, is replaced with ^{15}N, which is a heavy isotope. Since the density is equal to weight divided by volume, the ^{15}N which has one extra neutron in its nucleus is 1/14 times denser than ^{14}N.

As a density gradient of cesium chloride is established by the centrifugal force, the DNA molecules float "up" and sink "down" within the gradient to reach their equilibrium density positions. The difference in density between the heavy (^{15}N) DNA and the light (^{14}N) DNA causes DNA molecules to rest at different positions by forming **bands** in the gradient (Figure 3.7).

Final observations

- ***First generation (After one replication cycle)***

When the observation was made after one replication cycle in the ^{14}N medium, the entire DNA had a density that was exactly intermediate between that of ^{15}N-^{15}N DNA and that of ^{14}N-^{14}N DNA. The intermediate composition was **^{15}N-^{14}N DNA**.

- ***Second generation (After two replication cycles)***

Again, when the observation was made after two replication cycles, half of the DNA was that of intermediate density (**^{15}N-^{14}N DNA**) and half was that of the density of **^{14}N-^{14}N DNA**.

The observations made in this experiment exactly tested and proved the predication of the semi-conservative model. Therefore, through this experiment it has been known that DNA replication follows semi-conservative model. At the same time, it disproved the claim that DNA replication follows either conservative or dispersed replication models.

2. Conservative DNA replication model

In this model, the two parental DNA strands come together right after replication; and as a whole, these two parental DNA strands serve as template for the synthesis of completely new daughter DNA strands. As a result, one daughter DNA molecule contains parental DNA strands, while the other daughter DNA molecule contains newly synthesized DNA strands

3. Dispersive DNA replication model

In this model, the parental double helix is broken or cleaved into double-stranded DNA that acts as templates for the synthesis of new double helix molecules. The segments then reassemble into complete DNA double helices, each with parental and daughter DNA segments interspersed. After the replication, although the two daughter DNA molecules are identical in their base pair sequence, the parental double stranded DNA has become dispersed throughout both in the daughter DNA molecules

3.2.2 Importance of DNA replication

Genes duplicate themselves very accurately by DNA replication. The three main importance of DNA replication are:

Reproduction: One of the most fundamental properties of all living things is the ability to reproduce. It is through reproduction that parents faithfully pass on their genetic information specifying their structure and function to their young ones. At organism level, organisms reproduce either by asexual or sexual reproduction methods. At cellular level, cells duplicate by cellular division. And at the genetic level, the genetic material duplicates by DNA replication.

Repair: DNA is the centre of instructions that govern the cell's protein production, growth, and many other activities in the cells. With this enormity of precise responsibility, any minor mistakes in the replication process can bring

potentially harmful changes in the cell's behaviour or for that matter, the whole organism. Therefore, DNA employs various error repair mechanisms to ensure accurate DNA replication.

Growth: DNA Replication is required for the growth of organisms. DNA replication occurs in two different forms of cellular division. They are mitosis and meiosis. In mitosis, a single parent cell divides and gives rise to two identical daughter cells. Each of the daughter cells has the exact amount of genetic material. For example, growth of limbs, organs, hair etc. On the other hand, in meiosis, cells divide and give rise to two haploid sex cells. Thus, DNA replication plays a vital role in both mitosis and meiosis.

3.2 3 Enzymes and proteins involved in DNA replication

a. DNA polymerases

In 1955, Arthur Kornberg and his colleagues were the first ones to identify an enzyme that could synthesize DNA. Back then this enzyme was originally called **Kornberg enzyme**. But now it is called **DNA polymerase I**. (enzymes that catalyzes the synthesis of DNA). There are five DNA polymerases: ***DNA polymerase I, DNA polymerase II, DNA polymerase III, DNA polymerase IV and DNA polymerase V.***

On one hand, **DNA polymerase I** and **III** are functionally required for replication. DNA polymerase **III** along with other DNA polymerases **(I and II)** has the capability to elongate an existing DNA strand. But cannot initiate DNA synthesis, DNA polymerases can polymerize nucleotides only in 5′ → 3′ direction.

b. DNA helicase

DNA helicase is an enzyme that unwinds or unzips the double stranded DNA by breaking the hydrogen bonds between the complementary bases.

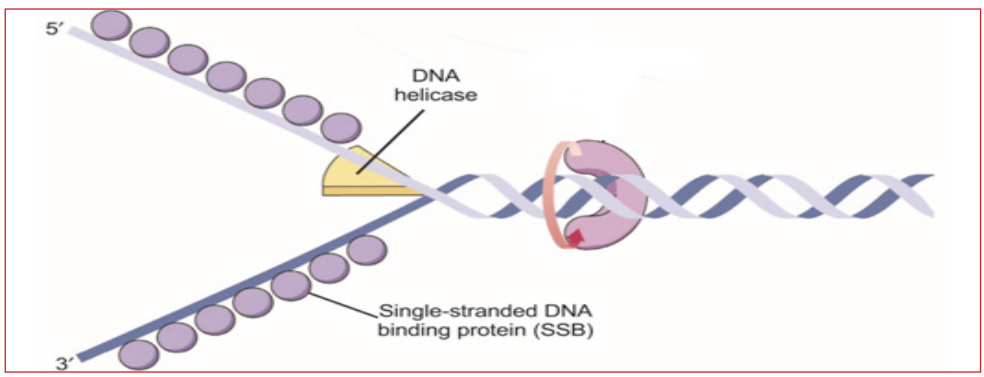


Figure 3.9: Diagram showing DNA helicase, single-stranded DNA binding protein

The action of DNA helicase can be compared with a zipper. When we open a zip, the zipper runs on a zip and makes a Y-shape structure with the two strands of interlocking teeth. In the same way, DNA helicase unzips the double stranded DNA and form a Y-shaped fork known as a replication fork.

c. Single-strand DNA-binding proteins (SSB)

In DNA replication when helicase unwinds the double stranded DNA, the two separating strands of DNA have the tendency to reform or reanneal into double stranded DNA. A protein called **single-strand DNA-binding (SSB)** proteins bind to each single-strand DNA and stabilize them, so that the separating two strands of DNA do not reform double stranded DNA by complementary base pairing (Figure 3.9).

d. DNA ligase

At the end of DNA replication right after the DNA Pol I is removed and replaced all the RNA primer nucleotides with DNA nucleotides, normally as single-strand nick (gap) is left between the two DNA fragments (Figure 3.9). This nick is the point where the sugar-phosphate backbone between adjacent nucleotides is unconnected. So, what DNA ligase does is that it joins the two fragments resulting into a longer and continuous DNA strand.

Chemically, DNA ligase catalyzes the formation of a phosphodiester bond between the 3′-OH and the 5′-phosphate groups on either side of a nick. As a result, it seals the nick (gap).

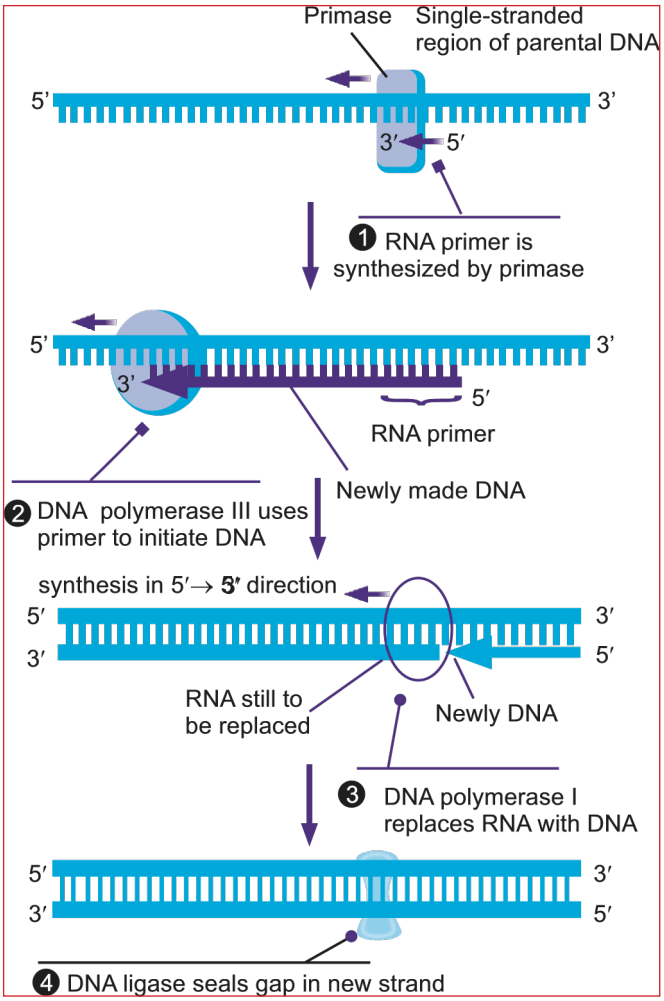


Figure 3.10: Flow diagram showing DNA ligase sealing the gap in a new DNA strand

3.2.4. Genes and chromosome

The DNA molecule is packaged into thread-like structures called chromosomes in cell. Chromosomes are not visible in the cell's nucleus, not even under a microscope, when the cell is not dividing. Each chromosome is made up of DNA tightly coiled many times around proteins called histones that support its structure.

A gene is the basic physical and functional unit of heredity. Genes are made up of DNA. Some genes act as instructions to make molecules called proteins. However, many genes do not code for proteins.

3.2.5 Significance of telomere in permitting continued replication

A telomere is a region of repetitive nucleotide sequences at each of a chromosome. It protects the end of the chromosome from being deleted or from fusion with neighboring chromosomes. In vertebrates, the repetitive sequence of nucleotides in telomeres is TTAGG. In humans, this sequence is repeated about 2500 times.

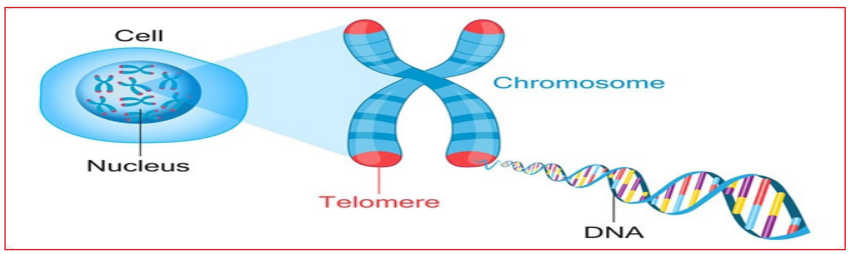


Figure 3.11: Diagram showing the region of telomere

Source: adapted fromhttps://www.news-medical.net/life-sciences/What-are-Telomeres.aspx

Telomeres and cancer

Telomeres maintain genomic integrity in normal cells, and their progressive shortening during successive cell divisions induces chromosomal instability. In the large majority of cancer cells, telomere length is maintained by telomerase. Shortening of telomeres is associated with each round of cell division owing to the inability of conventional DNA polymerases to replicate the ends of linear chromosomes, the so-called '**end replication problem'**. Cancer cells are characterized by their rapid and uncontrollable division of cells. These cells have active telomerase to help them divide uncontrollably and become immortal. The enzyme telomerase is used to extend the life span of cancer cells. In the absence of telomerase, the cancer cells would become inactive and would stop dividing resulting into death of the cancer cells because of Shortening of telomeres after each division, which causing the cell to die. Cancer therapies can take advantage of this concept by designing drugs that can inhibit telomerase activity, thereby killing the cancer cells. Telomere biology is an important aspect of human cancer. Many scientists are hoping and working hard to understand the best way to use anti-telomerase therapy and advance the treatment of cancer.

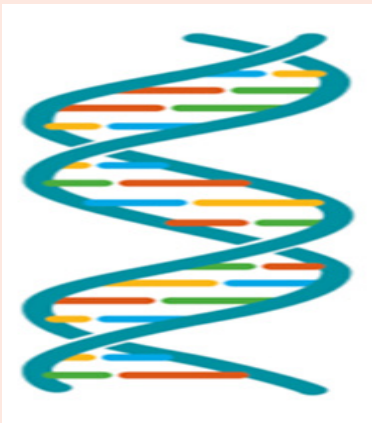
Application activity 3.2

Observe the diagram carefully and answer the following questions

1. Label this diagram
2. On the diagram the colors are different? Explain why?
3. On the diagram, the colors are arranged in this order e.g sky blue is paired with yellow, green –red, explain

a. why sky blue is not paired with red?

b. Why red is not paired with yellow?



(Source: adapted from https://www.compoundchem.com/2015/03/24/dna/)

3.3 Nature of gene, genetic code and protein synthesis

Activity 3.3

Research activity

Make a research on gene, genetic code and process of protein synthesis using different biology books and internet. Make short notes on them.

3.3.1. Protein synthesis

A complete DNA set of an organism is called **genome**. Protein synthesis begins with genes. A gene is a functional segment of DNA that provides the genetic information necessary to build a protein and it is also DNA that encodes for a *particular trait (can be physical appearance or hidden feature kown as genetic)*. *For example,* black hair, brown hair Genes are located on the chromosomes. Each particular gene provides the code necessary to construct a particular protein.

Gene expression which is a process to transform the information coded in a gene to a final gene product, ultimately dictates the structure and function of a cell by determining which proteins are made.

DNA which specifies protein synthesis is confined in the **nucleus** while the process of protein synthesis takes place in the **cytoplasm.**

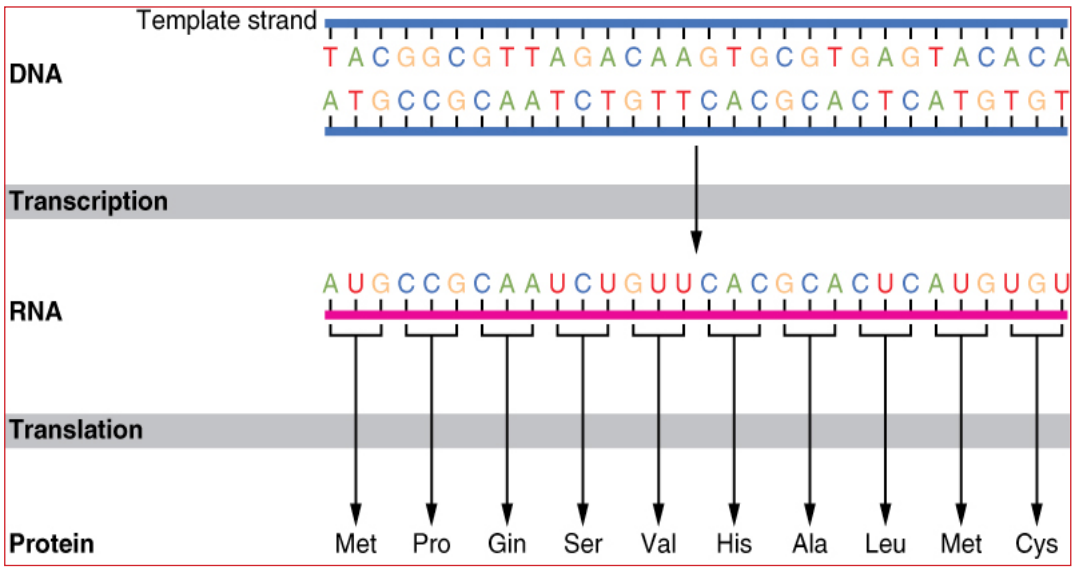


Figure 3.12: Genetic Code.

Source: *https://opentextbc.ca/anatomyandphysiology/chapter/3-4-protein-synthesis/*

DNA holds all of the genetic information necessary to build a cell's proteins. The nucleotide sequence of a gene is ultimately translated into an amino acid sequence of the gene's corresponding protein.

Application activity 3.3

Draw and label:

1. A diagram showing transcription
2. A diagram showing all steps of transcription

A. Transcription (From DNA to RNA)

It is known that DNA is housed within the nucleus, and protein synthesis takes place in the cytoplasm, thus there must be some sort of intermediate messenger that leaves the nucleus and manages protein synthesis.

This intermediate messenger is **messenger RNA (mRNA)** which is a single-stranded nucleic acid that carries a copy of the genetic code for a single gene out of the nucleus and into the cytoplasm where it is used to produce proteins.

A gene is made up of a sequence of nucleotides that forms part of a DNA molecule that codes for a specific polypeptide.

The genetic code is the set of rules by which information encoded in genetic material (DNA or RNA sequences) is translated into proteins (amino acid sequences) by living cells using ribosome machinery. Gene expression begins with the process called **transcription**, which is the synthesis of a strand of mRNA that is complementary to the gene of interest. This process is called transcription because the mRNA is like a transcript, or copy, of the gene's DNA code.

During transcription, a specific region on the DNA molecule un zips/ unwinds by breaking hydrogen bonds between complementary bases. This is catalyzed by an enzyme DNA helicase. The DNA strands act as a template.

Transcription begins in a fashion somewhat like DNA replication, in that a region of DNA unwinds and the two strands separate, however, only that small portion of the DNA will be split apart. The triplets within the gene on this section of the DNA molecule are used as the template to transcribe the complementary strand of mRNA (Figure 3.11). **A codon** is a three-base sequence of mRNA, so-called because they directly encode amino acids. Like DNA replication, there are three stages to transcription: **initiation, elongation, and termination**.

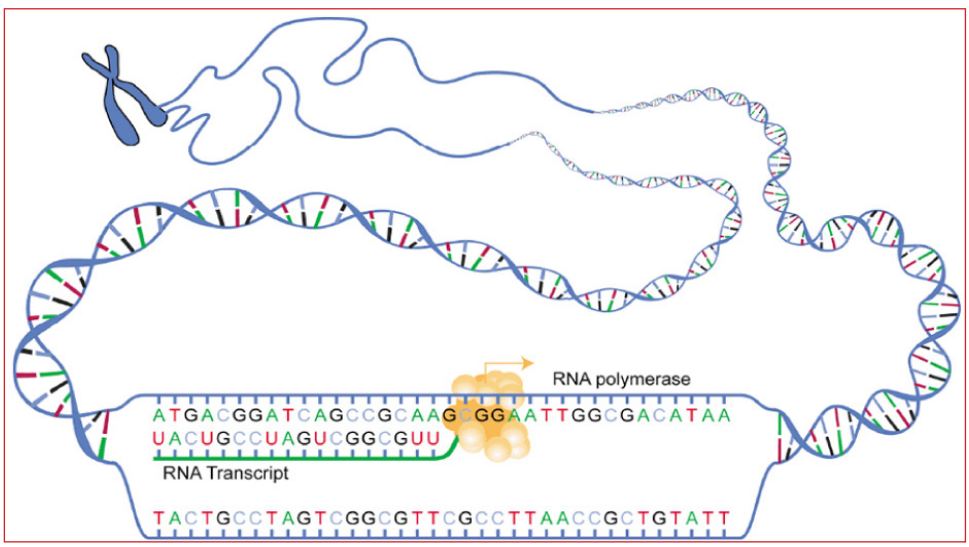


Figure 3.13: Transcription (from DNA to mRNA). Source: https://opentextbc.ca/anatomyandphysiology/chapter/3-4-protein-synthesis/

In the first of the two stages of making protein from DNA, a gene on the DNA molecule is transcribed into a complementary mRNA molecule

Stage 1:

Initiation. A region at the beginning of the gene called a promoter—a particular sequence of nucleotides—triggers the start of transcription.

Stage 2:

Elongation. Transcription starts when RNA polymerase unwinds the DNA segment. One strand, referred to as the coding strand, becomes the template with the genes to be coded. The polymerase then aligns the correct nucleic acid (A, C, G, or U) with its complementary base on the coding strand of DNA. RNA polymerase is an enzyme that adds new nucleotides to a growing strand of RNA. This process builds a strand of mRNA.

Stage 3:

Termination. When the polymerase has reached the end of the gene, one of three specific triplets (UAA, UAG, or UGA) codes a "stop" signal, which triggers the enzymes to terminate transcription and release the mRNA transcript.

Requirements for transcription

- DNA molecule to act as a template.
- The appropriate enzymes i.e. DNA helicase and RNA polymerase.
- Free RNA nucleotides.

ATP as source of energy

B. Translation (From RNA to protein)

Activity 3.4

a. The ribosome binds to the mRNA molecule to start translation of its code into a protein. What happens to the small and large ribosomal subunits at the end of translation?

b. Using charts showing the process of translation and explain how translation takes place.

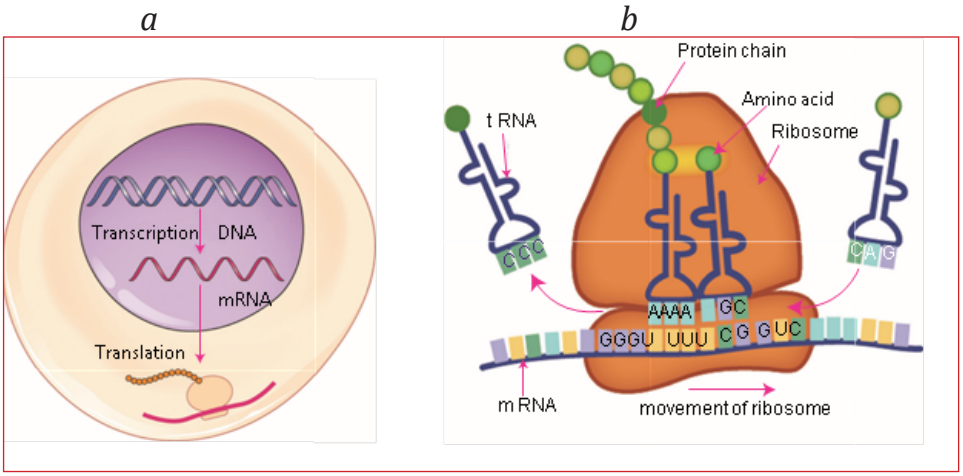
c. In your free time, watch a video on translation and make short summary on the process of translation.

This step is sounding like translating a book from one language into another, where the codons on a strand of mRNA must be translated into the amino acid alphabet of proteins. **Translation** is the process of synthesizing a chain of amino acids called a **polypeptide**.

Translation requires two major aids: first, a "translator," the molecule that will conduct the translation, and second, a substrate on which the mRNA strand is translated into a new protein, like the translator's "desk." Both of these requirements are fulfilled by other types of RNA. The substrate on which translation takes place is the ribosome.

Remember that many of a cell's ribosomes are found associated with the rough **ER**, and carry out the synthesis of proteins destined for the Golgi apparatus. **Ribosomal RNA (rRNA)** is a type of RNA that, together with proteins, composes the structure of the ribosome. Ribosomes exist in the cytoplasm as two distinct components, a small and a large subunit. When an mRNA molecule is ready from 5' end to 3' end to be translated, the two subunits come together and attach to the mRNA. The ribosome provides a substrate for translation, bringing together and aligning the mRNA molecule with the molecular "translators" that must decipher its code. Generally, ribosome is composed of two dissociable subunits called the large and small subunits. In prokaryotes (bacteria), ribosome has a sedimentation coefficient of 70S; it is made up by 30S small subunit and 50S large subunit (Figure 6.10). In eukaryotes, ribosome has a sedimentation coefficient of 80S; it is made up of 40S small unit and 60S large unit.

The other major requirement for protein synthesis is the translator molecules that physically "read" the mRNA codons. **Transfer RNA (tRNA)** is a short single stranded and backed twisted helix. It has paired bases in some nucleotides and its folding form three main loops. It is also a type of RNA that ferries the appropriate corresponding amino acids to the ribosome, and attaches each new amino acid to the last, building the polypeptide chain one-by-one. Thus, tRNA transfers specific amino acids from the cytoplasm to a growing polypeptide. The tRNA molecules must be able to recognize the codons on mRNA and match them with the correct amino acid.



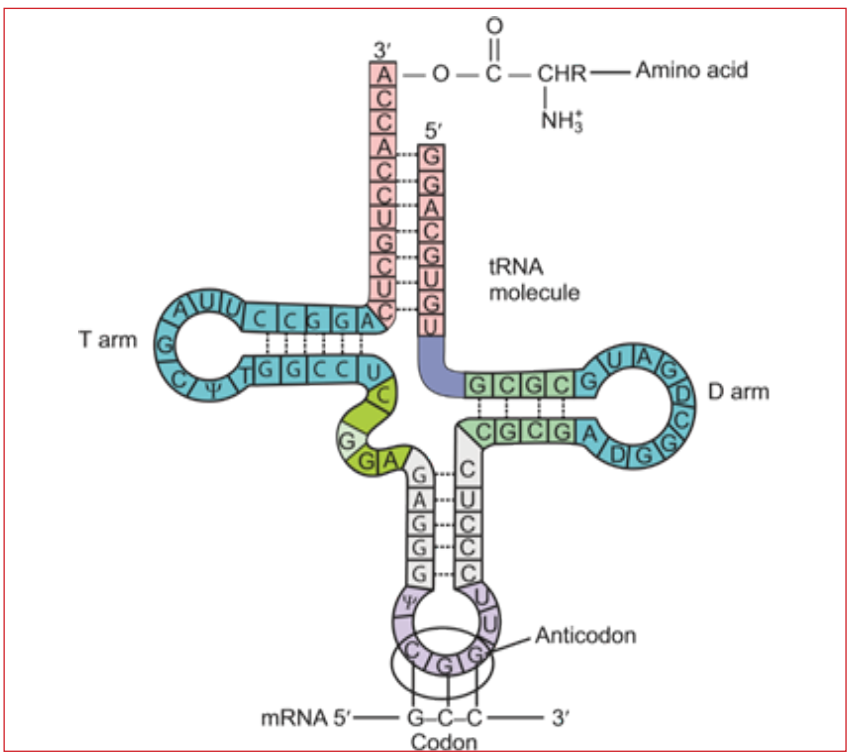


Figure 3.14: Role of ribosomes in the formation of polypeptide chain and t-RNA structure

The tRNA is modified for this function. On one end of its structure is a binding site for a specific amino acid. On the other end is a base sequence that matches the codon specifying its particular amino acid. This sequence of three bases on the tRNA molecule is called an **anticodon**.

By nature in both eukaryotes and prokaryotes, the 5' to 3' nucleotide sequence of the coding DNA strand exactly corresponds or specifies the same N-terminal to C-terminal amino acid sequence of the encoded polypeptide (Figure 3.12).

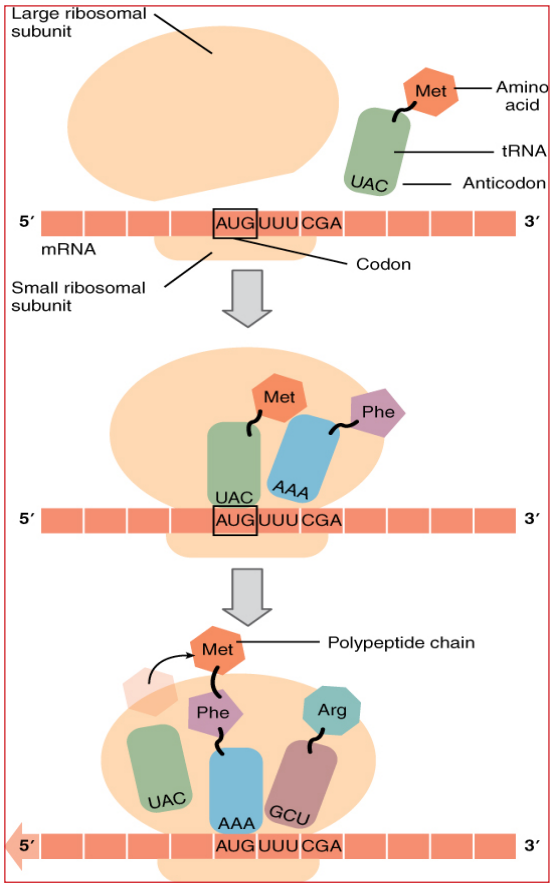


Figure 3.15: Translation (from RNA to Protein)

During translation, the mRNA transcript is "read" by a functional complex consisting of the ribosome and tRNA molecules. tRNAs bring the appropriate amino acids in sequence to the growing polypeptide chain by matching their anti-codons with codons on the mRNA strand.

With four different nucleotides (A, C, G, U), a three-letter code (codon) can give 64 different possible codons (i.e. $\mathbf{4^3 = 64}$) or **(4 × 4 × 4 = 64)**. These 64 possible codons are more than enough to code for the 20 amino acids found in living cells. The genetic code allows an organism to translate the genetic information found in its chromosomes (by m-RNA) into mature functional proteins.

3.3.2 Characteristics of genetic code

The following are some characteristics of genetic code:

1. **Genetic code as a triplet codon:** A codon consists of a group of three nucleotides. And each codon codes for a specific amino acid in a polypeptide chain with some exceptions.
2. **Genetic code is used without comma:** The three nucleotides in a codon are read in a continuous fashion without any comma. Examples: AUG, UAG, UGA and UAA.
3. **Genetic code is non-overlapping:** The codons in the m-RNA sequence are read successively without overlapping.
4. **Genetic code is almost universal:** For many long years, it was thought that the genetic code is universal, which led us into believing that all living organisms have the same genetic code. However, recent studies have revealed that there are some organisms where there is difference in genetic code (**Table 3.3**). That is the reason why it is appropriate to use the phrase "almost universal" rather than the word "universal." The examples of organisms or organelles where genetic codes have different meanings:

Table 3.3: Genetic code

Organism or organelles	Codon	Amino Acid
Mitochondria	AUA	Met not Ile
Mitochondria	UGA	Trp not Stop codon

5. **Genetic code is "degenerate":** A codon is thought to code for a particular amino acid. That is one codon for one amino acid. But more than one codon can code for a particular amino acid, with two exceptions of AUG and UGG. This multiple coding by a single codon is called the **degeneracy or redundancy** of the code. **Example:** UUU and UUC codons code for the same specific phenylalanine amino acid. In the same way, CAU and CAC codons code for the same specific histidine amino acid (Figure 6.2).

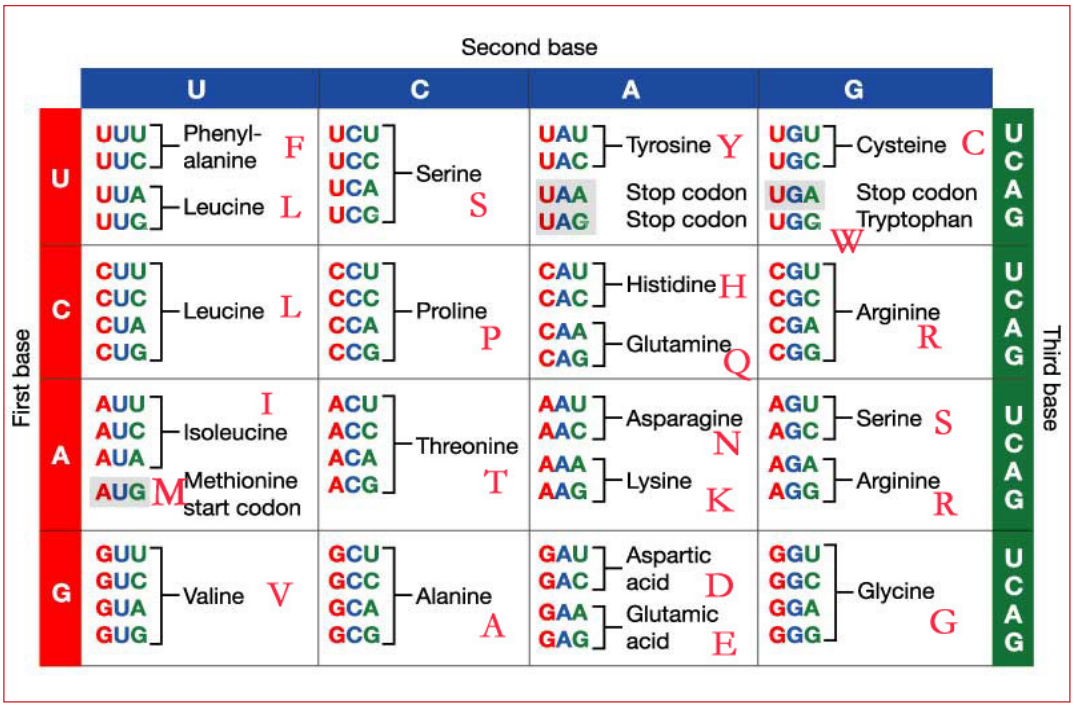


Figure 3.16: Genetic Code

Application activity 3.2

Use the following genetic code and translate the following segment of RNA into a sequence of five amino acids: GUC-GCG-CAU-AGC-AAG

1st letter	Second Letter U	Second Letter C	Second Letter A	Second Letter G	3rd letter
U	UUU Phe, UUC Phe, UUA Leu, UUG Leu	UCU Ser, UCC Ser, UCA Ser, UCG Ser	UAU Tyr, UAC Tyr, UAA Stop, UAG Stop	UGU Cys, UGC Cys, UGA Stop, UGG Trp	U C A G
C	CUU Leu, CUC Leu, CUA Leu, CUG Leu	CCU Pro, CCC Pro, CCA Pro, CCG Pro	CAU His, CAC His, CAA Gln, CAG Gln	CGU Arg, CGC Arg, CGA Arg, CGG Arg	U C A G
A	AUU Ile, AUC Ile, AUA Ile, AUG Met	ACU Thr, ACC Thr, ACA Thr, ACG Thr	AAU Asn, AAC Asn, AAA Lys, AAG Lys	AGU Ser, AGC Ser, AGA Arg, AGG Arg	U C A G
G	GUU Val, GUC Val, GUA Val, GUG Val	GCU Ala, GCC Ala, GCA Ala, GCG Ala	GAU Asp, GAC Asp, GAA Glu, GAG Glu	GGU Gly, GGC Gly, GGA Gly, GGG Gly	U C A G

How to read the genetic code?

The genetic code is an **mRNA** code read in three letter blocks (codons) in the 5′ → 3′ direction. **Example:** Say you want to find out the codon of **ACG**.

- Firstly, locate and read letter "A" on the **first base** column on the left-hand side of the table.

- Secondly, locate and read the letter "C" on the second base row and locate the same letter down the column where it pairs with the previous first letter "A". So you have AC bases now.
- Thirdly, locate and read the letter "G" on the third base column where this letter makes the third letter with the previous AC bases. Now you have the codon ACG, which codes for threonine (Thre) amino acid.

N.B: Out of the total 64 codons, 61 sense codons specify one of the 20 amino acids. The other three nonsense codons are **Stop Codons** and, therefore, do not specify any amino acid. The sense codon AUG, which specifies Methionine, is a **Start Codon**

6. **Genetic code has start and stop codons:** Out of 64 codons, only 61 codons are called **sense codons** (Figure 6.2). The other three codons are called **nonsense codons or stop codons or chain-terminating codons**. These three codons are UAG, UAA, and UGA; they do not specify any amino acid, and there are no t-RNAs to carry the appropriate anticodons. The AUG codon, which code for methionine, is most of the time the **start codon or initiation codon** for protein synthesis in both eukaryotes and prokaryotes.
7. **Wobble hypothesis:** Francis Crick has pointed out that the complete set of 61 sense codons can be read by fewer number than 61 t-RNAs. The simple reason being, the pairing properties in the bases in the anticodons are wobble in nature. Here, the word "wobble" simply means "fluctuating" or "unsteady."

For example: The two different leucine codons (CUC, CUU) can be read by the same leucine t-RNA molecule, contrary to regular base-pairing rules (Figure 6.3).

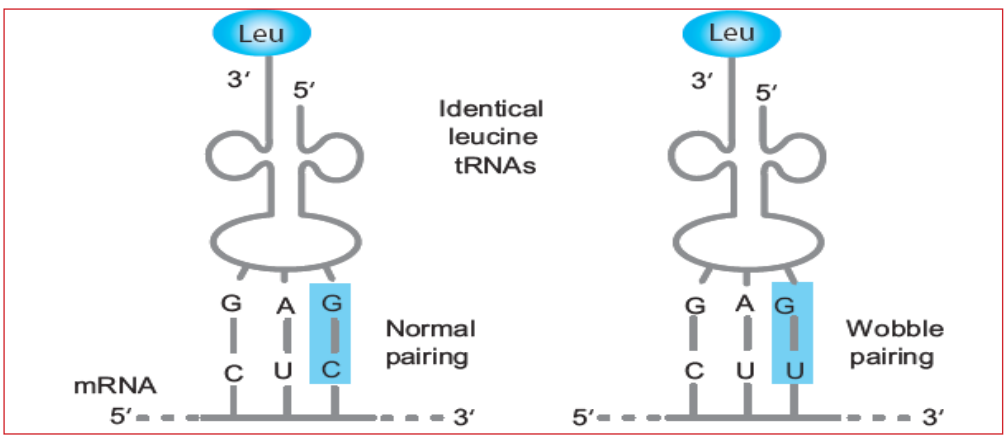


Figure 3.17: Example of base-pairing wobble. The same leucine t-RNA molecule (anticodon GAG) can read two different leucine codons (CUC, CUU)

DNA is extremely stable and replicates accurately

According to central dogma concept, m-RNA is copied from DNA and m-RNA is then translated to form proteins. Therefore, it is critical to maintain the integrity of DNA to accurately produce the desired and correct amino acids (proteins).

DNA is the repository of genetic information gathered over millions of years and it is stored in a stable form inside the cell. The stability of DNA is a property critical to the maintenance of the integrity of the gene.

The stability of DNA can be explained and evidently supported by the fact that DNA has been extracted from Egyptian mummies and extinct animals such as the woolly mammoth and it can also be extracted from dried blood sample or from a single hair at a crime scene which is old enough. DNA molecule is a stable structure and replicates accurately in order to avoid any mutation or change in nucleotides sequences in DNA. The stability of DNA can be attributed to important factors — **Hydrogen bonds** and **base stacking**

Hydrogen bonds

Hydrogen bond is the **attractive force** between the hydrogen attached to an electronegative atom (O) of one molecule and an electronegative atom (N) of a different molecule (Figure 6.4). In the structure of DNA, the strong electronegative atom is the oxygen (O) and Nitrogen (N), while H atom has positive charge. In the structure of DNA (Figure 6.4), thymine and adenine have **two hydrogen bonds**; while guanine and cytosine have **three hydrogen bonds**. Hydrogen bonds play very important role in binding the bases of the opposite strands in the DNA. Hydrogen bonds are very weak by themselves. But in a DNA sequence, there will be thousands of these H-bonds which make DNA very stable.

Base stacking

In DNA, the stacked base pairs also attract to one another through Van der Waals forces. The energy associated with a single Van der Waals interaction has small significant to the overall DNA structure. But the large amounts of these interactions help to stabilize the overall structure of the helix

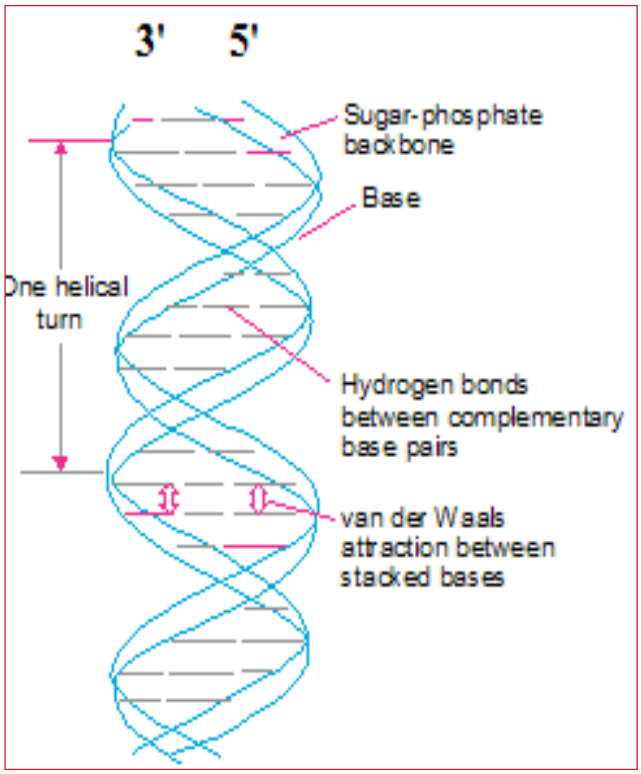


Figure 3.18: Hydrogen bonding and base stacking enabling stability of DNA

3.4 Effects of alteration of nucleotide sequence

Activity 3.5

Make a research using books from school library and internet on effects of alteration of nucleotide sequence, write a short summary on your research and discuss the effects of alternation of nucleotide sequence.

Change in nucleotide (mutation) sequence leads to change in polypeptides

Amino acids (proteins) are the ultimate product of the nucleotide sequence present in genes (DNA). Thus, any change in the nucleotide sequence of a gene can result into producing wrong or different polypeptide chain. In other words, gene mutation is a change in sequence of nucleotides that results in change in the synthesis of polypeptide chains.

One of the best examples is Sickle-cell anaemia. In this disease, the nucleotide "T" in the DNA sequence is replaced by "A" nucleotide.

The minor substitution in the nucleotide sequence is transcribed as a mutant codon on the m-RNA. And during translation, due to mutant codon on the m-RNA, valine is synthesized instead of glutamic acid. Valine distorts red blood cells and cause sickle-cell anaemia. You will be studying next about it in next section.

Another example is Albinism. Albinism occurs due to mutation in the gene for tyrosinase, an enzyme which coverts tyrosine to DOPA (dihydroxyphenylalanine) Melanin, skin pigment, is derived from DOPA. Melanin absorbs light in the ultraviolet (UV) range and protects the skin against harmful UV radiation from the sun. People with albinism produce no melanin. Therefore, they have white skin, white hair, eyes with red iris, and they are very sensitive to light. Mutation in the gene of tyrosinase

Sickel cell anaemia

In 1910, J. Herrick first described sickle-cell anaemia. He found out that in conditions of low oxygen tension, the normal disc-shaped red blood cells of people with sickle-cell anaemia get distorted into sickle-shaped red blood cells. Sickle-cell anaemia is a genetic disease that affects haemoglobin molecules. Haemoglobin is a protein found in red blood cells and is responsible for the transportation of oxygen through the body. Haemoglobin, the molecule affected in sickle-cell anaemia, consists of four polypeptide chains:

Two a**-globin polypeptides** and **two** b**-globin polypeptides**-each of which is associated with a haeme group (a non-protein chemical group involved in oxygen binding and added to each polypeptide after the polypeptide is synthesized).

Cause

The mutation causing sickle cell anaemia is a single nucleotide substitution (A to T) in the DNA of haemoglobin coding gene. The change in a single nucleotide is transcribed as a codon for **valine amino acid (GUG)** on the m-RNA instead of **glutamic acid (GAG)** Eventually, due to change in the codon, valine amino acid is translated instead of glutamic acid at the 6th position from N-terminus of the haemoglobin polypeptide chain. This defective form of haemoglobin in persons with sickle cell anaemia is referred to as **HbS**.

Symptoms

The sickled red blood cells are fragile and break easily, resulting in the anaemia. Normal red blood cells normally squeeze and pass through blood capillaries smoothly. However, sickled cells are not flexible and therefore have the tendency to get clogged in capillaries. As a result, blood circulation is impaired and tissues become deprived of oxygen. Oxygen deprivation occurs at the extremities, the heart, lungs, brain, kidneys, gastrointestinal tract, muscles, and joints.

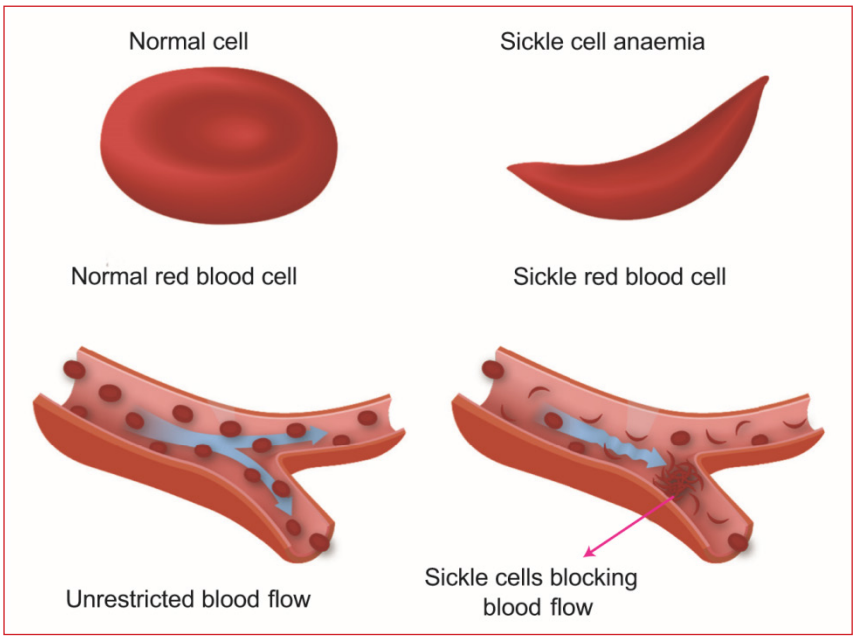


Figure 3.19: Difference between normal and sickle red blood cells

Sickle cell anaemia is an autosomal recessive disorder that affects **1 in 500 African americans** and is one of the most common blood disorders and in the United States. By autosomal disorder, it means that in order for full disease symptoms to manifest in an individual they must **carry two copies (homozygous genotype = SS, HbS & HbS)** of the **HbS gene**. However, the individuals who are heterozygous (**genotype = AS, i.e., HbA and HbS**) have what is referred to as sickle cell trait, a phenotypically dominant trait.

Although heterozygous (AS) individuals are clinically normal, their red blood cells can sickle under very low oxygen pressure. Their red blood cells may sickle when they are at high altitudes in airplanes with reduced cabin pressure

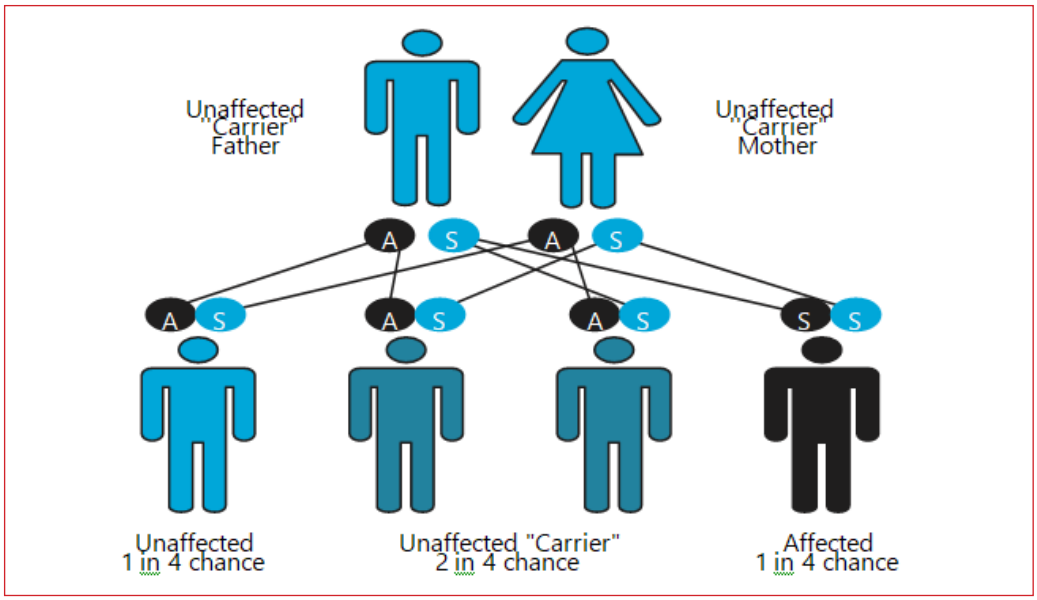


Figure 3.20: Diagram showing sickle-cell anaemia as autosomal recessive disorder

Application activity 3.4

Show your understanding of the causes and symptoms of sickle cell anaemia.

Skills lab 3

Extracting DNA from banana

Apparatus and reagents: Banana,10% Saline solution, Ethanol, Mortar, Filter paper, Test tube, Beaker, Soap (Dish wash) and Glass rod

Procedure:

1. Put one banana into the mortar. Crush banana completely, making sure it is completely pulverized
2. Pour 10% saline solution into mortar and stir gently to avoid creating foam
3. Insert a filter into a clean beaker so it does not touch the bottom of the cup
4. Pour the mixture from step 3 into the filter. After a few minutes, some liquid, called the filtrate, should have collected in the bottom of the cup. Remove the filter and set it aside
5. Add a few drops of soap into the filtrate 4 and stir gently

6. Get a test tube of cold alcohol. Use a pipette or eyedropper to collect your filtrate. Add it to the alcohol. Let it sit undisturbed for about 5 minutes. Do not shake, the white material coming out of solution as a precipitate is DNA
7. Dip the glass rod into the tube, slowly rotating it to spool out the banana's DNA

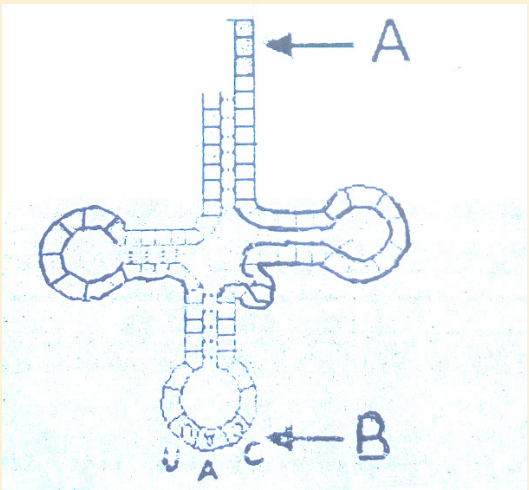
Questions

Prove that your results would be different if you were to use a fruit or a vegetable other than bananas? Explain

End unit assessment 3

Section A: Multiple choice questions

1. Use the figure below to answer the questions that follow



i. The above diagram refers to a molecule of
   a. mRNA
   b. tRNA
   c. DNA
   d. rRNA

ii. Item labeled A refers to
   a. The codon
   b. Amino acid attachment binding site
   c. The anticodon
   d. Hydrogen bond

iii. Item labeled B refers to

a. The codon

b. Amino acid attachment site

c. Hydrogen bond

d. The anticodon

2. DNA Replication is the process of

a. Copying DNA from RNA b Copying DNA from proteins

c Copying DNA from DNA d Copying DNA from ribosome

3. Nitrogenous bases of the two strands of DNA are linked with

a Hydrogen bonds b Covalent bonds

c Ionic bonds d Phosphodiester bonds

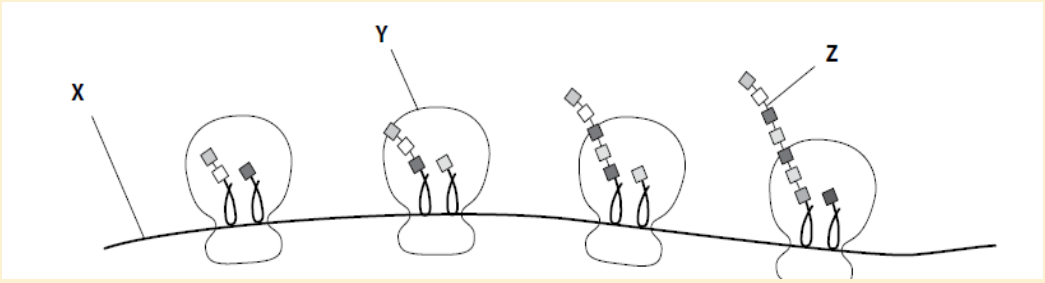
4. DNA does not have

a. Adenine b Cytosine

c. Guanine d Uracil

Section B: Short answer type questions

5. The drawing shows a polyribosome



a. Name X, Y and Z.

b. In which direction are the ribosomes moving? Explain how you were able to decide on their direction of movement.

6. Suggest why:

a. A mutation in which one nucleotide of a triplet code is altered often makes no difference to the protein molecule coded by the DNA.

b. The addition or deletion of three nucleotides in the DNA sequence of a gene often has less effect on the encoded protein than the addition or deletion of a single nucleotide.

7. The table shows all the messenger RNA (mRNA) codons for the amino acid leucine. Copy the table and write it in, for each codon, the transfer RNA (tRNA) anticodon that would bind with it and the DNA triplet from which it was transcribed.

mRNA codon	tRNA anticodon	DNA triplet from which mRNA was transcribed.
UUA		
UUG		
CUU		
CUC		
CUA		
CUG		

8. The diagram shows the sequence of bases in a short length of mRNA.

AUGGCCUCGAUAACGGCCACCUAA

a. What is the maximum number of amino acids in the polypeptide for which this piece of mRNA code?

b. How many different types of tRNA molecule would be used to produce a polypeptide from this piece of mRNA?

c. Give the DNA sequence which would be complementary to the first 6 bases in this piece of mRNA?

d. Name the process by which mRNA is formed in the nucleus.

e. Give two ways in which the structure of a molecule of tRNA differs from the structure of a molecule of mRNA.

Section C: Long answer type questions

1. a) Describe the role of RNA polymerase in transcription.

b) Which other enzyme is involved in transcription and what is its role?

c) Why is splicing of pre-mRNA necessary?

d) A sequence of bases along the template strand of DNA is ATGCAAGTCCAG.

i. What is the sequence of bases on a messenger RNA molecule that has been transcribed from this part of the DNA molecule?

ii. How many amino acids does the sequence code for?

iii. A gene is made up of 756 pairs. The mRNA that is transcribed from this gene is only 254 nucleotides long. Explain why there is this difference.

2. a) Describe why the genetic code is described as

i. Universal

ii. Degenerate

iii. Non-overlapping

b. State three ways in which the molecular structure of RNA differs from DNA.

c. Distinguish between a codon and an anticodon

d. Explain why:

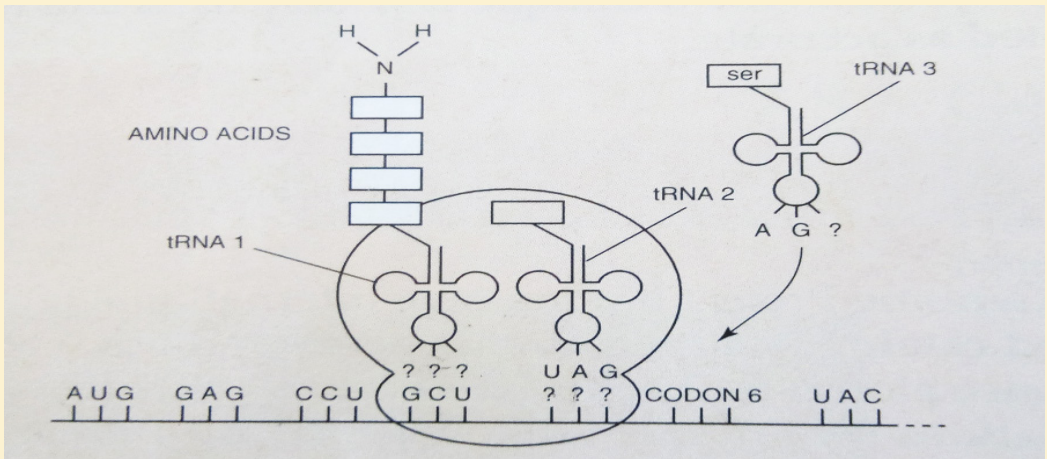
i. DNA needs to be chemically stable

ii. mRNA needs to be easily broken down (chemically unstable)

3. The following codon dictionary shows all 64 triplet codons which may occur in mRNA and the amino acids that are coded, as well as the chain termination codon which are labelled stop.

First base	Second base U	Second base C	Second base A	Second base G	Third base
U	UUU Phenylalanine	UCU Serine	UAU Tyrosine	UGU Cysteine	U
	UUC Phenylalanine	UCC Serine	UAC Tyrosine	UGC Cysteine	C
	UUA Leucine	UCA Serine	UAA Stop	UGA Stop	A
	UUG Leucine	UCG Serine	UAG Stop	UGG Tryptophan	G
C	CUU Leucine	CCU Proline	CAU Histidine	CGU Arginine	U
	CUC Leucine	CCC Proline	CAC Histidine	CGC Arginine	C
	CUA Leucine	CCA Proline	CAA Glutamine	CGA Arginine	A
	CUG Leucine	CCG Proline	CAG Glutamine	CGG Arginine	G
A	AUU Isolecine	ACU Threonine	AAU Asparagine	AGU Serine	U
	AUC Isolecine	ACC Threonine	AAC Asparagine	AGC Serine	C
	AUA Isolecine	ACA Threonine	AAA Lysine	AGA Arginine	A
	AUG Methionine (Start)	ACG Threonine	AAG Lysine	AGG Arginine	G
G	GUU Valine	GCU Alanine	GAU Aspartic acid	GGU Glycine	U
	GUC Valine	GCC Alanine	GAC Aspartic acid	GGC Glycine	C
	GUA Valine	GCA Alanine	GAA Glutamic acid	GGA Glycine	A
	GUG Valine	GCG Alanine	GAG Glutamic acid	GGG Glycine	G

Use this dictionary to answer questions about the diagram below which summarizes the processes of protein synthesis



a. Which is the first codon used in protein synthesis from this mRNA?
b. What is the sequence of the first 4 amino acids from the amino terminal of the growing polypeptide?
c. What is the anticodon sequence in tRNA 1?
d. Give the codon which is recognized by tRNA 2.
e. Explain what changes will occur in the translation apparatus to allow codon 6 to be translated.
f. What are the possible codon sequences for codon 6?
g. The figure above gives information about the seven amino acids of an 80 amino acid polypeptide.

What would be the effect on this polypeptide if there was a base substitution in the DNA sequence of the gene so that the UAC codon in the diagram became a UAG codon?

UNIT 4

DIVERSITY OF SPECIALISED TISSUES

Key unit competence: Describe different specialised plant and animal tissues and their adaptations.

Introductory activity 4

In an anthill, there are different groups of termites such as a queen, workers and soldiers. Each group has a specific role to play in the colony. The structure of termites of each group is related to their role for example soldiers that protect the colony have mouth parts shaped like a pair of scissors building and a slightly larger abdomen for storing water. The queen is the largest of all and has a role of laying eggs. Workers have mouth parts for cutting and chewing food or soil particles. Some members of workers are in charge of caring for the young while others find food and defend the colony or remove dead members. Their specialization and division of labor bring about efficiency in the colony. Based on what you read and understood in this passage, how would you link this passage with how body parts of an animal and a plant function

4.1 Plant tissues

Activity 4.1

Study of plant tissues

Objective: To familiarize you with the general architecture of plant tissues.

Materials required

Fresh onion bulb, forceps, scalpel, clean glass slides, glass cover slips, dilute lugol's iodine solution, glass eye dropper (teat pipette), whatman filter papers (cut into strips).

Procedure

1. Cut an onion bulb into half and then each half into four/six segments, the fleshy: scale leaves will readily separate.

2. Hold one of the leaves with forceps over a glass slide with concave face of the leave facing you. Applying gentle pressure with a scalpel snaps the leave backwards and pulls gently. The translucent paper- thin piece of epidermis will appear as a ragged edge on the broken leaf.
3. Using forceps and sharp scalpel or razor blade remove a small piece of the epidermis and place it on a drop of water over the centre of a clean and dry glass slide.
4. Gently cover the epidermis with a cover slip, taking care that water bubble (s) does not get trapped in the preparation.
5. Examine first the unstained wet mount under low power objective.
6. With a dropper place a drop of dilute iodine solution at one edge of the cover slip.
7. Study the stained preparation first under low power objectives (4_x or10_x) and then under 40_x).

Questions: 1. Draw and label the onion tissues you are observing.

2. What are the differences between images seen under low power objectives and highpower objective.

The study of tissues is known as **Histology**. A **tissue** is a group of associated, similarly structured cells that perform specialized functions for the survival of the organism.

In histology, **differentiation** is the process by which structures become modified and specialized to perform specific functions. Differentiation is also known as **'specialization'**. In animals, the first type of cells in the developing embryo is stem cells. These are unspecialized cells that go on to form all the different types of cells in adult.

Plant tissues can be divided into two main groups, Meristematic tissues (apical, lateral, and intercalary meristems) and Permanent tissues (ground tissues and vascular tissues).

4.1.1 Meristem tissues

Meristem tissue is a group of cells which retain the ability to divide by mitosis. Meristematic tissues are specialized to carry out specific functions such as reproduction, growth, photosynthesis and replacement of old or damage tissues. The cells making a meristem tissue are small, have a central large nucleus and dense cytoplasm, thin walled, with no or small vacuole, and no specialized features. The cells are rectangular and closely packed with no intercellular air spaces.

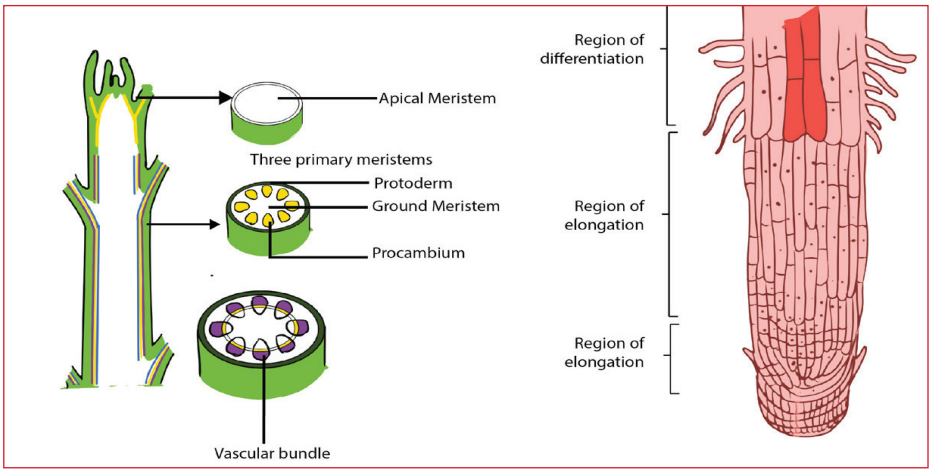


Figure 4.1: Structure of meristematic cells

Types of meristematic tissues

Meristematic tissues are subdivided into apical meristems, lateral meristems (cambium) and intercalary meristems

a. Apical meristems

They are located in the root and shoot apex (at the growing points of roots and stems). They are responsible for primary growth, leading to the increase of primary plant body.

b. Lateral Meristems (cambium)

Lateral meristems are in lateral parts of the plant, where they are responsible for Secondary growth. The cambium gives rise to secondary vascular tissues (secondary Xylem and secondary phloem) in dicotyledonous plants.

c. Intercalary meristems

These are found in the region of permanent tissues like at nodes of monocotyledonous Plants (e.g. sugar cane). It allows growth in length to occur between internodes.

Functions of meristematic tissues

- The main function of meristematic tissue is to produce new cells by mitosis.

The cells elongate and differentiate to form new cells for primary growth of shoot and root.

- Vascular cambium produces new cells to increase the diameter of stems androots during secondary growth.

- Cork cambium called (phellogen) produces the outer cork layer called phellem which consists of suberized cells. The cork layer reduces water evaporation from the plant and protects the plant against the entry of pathogens.
- The intercalary meristems allow growth and increase in length in regions other than the tips.

4.1.2 Permanent tissues

Permanent tissues consist of two groups of tissues such as: ground and vascular tissues.

a. Ground tissues

The ground or fundamental tissues are plant tissues which function in storage, metabolism and support. There are three types of ground tissues: **parenchyma, collenchyma** and **sclerenchyma** tissues.

i. Parenchyma tissues

Parenchyma is a soft plant tissue made up of thin-walled cells that forms the greater part of leaves, stem pith, roots, and fruit pulp. They are the main sites for physiological and biochemical processes in the plants including photosynthesis, protein synthesis and storage of starch and mineral ions. Parenchyma tissues can be found in epidermis, mesophyll, endodermis, pericycle, aerenchyma and secretory cells.

Characteristics

- Parenchyma tissues consist of large living cells, with relatively thin wall containing cellulose, pectin and hemicellulose.
- Parenchyma tissues consist of cells, usually having a large central vacuole.
- They are often partially separated from each other.
- Spongy cells present intercellular spaces that intervene in gaseous exchange and transpiration through stoma. They are usually stuffed with plastids.
- Parenchyma tissues consist of cells with polygonal and spherical shapes in the leaf. They form the mesophyll and are located between upper and lower epidermises. They are responsible for photosynthesis.

Functions of parenchyma tissues

- In the leaves, parenchyma tissues form the mesophyll and are sites for photosynthesis, gaseous exchange and transpiration.
- They store food substances such as starch, proteins and lipids

- They can be modified to form specialized cells to carry out other function in epidermis, endodermis, pericycle, parenchyma, and secretory cells.

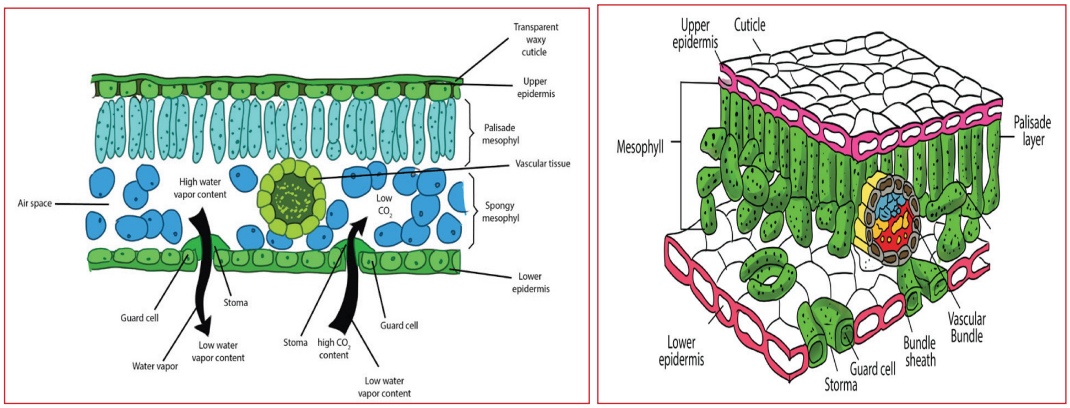


Figure 4.2: Diagram showing parenchyma tissue in the leaf

Adaptations of parenchyma for its function

- Parenchyma tissues are made of unspecialized cells with variety of functions:
- Parenchyma can become specialized to carry out specific functions e.g. mesophyll has cells with many chloroplasts, and aerenchyma which has air Spaces. All of these adaptations help in photosynthesis and gas exchange.
- They have isodiametric cells and function as packing tissue and storage tissue.
- Cells are loosely packed with many large intercellular spaces. This permits diffusion of gases.
- They have thin cellulose cell wall which is permeable so that it permits passage of materials.
- The walls are transparent and permit entry of light in photosynthesis cells.
- Large cells with large vacuoles provide space for storage of substances, where the entry of water causes vacuole to expand and cells become turgid
- Leucoplasts act as storage of starch while chromoplasts present in some cells e.g. in petals attract insects for pollination.

ii. Collenchyma tissues

Their cells are elongated with irregularly thickened cell walls that provide structural support, particularly in growing shoots and leaves. Their thick cell walls are composed of cellulose and pectin. These cells are often found under the epidermis, or the outer layer of cells in young stems and in leaf veins.

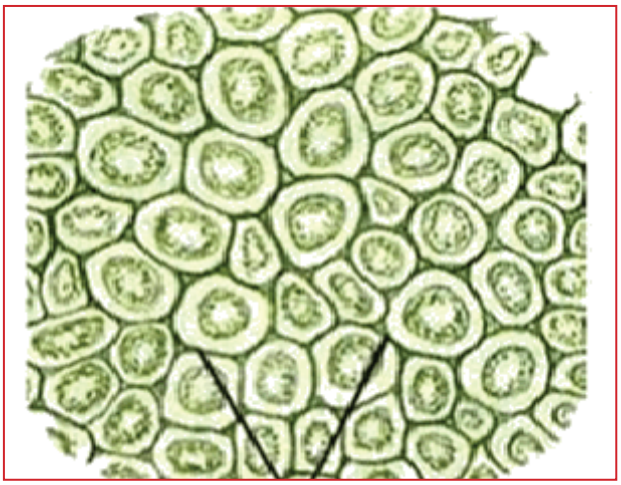


Figure 4.3: Illustration of collenchymas

iii. Sclerenchyma tissues

Sclerenchyma is found in hard parts of the plant body. They are very common in roots, stems, leaves and petioles. They may be present in patches, groups or layers.The cells of the sclerenchyma are dead, they are elongated, narrow, and thick walled and lignified. They are pointed at both ends where it gives strength, rigidity and flexibility to the plant body. They consist of fibres and sclereids. Fibres are long, narrow, thick and liquefied cells usually tapering at both ends. Sclereids cells are normally short with very thick walls, irregular and not tapering at the ends.

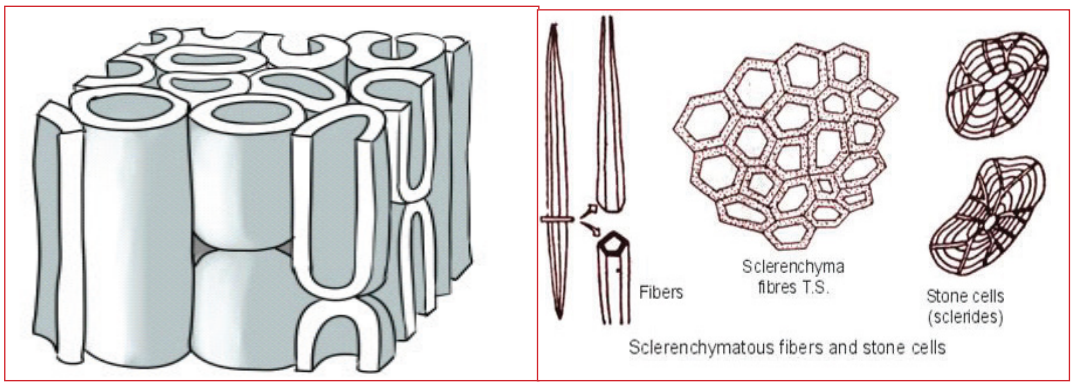


Figure 4.4: Sclerenchyma tissues structures

Table 4.1: Comparison between collenchyma and sclerenchyma tissues

Collenchyma	Sclerenchyma
Made of living cells	Made of dead cells
Tapering ends do not overlap	Tapering ends overlap and interlock
Ensure mechanical support and flexibility	Ensure mechanical support only
Cell wall is not lignified.	Cell wall is lignified.

b. Vascular tissues

The vascular tissue system consists of two kinds of conducting tissues: **the xylem** responsible for conduction of water and dissolved mineral nutrients, and the **phloem** responsible for conduction of elaborated food.

i. Xylem

The xylem tissues are made of **dead cells** which have the cell walls removed at the end of the cells, forming tubes through which the water and dissolved mineral ions can flow. Xylem vessels are involved in the movement of water through a plant from its roots to its leaves via the stem. During this process water is absorbed from the soil through root hair cells, moves by osmosis from root cell to root cell until it reaches the xylem, and finally it is transported through the xylem vessels up the stem and then to the leaves.

Xylem vessels are hollow tubes or lumen with a thick strengthened cellulose cellwall. The hollow tubes act like pipes allowing water and dissolved minerals to flow through them. They develop from cylindrical cells arranged end to end, in which the cytoplasm dies and the cell walls between adjoining cells breaks down leaving a dead empty tube. The cell walls in xylem vessels contain a substance called lignin which strengthens the cells and gives structural support.

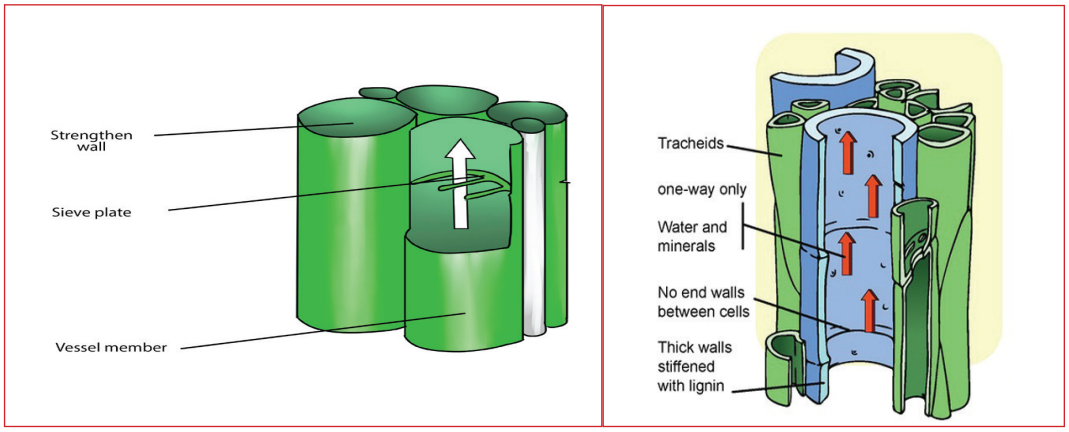


Figure 4.5: Xylem vessel

ii. Phloem

Phloem vessels are involved in translocation of elaborated substances. Dissolved sugars produced during photosynthesis, and other soluble food molecules are moved from the leaves to growing tissues such as the tips of the roots and shoots and storage tissues such as in the roots. In contrast to xylem, phloem consists of columns of living cells. The cell walls of these cells do not completely break down, but instead form small holes at the ends of the cell. The ends of the cell are referred to as **sieve plates**. The connection of phloem cells effectively forms a tube which allows dissolved sugars to be transported.

Phloem tubes carry food substances like sugar and amino acids produced in leaves during photosynthesis to every part of the plant. The movement of food substances through the plant is called **translocation.**

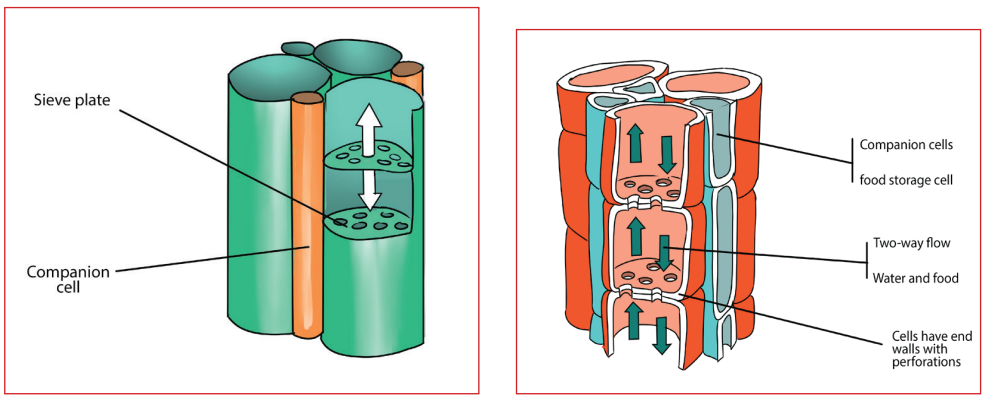
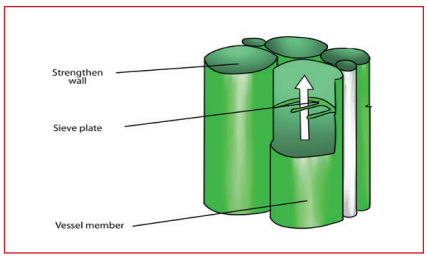
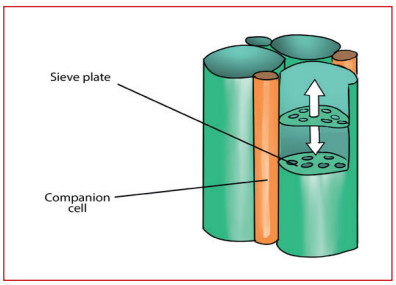


Figure 4.6: Phloem tube cells showing sieve plates that are reinforced cell walls between. Modified (from: https://dr282zn36sxxg.cloudfront.net/datastreams/f-)

Table 4.2: Comparison between Xylem and Phloem tissues

	Xylem	Phloem
Diagrams		
Transport	Water and mineral from the roots to the shoots and leaves	Sugar and amino acids produced in leaves during photosynthesis to every part of the plant.

Process	Transpiration	Translocation
Structure	Cylindrical cells arranged end to end, in which the cytoplasm dies and the cell walls between adjoining cells breaks down leaving a dead empty tube with strengthened cell walls.	Phloem tubes are made up of columns of living cylindrical cells. The cell walls between adjoining cells develop holes like a sieve allowing transport through the tube.
Components	Dead cells and Fibers	Living cells and companion cells
Direction of flow	Upwards	Up and downwards
Permeability	Impermeable	Permeable
Cytoplasm	None	Cytoplasm lining
Cell wall thickness	Thick	Thin
Cell wall materials	Formed by Lignin	Formed by Cellulose

Application activity 4.1

You are provided with a table below showing different steps in building a house. There are other steps in building a plant similar to those of building a house. Read carefully the steps given to building a house and find others which are linked to building a plant

	Building a house	Building a plant
1.	Foundation is laid	
2.	Construction of the frame	
3.	Installation of plumbing, heating	
4.	Waterproof walls and roof	
5.	Food stored in appropriate places	

4.2 Animal tissues

Activity 4.2

Study of animal cells

Objective: To appreciate some basic characteristics of a typical animal cell.

Materials required

Sterilized cotton buds, clean glass slides, glass cover slips, methylene blue or toluidine blue (0.5%) solution, glass eye dropper (teat pipette), whatman filter papers (cut into strips), a jar containing absolute alcohol/ laboratory disinfectant, disposable polythene bag.

Procedure

1. Gently rub the cotton bud over a small area of the inner surface of your cheek along the lower side of the gum
2. Smear the cotton bud over a small area at the centre of the slide
3. With the help of a dropper place a drop or two of methylene blue/ toluidine blue solution
4. Cover the smear with a coverslip taking care not to trap air bubbles in the preparation
5. Drain excess stain by withdrawing any excess staining solution with a strip of filter paper
6. Observe the smear under the low power magnification of a microscope. You may increase the magnification once the cells are in focus.

Make a labeled diagram of the preparation made and record your observations for future reference.

Caution: In order to avoid possible transmission of disease cheek cell sampling should be carried out carefully taking precautions listed

1. Use cotton bud from a freshly opened pack
2. Immediately after making the smear discard the used bud in a disposable polythene bag, which should be sealed and then disposed in accordance with the regulations governing the disposal of laboratory waste

There are four basic types of animal tissues such as **epithelial tissue, muscle tissue, nervous tissue and connective tissue**

4.2.1 Epithelial tissue

Epithelial tissue consists of closely packed cells arranged in single or multilayered sheets. It is made up of layers of tightly packed cells that form the external surfaces of the body and cover the outer and the inner surfaces of the organs. Some are specialized to form glandular tissues (glands). The epithelium lining the inside of the heart, blood vessels and lymph vessels is referred to as **endothelium**. Two criteria for classifying epithelia are: **the number of cell layers and the shape of cells on the free surface.** The following are the types of epithelium tissues:

a. Simple cuboidal epithelium

This is a tissue with cells that are cubical in shape. Cuboidal cells are specialized for secretion and they make up the epithelia of kidney tubules and many glands including salivary glands, and thyroid gland

Figure 4.7: Simple cuboidal epithelium

b. Simple squamous epithelium

It is thin, leaky and functions in the exchange of material by diffusion. This type of epithelium lines blood vessels and the air sacs of lungs, where diffusion of nutrients and gases is critical.

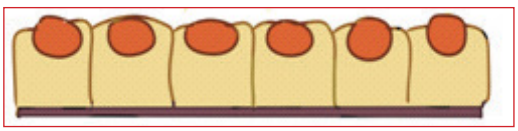


Figure 4.8: Simple squamous epithelium

c. Simple columnar epithelium

These are columnar in shape with free surface containing extensions of micro villi. It lines the intestines. This epithelium secretes digestive juices for the final stages of digestion and absorbs nutrients to blood stream.

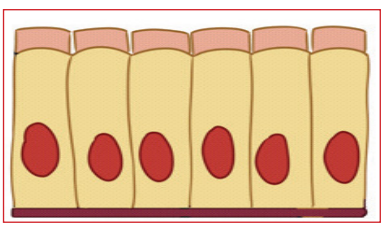


Figure 4.9: Simple columnar epithelium

d. Pseudo-stratified ciliated columnar epithelium

It forms a mucous membrane that lines the nasal passages of many vertebrates. The beating cilia move the film of mucus along the surface.

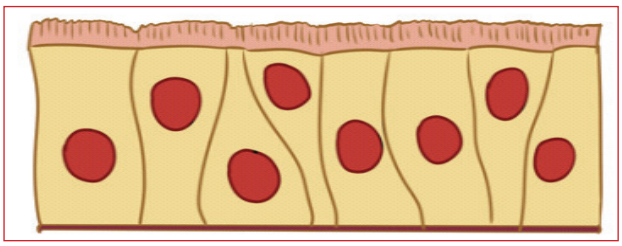


Figure 4.10: Pseudo-stratified ciliated columnar epithelium.

e. Stratified squamous epithelium

Itv regenerates rapidly by cell division near the basal lamina. The new cells are pushed outward to replace cells that are sloughed off. This epithelium is commonly found on surfaces subject to abrasion, such as the outer skin and lining of the esophagus, anus, and vagina.

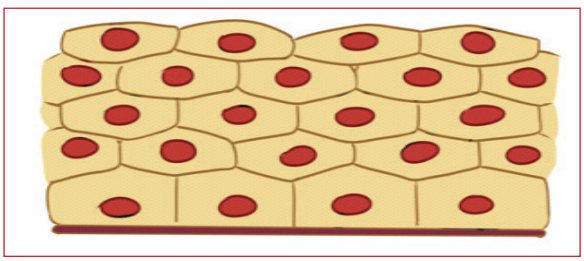


Figure 4.11: Stratified squamous epithelium

f. Transitional epithelium

In this type of stratified epithelium, the surface cells change their shape from round to squamous. Transitional epithelium lines urinary bladder. When the bladder is empty, the surface cells are rounded. As the bladder fills urine, these cells become flattened. Transitional epithelium enables the bladder to fill and stretch without tearing the lining.

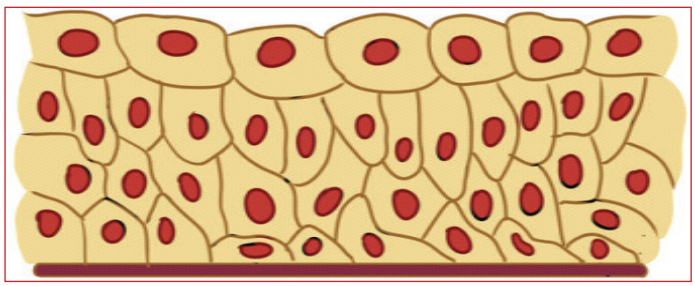


Figure 4.12: Transitional epithelium

g. Stratified columnar epithelium

It is a rare type of the epithelial tissue composed of column shaped cells arranged in multiple layers. They are found in the conjunctiva or the eye, in parts of the pharynx, anus, uterus, the male urethra and vas deferens.

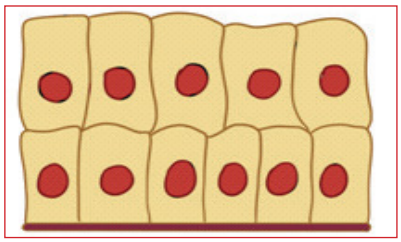


Figure 4.13: Stratified columnar epithelium.

h. Stratified cuboidal epithelium

It is a type of epithelial tissue composed of multiple layers of cube-shaped cells. Only the most superficial layer is made up of cuboidal cells and the other layers can be cells of other type. It has several locations in the body including sweat gland ducts, egg-producing vesicles and ovaries.

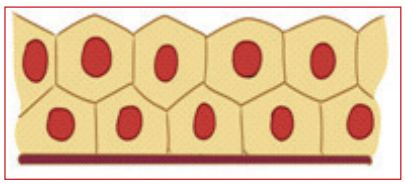


Figure4. 14: Stratifiedcuboidalepithelium

4.2.1 Main characteristics of epithelial tissues

a. Polarity

All epithelia have a **free surface** and a lower attached **basal surface** that differ in structure and function. For this reason, epithelium is described as showing polarity.

b. Supported by connective tissue

All epithelia are supported by connective tissue. For instance, deep to the basal lamina is **reticular lamina**, an extracellular material containing collagen protein fiber which forms the basement membrane. The basement membrane reinforces the epithelium and helps it to resist stretching and tearing.

c. They are avascular

It have no blood vessel in them. Nutrients and gases are supplied by blood through the connective tissue by simple diffusion

d. Regeneration

Epithelium have a high regenerative capacity and can reproduce rapidly as long as they receive adequate nutrition.

Functions of epithelium

- Epithelium forms a protective layer: The epithelium of the skin protects the body from mechanical damage, entry of pathogens, ultraviolet rays' and dehydration. Epithelium lining the respiratory air passages secretes mucus which traps inhaled dust particles and microbes.
- The ciliated epithelium cells have cilia that propel the mucus and trapped particles to the throat.
- Glandular tissues secrete the digestive enzymes, hormones, mucus, sweat and sebum.
- Acts as a barrier and regulates movement of substances across kidney
- Some epithelial cells can divide mitotically producing new cells to replace damaged or dead cells.
- Some epithelial cells such as taste buds and retina cells are specialized to form sensory receptors.

4.2.2 Muscular tissues

Muscle tissues consist of elongated cells held together by connective tissue. Muscle cells are highly specialized in that they are able to shorten to a half or even a third of their resting length by the process of contraction.

The contraction is caused by two types of fibrous proteins: **myosin** and **actin.** Muscles in the body provide the necessary force for the motion and they convert chemical energy into kinetic or mechanical energy. There are three types of muscle tissue:

- **Smooth muscle** which is found in the inner linings of organs;
- **Skeletal or striated muscle**, which is attached to bone and helps in movement of the body;
- **Cardiac muscle** which is found only in the heart.

Smooth and cardiac muscles are involuntary muscles whereas skeletal muscles are called voluntary muscles because they are under voluntary (conscious) control.

a. Smooth Muscle

Smooth muscle is also called unstriated, unstriped, involuntary or visceral muscle.

It is found in the walls of the hollow internal organs such as blood vessels, intestinal tract, urinary bladder, and uterus. Smooth muscles have the following features;

- It is under control of the autonomic nervous system; they cannot be controlled onsciously, so they are also called involuntarily muscle. They do not have striations.
- Smooth muscle cells contract slowly and rhythmically

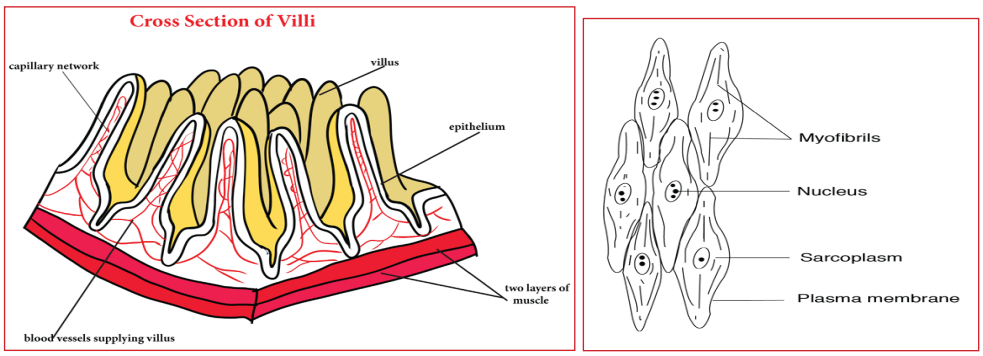


Figure 4.15: Smooth muscle cells

b. Cardiac tissue

Cardiac tissue (figure 4.16 a) is found in the walls of the heart and it is under control of the autonomic nervous system. Cardiac muscle has the flowing basic features.

- It contracts and relaxes continuously.
- It is branched and connected to other cardiac muscle fibers through intercalated discs (Figure 4.15 b), which are reinforced membranes that hold the cells together during contractions. These interconnections or intercalated discs between the fibers ensure a rapid and uniform spread of excitation throughout the wall of the heart which in turn ensures a synchronous contraction.
- They are myogenic (their contraction originate from within the heart itself).

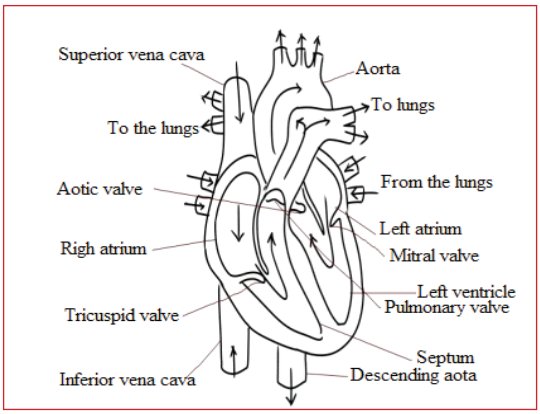


Figure 4.16: Cardiac muscle tissue (a)

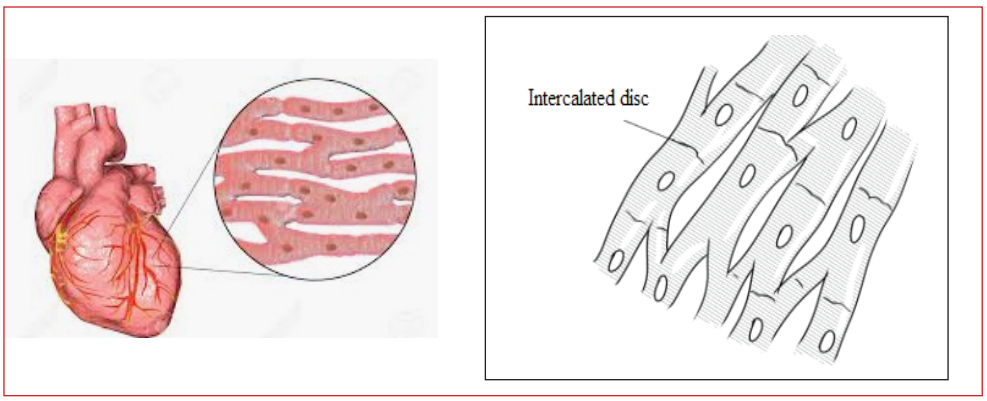


Figure 4.16: Cardiac intercalated disk (b)

c. Skeletal Muscle

Skeletal muscle is also called striated, striped, or voluntary. They are attached to bone, and are responsible for body movements and body posture. There are approximately 639 skeletal muscles in the human body.

Characteristics of skeletal muscles

- They are under control of voluntary nervous system
- They are attached to bone and this is the reason why they are called skeletal muscles.
- They are made of elongated and cylindrical muscle fibres
- They appear under microscope to have alternate light and dark bonds and this is why they are called striated muscles.
- Their muscle fibres are multinucleated (many nuclei per cell)
- These muscle cells also contain light and dark stripes called striations

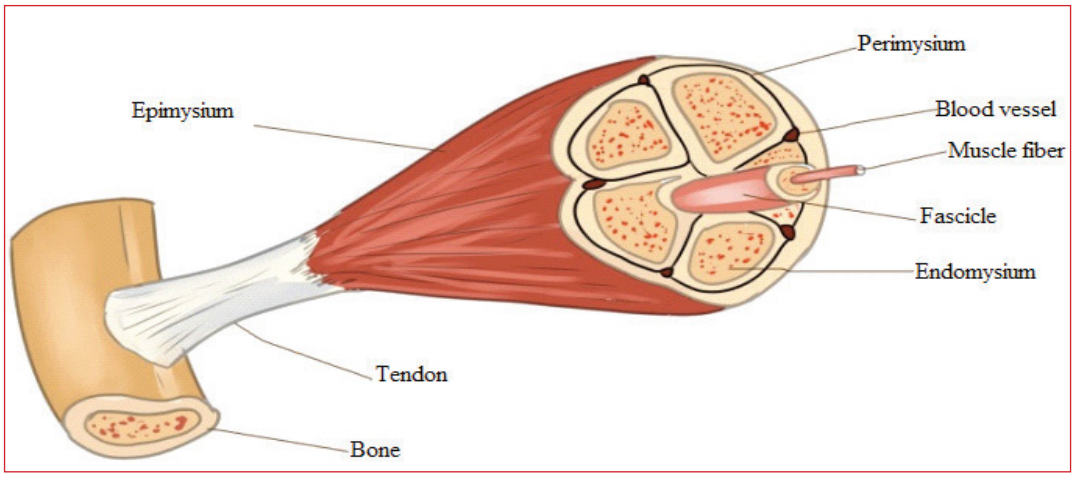


Figure 4.17: Skeletal muscle structure.

General functions of muscle

The main function of muscle is its contribution to motion, where body movements such as walking, breathing, and speaking, as well as movements associated with digestion and the flow of fluids take place. Muscles contribute to the heat production, maintenance of posture and body support and communication through facial expression, writing and speech.

4.2.3 Nervous tissue

Nervous tissue is composed principally of densely packed cells called the nerve cells (neurons) that together form the nervous system including the brain and spinal cord. Neurons are specialized for transmitting electrical nerve impulses.

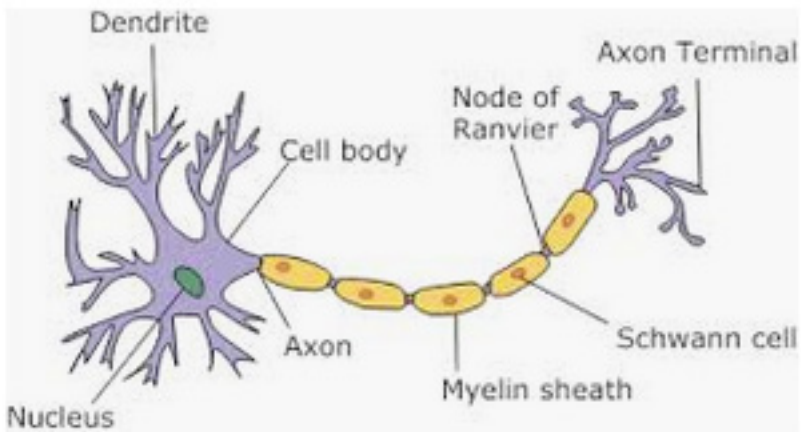


Figure 4.18: Typical neuron structure

A typical neuron has three main parts: Cell body, dentrites and axon.

a. **Cell body or soma**
   - It is the main part from which, extensions derive (Axon and Dendron).
   - It is made of a great spherical nucleus, granular cytoplasm and controls all nerve cell activities.

b. **Dendrites (Dendron when single):** small branches attached to the cell body and receive nerve impulse from other neurons

c. **Axon or cylindrax:** It is the thinner nerve fibre that carries messages away from the cell body and can be as long as 1 m. In some neurones, the axons have a fatty myelin sheath formed by Schwann cells which wrap themselves around the axon to increase the speed of impulse transmission.

4.2.4 Connective tissues

Connective tissue is made up of many different types of cells that are all involved in structure and support of the body. **Bone, blood, fat,** and **cartilage** are all connective tissues. Connective tissues can be densely packed together, as bone cells are or loosely packed, as adipose tissue (fat cells) are. A connective tissue is made up of a variety of cells embedded in a large amount of intracellular substance called matrix and fibers which are non-living products of the cells.

a. **Common functions of connecting tissues:**
   - Connective tissues protect and support the body and internal organs.
   - They act as connecting systems, binding all other tissues together.
   - They also form surrounding sheaths to separate the various organs.

b. **Cells of connective tissue**

The specialized cells of the various connective tissues produce the extracellular matrix. The names of the cells end with suffixes that identify the cell functions as blasts, cytes, or clasts. **Blasts** create the matrix, **cytes** maintain it, and **clasts** break it down for remodeling. For example: **Fibroblasts** are cells that form fibrous connectivetissue and **fibrocytes** maintain it, **chondroblasts** form cartilage and **chondrocytes** maintain it, and **osteoblasts** form bone, **osteocytes** maintain it, and **osteoclasts** break it down **Adipose,** or **fat cells**, also called **Adipocytes**, contain large amounts of lipid. The lipid pushes the rest of the cell contents to the periphery, so that each cell appears to contain a large and centrally located lipid droplet with a thin layer of cytoplasm around it.

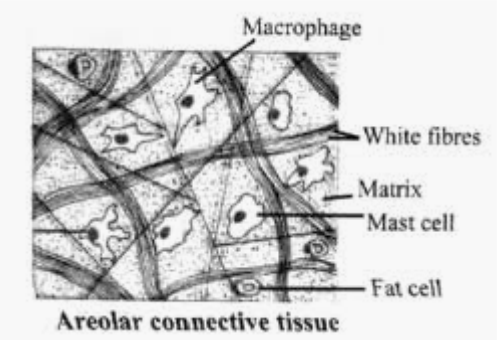


Figure 4.19: Structure of connective tissue

Adipose cells are rare in some connective tissue types like cartilage but they are abundant in others like loose connective tissue, and they are predominant in adipose tissue.

Mast cells are commonly found beneath membranes in loose connective tissue and along small blood vessels of organs. They contain chemicals such as heparin, histamine and proteolytic enzymes. These substances are released in response to injury such as trauma and infection and play important roles in inflammation.

White blood cells continuously move from blood vessels into connective tissues. The rate of movement increases dramatically in response to injury or infection. In addition, accumulations of lymphocytes, a type of white blood cell, are common in some connective tissues, such as in the connective tissue beneath the epithelial lining of certain parts of the digestive system.

Macrophages are found in some connective tissue types. They are derived from monocytes, a white blood cell type. Macrophages are either **fixed** and do not move through the connective tissue in which they are found or are **wandering macrophages** and move by amoeboid movement through the connective tissue.

Macrophages phagocyte foreign or injured cells, and they play a major role in providing protection against infections.

Note that there are three structural major components of the extracellular matrix of connective tissue such as fluid, ground substance consisting of non-fibrous protein and other molecules and protein fibers. The structure of the matrix gives connective tissue types most of their functional characteristics, such as the ability of bones and cartilage to bear weight, tendons and ligaments to withstand tension, and dermis of the skin to withstand punctures, abrasions, and other abuses.

c. Fiber connective tissues

Another type of connective tissues consists of fibers. Fibers are of different types including: **Connective tissue fibers:** which are made of protein and are of three kinds: collagenous, elastic and reticular fibers.

Collagenous fibers: These provide strength combined with flexibility. They are made up of collagen, probably the most abundant protein in the animal kingdom.

- **Elastic fibers:** These are easily stretched but are also resilient, snapping back to their original length when tension is released. Shaped as long threads, elastic fibers are made of a protein called elastin.
- **Reticular fibers:** These are thin collagen fibers coated with glycoprotein. They are very short, thin fibers that branch to form a network and appear different microscopically from other collagen fibers. Reticular fibers are not as strong as most collagen fibers, but networks of reticular fibers fill space between tissues and organs.

d. Loose connective tissue

This is also called areola connective tissue and is the most widespread connective tissue in all animal tissues. It binds epithelial tissues to underlying tissues and **functions as packing material, holding organs in place.** Loose Connective tissue has the following main components;

Fibers: collagen, elastic and reticular Cells; fibroblasts and macrophages. Fibroblasts secrete the protein ingredients of the extracellular fibers. Macrophages are cells that roam the maze of fibers, engulfing both foreign particles and the debris of dead cells by phagocytosis.

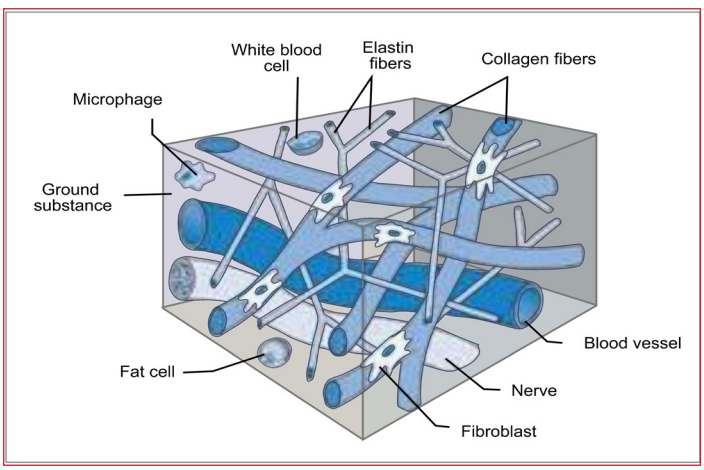


Figure 4.20: Loose connective tissue

e. Fibrous connective tissue

Fibrous Connective tissue is dense with collagenous fibers. The fibers form parallel bundles, which maximize non-elastic strength. Fibrous Connective tissue is found in **tendons**, which attach muscles to bones, and **ligaments,** which connect bones at joint.

f. Adipose tissue

Adipose tissue is a specialized form of loose connective tissue that stores fats in adiposecel ls distributed throughout its matrix. **Adipose tissue** consists of **adipocytes,** or **fat cells,** which contain large amounts of lipid.

Unlike other connective tissue types, adipose tissue is composed of large cells and a small amount of extracellular matrix that matrix that consists of loosely arranged collagen and reticular fibers with some scattered elastic fibers. Blood vessels form a network in the extracellular matrix. The fat cells are usually arranged in clusters or lobules separated from one another by loose connective tissue. Adipose tissue functions as:

- An insulator against heat loss
- A protective tissue to delicate internal organs
- A site of energy storage in the form of fat.

Figure 4.21: Adipose tissue

g. Bone and cartilage tissue

Cartilage has an abundance of collagenous fibers embedded in a rubbery matrix made of a protein-carbohydrate complex called **chondroitin sulfate**. Cartilage is composed of specialized cells, called **chondrocytes**, surrounded by a gelatinous matrix of collagen, a tough protein. The cartilage surface is covered by a membrane known as the **perichondrium.** There are three types of cartilage (hyaline cartilage, yellow elastic and white fibrous cartilage.)

- Hyaline cartilage is semi-transparent and is often stained light blue or pink in tissue sections. It is extremely very strong but very flexible and elastic.

  Hyaline cartilage occurs in the trachea, larynx, tip of the nose, connection between the ribs and the breastbone; and at the ends of bones where they form joints. It also forms much of the fetal skeleton.
- Elastic cartilage is similar to hyaline cartilage, but in addition to the collagenous fibers.The matrix of the elastic cartilage also contains an abundant network of branched elastic fibers. This type of cartilage is found in the lobe of the ears, the epiglottis and in the parts of the larynx. They provide flexibility and elastic support.
- Fibro-cartilage (White fibrous cartilage) is an extremely tough tissue. It is found as discs between the vertebrae, bones, anterior joint between the two halves of pelvic girdle and at points where tendons inserted on bones near hyaline cartilage. It resists compression and absorbs shock in some joints.

Bone tissue

This is a firmer and denser material that has the following features:

- Hard and compact
- Has many collagen fibres
- Its matrix has inorganic salts such is calcium carbonate and calcium phosphate
- Has few cells located in the lacunae in the matrix
- Has osteoblasts as mature and non-dividing cells
- Have a harversian canal
- Consists of irregular cylinder with layer of matrix call lamellae

The following are the main functions of bone tissue:

- Structural support of the body
- Protection of internal organs, heart and lungs.
- Attachment of the muscles to effect movement
- Production of blood cells

h. Blood tissue

Blood is a flowing made up of particles suspended in a fluid composed of fluid called plasma, and several kinds of cells. Within the blood plasma, there are erythrocytes (red blood cells), leukocytes (white blood cells), thrombocytes

(platelets) and other substances. Blood performs the following important functions:

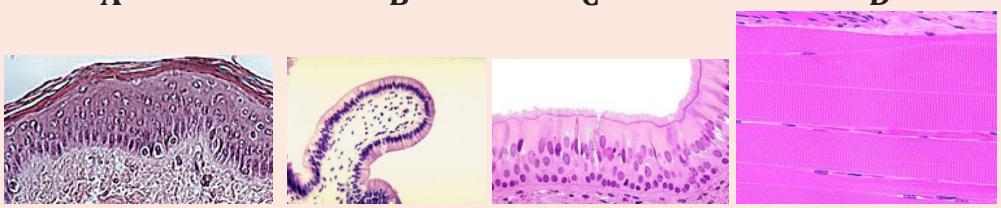
- Blood transports absorbed substances such as glucose, amino acids, mineral ions and vitamins from the small intestine.
- Blood transports the respiratory gases (Oxygen and Carbon dioxide).
- Blood transports the excretory wastes such as urea, uric acid to excretory organs to be removed out of the body.
- Blood transports hormones e.g. insulin from pancreas to the liver where it is stored.

Application activity 4.2

The following diagrams (A, B, C and D) represent animal tissues. Observe and analyse them well.

1. Name A, B, C and D
2. Describe the functions of A, B, C and D

A **B** **C** **D**



4.3 Levels of organization

Activity 4.3

Visit a classroom block, administration block or any building in school which is constructed with bricks and use it to answer the following questions.

1. What is the smallest unit or component of the classroom block?
2. How are bricks arranged?
3. Do you think the brick has other smaller particles in it?
4. How many bricks does a classroom block have?
5. How are walls, classrooms, washrooms and other apartments of the block formed?
6. Arrange the following in their ascending order of size (from the smallest to the largest); whole block, wall, a brick, a room, course (a line of bricks).
7. Relate the above arrangement of a building to levels of organization in multicellular organisms from smallest level to the largest level

The human body is organized into structural and functional levels of increasing complexity.

Each higher level incorporates the structures and functions of the previous level. The simplest is the cells, organized into tissues, organs, and organ systems. All of the levels of organization of the human body are represented in the following figure

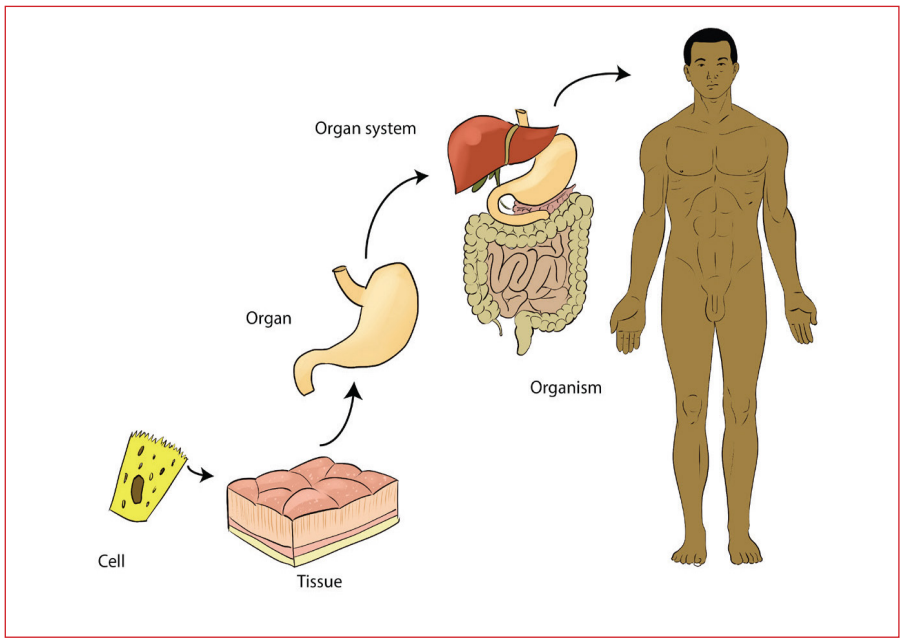


Figure 4.22: Levels of organization of the human body

4.3.1 Cells

A cell is a basic structural and functional unit of a living organism. There are many different types of human cells, though they all have certain similarities. Each type of cell is made of chemicals and carries out specific chemical reactions.

4.3.2 Tissues

A **tissue** is a group of cells with similar structure and perform a particular function. There are four groups of tissues **(**Epithelial tissues, Connective tissues, Muscle tissues, Nerve tissue)

4.3.3 Organs

An **organ** is a group of tissues precisely arranged so as to accomplish specific functions. Examples of organs are the kidneys, individual bones, the liver, lungs, and stomach. Examples of ogans in plants are: roots, stem and leaves.

4.3.4 Organ systems

An **organ system** is a group of organs that all contribute to a particular function.

Examples are the urinary system, digestive system, and respiratory system. For example, the urinary system consists of the kidneys, ureters, urinary bladder, and urethra.

These organs all contribute to the formation and elimination of urine.

The Human body has 11 organ systems: circulatory, digestive, endocrine, and excretory (urinary), the lymphatic, integumentary, muscular, nervous, reproductive, respiratory, and skeletal systems.

Table 4.3: Major organ systems of the human body

Systems	Functions	Organs, Tissues, and Structures Involved
Cardiovascular	Transporting nutrients, oxygen, and other substances to the body cells, and carbon dioxide, wastes, and other substance away from cells	Heart, blood, blood vessels
Lymphatic	Defense against infection and disease, transfer of lymph between tissues and the blood stream	Lymph, lymph nodes, lymph vessels, tonsils, adenoids, thymus, and spleen
Digestive	Food transformation and absorption of nutrients, minerals, vitamins, and water	Salivary glands, oesophagus, stomach, liver, gallbladder, pancreas, small intestine, large intestine
Endocrine	Communication within the body with hormones; directing long-term change over other organ systems to maintain homeostasis	Among many, the pituitary gland, pineal gland, thyroid, parathyroid gland, adrenal glands, testes, and ovaries

Nervous	Receiving, transferring and processing information; directing short-term change over other organ systems inorder to maintain homeostasis	Brain, spinal cord, nerves, and sense organs (eyes, ears, tongue, skin, nose)
Reproductive	Production of sex cells (gametes) and sex hormones; production of offspring	Fallopian tubes, uterus, vagina, ovaries, testes, vas deferens, seminal vesicles, prostate, and penis
Respiratory	Release of air to sites where gas exchange can occur between blood and air (lungs)	Mouth, nose, pharynx, larynx, trachea, bronchi, lungs, and diaphragm
Urinary	Control of pH, removal of excess water, salts, and waste products from blood and body.	Kidneys, ureter, urinary bladder, and urethra
Skeletal	Support and protection of soft tissues of body; mineral storage, production of blood cells; movement at joints	Bones, cartilage, ligaments

Application activity 4.3

Explain why the cell as level of organization of human body is said to be:

a. Basic unit of human body
b. Structural unit of human body
c. Functional unit of human body

4.4 Advantages and disadvantages of being unicellular or multicellular

Activity 4.4

A cow is multicellular while an amoeba unicellular. The amoeba is microscopic living that can't be seen by our naked eyes; we need a microscope in order to see it. Make a list of advantages of being multicellular and a list of disadvantages of being unicellular

4.4.1 Advantages of unicellular organisms

- Unicellular organisms need fewer nutrients and can survive in unfavorable conditions.
- Some of the organisms can generate energy through photosynthesis for example euglena.
- Sometimes different bacteria work together to work to their advantages.
- Unicellular organisms can multiply quickly and have less energy/resource demands.

4.4.2 Disadvantages of unicellular organisms

Unicellular organisms only have one cell that is used to function their entire being.

This is a disadvantage compared to multicellular organisms, which have many cells and function more easily and properly.

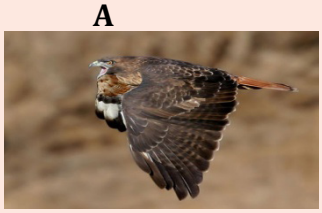
4.4.3 Advantages of a multicellular state of an organism

- Multicellular organism usually has a wider range of functions because of the aggregation of different types of cells.
- Multicellular organisms have many more necessities and can only survive in certain conditions.
- Multicellular organisms such as animals are unable to make their own food so they survive by eating living things such as vegetables, fruits, and meat. They can also eat things that are produced by other living things such as eggs, milk, and honey.

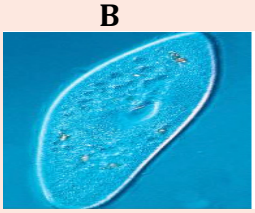
Application activity 4.4

1. The diagrams below represent two living things A, B. Identify the unicellular and multicellular and explain why?

A



B



2. Arrange the following terms in their descending order of size: mitochondrion, tissue, organ, cell, organ system and organism.

Skills lab 4

Examining plant tissues

Materials

A fresh onion, microscope, slides, cover slips, iodine solution and scalpels.

Procedure

Examine the onion tissues under low and high-power magnification. Draw and label your observations

End unit assessment 4

Section A: Multiple choice questions

1. Which type of tissue forms glands?

a. Epithelial, b. Connective, c. Nervous, d Muscles

2. What are the four types of animal tissues?

a. Epithelial, squamous, muscular, connective

b. Epithelial, connective, muscular, cardiac

c. Connective, muscular, epithelial, nervous

d. Cuboidal, ciliated, glandular, columnar

Section B: Short answer type questions

3. Complete the following table by filling in the examples of the respective tissues

Categories of tissues according to their functions	Examples of tissues
Growth tissues	
Protective tissues	
Storage tissues	
Support tissues	
Conducting tissues	
Secretory tissues	

Section C: Long answer type questions

4. Describe how epithelial tissues have adapted to their functions
5. Describe the three main functions of the blood

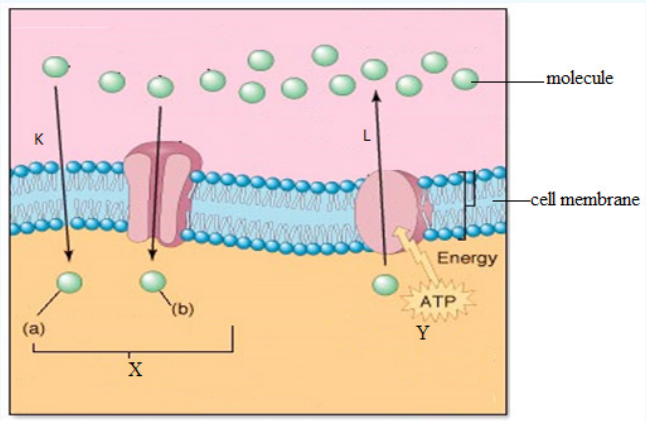
UNIT 5

TRANSPORT ACROSS THE CELL MEMBRANE

Key unit competence: Explain the physiological processes by which materials move in and out of cells and the significance of these processes in the life of organisms.

Introductory activity 5

Observe the figure below and answer the following questions. Different molecules are moving as you see them on this figure.



1. Given that the molecules are on both sides of the cell membrane, why K and L are happening?
2. The origin of arrow L has ATP while the origin of K has no ATP, explain why.

5.1 Types of transport of substances across the cell membrane

Activity 5.1

a. Identify all types of molecules transported across the cell membrane.

b. Discuss different types of transport of substances across the cell membrane

Different types of transport of substances across the cell membrane exist. Their main types are **active transport** which requires energy stored in ATP (adenosine triphosphate) and **passive transport** which does not require energy. The internal environment of a cell is maintained differently from that of its external environment by a thin surface membrane called the **cell membrane** or **plasma membrane** or **plasmalemma**. The plasma membrane is a **phospholipid bilayer** with phosphate heads and fatty acid tails. It governs the entry and exit of molecules and ions. This property of the plasma membrane that regulates the exchange occurring between the cell and its medium is referred to as "**cell permeability"**. A cell membrane, therefore, determines which substances can enter the cell (comprising those which may be important for the vital activities within the cell) and also regulates the outflow of substances (consisting of excretory waste and water).

This feature of the membrane not only maintains difference in the composition of intracellular and extracellular fluid, but also establishes a balance in their osmotic pressure. Therefore, a membrane may be permeable to some substances while impermeable to others. This is called "**selective permeability**". The lipid bilayer (phospholipid bilayer) of the membrane is permeable to non-polar and uncharged molecules such as O2, CO2 and steroids but is impermeable to charged or polar molecules and ions like glucose. It may be slightly permeable to water and urea though being polar molecules due to their smaller size.

A **concentration gradient** refers to difference in the concentration of a substance from one region to another across a plasma membrane. In such a case, the solute will have a tendency to move from a region of high to that of low concentration.

Due to the distribution of positively and negatively charged ions, the inner surface of plasma membrane is more negatively charged than the outer. This difference in the **electrical charge** between two regions creates an electrical potential and since this is established across a plasma membrane, it is termed as **membrane potential**.

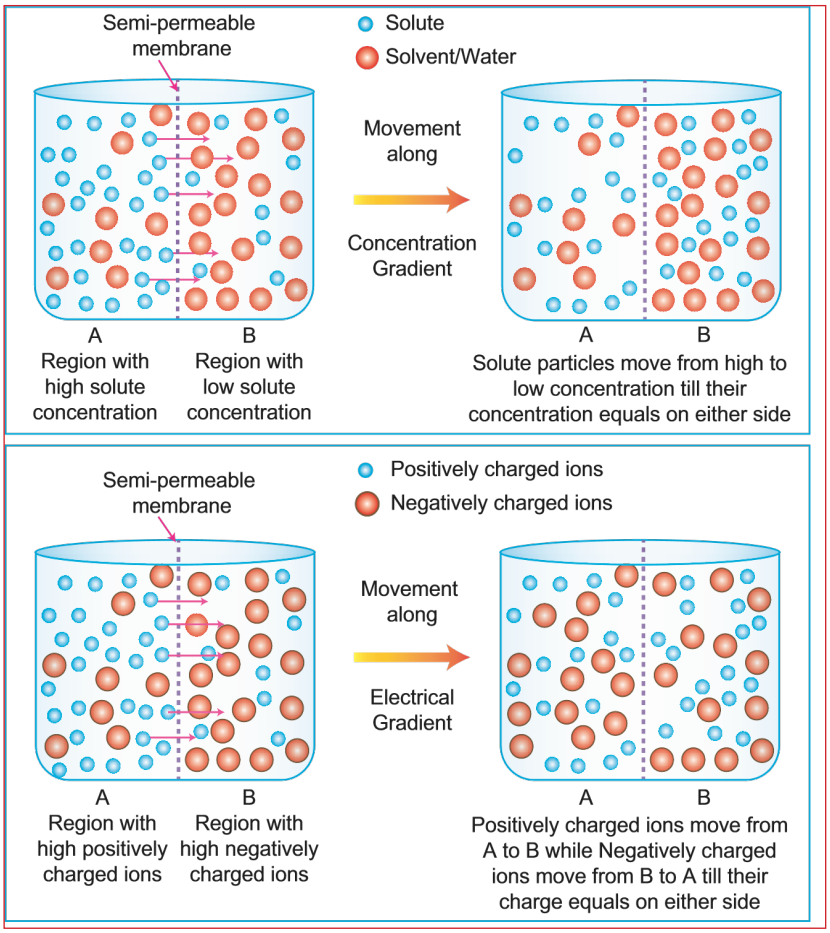


Figure 5.1: Movement of particles or ions with respect to concentration and electrical gradient across a semi-permeable membrane.

Table 5.1: Types of transport of substances across the cell membrane.

Type	Name	Direction	Requirements	Examples
I. Passive transport	1. diffusion	Toward lower concentration	Concentration gradient	Lipid- soluble molecules, water and gases
	2. facilitated transport	Toward lower concentration	Channel or carrier and concentration gradient	Some sugars and amino acids
II. Active transport	1. active transport	Toward higher concentration	Carrier plus energy	Sugars, amino acids and ions
	2. exocytosis	Toward outside	Vesicle fuses with plasma membrane	Macromolecules
	3. endocytosis	Toward inside	Vesicle formation	Macromolecules

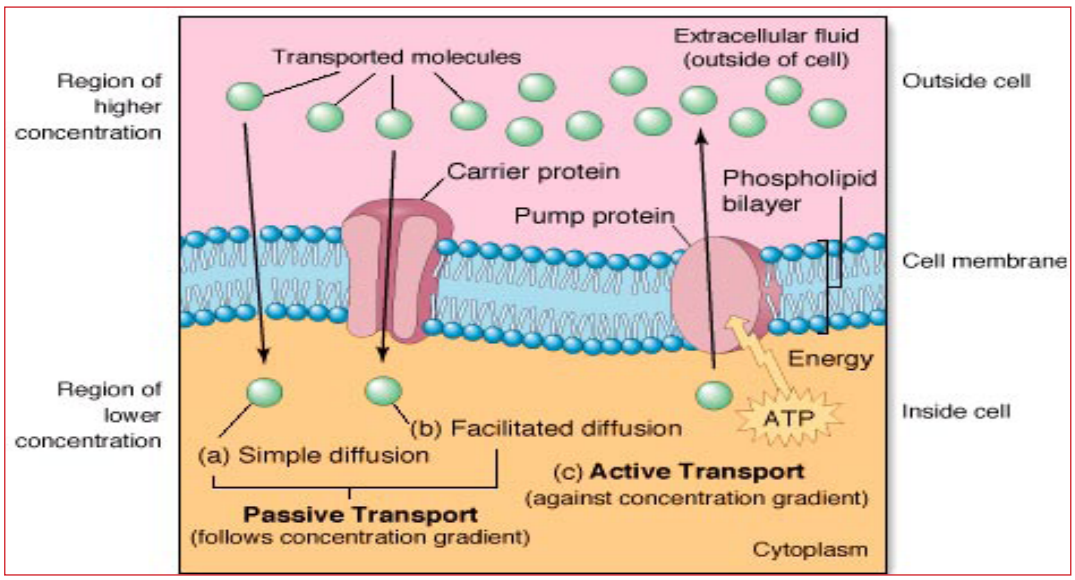


Figure 5.2: Drawing showing active and passive transport

Passive transport involves the movement of molecules along the electrochemical gradient or concentration gradient without the use of ATP (**Downhill transport**). It occurs by diffusion or osmosis.

Active Transport drives the molecules against their electrochemical gradient by hydrolysis of ATP (**Uphill transport**).

Application activity 5.1

1. Use the following list of terms to complete these statements

Terms list: active transport, shrinks, diffusion, osmosis, Turgor pressure, higher, exocytosis.

Statements:

i. In hypertension solution, a cell ..... .

ii. In lungs, CO2 diffuses out of blood by the process of .....

iii. Reabsorption of water in kidney tubule takes place by the process of ..... .

iv. The pressure exerted by plants' cells on cell wall is .....

v. The larger the surface area of membrane, the ..... is the rate of diffusion.

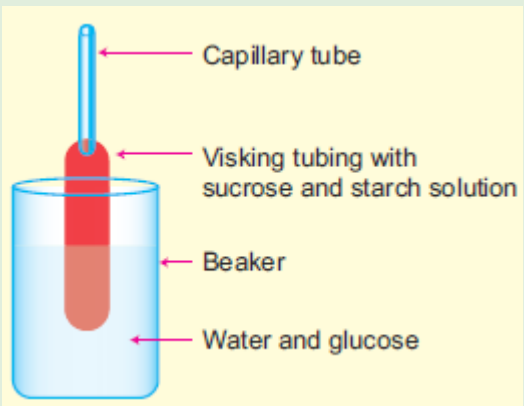
2. During the dry seasons, most plants wilt and finally die. Relate this drying process to the transport of substances across the cell membrane.

5.2 Diffusion and factors affecting the process of diffusion

Activity 5.2

a. Materials Required: Visking tubing with capillary, Beaker with water, Sucrose solution (10%), pieces of beetroot.

b. Illustration:



Procedure:

1. Fill the visking tubing with sucrose and starch solution.

2. Fill a beaker with water and glucose. Now, put some pieces of beetroot into the visking tubing.
3. Partly submerge the visking tubing into the beaker.
4. Observe the change in the level of liquid in the capillary tube attached to the visking tubing.
5. Observe the movement of red pigment from a region of high concentration in the vacuoles to a region of low concentration in the solution outside the pieces of beetroot.

Tasks:

1. Identify the type of this movement or transport.
2. Discuss factors affecting the process of diffusion and its significance in living organism

5.2.1 Simple and facilitated diffusion

Diffusion is the movement of molecules such as O_2, CO_2 from their higher to their lower concentration that is, down their concentration gradient until equilibrium is achieved and they are distributed equally.

It is included in **passive transport** which does not require energy.

Example: Diffusion of oxygen from air sacs (alveoli) to the blood in lung capillaries depends on the concentration of oxygen in alveoli; gaseous exchanges (O_2 and CO_2) in plant occurs also by diffusion.

Simple diffusion is the simplest mechanism in which a molecule dissolves in the phospholipid bilayer, diffuses across it and then dissolves in the aqueous solution present on the other side of the cell membrane. It neither requires ATP nor any protein. The direction of movement is determined by the concentration gradient (i.e., molecules flow from a region of higher concentration to a region of lower concentration) or electrical gradient. Therefore, any molecule that is soluble in the phospholipid layer is capable of crossing the plasma membrane. This is the reason why only small, relatively hydrophobic (water repelling) molecules (example - benzene), gases (O_2, CO_2) and even small polar, uncharged molecules diffuse easily across the plasma membrane while other larger molecules are restricted. Diffusion is also regarded as the random mixing of particles in which the particles continue to move down their concentration gradient until an equilibrium is reached and the particles are evenly distributed throughout the solution.

Facilitated diffusion (also known as facilitated transport or passive-mediated transport) is the process of spontaneous passive transport of molecules or ions across a biological membrane via specific **transmembrane integral proteins.**

5.2.2 Factors affecting the rate of diffusion

1. Concentration gradient: The greater the concentration difference between the two sides of the membrane, the faster is the rate of diffusion.
2. Temperature: As the temperature increases, the rate of diffusion increases.
3. Size of diffusing molecules: Smaller molecules have faster rate of diffusion while the ones with larger mass, diffuse slowly.
4. Surface area to volume ratio: The larger the surface area of membrane available for diffusion, the higher is the rate of diffusion.
5. Thickness the membrane: The greater the distance across which diffusion is to occur, the longer it takes for molecules to pass through.

5.2.3 Significance of diffusion

Diffusion plays an important role in living systems. Below are a few examples where its diverse significance can be understood.

1. In the human body, nutrients (in the form of ions and small molecules) are absorbed from the food by the surrounding blood cells in the vessels by way of diffusion.
2. In the lungs, CO_2 diffuses out of blood in alveolar sacs whereas O_2 (present in high concentration in the inhaled air) diffuses into the cells in the blood vessels (with low O_2 concentration).
3. Cutaneous respiration (through skin) is the most common mode of respiration in lower non-chordates wherein gases directly diffuse through the air into the surface epithelium of the organisms.
4. The eyes lack a great number of blood vessels (which carry oxygen) and therefore, needs an extra supply of oxygen. The atmosphere provides this extra needed oxygen, which is taken up by the eye through direct diffusion of O_2 into the cornea, the hardouter covering on the eye. In absence of diffusion, the eyes would dry out.
5. For medicines taken orally as pills, the medicine must somehow find its way into the bloodstream. Once in the stomach, the medicine from the pill is absorbed into the lining of the stomach and then into the bloodstream, both by the process of diffusion.
6. Gaseous exchange during the process of respiration and photosynthesis takes place with the help of diffusion.

7. Transpiration or loss of water from the aerial parts of the plants involves the process of diffusion.
8. Diffusion is involved in passive uptake of mineral salts.
9. Odour molecules of the flowers to attract the pollinating animals, spreads in the air by diffusion.
10. Diffusion plays an important role in imbibition (special type of diffusion involving the absorption of water molecules by solids such as absorption of water by wood or seeds) and osmosis.

Application activity 5.2

1. Choose from term listed below, use them to complete the following statements:

List of terms: diffusion, osmosis, facilitated diffusion, imbibition.

Statements:

i. Transpiration or loss of water from the aerial parts of the plants involves the process of .....

ii. Diffusion which involves the carrier protein is called....

2. Use the following data.

Thickness of the membranes (µm)	Rates of diffusion (molecules/ minute)
5	10
6	8
8	7
7	5

a. Plot those data on a graph placing the thickness of the membranes on X- axis and rates of diffusion on Y- axis.

b. Interpret your graph.

c. Apart from distance, identify other possible factors affecting diffusion.

5.3 Process of osmosis

Activity 5.3

Aim: To investigate the process of osmosis.

Materials: Irish or sweet potatoes, knife, water, moist salt or moist sugar, Petri dish or beaker.

Procedure

i. Cut a potato into 2 pieces using a knife.
ii. Use a knife to shape each piece in a way allowing it to be stable in a Petri dishes.
iii. Label Petri dish A and B.
iv. Make a small depression in each potato piece.
v. Fill a half of Petri dish A with distilled water.
vi. Place a moist sugar or salt in the depression of potato piece of Petri dish A.
vii. Place the potato piece A in Petri dish A.
viii. Fill a half of Petri dish B with 60 % sugar or salt solution.
ix. Place distilled water in the depression of potato piece of Petri dish B.
x. Place the potato piece B in Petri dish B.
xi. Observe during at least 30 minutes.

Tasks

1. Identify the investigated process.
2. Interpret your observations.
3. Dicuss factors affecting this process.
4. Discuss the significance of the process in living organisms.

Osmosis is the movement of water molecules from molecules from **hypotonic solution** (less concentrated solution having many molecules of water and few molecules of solutes) to **hypertonic solution** (highly concentrated solution containing few molecules of water and many molecules of solutes) through a differential or selective or semi- permeable membrane due to concentration gradient.

In osmosis, the movement of water (solvent) occurs due to the difference of chemical potential (water potential in case of water) on the two sides of the cell membrane.

The kinetic energy or free energy possessed by the molecules of a substance is called **chemical potential**. The chemical potential of water is called **water potential**. The chemical potential of pure water (solvent) is higher than that of the same water in a solution. Presence of solute particles decreases the chemical potential (free energy) of water. The lowering of chemical potential (free energy) is due to attraction and collision between solvent (water) and solute molecules. Thus, in terms of thermodynamics, '*Osmosis is the movement of water or solvent molecules from the region of their higher chemical potential (free energy) to the region of their lower chemical potential (free energy) across a semipermeable membrane'.*

When a cell is placed in a solution containing a solute (e.g., salt or sugar) dissolved in water, any of the three conditions may arise:

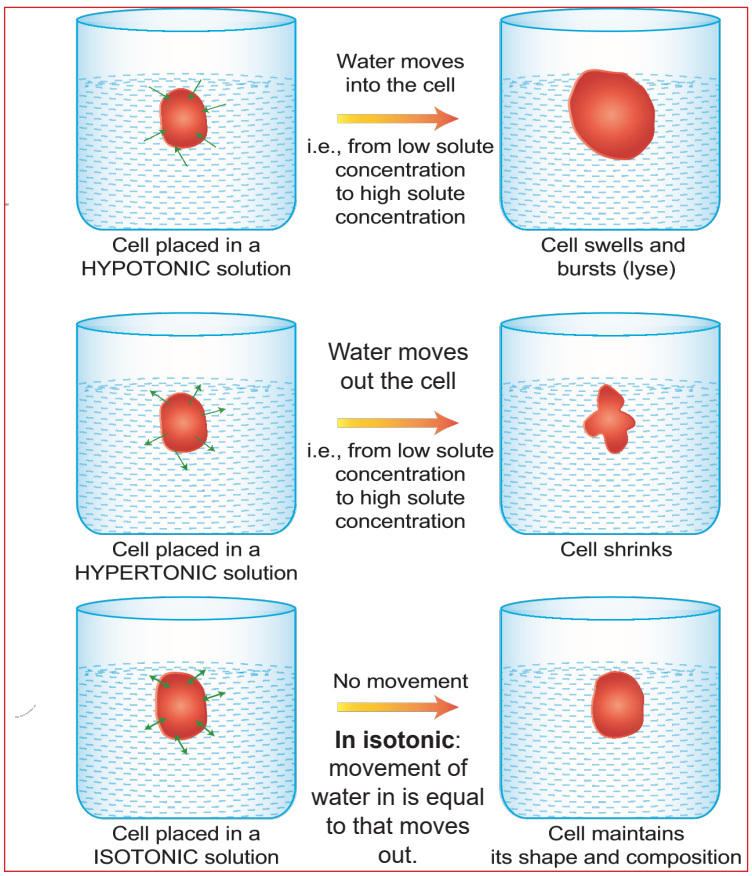


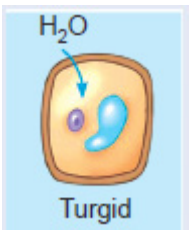
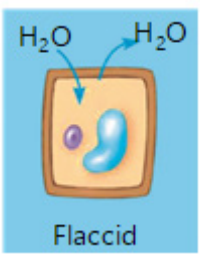
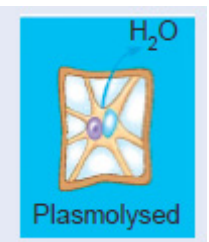
Figure 5.3: Movement of water molecules when a cell is placed in three types of solution— Hypotonic, Hypertonic and Isotonic with respect to the cell.

i. If the medium is **hypotonic** with respect to the cell, i.e., if it has solute concentration lower than the cell interior, water will tend to move into the cell. This may lead to swelling of the cell and even cause it to burst if it is animal cell. The plant cell is termed turgid. For example, red blood cells when placed in a hypotonic solution, there is **hemolysis**.

ii. If the medium is **hypertonic** with respect to the cell, i.e., has high solute concentration than the cell interior, then water will tend to move out of the cell into the medium. This would cause cell to shrink in size. For example, a plant cell when placed in hypertonic solution, shows **plasmolysis** in which the plasma membrane shrinks and becomes widely separated from the cell wall.

iii. If the medium is **isotonic** with respect to the cell, i.e., the solute concentration is equal to that in the cell, the net movement of water across the membrane would be zero. The cell size and concentration would remain constant. The cell is termed **flaccid**. For example, 0.9% solution of NaCl is nearly isotonic to blood serum.

Difference between turgidity, flaccidity and plasmolysis

Turgidity	Flaccidity	Plasmolysis
Cell which has taken up water and become swollen. Cells become turgid when placed in hypotonic solution. 	Cell which has lost water and become wilt in which there is a gap between cell wall and protoplasm. Cells become flaccid when placed in isotonic solution. 	Cell which has lost much of its water and has shrunk, in which cytoplasm has moved away from the cell wall. Cells become plasmolysed when placed in hypertonic solution. 

Food preservation by salting using hypertonic solutions

When a cell is placed in a hypertonic solution, water actually flows out of the cell into the surrounding solution thereby causing the cells to shrink and lose its turgidity. Hypertonic solutions are used for antimicrobial control.

Salt and sugar are used to create hypertonic environment for microorganisms and are commonly used as food preservatives.

"Salting is the preservation of food with dry edible salt. It is related to pickling (preparing food with brine, i.e., salty water). It is one of the oldest methods of preserving food. Salting is used because most bacteria, fungi and other potentially pathogenic organisms cannot survive in a highly salty environment, due to the hypertonic nature of salt. Any living cell in such an environment will become dehydrated through osmosis and die or become temporarily inactivated."

Salting methods

Cut your vegetables up in pieces before you put them into the saltwater to preserve food by salt-curing. As you chop a vegetable and put it into the saltwater, it makes its own juice. Nowadays, you might want to use a smaller container. Just make sure the water has plenty of salt added. Let the vegetables stand in the saltwater for at least 10 days in order to "pickle." Pickle simply means preserve in brine. Then cover tightly with a lid. Preserve meats by salt-curing. Rub meat completely with salt pellets and allow it to cure for 4 to 8 weeks. At the end of this time, the meat will be almost dry. It can be stored this way for a long time. This method is called "**dry-curing**."

Soak meat in a solution of brine for a period of 3 to 4 weeks. It will be ready to eat, but it won't last long this way. You can also use a syringe to inject brine into the muscles of the meat in order to preserve the food by salt-curing. It will be ready to eat in 2 to 3 weeks. Just remember that these wet methods of salt-curing meat do not preserve it as long as the dry method does.

Osmosis in animal cells

When there is more water outside an animal cell than inside or animal cell is kept in hypertonic solution, more water particles will enter the cell than leave. This will lead to swelling of the cytoplasm and push it outwards. Consequently, the cell membrane will stretch and finally the cell will burst. On the other hand, when there is less water outside the cell (hypotonic solution) in comparison to inside, more water molecules move out of the cell and finally cell will shrink. Therefore, both the conditions are harmful for animal cells, so, the water concentration surrounding the animal cell must be kept constant for the cells to carry out their functions normally.

Process of osmosis in plant cells

Unlike the animal cells, the plant cells do not have the ability to osmoregulate the water that enters the cells. Therefore, the water tends to move into the cells continuously due to the **water potential**. Water Potential is a key concept for understanding the movement of water, i.e., the plant-water relation.

Pure water has the highest water potential which at room temperature in absence of any pressure is zero. If solutes are added to water, its water potential decreases because the number of water molecules with kinetic energy would tend to be low. This magnitude of decline in water potential due to presence of solutes is referred to as the **solute potential**.

The continuous uptake of water by the plant cells causes the cells to swell to the limit when the hydrostatic pressure within the cell prevents any more water to get in. This pressure is known as **Osmotic pressure** and the cells are said to be **turgid**. One of the critical functions of plant cell walls is thus to prevent cell swelling as a result of this osmotic pressure. In contrast to animal cells, plant cells do not maintain an osmotic balance between their cytosol and extracellular fluids. Consequently, osmotic pressure continually drives the flow of water into the cell. This water influx is tolerated by plant cells because their rigid cell walls prevent swelling and bursting. Instead, an internal hydrostatic pressure called **Turgor pressure** builds up within the cell, eventually equalizing the osmotic pressure and preventing the further influx of water.

Turgor pressure is responsible for much of the rigidity of plant tissues. In addition, turgor pressure provides the basis for a form of cell growth that is unique to plants. In particular, plant cells frequently expand by taking up water without synthesizing new cytoplasmic components. Cell expansion by this mechanism is signaled by plant hormones (auxins) that activate certain proteins which allow turgor pressure to drive the expansion of the cell in a particular direction. As this occurs, the water that flows into the cell accumulates within a large central vacuole, so the cell expands without increasing the volume of its cytosol. Such expansion can result in a ten to hundred fold increase in the size of plant cells during development. The pressure exerted on the contents of a plant cell by the cell wall that is equal in force and opposite in direction to the turgor pressure is known as **wall pressure**.

Adaptations of plants and animals to salty conditions

Plants in salty areas take up more salt from the soil resulting in an increase in salt concentration in the cells and thus maintaining a water potential that is more negative than that of the soil.

The difference in osmotic potential between plant cells and soil water leads to the movement of water into the cells through the cell membrane via osmosis. Water is evaporated from the leaves. This also helps the movement of water from the roots up the stem to the leaves. Some plants restrict the opening of stomata to conserve their water in salty conditions and some turn down leaves to decrease surface area of evaporation. Plants have glands to store salt which burst when concentration of salt increases and causes the release of salt to the soil again. Some plants regulate salt levels by transporting sodium and chloride ions into the central vacuole. High salt concentration in the vacuole causes more water uptake and swelling.

Some plants avoid salt stress by releasing leaves in which excess sodium chloride accumulates in petioles.

Animals adapt to the salty conditions very well as plants. For example, fishes in salt water intake a lot of water and reduce the loss of water by excreting less amount of urine by having a kidney with relatively few small glomeruli. Fishes also have chloride secretory cells on their gills which actively transport salts from the blood to the surroundings. Salt glands are also found in other animals inhabiting salty conditions. Therefore, specially developed kidneys, gills, and body functions help equalizing salt concentrations across membranes through osmosis.

Significance of osmosis

Listed below are a few examples that illustrate the importance of osmosis:

1. Osmosis is of prime importance in living organism, where it influences the distribution of nutrients and the release of metabolic waste products. Living cells of both plants and animals are enclosed by a partially permeable membrane called the cell membrane, which regulates the flow of liquids and of dissolved solids and gases into and out of the cell.
2. It helps maintain the pressure on either side of the cell membrane thereby preventing the cells to become turgid and burst or to become flaccid.
3. Plant roots absorb water and minerals from soil and take it upwards to the leaves and other plant parts which are essential for plant growth.
4. Purification of blood by kidneys also involves osmosis. Osmosis maintains the balance of inter- and intracellular fluids.
5. Reverse osmosis is used to purify water.
6. Plants wilt when watered with saltwater or provided too much of fertilizer as this makes the soil hypertonic than the plant roots and disrupts water uptake.

But osmosis may also be harmful, especially, in case of marine and freshwater fishes which have to constantly regulate the movement of water out or into their body (called osmoregulation).

Application activity 5.3

I. Associate the column A and B

Column A	Column B
1. It occurs when a plant cell is placed in hypotonic solution	a. crenation
2. It happens when a plant cell is placed in hypertonic solution	b. lysis
3. It takes place when animal cell is placed in hypotonic solution	c. Plasmolysis
4. It is undergone by an animal cell put in hypertonic solution	d. turgidity

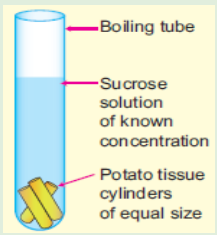
II. Relate the mineral salts absorption by the plant roots to osmosis.

5.4 Water potential, osmotic potential, wall pressure

Activity 5.4

Aim: To investigate and present the effects of immersing plant tissue in solutions of different water potentials and using the results to estimate the water potential of tissue.

Materials required: Potatoes (plant tissue), Cork borer, Measurement scale, Knife/Blade, Boiling tubes, Aluminium foil, Graph paper, Sucrose solution (0.0M, 0.2M, 0.4M, 0.6M, 0.8M and 1M), Water.



Procedure:

1. Using a cork borer, cut cylinders of potato tissue.
2. Slice the cylinders into 4 cm length each. This is the initial length (Li).

3. Take sucrose solutions of different concentration in boiling tubes and label them.
4. Immediately add 3 potato tissue cylinders in each boiling tube. Seal the tube with an aluminium foil paper to prevent water loss by evaporation.
5. Leave the tube rack aside for 1h.
6. Measure the length of the cylinders in each tube. This is the final length (Lf).
7. Calculate the % change in length for each using the formula: % change in length = [(Lf– Li)/ Li] × 100.
8. Calculate the average of the three readings obtained for each tube.
9. Plot a graph of mean % change in length versus the sucrose concentration used.
10. Draw the best fit line for all the points obtained.
11. Using the graph, determine the sucrose concentration at which the tissue showed no change in its length. This is the water potential of the potato tissue used (in terms of molarity).

Questions: Discuss the following questions after observing the results drawn.

1. What happened to the potato tissue cylinders? Did they swell or shrink?
2. Which process do you think brought the change?

Water potential (Ψ) is a measure of the tendency or capacity of water molecules to move from one place to another. In other words, it is the p**otential energy** of water

The Ψ of pure water is 0 and addition of solutes makes **Ψ negative** (-). So, Ψ is generally comprised between 0 and except in glomerulus of kidney nephron where Ψ is greater than 0.

Units of measuring water potentials

Water potential is measured in **kPa (KiloPascal).** Confusingly, pure water – which has the highest water potential – has a value of 0 kPa Dissolving solutes in water reduces water potential. So, water potential values go down from 0 to negative figures. The larger the negative figure the more solute dissolved and the lower the water potential. Below, there is a ladder showing water potential, free water molecules and kPa values.

Table 5.2: Decrease of water potential as solute concentration increases.

Highest water potential: 0 kPa	Pure water:	No solutes dissolved.
Lower water potential: -10 kPa	Dilute solution:	Small amount of solute dissolved
Very low water potential: -500 kPa	Concentrated solution:	Large amount of solute dissolved

Osmotic (solute) potential: ΨS

Osmotic (solute) potential is the potential of a solution to cause water movement into the cell across a partially permeable membrane as a result of dissolved solutes. The amount that the solute molecules lower the Ψ shows the solute potential.

ΨS: **is always negative**

Pressure potential: ΨP.

Pressure potential is the capacity of pressure to contribute to water movement. The more the pressure inside the cell, the more the tendency will be for water to leave it.

ΨP is generally positive except in plant xylem in which there is a tension (negative pressure) and so negative ΨP.

Calculation of water potential

$\Psi = \Psi S + \Psi P$

Where:

Ψc or Ψ: water potential of the cell

ΨS: osmotic (solute) potential

ΨP: ¬pressure potential

Wall pressure is the pressure that the plant cell wall exerts against the internal cell content. This pressure prevents the bursting of plant cells placed in hypotonic solutions.

Application activity 5.4

1. If 10 grams of salts are added pure water, does its water potential increase or decreases? Justify your answer.
2. If the solute potential of beetroot cells is -1400 kPa and their water potential is -950 kPa, what is their mean pressure potential? Show the formula and calculations.

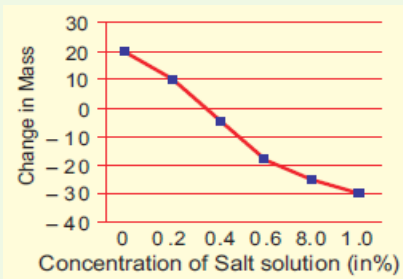
5.5 Process of active transport

Activity 5.5

Aim: To interpret data on movement of solvents and ions in and out of the cell in the given graph.

Materials required: Given data and the plotted graph.

Background experiment of the given graph: Using a cork borer, cylinders of potato tissue were cut. The cylinders were sliced into 5 cm length each and weighed. This is the initial mass (Mi). Different concentrations of salt solutions (0%, 0.2%, 0.4%, 0.6%, 0.8% and 1% NaCl) were taken in different boiling tubes. One potato tissue cylinder was added to each boiling tube. The tube was sealed and left aside for 24h. Next day, the weight of each cylinder was measured to obtain the final mass (Mf). The change in weight was then calculated by subtracting Mi from Mf. When the data were plotted on a graph paper, it gave the below shown result.



Procedure

1. Read and understand the background experimental details and the graph thoroughly.
2. Based on your understanding, interpret the result in terms of answering the below mentioned questions:

Question 1: What pattern do you observe with respect to some potatoes gaining water and some losing water? Why?

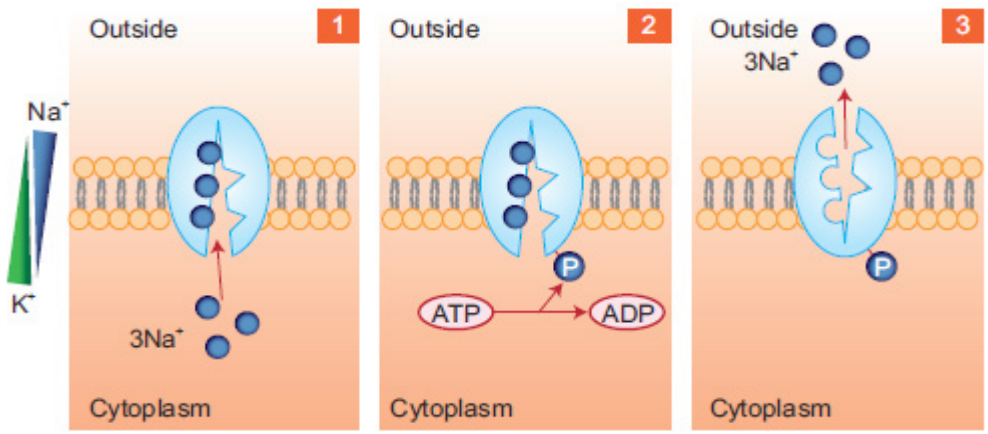
Question 2: Which of the salt concentrations are hypotonic and hypertonic with respect to potato tissue?

Active transport is the movement of ions or molecules from a region of lower concentration to higher concentration across the plasma membrane (Uphill transport). For this, the energy is provided either by another coupled reaction or by direct hydrolysis of ATP.

5.5.1 Process of active transport

i. **Primary active transport**: It involves direct hydrolysis of ATP. Example includes ion pumps, for example, Na^+–K^+ pump (Na^+–K^+ ATPase), responsible for maintaining gradients of ions across the plasma membrane; Ca^{2+} ions are actively transported across the plasma membrane with the help of Ca^{2+} pump which is powered by ATP hydrolysis, and; H^+ ions are actively transported out of the cells by ion pumps in plasma membranes of bacteria, yeasts and plant cells.

ii. **Secondary active transport** (Active Transport Driven by Ion Gradients): Molecules are transported against the concentration gradient not using energy derived directly from ATP hydrolysis but coupled with the movement of second molecule in an energetically favourable direction, i.e., from higher concentration to lower concentration. For example, glucose is transported with the coupled transport of Na^+ ions. Na^+ gradient is responsible for transport of glucose against concentration gradient from the intestinal lumen to the cell.



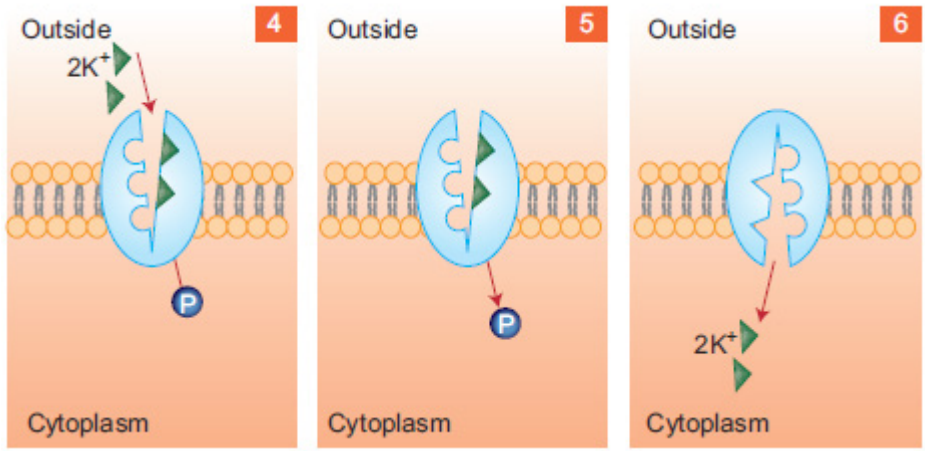


Figure 5.4: Working of Na^+ – K^+ pump.

The concentration of Na^+ is more outside than inside while that of K^+ ions is more inside. Steps involved:

1. 3 Na^+ ions bind to the pump facing the cytoplasm,
2. Binding of Na^+ promotes ATP hydrolysis and thus phosphorylation of pump,
3. Conformational change in transporter causes it to face outwards and low binding affinity for Na^+, so 3 Na^+ released outside,
4. High binding affinity for K^+, so 2 K^+ ions bind to pump,
5. Binding of K^+ promotes dephosphorylation and therefore, conformational change in pump,
6. Low affinity for K^+, so 2 K^+ ions are released into the cytoplasm.

The transporter simultaneously binds to one molecule of glucose and two ions of Na^+. Energetically favorable movement of Na^+ drives the uptake of glucose against its concentration gradient.

The coordinated uptake of molecules may be symport, uniport and antiport.

a. **Symport**: When two molecules transport in the same direction, e.g., coordinated uptake of glucose and Na^+
b. **Uniport**: Transport of only a single molecule, e.g., diffusion of glucose.
c. ***Antiport***: When two molecules are transported in the opposite direction, e.g., Na^+– Ca^{2+} antiporter transports Na^+ into the cell and Ca^{2+} out. Another example is Na^+–H^+, which transports Na^+ into the cell with the export of H^+, thereby removing excess of H^+ and preventing acidification of cell cytoplasm.

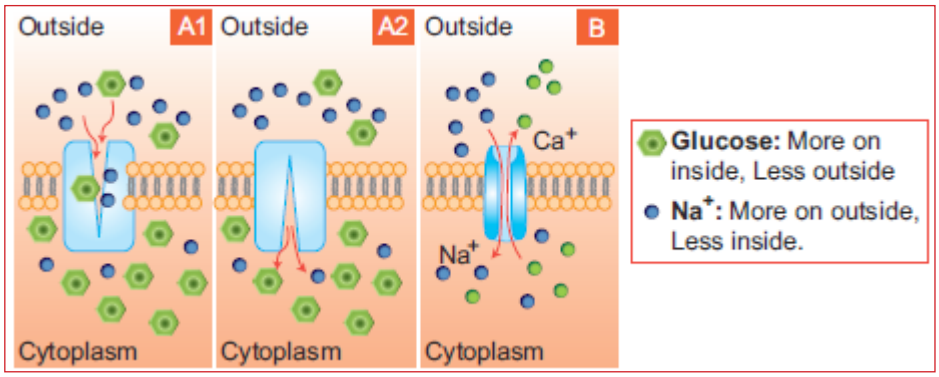


Figure 5.6: Seconadry active transport

A (1 and 2) - Symport of 1 molecule of glucose with 2 molecules of Na^+ ions by secondary active transport. Note that the two molecules are transported in the same direction. B- Antiport of 1 molecule of Na^+ into the cell and 1 molecule of Ca^{2+} out of the cell. Note that the two molecules are transported in opposite direction

5.5.2 Factors affecting the process of active transport

Any factor that affects **energy production** (during cell respiration) affects the rate of active transport. Factors affecting rate of active transport include the following:

i. **Oxygen concentration**: Oxygen is used to break down food to release energy. When the concentration of oxygen is low, less energy is produced; hence rate of active transport is slow. The higher the oxygen concentration, the more energy is released and therefore the rate of active transport is increased.

ii. **Temperature**: Increase in temperature up to optimum levels increases rate of chemical reactions that release energy in the cell. Increase in energy enhances the rate of active transport. Temperatures above optimum levels denature enzymes that speed up chemical reactions. This results in low energy production and therefore rate of active transport is slowed down. Low temperatures inactivate enzymes hence less energy is produced. This slows down active transport.

iii. **Enzyme inhibitors**: Enzyme inhibitors are substances that slow down the rate of enzyme activity. Presence of enzyme inhibitors slows down the rate of active transport. These block the enzyme active sites which makes it hard for the enzymes to bind and react with the substrates.

iv. **Cofactors and coenzymes**: Cofactors and coenzymes are substances that activate enzymes. Their presence increases the rate of chemical reactions leading to more energy production. This increases rate of active transport. **A cofactor** is nonprotein adjunct required by an enzyeme in order to function;many cofactors are metal ions (such as Mg^{2+},Magnesium ions), others are coenzymes. **A coenzyme** is a nonprotein **organic** molecule that aids the action of the enzyme to which it is loosely bound.Examples of coenzymes are Nicotinamide adenine dinucleotide (NAD), Flavine adenine dinucleotide (FAD).

v. **pH** : This is the acidity or alkalinity of a solution. Some enzymes function best in acidic, alkaline or neutral pH. If the pH of a chemical reaction is altered, enzyme activity will be slowed down or stopped. This will slow down or stop energy production. Consequently, active transport will be slowed down or may stop.

It is known that active transport is carried out with the help of pumps. There are two factors which importantly affect the active transport, including the rate of transport by individual active transporters and the number of active transporters present in the membrane or in another term the surface area.

Furthermore, the rate of transport by individual transporter in turn depends upon the nature of transporter, electrochemical gradient or electrochemical driving force on either side of the membrane, and the conditions under which a transporter must operate.

5.5.3 Significance of active transport in organisms

i. In the intestinal lining, glucose is absorbed by active transport from a lower concentration to a higher concentration in the cells lining the intestine.

ii. Na^+ and K^+ gradients established by the Na^+–K^+ pump is required for the propagation of electric signals in nerves and muscles.

iii. Ca^{2+} ions are actively transported by Ca^{2+} pump which is required for muscle contraction.

i. H^+ ions are actively pumped out of the cell lining the stomach which results in the acidity of gastric fluids which help in the digestion. H^+ ions are actively transported into the endosomes and lysosomes with the help of pumps. Active transport is also important for the transport of nutrients, including ions, sugars, amino acids into the cells and transport of toxic substances out of the cell (e.g., ABC transporters in bacteria and eukaryotic cells).

Application activity 5.5

The following data is provided.

Concentration of oxygen in a cell (mol /L)	Rates of active transport (molecules/ minute)
10	10
12	11
13	12
14	13

a. Plot those data on a graph placing the thickness of the membranes on abscissa axis and rates of active transport on ordinates axis.
b. Interpret your graph.
c. Suggest other possible factors affecting active transport.

5.6 Endocytosis and exocytosis

Activity 5.6

Discuss on the process of endocytosis and exocytosis and draw the diagram showing the process of endocytosis and exocytosis. Present your findings to your classmates.

5.6.1 Endocytosis

Christian de Duve (1963) coined the term "**endocytosis**" which is responsible for ingestion of large particles (such as bacteria), macromolecules and fluids into the cell in the form of small vesicles. Unlike all the above mentioned processes involved in transport molecules, endocytosis is the only means by which large molecules or particles can be taken up by the cell, especially in eukaryotes. It is further categorized into:

Phagocytosis, also called "**cell eating**". It involves ingestion of bacteria, cell debris or even intact cells.

Pinocytosis, also called "**cell drinking**". It involves uptake of fluids by the cell.

5.6.1 Phagocytosis

This serves as a means of food capturing by bacteria and many protozoans while in eukaryotic cells it serves as a defense mechanism to fight against harmful

microorganisms and even to get rid of the cells that have stopped functioning normally or are aged. In mammals (such as man), macrophages (of spleen and liver) and neutrophils are key components of the immune system that show phagocytosis and are therefore also called "**professional phagocytes**".

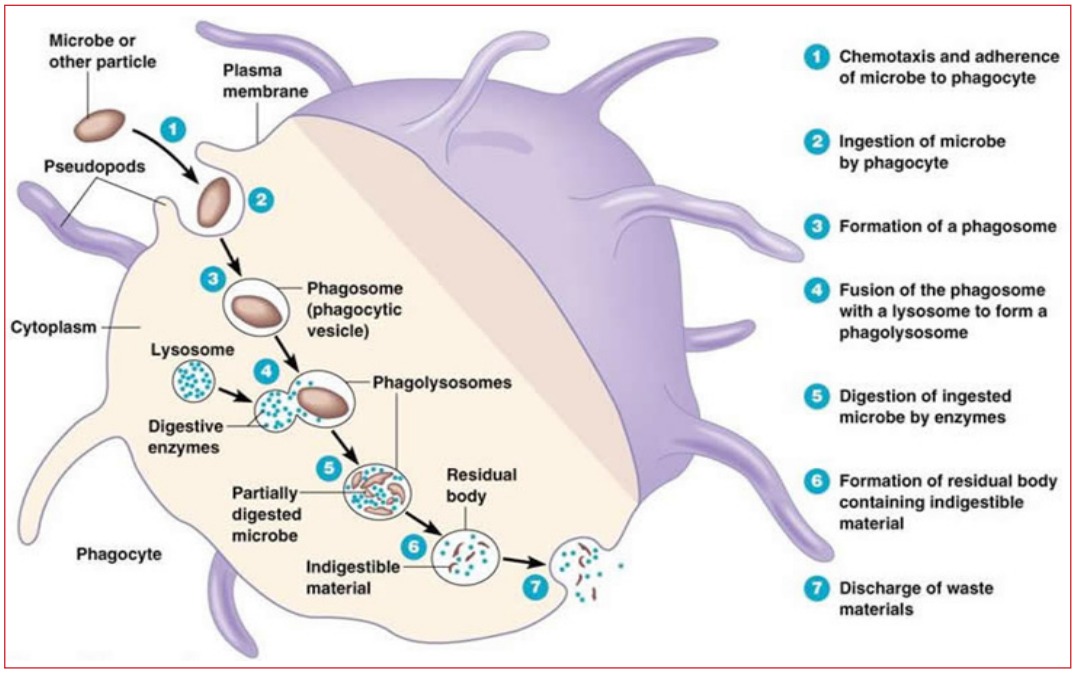


Figure 5.6: Phases of phagocytosis of microbes by a white blood cell

5.6.2 Pinocytosis

It is also called "fluid endocytosis" and is used primarily for the uptake of extracellular fluids. It is a non-specific process which involves engulfing of either pre-dissolved or already brokendown substances. This non-specificity in the ingested substance distinguishes it from phagocytosis which takes up specific substances from the exterior. Also, phagocytosis involves breakdown of the particle which is lacking in case of pinocytosis

5.6.3 Exocytosis

Unlike endocytosis in which macromolecules or fluids are taken into the cell, exocytosis results in secretion or release of substances out of the cell. It also involves membrane enclosed secretory vesicles which are formed within the cell and fuse with the plasma membrane to drain off all its contents into the surrounding medium.

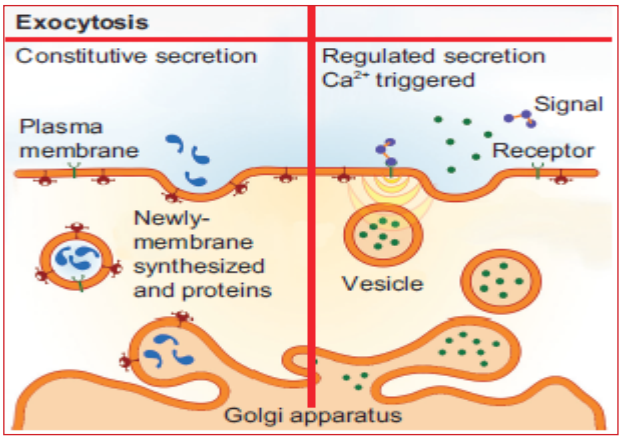


Figure 5.7: Exocytosis

Table 5.2: Comparison of Endocytosis and Exocytosis

Endocytosis	Exocytosis
Eukaryotic cells take up macromolecules from the surrounding by endocytosis that cannot pass through the cell membrane.	Cells expel large molecules or particles that cannot pass through the cell membrane.
It helps to ingest molecules to the interior of the cell.	It helps in expelling molecules outside of the cell.
Material to be internalized is surrounded by plasma membrane which buds off inside the cell to form a vesicle containing the ingested material.	Molecules to be transported are surrounded by vesicles which move towards the cell membrane and get attached to it. Molecules are pushed off from the membrane.
It leads to formation of vesicles.	It leads to destruction of vesicles.
It can be further categorized into following two types: Phagocytosis (Cell eating): Cell takes in bacteria or food, Pinocytosis (Cell drinking): Cell ingests a liquid material	There is no further categorization.
Examples: Uptake of nutrients, food particles, proteins and specific molecules, destruction of pathogen by cells.	Examples: Secretion of digestive enzymes, antibodies, hormones, discharge of neurotransmitter from presynaptic neurons.

Application activity 5.6

1. Use the following terms listed below to complete the following statements

Terms list: Osmosis, Pinocytosis, active transport, plasmolysis, antiport, Phagocytosis, Christian de Duve.

Statements:

i. The process of cell drinking is known as ..... .
ii. Ca^{2+} ions are required for ..... .
iii. When two molecules are transported in opposite direction, it is ..... .
iv. ..... involves ingestion of bacteria.
v. (v) Endocytosis is discovered by ……..

2. Draw and interpret the phagocytosis of Entamoeba histolytica by a macrophage.

Skills lab 5

Aim: Meat preservation by salting method and money generation.

Suppose that there is no refrigerator at your home or butcher. Practise the salting method studied in class to preserve your meat which will be eaten or sold for earning money.

Materials: Container such as a bucket, salt, string, knife, fish/ meat, suspension metal.

Procedure

i. Using a knife, make a hole in the meat.
ii. Insert the string in those holes.
iii. Place many salt molecules on that meat.
iv. Suspend that meat on the suspension metal for its preservation.
v. Sell the preserved meat to earn money.

4. Portfolio Report:

i. Write your skills lab project implementation report focusing on how this skill lab has helped you to get money and new biological skills, submit it to your teacher.
ii. Bring a product (preserved meat /fish) and present it to the whole class.

Note: Invent or discover other skill labs related to this unit.

End unit assessment 5

I. Choose whether the given statements are True (T) or False (F)

1. Passive transport occurs by diffusion or osmosis.
2. Simple diffusion involves uphill transport of ions or molecules.
3. Osmosis is the movement of water or solvent molecules from the region of their higher chemical potential (free energy) to the region of their lower chemical potential (free energy) across a semipermeable membrane.
4. Not all transport mechanisms occurring across a cell membrane require ATP utilization.
5. Molecules or substances that are large in size are transported across the membrane by active transport.
6. In the human body, nutrients (in the form of ions and small molecules) are absorbed from the food by the surrounding blood cells in the vessels by way of osmosis.
7. Purification of blood by kidneys involves diffusion.
8. Reverse osmosis is used to purify water.
9. In the intestinal lining, glucose is absorbed by active transport from a lower concentration to a higher concentration in the cells lining the intestine.
10. Salting is one of the oldest methods of preserving food.

II. Multiple choice questions

1. …….. is the movement of ions or molecules from a region of lower concentration to higher concentration across the plasma membrane.

   a. Active transport b. Passive transport
   c. Pinocytosis d. Exocytosis

2. In the absence of …….. eyes would dry out.

   a. osmosis b diffusion
   c endocytosis d exocytosis

3. Gaseous exchange during the process of respiration and photosynthesis takes place with the help of

   a. osmosis b. diffusion
   c. endocytosis d. exocytosis

4. Transpiration involves the process of
   a. osmosis b. diffusion
   c. endocytosis d. exocytosis
5. ..... is important for the transport of nutrients into the cells and toxic substances out of the cell.
   a. Active transport b. Passive transport
   c. Pinocytosis d. Exocytosis
6. For transport by simple diffusion
   a. Particles should be small in size
   b. Particles should be soluble in lipid
   c. Both of the above
   d. None of the above
7. Which of the following transport mechanisms describes the process by which a macrophage engulfs bacteria?
   a. Active transport
   b. Endocytosis
   c. Transcytosis

III. Long answer type questions

1. In your own words, explain the processes by which materials move in and out of cells.
2. Give four examples, showing significance of diffusion in living systems.
3. Give four examples, showing the importance of osmosis in living systems.
4. In your own words, explain the significance of Active transport in living organisms.
5. With examples, explain how can you apply the knowledge of hypertonic environments in food preservation by salting?
6. How do plants and animals adapt to salty conditions?
7. Justify the statement:

The interplay between HIV and the plasma membrane has much to offer in terms of understanding viral tropism and pathogenicity and normal cellular functions, and for developing new antiviral approaches.

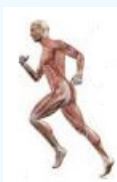
UNIT 6

SUPPORT, LOCOMOTION AND MUSCLES

Key unit competence: Explain the modes of locomotion in protists, insects, fish, amphibians, birds and mammals and the structure of muscles in relation to movement.

Introductory activity 6

Observe the following living organisms movements and respond to the following questions.




1. Among the above which ones are moving? Suggest reasons why animals carry out locomotion.
2. Discuss all adaptations that enable those organisms to move from one place to another.

6.1 Need for locomotion and non-muscular movements

Activity 6.1

Answer the following questions:

1. Why do different animals and humans move?
2. Describe the locomotion of Amoeba and Paramecium.

6.1.1 Need for locomotion

Movement or **displacement** is the change of position from one place to another. It is done either by a body part or the whole organism (locomotion). **Locomotion**, also called **taxis**, is the movement of the whole organism from one place to another. Animals need a locomotion for a variety of reasons such as

i. to find food, water and shelter.
ii. to find a mate
iii. to find a suitable microhabitat
iv. to escape dangerous fire or predator
v. to avoid competition with other animals of the same or different species
vi. to avoid overcrowding
vii. to avoid unfavourable condition.

Locomotion requires the support systems (skeletons/ skeletal systems) to which muscles are attached in most animals.

6.1.2 Non-muscular movements

Non-muscular movements are movements which do not involve muscles. Non-muscular locomotion or movement is identified in animals that belong into Kingdom Protoctista. In this kingdom, there is:

i. amoeboid locomotion e.g in moeba
ii. ciliary / ciliated locomotion in paramecium
iii. flagellar locomotion in euglena

a. Amoeboid movement

Amoeboid movement is the movement demonstrated by Amoeba and some other cells that are capable of changing their shape (e.g. phagocytes).

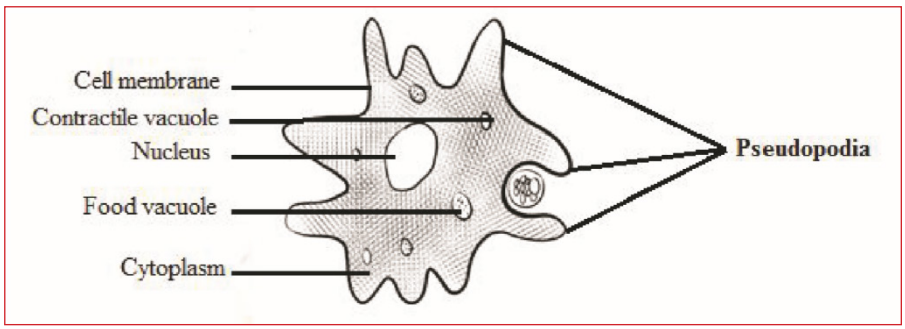


Figure 6.1: Drawing showing the structure of Amoeba proteus

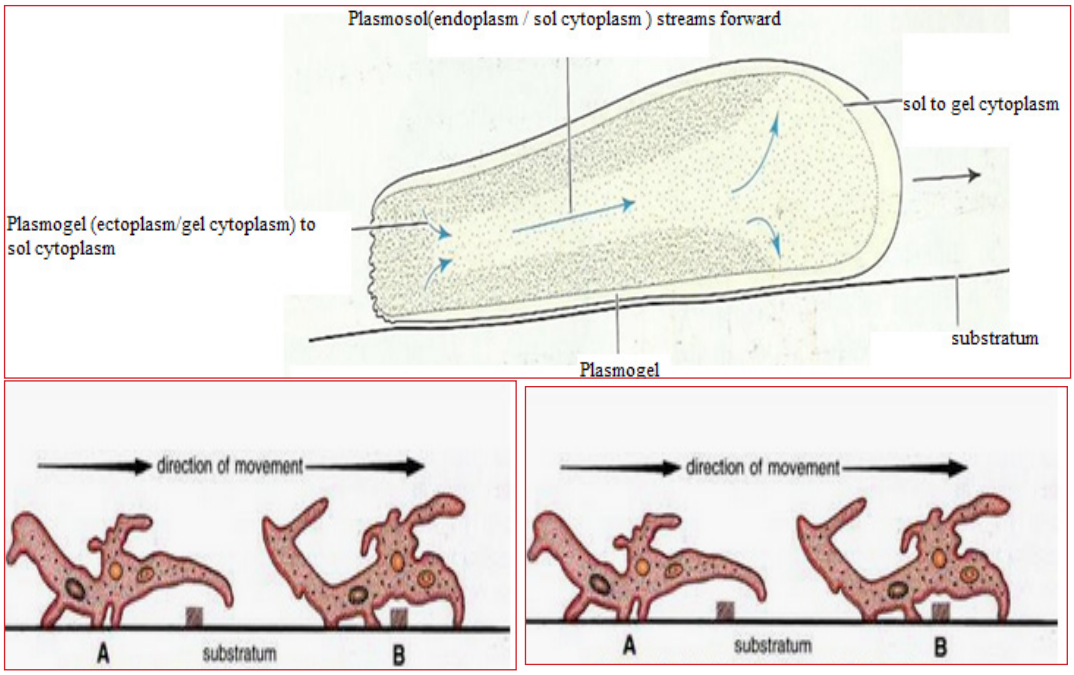


Figure 6.2: Drawing showing the amoeboid movement

In this locomotion:

i. The plasmagel is converted to plasmasol, which slides towards the front of the cell, forming a pseudopodium and propelling the cell forward.

ii. On reaching the tip of the pseudopodium, this plasmasol is reconverted into plasmagel; at the same time the plasmagel at the rear of the cell is converted into plasmasol and streams forward, thus maintaining continuous movement. This cytoplasmic streaming requires Ca2+ ions and ATP.

iii. Amoeboid locomotion is brought about by reversible changes in the actin filaments of the cell's cytoskeleton. Cross-linking of these filaments by other proteins creates a three-dimensional network with gel-like properties in the plasmagel region.

iv. Disassembly of this network causes reversion to the sol state of plasmasol.

b. Ciliated locomotion

Cilia (singular: cilium) are numerous shorter hair -like appendages extending from the surface of a living cell. Some living organisms, such as Paramecium, move by beating cilia.

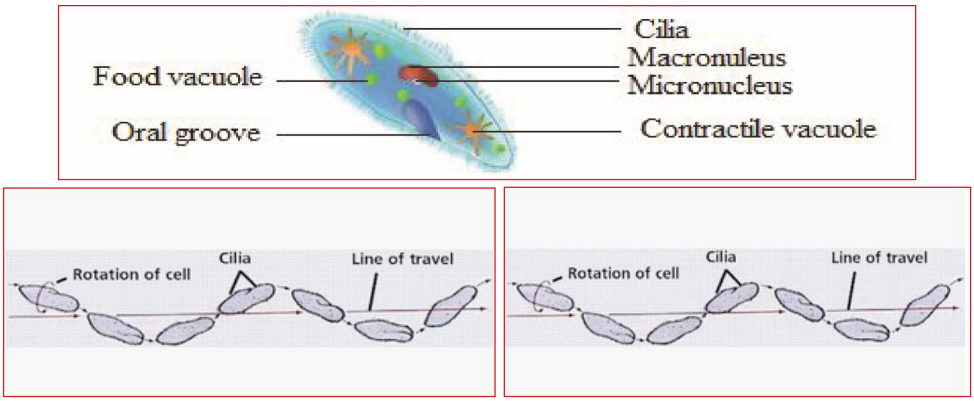


Figure 6.3: Locomotion in a Paramecium

c. Flagellar locomotion

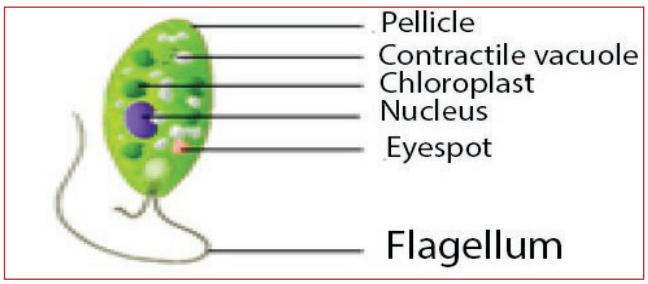


Figure 6.4: Drawing showing the structure of Euglena

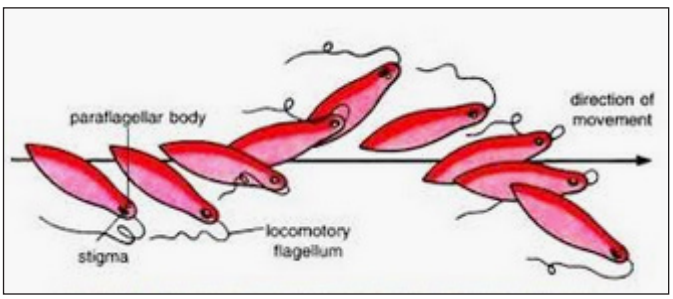


Figure 6.5 Locomotion in euglena

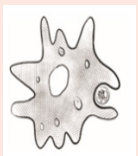
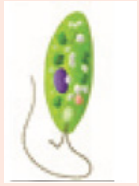
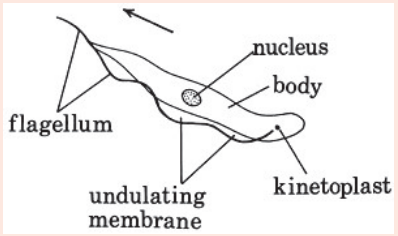
Flagella (singular: flagellum) are long, thread-like appendages on the surface of some living cells that are capable of either undulating or rotational movement. Cilia and flagella have similar structure except that cilia are short and many. Both cilia and flagella consist of fine tubes composed of an extension of plasma membrane. **Euglenas** do not have cell walls, but they have an intricate cell membrane called a **pellicle**. The pellicle is folded into ribbon-like ridges, each ridge supported by microtubules.

The pellicle is tough and flexible, letting euglenas **crawl** through mud when there is not enough water for them to swim. During cilia or flagellum locomotion,

tubules slide past each other in a movement similar to that of actin and myosin filaments in skeletal muscles. Hence, **Ca^{2+} ions** and **ATP** are also required in the ciliary locomotion. Considering the place where organisms move, there is aquatic locomotion (swimming), terrestrial locomotion (walking, running and hopping) and aerial locomotion(flight).

Application activity 6.1

1. Classify locomotions based on:
   a. Types of moving organisms
   b. Place where animal move
2. Draw a diagram showing how Amoeba proteus move from one place to another.
3. You are provided with Amoeba, Paramecium, Euglena and Trypanosoma in the table below.

			
A	B	C	D

   i. Identify those organisms based on their structures.
   ii. Relate the structures of those organisms to their locomotion.

6.2 Movement and support of fish in water, mammals and annelids.

Activity 6.2

1. Observe the freshly collected fish or the figure, to label fins and lateral line.

2. Dissect a fresh fish or observe the above given diagram. Redraw and show the swim bladder and the arrangement of muscles
3. If you have a live fish, put it in water and observe its locomotion.
4. From what you have observed, draw and label the external and internal features that contribute to fish locomotion.
5. In your free time, use your library books and internet to find how mammals and annelids move.

6.2.1 Movement and support of fish in water

Fish like other aquatic animals are adapted to such habitat in terms of locomotion due to its structural adaptive features particularly skeleton which gives shape as well as muscles arrangement and swim-bladder.

Adaptive features of fish for locomotion in water

The streamlined body shape of the fish reduces friction between water and fish. The body of fish is mostly covered by scales which overlap one another and point backwards and lie close to the body. The scales are covered by mucus which reduces the drag.

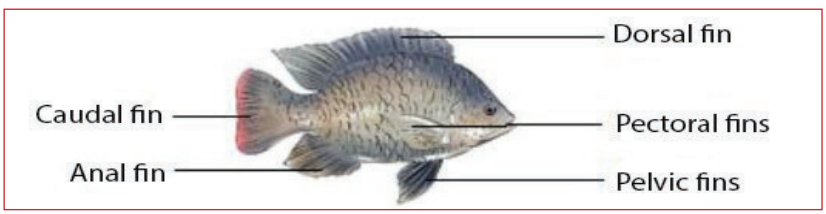


Figure 6.6: External adaptations of fish for locomotion

Tail or caudal fin has a large surface area, which increases the amount of water that is displaced as it provides much of the push during swimming. Paired

pectoral and pelvic fins bring about downward and upward movement. With pectoral fins, the control of direction of a fish in water is possible whereas the pelvic fins bring about the balance, preventing diving and rolling. There are also unpaired dorsal and anal fins for stabilizing the fish and thus preventing it from rolling or yawing. Fish is also adapted to locomotion in water by its strong tail muscles and highly flexible vertebrate column which enables the tail to move from side to side against water. In addition, inflexible head and neck maintain forward thrush.

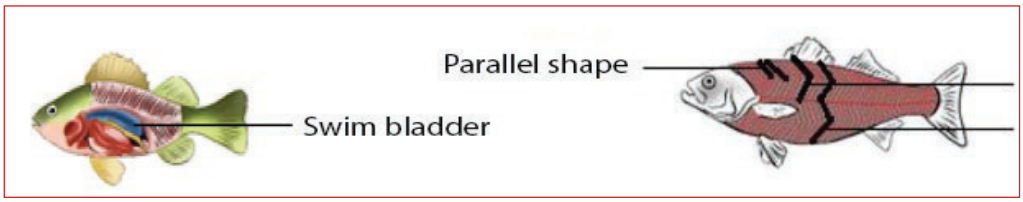


Figure 6.7: Internal adaptations of fish for swimming

Internally, a fish is adapted to swimming by swim bladder and muscles. Air or gas filled sac called swim-bladder, outgrowth of the pharynx, helps a fish to change its buoyancy as it alters the gas pressure in the bladder. So that, it floats at any depth in water without using its muscles. Swim-bladder also helps fishes to maintain a density that is equal to that of the surrounding water. Muscles or myotomes / myomeres (segments or sheets of muscles separated from its neighbor by a sheet of connective tissue) enable fishes to move in water owing the shapes of muscles that are located on either side of vertebral column.

Myotomes contribute to the mechanism of swimming by its arrangements. They may be parallel, V-shape, or W-shape arranged in bundles or blocks that are separated by myosepta. Although there are such arrangements, the myoseptal organization and orientation of fibres is complex. In bony fish, myomeres are V-shaped with new myomeres added posteriorly. With those myotomes, a fish swim by passing a wave of contracting muscle from anterior to posterior. Muscles near the head of the fish contract first and contraction proceeds posteriorly down the length of the fish to the caudal fin. Thus, a fish moves forward from the contraction and relaxation (antagonistic) of myotome on either side of the body.

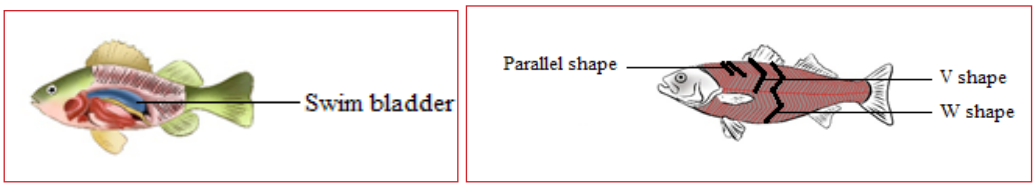


Figure 6.8: Internal adaptations of fish for swimming

Undulatory swimming of the fish is also powered by the segmental body musculature of the myotomes. Myotome and myosepta orient more perpendicularly to midline to push aside. Therefore, the fish can bend laterally. With contraction muscle fibres shorten by half their length while maintaining volume. Without myosepta, but simply a series of interconnected muscle fibres, then the wave would be much dampened.

6.2.2 Movement and support of mammals

Mammals are vertebrate animals constituting the class Mammalia, and characterized by the presence of mammary glands which in females (and sometimes males) produce milk for feeding (nursing) their young. They include, for example, dogs and humans. Most terrestrial animals can move by walking or running. All animals living on land move due to the musculoskeletal system. The rigid nature of bone also gives a structure for muscles to pull, by their contraction, to create a movement as they act as levers. The synovial joints also allow certain movements. The support and movement differ from specimen to another. Thus, animals can walk and run on land for moving from one place to another. This is possible by their endoskeleton and its muscles. By its muscles, flexor (a muscle whose contraction bends a limb or other part of the body) and extensor (a muscle whose contraction extends or straightens a limb or other part of the body or any or a muscle that increases the angle between members of a limb, as by straightening the elbow or knee or bending the wrist or spine backward); contractions of those muscles cause the limbs act as levers for them which result to the foot being pressed downwards and backwards against the ground. For example, flexor and extensor work as illustrated below:

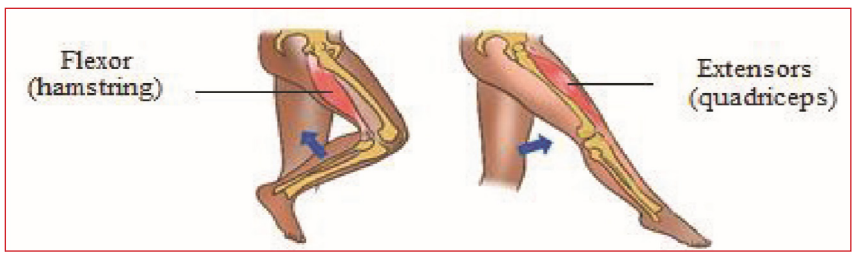


Figure 6.9: Flexor and extensor

Humans are bipedal as they walk on two legs. When standing upright, the weight is balanced over the two legs. When a stride is taken by the right leg, the heel is raised first by the contraction of the calf muscles. As this occurs, the weight of the body is brought over the left foot which is still in contact with the ground and acting as the prop for the rest of the body.

When the right leg extends the heel is the first part of the foot to touch the ground. The weight off the body is gradually transferred from the left side to a position over the right heel and then the body continues to move forward, over the right toes, backward pressure against the ground generally being exerted through the right big toe. Like human does, a bird also can walk on ground through the movement of contractions of its leg muscles particularly flexor and extensor.

Phases of walking

One way to think about the phases of walking is to think of what happens to each foot when we walk. In this situation, there are two phases: Stance phase and Swing phase (Figure 6.10).

1. Stance phase is the time when the foot is on the ground. During walking, it comprises about 60% of the walking cycle and for part of the stance phase, both feet will be on the ground for a period of time. During running the stance phase is less, and there is a period in the gait cycle when both feet are off the ground (float phase).
2. Swing Phase occurs when one foot is on the ground and one in the air. The foot that is in the air is said to be in the "Swing" phase of gait.

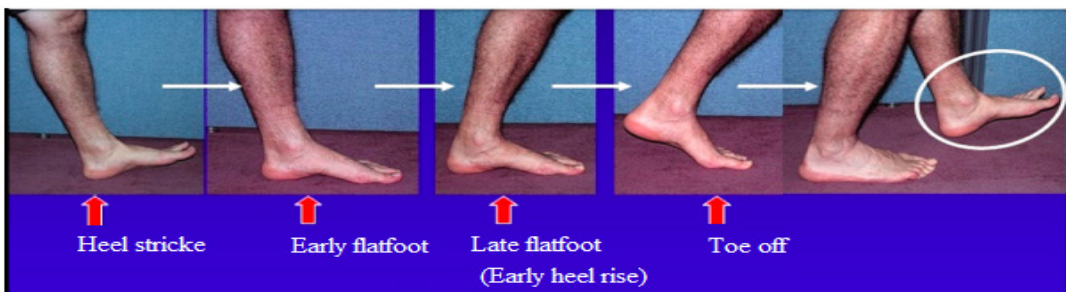


Figure 6.10: Phases of gait

Stages of stance phase

A more convenient and precise way to think about the stance phase (foot on the ground) of walking is to consider the five sub-stages that a single foot undergoes (Figure 6.10). They are as follows: Heel strike, Early flatfoot, Late flatfoot, Heel rise, and Toe off.

a. Heel strike

The heel strike phase starts the moment when the heel first touches the ground and lasts until the whole foot is on the ground (early flatfoot stage).

b. Early flatfoot

The beginning of the "early flatfoot" stage is defined as the moment that the whole foot is on the ground. The end of the "early flatfoot" stage occurs when the body's center of gravity passes over top of the foot.

The body's center of gravity is located approximately in the pelvic area in front of the lower spine, when we stand and walk. The main purpose of the "early flatfoot" stage is to allow the foot to serve as a shock absorber, helping to cushion the force of the body weight landing on the foot.

c. Late flatfoot

Once the body's center of gravity has passed in front of the neutral position, a person is said to be in the late flatfoot stage. The "late flatfoot" stage of gait ends when the heel lifts off the ground. During the "late flatfoot" phase of gait, the foot needs to go from being a flexible shock absorber to be a rigid lever that can serve to propel the body forward.

d. Heel rise

As the name suggests, the heel rise phase begins when the heel begins to leave the ground. During this phase, the foot functions as a rigid lever to move the body forward. During this phase of walking, the forces that go through the foot are quite significant: often 2-3x a person's body weight. This is because the foot creates a lever arm (centered on the ankle), which serves to magnify body weight forces. Given these high forces and considering that the average human takes 3000-5000 steps per day (an active person commonly takes 10,000 steps/day), it is not surprising that the foot can easily develop chronic repetitive stress-related problems, such as metatarsalgia, bunions, posterior tibial tendon dysfunction, peroneal tendonitis, and sesamoiditis.

e. Toe off

The toe off stage of gait begins as the toes leaves the ground. This represents the start of the swing phase.

f. Running

The defining difference between walking and running is that when running, there is a period of time both feet are off the ground (the "float" phase). Also, because running is associated with greater speeds, the forces that go through the foot when it lands can be substantially greater than during walking.

6.2.3 Support and locomotion in annelids

Annelids such as earthworms move by crawling.

a. Body segments at the head and just in front of the rear are short and thick (longitudinal muscles contracted, circuklar muscles relaxed) and anchoreedto the ground by bristles. The other segments are thin and elongate (circular muscles, longitudinal muscles relaxed)

b. The head has moved forward because circular muscles in the head segments have contracted.; Segments behing the head and at the rear are now thick and anchored, thus preventing the worm from slipping backward.

c. The head segments are thick again and anchored in their new positions the rear segments have realeased their hold on the ground and have been pulled forward.

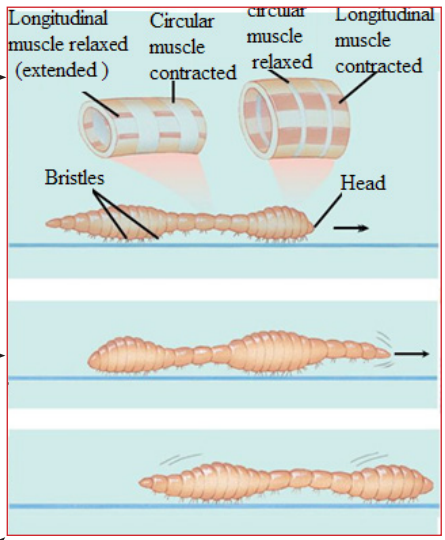


Figure 6.11: Peristalitic locomotion in an earthworm

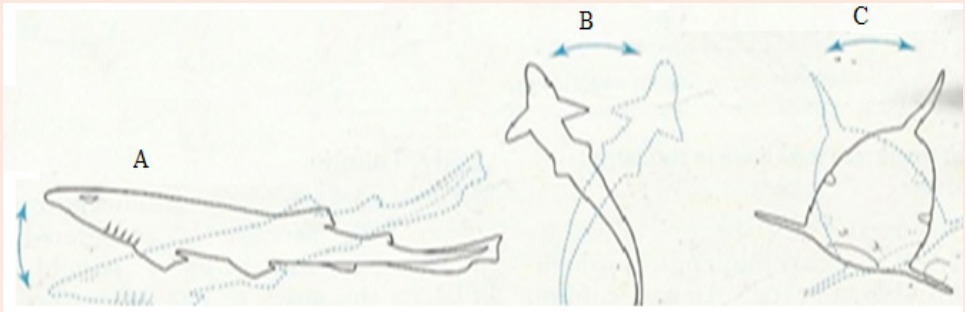
Earthworms are organisms having hydrostatic skeleton with soft-bodied animals due to fluid secreted within the body and surrounded by the muscles of the body wall. They are capable to move by aid of their muscles. These muscles are not attached to any structures and thus can pull against each other. The combined effect of muscle contraction and fluid pressure serves to maintain the shape and form of the animal. Generally, there are two muscle layers, longitudinal in which muscle fibres are arranged parallel to the long axis from one end of a segment to another and circular with muscle fibres arranged in concentric circles to the circumference of the worm.

When those muscles act antagonistically against each other, locomotion is achieved. The fluid which acts as presssurisable hydrostatic skeleton contained in body cavity or coelom presses against the muscles which in turn are able to contract against the fluid. Earthworm movement is also helped by bristles like setae or called chaetae (hair like structures on ventral surfaces) which anchor the worms to the substrate. Contraction of the circular muscles makes the worm thinner, but because liquid is essentially incompressible (and so maintains a constant volume) and the increase in pressure forces the liquid outwards,

stretching the worm, so the worm becomes longer and thinner. Contraction of the longitudinal fibres shortens the worm, former the coelomic liquid out to the sides and making the worm fatter. If the body is segmented, then such pressure is localized, and only certain segments will move or change shape.

Application activity 6.2

1. Categorize the main muscles that contribute to the locomotion in mammals?
2. Draw an earthworm's muscles that contribute to its locomotion.
3. Observe the following figure illustrating different instabilities of a fish in water and answer the following questions.



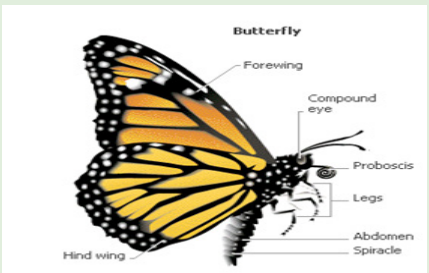
a. Identify each type of instability.
b. Interpret those instabilities.

6.3 Movement through air by birds and insects

Activity 6.3

You are provided with the bird (A) flying in the atmosphere and flying insect (B).

A



B.

1. Search, using internet and books, Identify the adaptations that enable those organisms to fly.
2. Compare the flight of birds and flight of insects.

6.3.1 Movement through air by birds

Bird can fly either by flapping their wings or gliding by spreading its wings. Like in animals moving on land, locomotion by flying in birds is brought about by the action of flexor and extensor muscles as well some other structures given diagram below like pectoralis major, pectoralis minor and keel of sternum.

Figure 6.12: Adaptive features for bird to flight

Based on the diagram below , wings move down by the contraction of pectoralis major and then move up under the contraction of pectoralis minor.

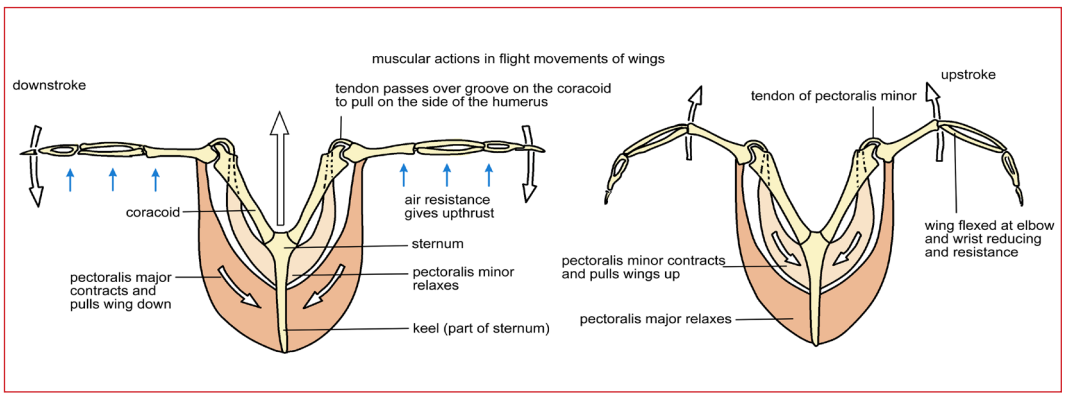


Figure 6.13: Muscular actions in flight movements of wings

Adaptations for flight in birds

i. Modification of the forelimbs to form wings to provide a large surface area for movement in air.

ii. Presence of large pectoral muscles, the pectoralis major and minor, which moves wings.

iii. A light skeleton made up of hollow and mainly small bones which can be easily moved in the air.

iv. A rigid skeleton made up of fused bones with a deep keel like extension of the sternum which provides a large surface area for the attachment of flight muscles.

v. An efficient breathing system with air sacs attached to the lungs necessary to provide oxygen for respiration and to remove the resulting carbon dioxide.

vi. A high metabolic rate for providing the high amount of energy required.

vii. An efficient circulatory system necessary for transporting both the nutrients and respiratory gases at speed related with the body needs.

viii. A high red blood cell count for efficient oxygen transport.

ix. A keen eyesight to enable them to judge distances correctly especially on landing.

x. A streamlined shape to reduce air resistance and allow smooth movement in the air.

xi. Ability to fold the legs away during flight so as not to cause any unnecessary friction with the air.

6.3.2 Movement through air by insects

Figure 6.14: Flying grasshopper

The pterygotes are insects that either have wings or evolved from winged ancestors. The wings are born, like the legs on the thorax. The insect body can be divided into head, thorax and abdomen. The thorax consists of three segments, the prothoracic segment nearest the head, the middle mesothoracic segment and the hindmost metathoracic segment. The last two segments, the mesothoracic and metathoracic, each usually bear one pair of wings. These wings are extensions of the cuticular plates of the thorax (the dorsal plate or tergite and the side-plates pleurites or pleura). The structure of insect flight muscles is shown by the following figure.

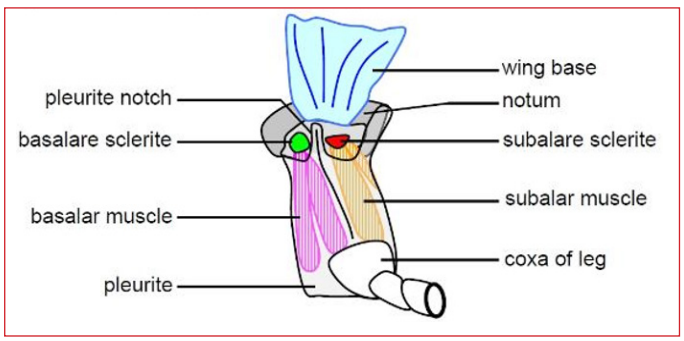


Figure 6.15.(a): Left side of winged thoracic segment of insect. (Adapted from https://cronodon.com/images/insect_flight_muscles_large.jpg)

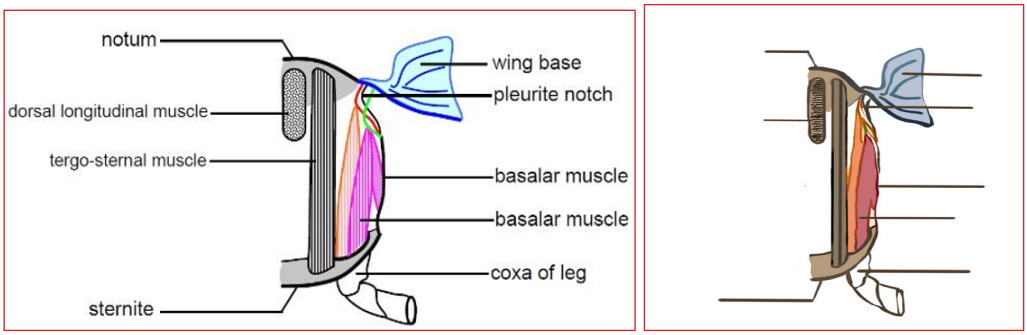


Figure 6.15. (b): Front view of winged thoracic segment of insect. (Adapted from https://cronodon.com/images/insect_flight_muscles_large.jpg)

Each thoracic segment is encased in four groups of cuticular plates: the notum (tergum) on the back, the sternum on the front and the pleura (singular pleuron) on the sides.

These four regions of the cutcicle are made up of cuticular plates, called respectably the tergites, sternites and pleurites, and softer artioculating membranes that connect the regions together. The flight muscles attach to certain of these plates or sclerites.

There are two sets of flight muscles: **direct** and **indirect** muscles.

The direct muscles attach to the wing base, or more specifically to sclerites (cuticular plates of the exoskeleton) in the pleura (the groups of cuticular plates making up the sides of the insect) that then attach to the wing base. The base of the wing attaches to the notum and pleuron. The notum (or tergum) is the plate that forms the insect's back and the pleuron its side.

Direct muscles attach to sclerites in the pleura at both ends. There are two paired sets of these muscles: the **basalar** muscles and the **subalar** muscles.

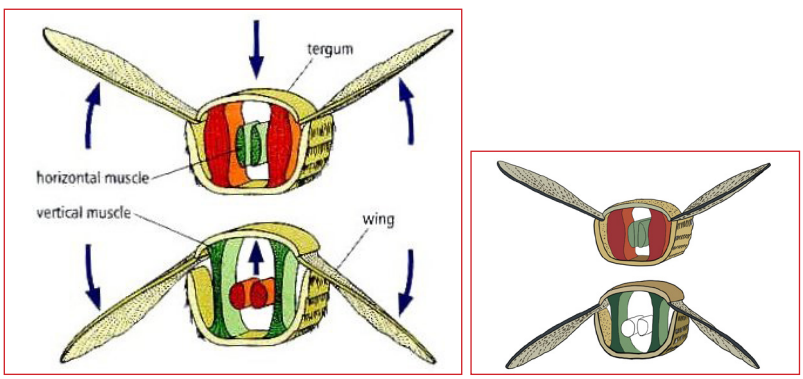


Figure 6.16: Insect wing movement in air.

Power for the wing's **upstroke** is generated by contraction of **dorsal-ventral** muscles (also called **tergosternal muscles**). These are called "indirect flight muscles" because they have no direct contact with the wings. They stretch from the notum to the sternum. When they contract, they pull the notum downward relative to the fulcrum point and force the wing tips up.

During flight, **upstroke** and downstroke muscles must contract in alternating sequence. There are two different mechanisms for controlling this muscle action, synchronous (neurogenic) and asynchronous (myogenic):

i. Insects with **synchronous** control have **neurogenic** flight muscles, meaning that each contraction is triggered by a separate nerve impulse.
ii. Insects with **asynchronous** control depend almost entirely on indirect flight muscles for **upstroke (dorsal-ventrals)** and **downstroke** (**dorsal-longitudinals**). These muscles have developed myogenic properties, that is, they **contract spontaneously** if stretched beyond a certain threshold. When the nervous system sends a start signal, the dorsal-longitudinal and dorsal-ventral muscles begin contracting autonomously, each in response to stretching by the other. Contractions continue until the muscles receive a "stop" signal from the nervous system.

Brief, during the **downstroke**, the tergo-sternal muscles relax as the dorsal longitudinals contract, depressing the wing and generating lift as the wings move forwards and downwards. Basalar muscles contract, as the subalar relax, tilting the leading edge of the wing downwards (to prevent stalling).During the **upstroke**, the dorsal longitudinal muscles relax as the tergo-sternals contract, lowering the notum and raising the wings during the recovering stroke as the wings move backwards and upwards. subalar muscle contract as basalar muscles relax, raising the leading edge of the wing.

Application activity 6.3

1. A winged insect was taken from your environment and its wings were removed. Summarize the effect of this action to the flight of that insect.
2. Relate the downstroke to the flight of insect and birds.

6.4 Comparison of jumping movements of grasshoppers and toads

Activity 6.4

Use a collecting net to catch a grasshopper and toad from school compound. Put them down on cemented ground for observing them very carefully when they make a jump and then answer to the following:

1. Identify and describe anatomic structures that enable grasshoppers to jump.
2. Illustrate how legs' muscles behave when they are resting and or jumping.

a. Hopping locomotion of grasshopper

Insects have a skeleton which is on the outside of the body called an **exoskeleton**. They can walk on the land, but they are mostly adapted to hopping owing to their muscles which are inside the hard shell as well as skeleton system. The muscles which make them capable to move are **flexors** and **extensors** which are **antagonists**, attached to internal surface of exoskeleton and the rear or back legs of a grasshopper which are long and muscular, adapted to hopping. Additionally, there are two main muscles:

i. the extensor tibiae muscle which contracts to extends the leg
ii. the flexor tibiae muscle which contracts to flex the leg.

Those muscles pull on tendons which are attached to the tibia on either side of the joint pivot.

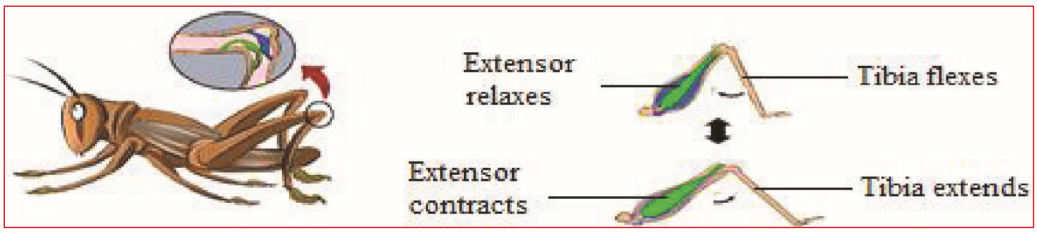


Figure 6.17: Muscles for jumping in grasshopper

As illustrated above, flexor muscles bend a joint whereas extensor ones straighten it. The flexor muscle contracts contracts and the lower leg is pulled towards the body. Thus, the hind leg is folded in a Z shape and ready for jumping. Being in resting or sitting position, the extensor muscle contracts which allow the legs jerk or move very quickly backwards propelling the grasshopper.

i. The hind legs are folded in the shape of Z in the position at rest (flexor muscles contract).
ii. Extensor muscles contract. The legs of the grasshopper jerk backwards.
iii. The grasshopper propels forward and upward into the air.

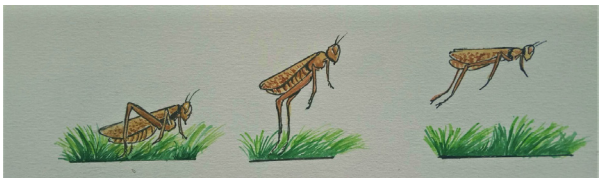


Figure 6.18: Stages of jumping in a grasshopper.

b. Jumping of amphibians

A **B** **C**

Figure 6.19: (a) Frog at rest.b. Walking frog. c. Hopping frog.

On land, frogs and toads move by hopping. When a frog is at rest, the hind legs are folded up in the shape of a letter Z. When it hops, the legs are quickly straightened out, lifting the animal of the ground. The forelimbs are used as shock absorbers on landing and they also prop up (give support) the front end of the body when the animal is at rest.

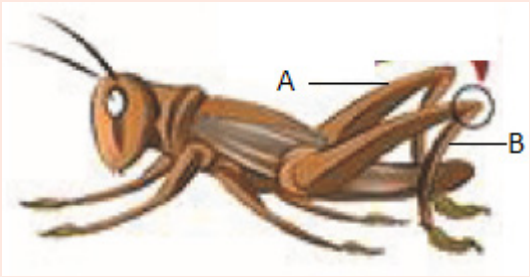
Figure 6.20: Stages of hopping in a frog

Following are the stages of jumping in a frog

i. Long hind legs are folded in the shape of Z when the frog prepares to jump.
ii. Hind legs become straight when the frog jumps.
iii. Forelimbs stretched to outside when the frog prepares to land.

Application activity 6.4

1. Develop a table comparing the hopping of grasshopper and that of the from a toad
2. Observe the following grasshopper and answer the following questions.



Label the structures A and B.

3. Draw a leg of grasshopper and the one of toad when are jumping.

6.5 Types of muscles

Activity 6.5

Aim: Dissection of a frog / toad heart and observation of myogenic contraction.

Materials required

Dissection pan with 4 needles, 20 ml of physiological liquid (Ringer's solution), plastic eyedroppers,

suture needle with thread attached, razor blade, magnifying hand lens, pins, chloroform, cotton wool, frog or toad, bell jar, forceps, glass beaker, gloves, and water.

Procedure :

Dissecting frog heart and observe myogenic contraction.

- Collect a living frog or toad from the nearest swamp
- Prepare 20ml of Ringer's liquid in a glass beaker

- Put the cotton wool imbibed of 10 ml of chloroform in the bell jar
- Put your frog in the bell jar for 5 minutes, then remove it
- Lay your frog dorsally and fix its four limbs with pins on the dissection dish
- Carry out the longitudinal section from the abdomen to the chest using surgical blade (razor blade) or scissor.
- Locate the pumping heart between the two lungs
- Use the suture needle with thread attached to tie blood vessels connected to heart
- Using the forceps and the surgical blade, remove gently the beating heart and put it in the beaker containing the Ringer's liquid
- Write down your observation in the next 5 minutes.
- Wash your hand after experiment.

4. Use models or computer aided simulations to observe the relationship between muscles, joints and musculo-skeletal attachments of the antagonistic muscles of fish, birds, frogs and rabbits.

There are 3 types of muscle: skeletal, smooth, and cardiac.

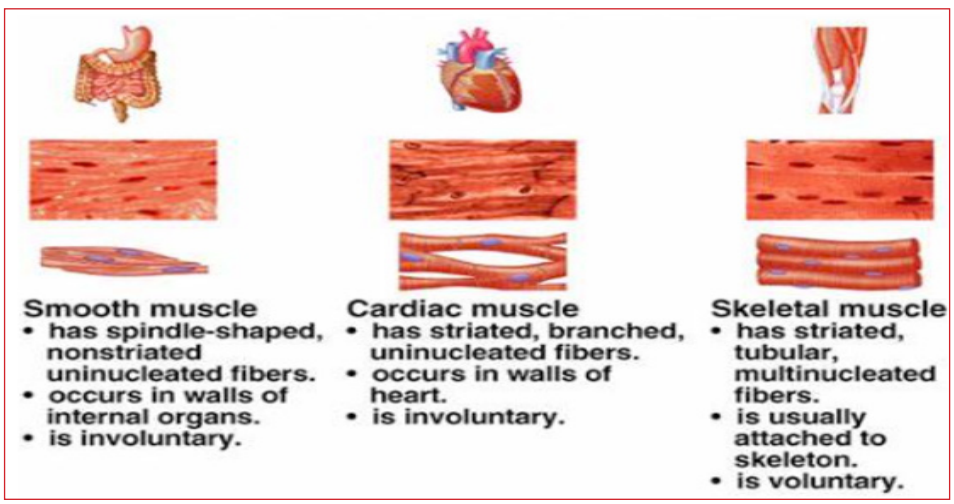


Figure 6.21: Structure of three types of muscles (New)

a. Skeletal muscle

Skeletal muscle, as its name implies, is the muscle attached to the skeleton. It is also called striated muscle. The contraction of skeletal muscle is under voluntary control. These muscles are mainly responsible for movement of the body. Other purposes are posture maintenance, support of the joints, and heat production. While its contraction is fast and strong, skeletal muscle tires easily.

Antagonistic skeletal muscles

Antagonistic muscles are pairs of muscles. The action of one member is opposite to that of the other member. Muscles can contract but they do not have the ability to lengthen (stretch) themselves. They are arranged in pairs such that after one muscle or muscle group contracts, a skeleton transfer the movement to stretch another muscle or muscle group. The pairs of muscles that stretch each other are said to be antagonistic.

The biceps and triceps muscles of the arm are an example of an antagonistic pair. Contraction of the biceps moves the arm toward the body and stretches the triceps. Contraction of the triceps extends the arm and stretches the biceps. In this example the bicep is said to be the flexor while the triceps is the extensor. Extensors are not as strong as flexors.

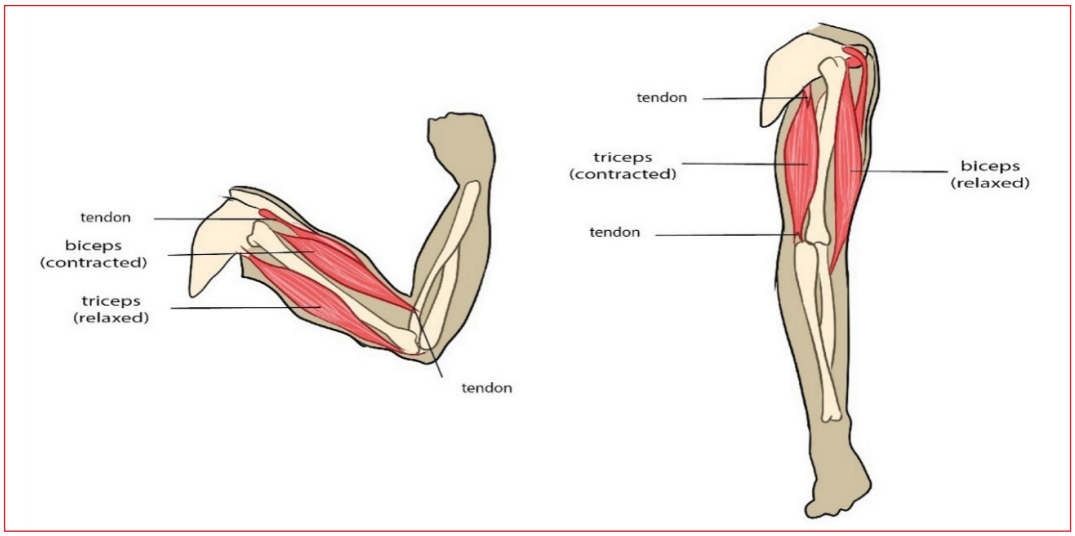


Figure 6.22: Antagonistic skeletal muscles

b. Smooth muscle

Smooth muscle is found in the walls of all the hollow organs of the body (except the heart). Its contraction reduces the size of these structures.Thus it regulates the flow of blood in the arteries, moves your breakfast along through your gastrointestinal tract, expels urine from your urinary bladder, sends babies out into the world from the uterus, and regulates the flow of air through the lungs. The contraction of smooth muscle is not under voluntary control. It is called involuntary muscle. It contracts slowly and is slow to tire.

c. Cardiac muscle

Your heart is made of cardiac muscle. This type of muscle only exists in your heart. Unlike other types of muscle, cardiac muscle never gets tired. It works

automatically and constantly without ever pausing to rest. Cardiac muscle contracts to squeeze blood out of your heart and relaxes to fill your heart with blood.

Application activity 6.5

1. Observe the following muscles and answer the following questions

Identify the muscles X and Z.

2. A nerve impulse moves from the central nervous system via the motor neuron and causes the muscle contraction. Link this contraction to the properties of this muscle.

6.6 Ultrastructure and functioning of striated muscle

Activity 6.6: Research Activity

1. Use the books from the school library and search information from about the ultrastructure and functioning of striated muscle.
2. Observe other biceps muscles and write your observations (shortening and thickening of the antagonistic muscles).
3. Research, using internet and library books, the structure of the motor end plate.
4. Use of computer aided simulations to demonstrate the structure and functioning of the sarcomere during muscle contraction with reference to sliding filament theory.
5. Use computer aided simulations to demonstrate the laws of muscle contraction (all or nothing, temporal summation and muscle fibre recruitment).

6.6.1 Ultrastructure of striated muscle

The striated appearance of skeletal muscle fibres arises due to the organization of two contractile proteins or myofilaments (actin filaments and myosin).

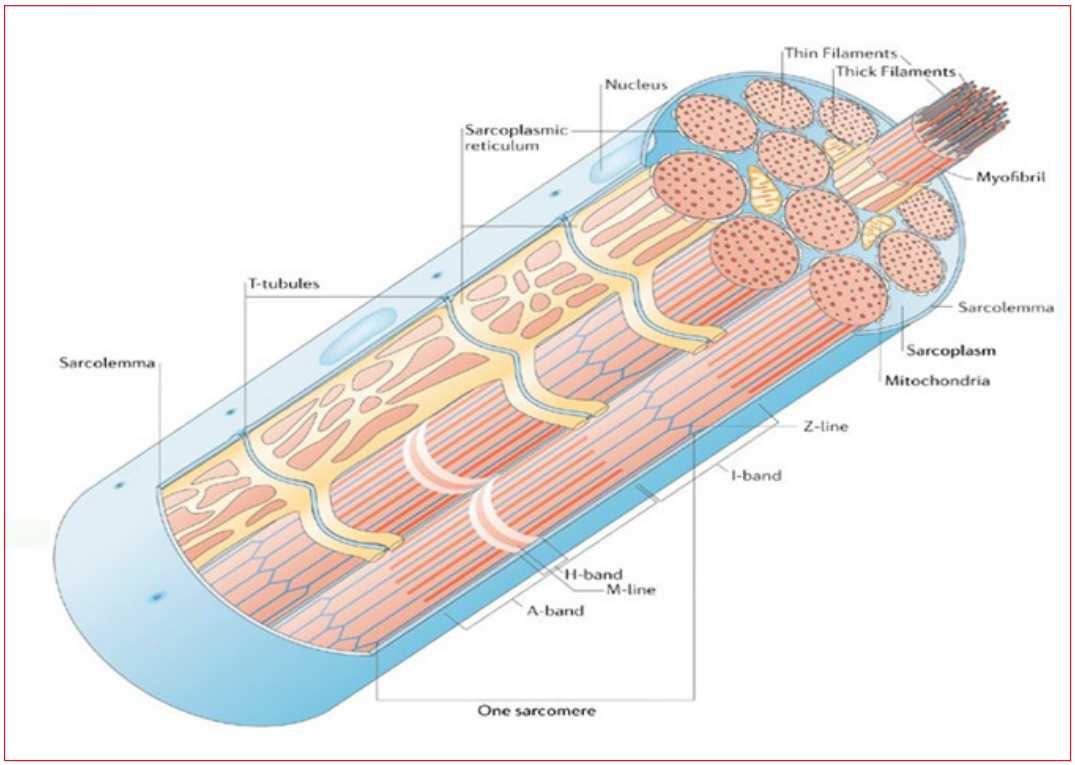


Figure 6.23: Diagram of a muscle cell (muscle fibre)

The functional unit of contraction in a skeletal muscle fibre is the sarcomere, which runs from Z line to Z line. A sarcomere is broken down into a number of sections:

- **Z** line – Where the actin filaments are anchored.
- **M** line – Where the myosin filaments are anchored.
- **I** band – Contains only actin filaments.
- **A** band – The length of a myosin filament, may contain overlapping actin filaments.
- **H** zone – Contains only myosin filaments.

A useful acronym is **MHAZI** – the M line is inside the H zone which is inside the A band, whilst the Z line is inside the I band.

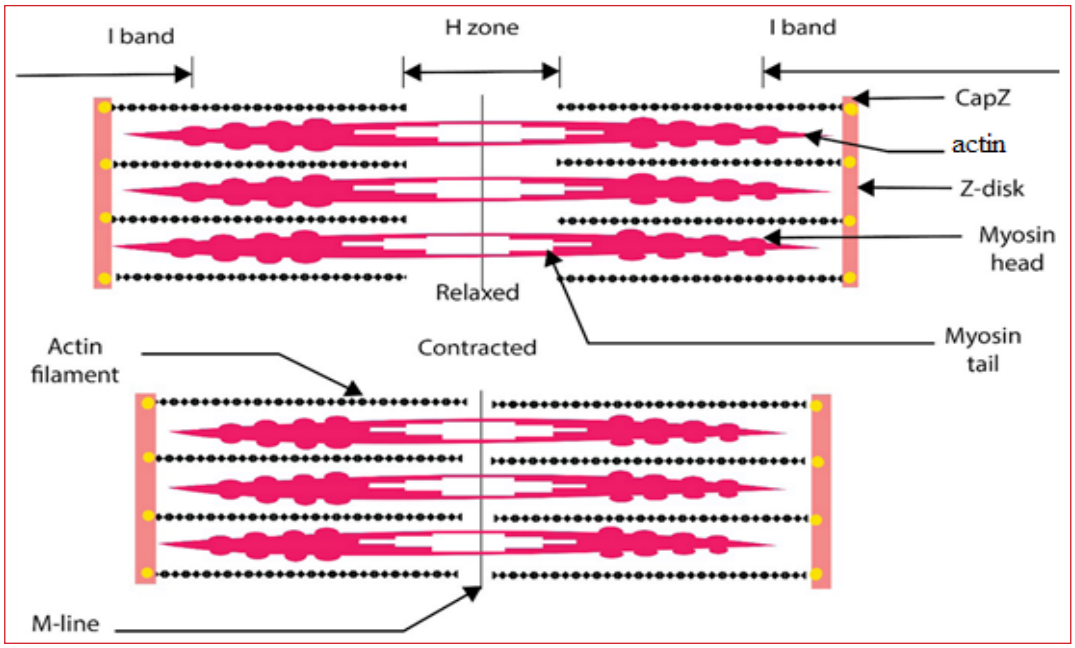


Figure 6.24: Sarcomere in contraction and relaxation

Based on their fibrous and dense tissues, their main function of striated muscles is movement through continuous contraction and relaxation. These muscles also help in; maintaining posture, stabilizing skeletal joints and producing body heat.

6.6.2 Functioning of striated muscle in contraction and relaxation

The excitability or the power of responding to an adequate stimulus is an innate property of the muscle. When a brief stimulus is given, the muscle contracts and this is followed by a wave of relaxation. This phenomenon is called a muscle twitch.

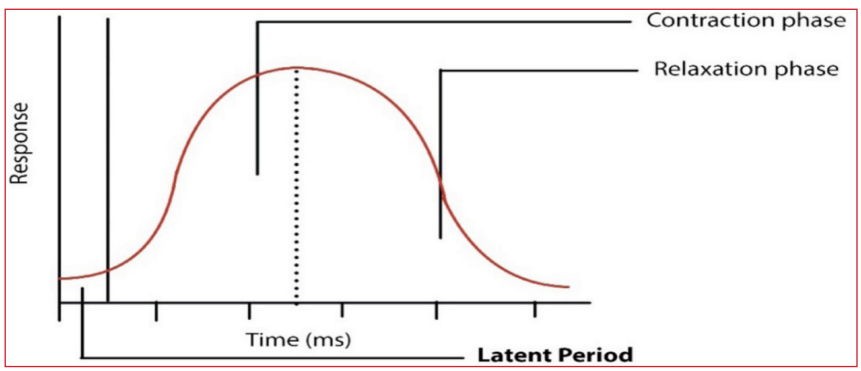


Figure 6.25: Muscle twitch

The Figure 11.21 shows a typical muscle curve of a skeletal muscle in response to single stimulation. The muscle curve can be recorded with the help of a kymograph. The curve indicates three phases: the latent phase, the contraction phase and the relaxation phase. The period between the stimulus and beginning of contraction is called the latent phase which lasts for about 0.01second. During this period chemical changes take place as a result of the stimulus. Latent period is required for traversing the excitation along the nerve and the neuromuscular junctions. The duration of the latent period varies with the species and depends on the type of muscle, temperature and condition of the muscle.

The contraction phase during which the muscle actually contracts lasts for about 0.04 second incase of frog muscle. Shortening of the muscle takes place due to chemical events which will be described in some details later. The third phase or the relaxation phase lasts for about 0.05 sec. The total time taken by a single muscle contraction is about 0.1 sec which varies with the temperature.

At low temperature contractions are prolonged, whereas with rising temperature the duration of contractions becomes shorter.

a. Muscle twitch, summation, and tetanus

A single action potential to the muscle fiber of a motor unit produces a muscle twitch, a rapid and succession of two or more action potentials is termed summation. At high stimulation frequencies, the overlapping twitches sum to one strong, steady contraction called tetanus.

If the impulses are applied to a muscle in rapid succession through several motor units, one twitch will not have completely ended before the next begins. Since the muscle is already in a partially contracted state when the second twitch begins, the degree of muscle shortening in the second contraction will be slightly greater than the shortening that occurs with a single twitch. There are two types of twitch which are slow-twitch muscles and fast-twitch fibers.

- Slow-twitch are slower-contracting fibers but they are very efficient at using oxygen to create energy without lactic acid build-up. These fibers are used for high-endurance events like marathons.
- Fast-twitch fibers are white fibers, that contract very quickly making them very strong and explosive but they also tire out very easily. The additional shortening due to the rapid succession of two or more action potentials is termed summation. At high stimulation frequencies, the overlapping twitches sum to one strong, steady contraction called tetanus.

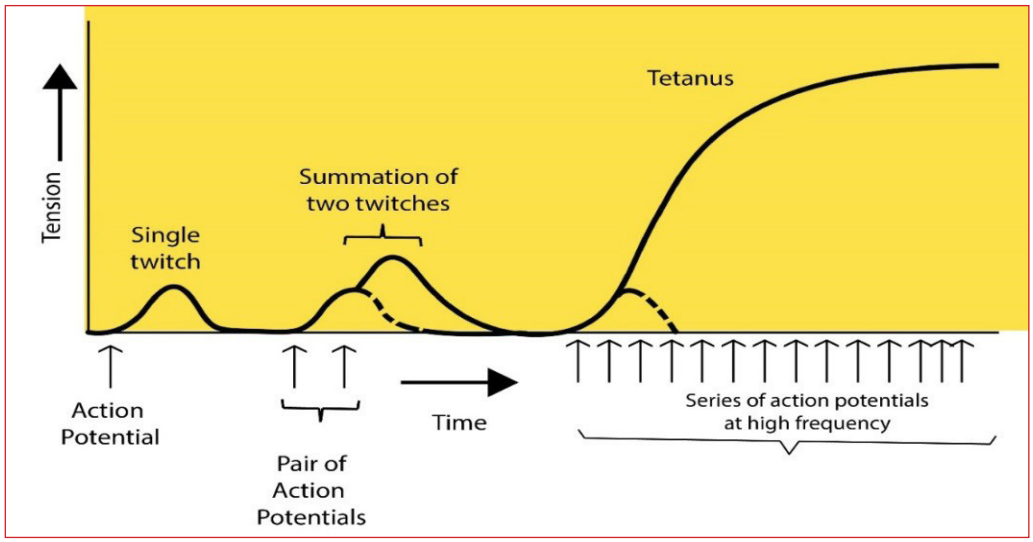


Figure 6.26: Patterns of muscle twitch, summation and tetanus

This figure compares the tension developed in a muscle fiber in response to a single action potential in a motor neuron, a pair of action potentials, and a series of action potentials. The dashed lines show the tension that would have developed if only the first action potential had occurred. Motor unit recruitment refers to the activation of additional motor units to accomplish an increase in contractile strength in a muscle. A motor unit consists of one motor neuron and all of the muscle fibers it stimulates.

b. Tetanic contractions

During normal activity such as locomotion, muscular contractions are not merely twitches lasting for a second or a fraction of it. They are sustained for a longer period during continued activity and exhibit compound or tetanic contractions.

This can be experimentally demonstrated by applying a number of stimuli to a muscle-nerve preparation in rapid succession with little interval between successive stimuli, the resulting contractions tend to fuse to give a maximum contraction. This sustained contraction is called complete tetanus which, however, varies with the kind of muscle and its condition.

If repetitive stimuli are applied to muscle with long periods of interval, the individual contractions can be seen because of little relaxation. This condition is known as incomplete tetanus.

More interesting information is available about the tetanus. When a muscle is in tetany, a musical note is produced by it which can be heard with the help of a stethoscope. The pitch of the note is indicative of the vibrations that are produced at a rate corresponding to the rate of application of stimuli. Most of the voluntary contractions are of tetanus types which are produced by a series of nerve impulses arriving in the muscle from the central nervous system.

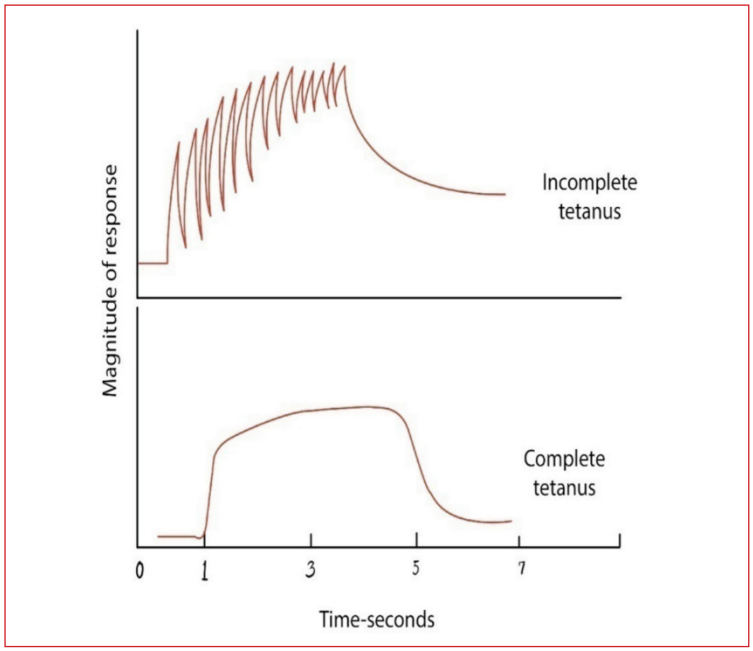


Figure 6.27: Diagram showing the condition of tetanus

6.6.3. Neuromuscular junction

This is a special kind of synapse where a motor nerve and muscle tissue meet. The membrane of the muscle fiber, the sarcolemma is very folded in this region and forms a structure known as an end plate. Electron microscopy shows us that the structure of the neuromuscular junction is remarkably similar to that of any other synapses.

The end of the motor nerve is full of mitochondria and synaptic vesicles which contain acetylcholine/neurotransmitter substances.

It appears that when an impulse arrives at the end of the motor neuron, it increases permeability of the pre-synaptic membrane to calcium ions in the synaptic cleft. The electrical impulse gets changed into a chemical message and gets stored into the synaptic vesicles. The calcium ions then push the vesicles to fuse with the presynaptic membrane thus discharging their neurotransmitter substances by exocytosis. The neurotransmitter then diffuses through the

synaptic cleft and get attached onto receptor sites on the sarcolemma. This causes the sodium gated channels to open thus causing a generator potential to be setup in the sarcolemma. If it reaches the threshold, an impulse is fired into the muscle fiber.

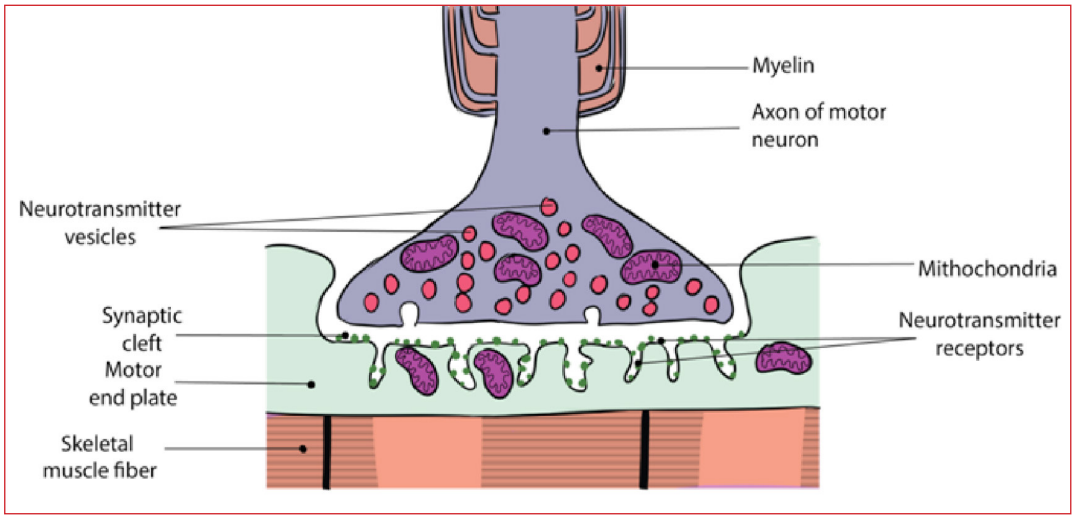


Figure 6.28: Neuromuscular junction

6.6.4. Laws of muscle contraction

The **all-or-none law** is the principle that the strength by which a nerve or muscle fibre responds to a stimulus is independent of the strength of the stimulus. If that stimulus exceeds the threshold potential, the nerve or muscle fibre will give a complete response; otherwise, there is no response. It was first established by the American physiologist **Henry Pickering Bowditch** in 1871 for the contraction of heart muscle.

A muscle contraction occurs when a muscle fiber generates tension through the movement of actin and myosin. The **sarcomere** is the functional unit of muscle contraction; it reaches from one Z-line to the next. In a relaxed muscle, the actin (thin filament) and myosin (thick filament) overlap.

In a muscle contraction, the filaments slide past each other, shortening the sarcomere. This model of contraction is called the **sliding filament mechanism**. **Sliding filament theory** states that " the actin filaments slide past myosin filaments because myosin filaments have cross-bridges that pull actin filaments inward, toward their Z line".

Table 6.1: Main components used in muscle contraction

No	Name	Function
1	Actin filaments	Slide past myosin , causing contraction .
2	Ca2+	Needed for myosin to bind to actin
3	Myosin filaments	Pull actin filaments by means of cross-bridges; are enzymatic and split ATP
4	ATP	Supplies energy for muscle contraction

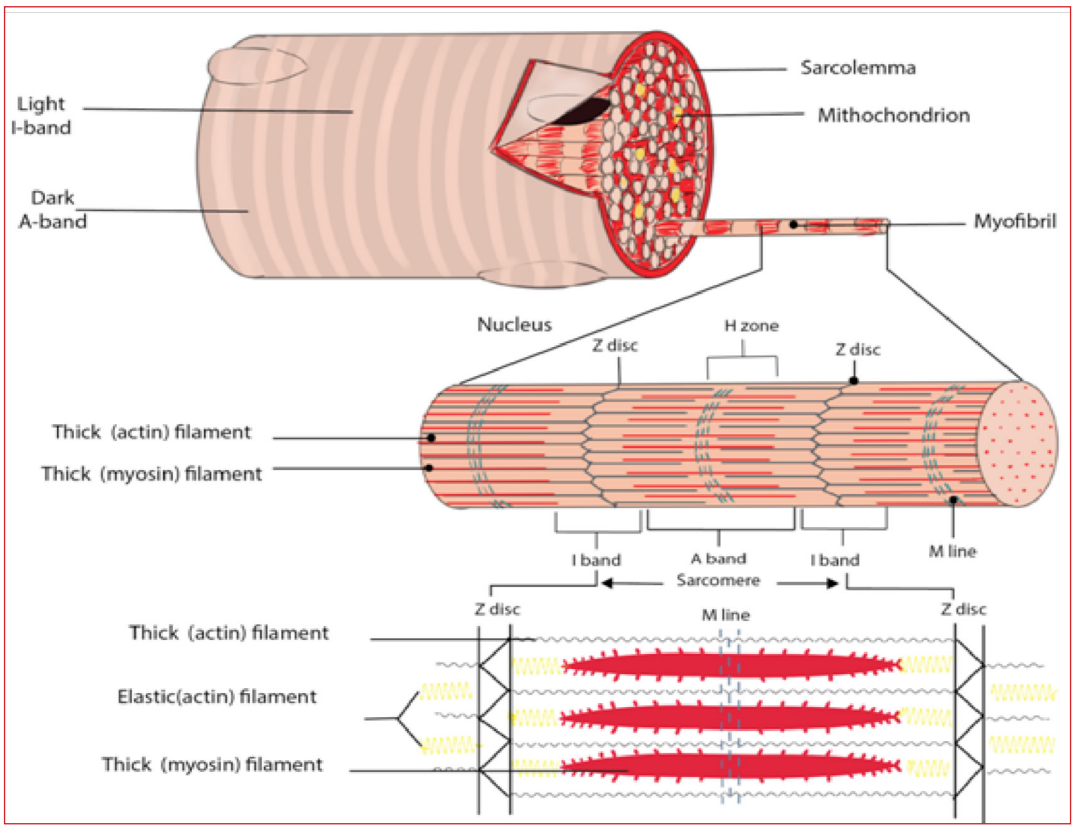


Figure 6.29: Sarcomere

Each muscle fiber contains cellular proteins and hundreds or thousands of myofibrils. Each myofibril is a long, cylindrical organelle that is made up of two types of protein filaments: actin and myosin. The actin filament is thin and threadlike; the thin actin filaments are anchored to structures called Z lines. The region from one Z line to the next makes up one sarcomere and the myosin filament is thicker. Myosin has a head region that uses energy from ATP to walk along the actin thin filament.

The overlapping arrangement of actin and myosin filaments gives skeletal muscle its striated appearance. When each end of the myosin thick filament moves along the actin filament, the two actin filaments at opposite sides of the sarcomere are drawn closer together and the sarcomere shortens. When a muscle fiber contracts, all sarcomeres contract at the same time, which pulls on the fiber ends.

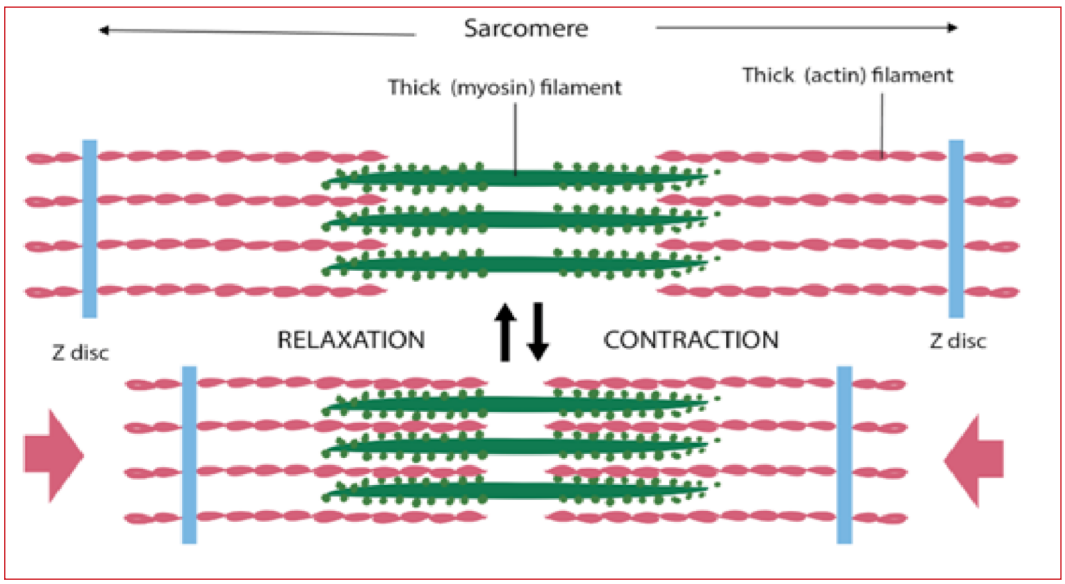


Figure 6.30: Muscle contraction

When each end of the myosin thick filament moves along the actin filament, the two actin filaments at opposite sides of the sarcomere are drawn closer together and the sarcomere shortens. In the contacted sarcomere, the A bands do not change in length, but the I bands shorten and the H zone disappears. This behaviour can be explained by the sliding filament model of muscle contraction.

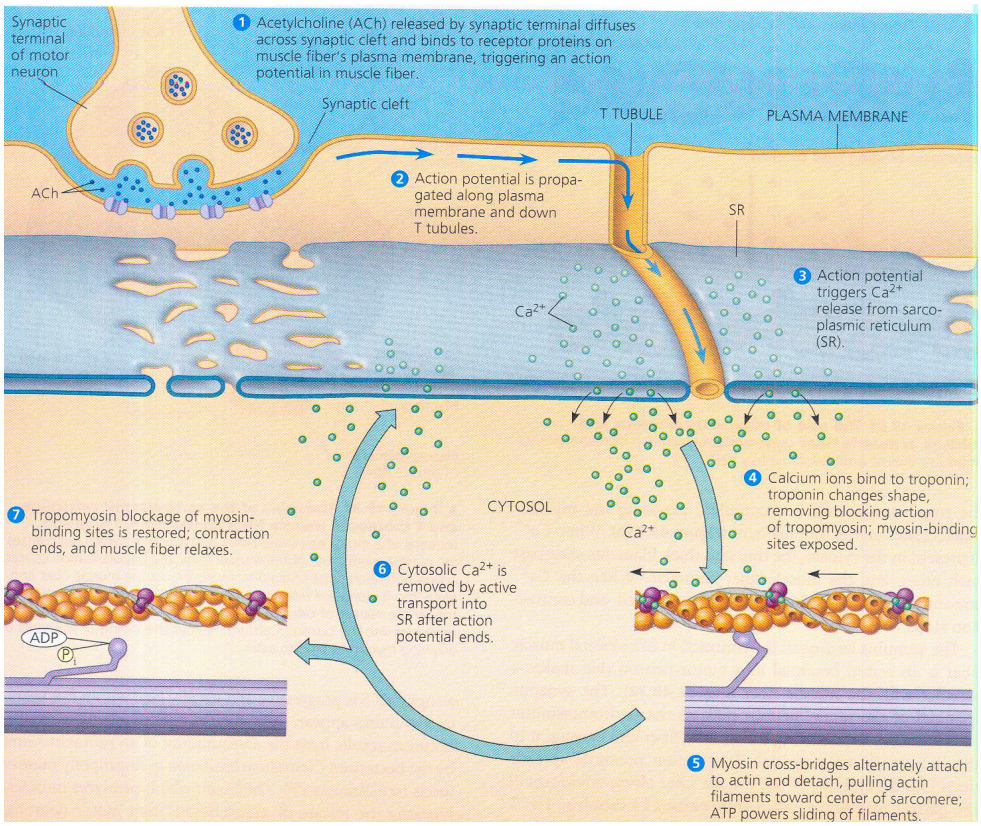


Figure 6.31: Nervous control of muscle contraction.

Stages of voluntary muscle contraction under control of the nervous system:

1. A nerve impulse (action potential or wave of depolarization) travelling along the motor neuron reaches the motor end plate.
2. Acetylcholine (Ach) is released into the synaptic cleft at the end plate, diffusing to the sarcolemma, and combines with the receptor sites (receptor proteins) of the muscle fiber.
3. When the threshold value of the generator potential is reached, an action potential is created in the muscle fiber. (Ach in the cleft region is then hydrolyzed and then the products i.e. acetic acid and choline are reabsorbed into the motor end plate).
4. The action potential is conducted to all microfibrils of the muscle fiber by the system of the transverse tubules (T tubules), and spread to the sarcoplasmic reticulum throughout the muscle fiber.
5. Calcium ions (Ca2+) are released from the sarcoplasmic reticulum and bind to the blocking molecules of the actin filament, exposing the binding sites (ATP is involved in this movement).

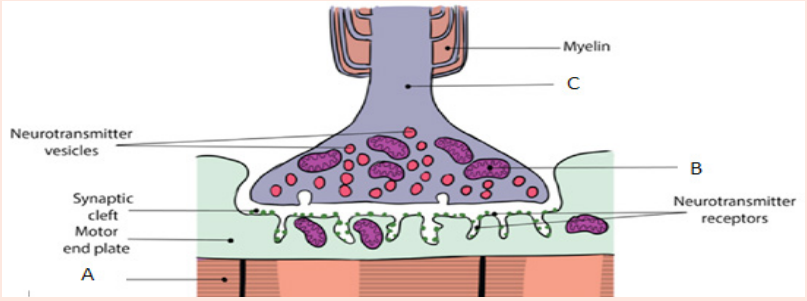
6. The 'heads' of the cross-bridging myosin molecules attach to the newly exposed binding sites on the actin filaments. Release of energy by ATP hydrolysis accompanies cross-bridge formation.
7. As a result, the shape of the myosin bridge changes. The 'bending' or 'rowing' action results. This is the power stroke. The fin filaments (actin molecules) are moved towards the center of the sarcomeres, producing muscle cell contraction.
8. Fresh ATP attaches to the myosin head, releasing it from the binding site, and causing the cross-bridge myosin to straighten (it becomes 'cocked' for repeated movement).
9. Myosin heads become attached further along the actin chain and repeats the movement sequence (referred to as a 'ratchet mechanism').
10. When nervous stimulation of the sarcomere ceases, calcium ions are rapidly pumped back into the sarcoplasmic reticulum, and the calcium ions concentration falls below the threshold for contraction activity. The binding sites on the actin filaments are blocked again.

How motor unit summation develops muscle tension

A skeletal muscle is an organ composed of multiple muscle cells or fibers, just like any organ is made up of a whole bunch of cells. These fibers are arranged in motor units, each of which is composed of a single motor neuron and all the muscle fibers that that motor neuron innervates. Each motor unit contracts in an **all-or-none fashion**. In other words, if the motor neuron is excited, it will stimulate all of the muscle fibers to contract - that is, all of the muscle fibers within that particular motor unit.

Application activity 6.6

1. You are provided with the following neuromuscular junction.

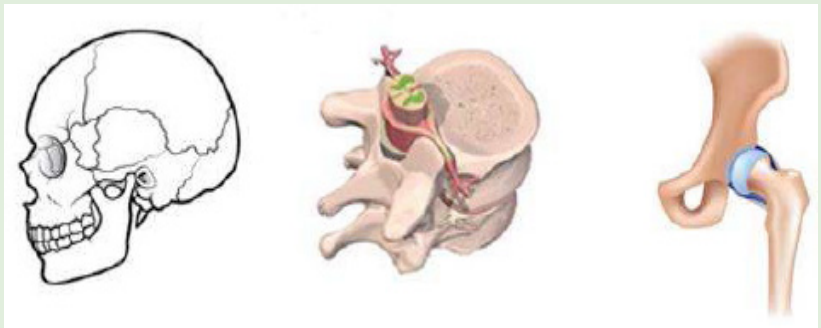


   a. Identify the structures A, B and C.
   b. Summarize the functions of B and C.
2. Draw a well labeled diagram of sliding filament model of muscular contraction

6.7 Types of joints

ACTIVITY 6.7

Discuss the following types of joints. Present your findings.



A joint is the junction between two or more bones. There are three major types of joints:

6.6.1 Immovable or fused joints or sutures

These joints include the skull, sacrum, pelvis, and coccyx. As the name suggests, these joints are points where joints fuse or grow together. The place where they grow together is called the suture. These joints provide strength, support, and protection.

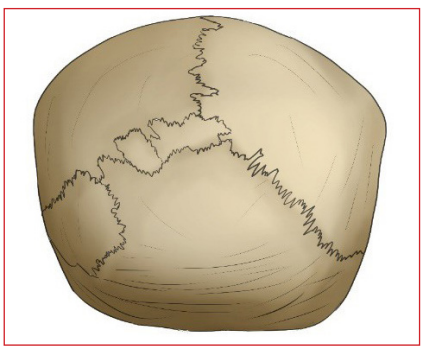


Figure 6.32: Fused joint

6.6.2 Slightly moveable joints

These joints are located between the vertebrae of the upper spine. There is cartilage within the joints. They help pad and protect the bones. The bones are held together by ligaments. The ligaments are tightly bound and limit the movement of the bones. This protects the spinal cord.

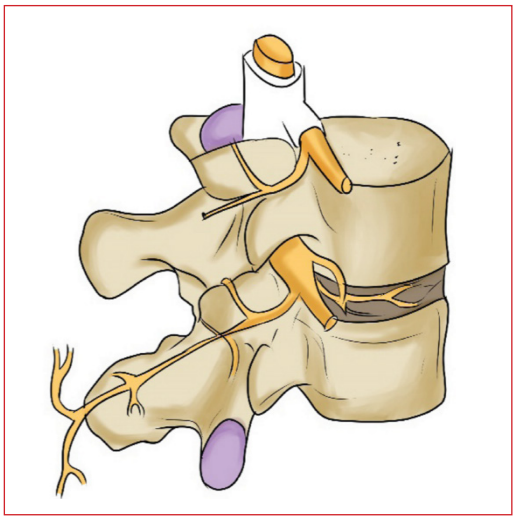


Figure 6.33: Sightly moveable joint

6.6.3 Freely moveable or synovial joints

At these joints the ends of the bones are covered with cartilage and there is a cavity that separates the bones. The bones are held in place by ligaments which stop the bones from moving too much. In addition to the ligaments the two bones are joined together by sleeve-like capsule. The capsule encloses the synovial cavity. The outer layer of the capsule is composed of ligaments. The inner layer of the capsule is the synovial membrane. The synovial membrane secretes the lubricating synovial fluid.

Lubrication is essential to prevent frictional wear and tear. The cartilage at the contact ends of the bones also reduces friction. The cartilage pads also act as shock absorbers against mechanical damage.

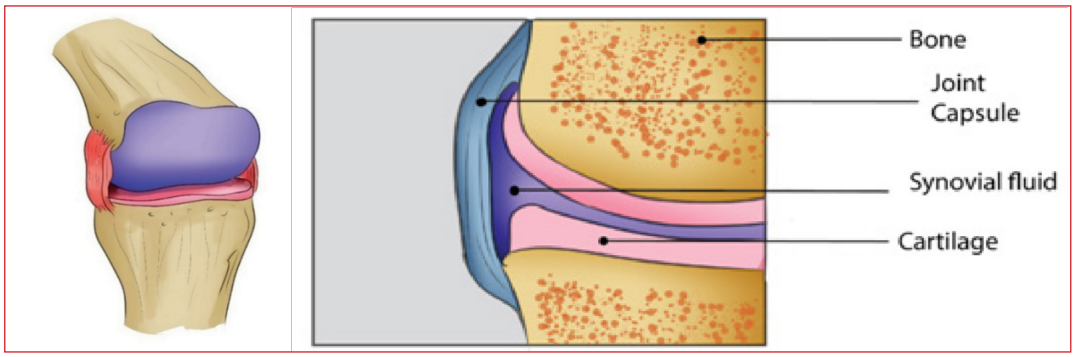


Figure 6.34: Synovial joint

There are four classes of synovial joints

i. **Gliding**: The bones of these joints move across each other, back-and-forth and side-to-side. Examples are between the carpals of the wrist and tarsals of the ankle.

ii. **Pivot**: These joints allow a turning movement. Examples are between the first and second vertebras when turning the head, between the ulna and the radius of the lower arm when turning the palm of the hand up or down.

iii. **Hinge**: These joints allow movement in one plane during flexion and extension. They act, as the name implies, like the hinge of a door. Examples are bending the elbow or knee.

iv. **Ball and Socket**: This type of joint permits movement in three planes, i.e., in all directions. Examples are the shoulder and hip joints.

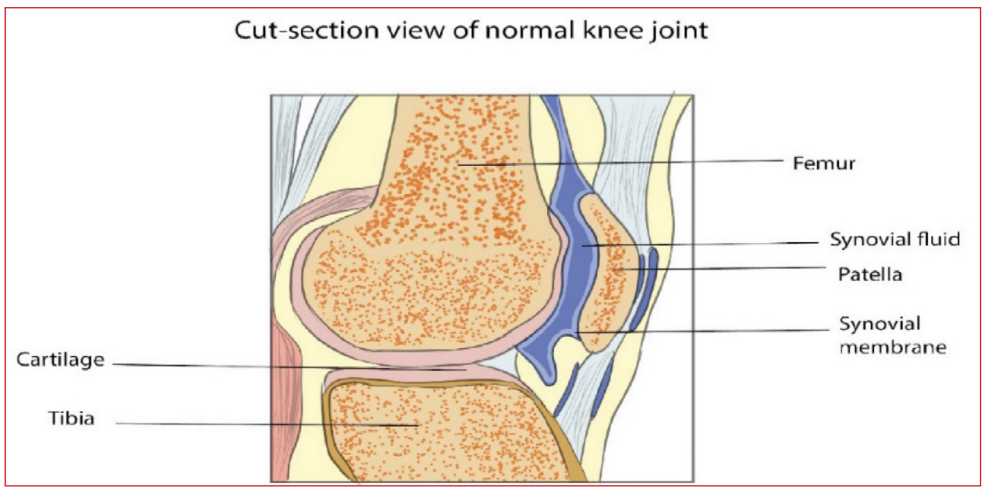


Figure 6.35: Cut-section view of normal knee joint

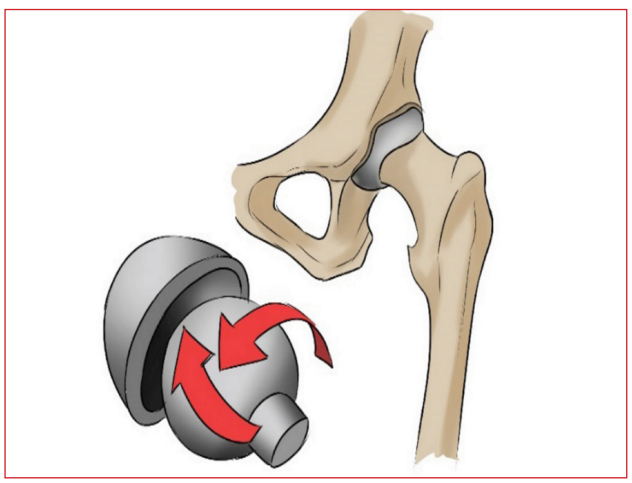


Figure 6.36: Ball and Socket joint

Table 6.2: Summary of the types of joints

Type of joint	General characteristics	Examples	Function
1. immovable /suture joint/fixed/ fused joint.	A thin layer of fibrous connective tissue exists between the bones ,holding them firmly in the position	-Between bones of skull; -between sacrum and ilia of the pelvic girdle -between bones of pelvic girdle.	Provides strength and support for the body ,or protection of delicate structures (such as brain)which cannot withstand any kind of deformation.
2. partially movable joint :			
a) gliding joint	Bones are separated from each other by cartilaginous pads (pieces)	-Joints between vertebrae -wrist and ankle bones.	-Bones glide/ slide over each other to a limited extent. - Collectively they provide a wide range of movement and confer strength on the limb.
b) swivel/ rotating/ pivot joint	Bones are separated from each other by cartilaginous pads	Joint between atlas and axis vertebrae	Permits shaking of head from side to side.
3. Freely movable / synovial joint:			

a) hinge joint	- Articulating bone surfaces are covered with cartilage and separated from each other by a synovial cavity containing synovial fluid. -relatively few muscles operate this joint.	Elbow, knee and finger joints	-Permits movements in one plane. -Capable of bearing heavy loads.
ball -and – sockets joint	- Articulating bone surfaces are covered with cartilage and separated from each other by a synovial cavity containing synovial fluid secreted by synovial membrane. -Variety of muscles attached to the bones of the joints	Shoulder and hip joint	-Permits movement in all planes, and some rotation rotation. -unable to bear very heavy loads.

Application activity 6.7

1. Associate the terms of column A and B

Column A	Column B
1. Immovable /suture joint/ fixed/fused joint	a. Elbow, knee and finger joints
2. Gliding joint	b. Between bones of skull
3. Hinge joint	c. Joints between vertebrae

Skills lab 6

Aim: To get money and biological skills from bred fish.

Materials : pond, male fish, small capital, fish dissecting kit.

Procedure

As a student teacher, you have got a lot of information about fish locomotion. Do the following activities for getting more skills and money:

1. In one of fields of your family or school, make a fish pond.
2. Use a tube or make a canal on land using a hoe to orient water in that pond.
3. Request or buy living fishes from other person's pond and place them in your pond.
4. Place different fish nutrients in your pond.your pond.
5. After those fish reproduction, take some of them and do the following practicals for becoming more skilled:

a. Place one of those fishes in a container such as a bucket, observe carefully the fish structure and locomotion and write a comprehensive account about them.

b. Dissect one of those fishes to identify all internal fish organs such as swimbladder contributing to their locomotion .

c. Sell some of those fishes to get money.

Portfolio Report

i. Write your skills lab project implementation report focusing on how this skill lab has helped you to generate money and new biological skills, submit it to your teacher.

ii. Bring a product (bred fish) and present it to the whole class.

End unit assessment 6

1. What is the basic reason for the fact that animals show locomotion whereas plants do not?
2. Briefly explain the role of each of the following in a mammalian locomotion:
   a. Bones
   b. Joints
   c. muscles
3. What is meant by endoskeleton?
4. Outline the main functions of the endoskeleton.
5. Explain the various types synovial of joints.
6. In relation to antagonistic muscles, explain how it is possible to lift and lower an object with your hands.
7. Outline the functions of fused joints and give an example.
8. What are the functions of muscle tissue?
9. What is the meaning of MHAZI in skeletal muscle fibres?
10. Explain what happened in refractory period in the sliding filament theory of muscle contraction.
11. Explain what happened when motor impulse reaches the end plate, the vesicles release acetylcholine into the synaptic cleft of the end plate.
12. Draw a well labeled diagram of human skeleton.
13. Describe ways of locomotion in Amoeba, Paramecium, Euglena and in Trypanosoma
14. Produce a cartoon showing different adaptive features of fish for aquatic locomotion.

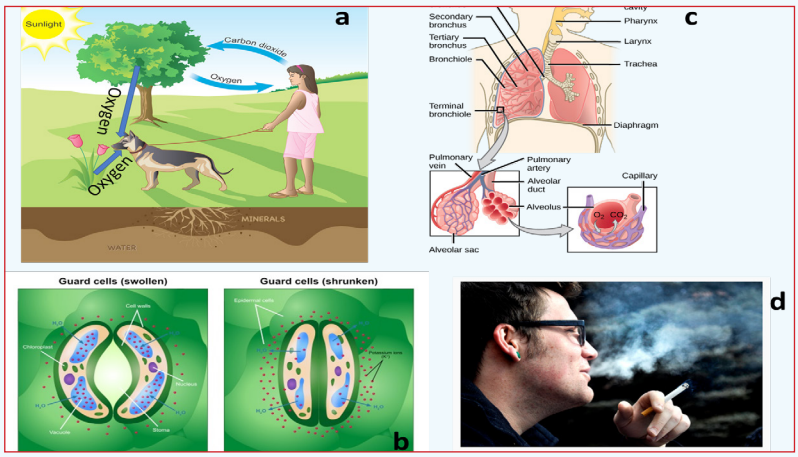
UNIT 7

GAS EXCHANGE IN PLANTS, ANIMALS AND THE EFFECTS OF SMOKING

Key unit competence : Describe structures of gaseous exchange organs in plants, respiratory organs in different groups of animals and the effects of tobacco smoking on the gas exchange system.

Introductory activity 7

Observe the following images and answer the following questions.



1. According to your observation, what is happening to each living organism?
2. What are the types of gas the dog is giving out?
3. Suggest the possible consequences undergone by that man who smokes.
4. Which structure are used by the plants in the process?
5. Discover the adaptations of that plant that enable the observed process to take place.
6. You are inhaling and exhaling air as shown on the figure c. Search and find the description of the pathway through which that air is passing in your body.

7.1 Gas exchange in animals and plants

Gas ehange is the one of the most impartant parts of a living orhanism in daily routine. This process is essential as it keeps that organism alive. During this process the waste product like **carbon dioxide** is replaced by **oxygen** for cellular repsitration that has been absorbed from the air through breathing and in plants the by-product of photosynthesis, oxygen is released into the air and replaced with carbon dioxide which is an essential ingredient for photosynthesis by **stomata**. Gas exchange is also responsible for the producing mainly oxygen as well a carbon dioxide in the air. Both plants and animals; meaning all living organisms do a form of gas exchange organs, **lungs** in "mammal, reptiles, birds and adult amphibians", **gills** in fish and **tracheae** in inects. All organ for gas exchange must be kept moit by the body to be able to function. These organs differ from one another but all do essentially the same thing; they receive the carbon dioxide from the blood and release it into the air and gather oygen from the air and supply it into the blood.

7.1.1 Gas exchange in plants

Like animals, plants have breathing surfaces that are "moist, thin, cover a large surface area" and have air space in them for the gaseous diffusion to take place. Unlike animals, most the plants have very similar breathing areas and techniques and breathe in carbon dioxide and breathe out oxygen. The surface where the majority of gas exchange take plance are usually **plants leaves** but it can also take place in other parts like **stem**, **roots** and **root hairs**. Plants breath through pores in their leaves called **stomata** (**in** singular **stoma**).

A. Structure of stoma and theories used to explain the mechanism of opening and closure of stomata

Activity 7.1

Aim: Observation of the stomata under a light microscope

Requirements

Light microscope, glass slide, cover slip, Commelina zebrine leaves, razor blade, forceps, Pasteur dropper and iodine solution.

Procedure

i. Identify Commelina zebrina or commelina tradescantia plant nearby the school. You can also use any other monocotyledonous plant with succulent leaves.

ii. Remove a leaf from a plant. Then peel off gently the lower epidermis. It must be thin enough to allow light to pass through

iii. Smear the epidermis on a slide containing one drop of dilute iodine solution.

iv. Put on a cover slip and then observe under the lower and medium magnification.

v. Repeat the observation in morning hours and in the afternoon hours.

Questions

1. Why should the sample used in the preparation must be transparent?
2. Draw and label structures observed under light microscope.

II. Describe the theories used to explain the opening and closure of stomata present your findings in class.

a. Structure of the stoma

Stomata (stoma in singular) are microscopic pores in epidermis of the leaves and stems of terrestrial plants.

They function in gas exchange between plant and the atmosphere and in transpiration.

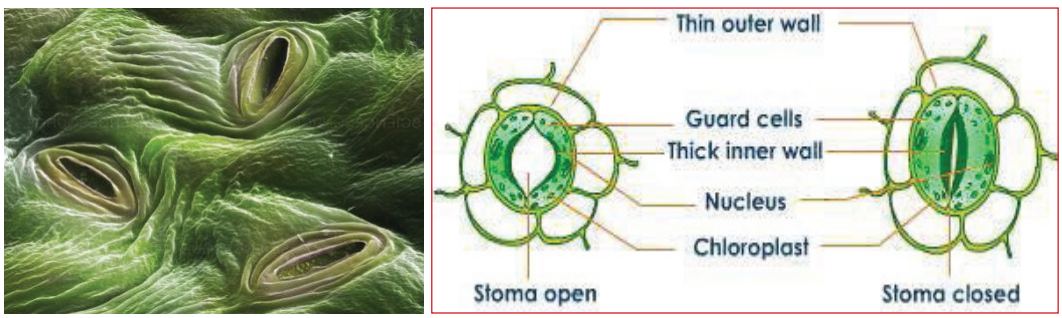


Figure 7. 1: Scanned Electron Micrograph (left) and structure of stomata (right)

Each stoma is bordered by two saucer shaped cells called guard cells, which are specialized epidermis cells whose movements control the size of the aperture (pore). Unlike other epidermis cells, guard cells have kidney shape and have many chloroplasts. Their inner cell wall is thick and less elastic while the outer cell wall is thin and more elastic. Guard cells shrink when the plant has too little

water. This closes the stomata. When the plant has enough water, the guard cells swell up again. This opens the stomata. In this way, the guard cells enable gaseous exchange. Oxygen in the atmosphere diffuses through the stomata into the air spaces betweenthe cells of the spongy mesophyll tissue while carbon dioxide diffuses through the stomata out to the atmosphere.

b. Theories used to explain the mechanism of opening and closure of stomata

Many theories have been proposed regarding opening and closing of stomata. The four important theories of stomatal movement are the following:

i. Theory of photosynthesis in guard cells
ii. Theory of starch sugar inter-conversion
iii. Theory of glycolate metabolism and
iv. Theory of active potassium pump.

The combined outcome of the four theories shows that in general stomata open during the day (light) and close during the night (dark). But how does this happen? In light, guard cells are stimulated. They absorb K+ ions from the neighboring cells. K+ ions make the guard cells more permeable to CO2. As the guard cells perform photosynthesis, the concentration of CO2 falls and the pH rises.

Elaborated starch therefore splits into malate. The high concentration of malate and the rise of pH in guard cells develop a decrease in water potential. Hence, the guard cells withdraw water from the neighbouring cells and extend backward leaving an open pore in between whereby water is lost by evaporation.

During the night, there is no light to stimulate neither the absorption of K+ ions nor the photosynthesis. Guard cells undergo cell respiration using photosynthetic products as source of energy (carbohydrates: malate, glucose). Therefore, the concentration of malate decreases making the guard cells hypotonic than neighbouring cells. As guard-cells lose their water content, they shrive and the pore in between closes. Stomatal transpiration ceases

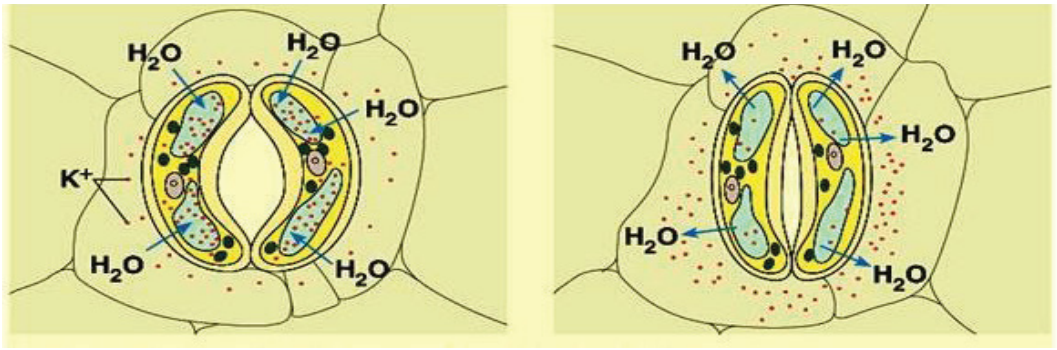


Figure 7.2: Ionic mechanism of opening and closing of stomata

Plant physiologists are certain that stomatal aperture varies as a result of changes in the turgidity of the guard cells. But they are less certain about how these changes are brought about, though the following observations have been made:

a. Most stomata open during the day and close at night.
b. Some stomata show a circadian (daily) rhythm of opening and closing even when kept in constant conditions.
c. Stomata generally close when a plant suffers water stress, for example, when transpiration exceeds water absorption.
d. The stomata of some desert plants close during the day and open at night to reduce transpiration.

Plants can therefore vary the stomatal aperture. This allows a compromise between the need to conserve water and the need to exchange gases for photosynthesis.

The compensation point is the point when the rate of photosynthesis is equal to the rate of respiration. This means that the CO2 released from respiration is equivalent to that which is taken up during photosynthesis. The compensation point is reached as light intensity increases. If the light intensity is increased beyond the compensation point,

the rate of photosynthesis increases proportionally until the point of light saturation is reached, beyond which the rate of photosynthesis is no longer affected by light intensity.

For a plant under water stress, its need to conserve water is greater than its need to obtain carbon dioxide for photosynthesis. Under these conditions a plant secretes abscisic acid (ABA). This is a chemical messenger which causes stomata to close. It is thought that ABA triggers a metabolic pump which actively

secretes potassium ions out of guard cells, causing the cells to lose water and become flaccid. In few words, the mechanisms of opening and closing of stomata occur in this way:

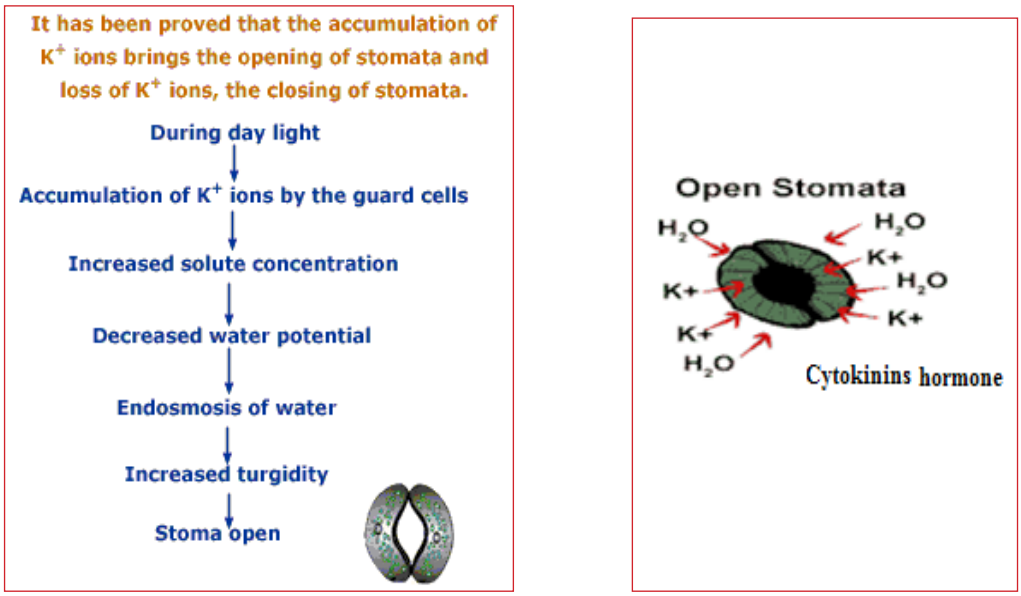


Figure 7.3: Drawing showing the mechanism of opening of stomata

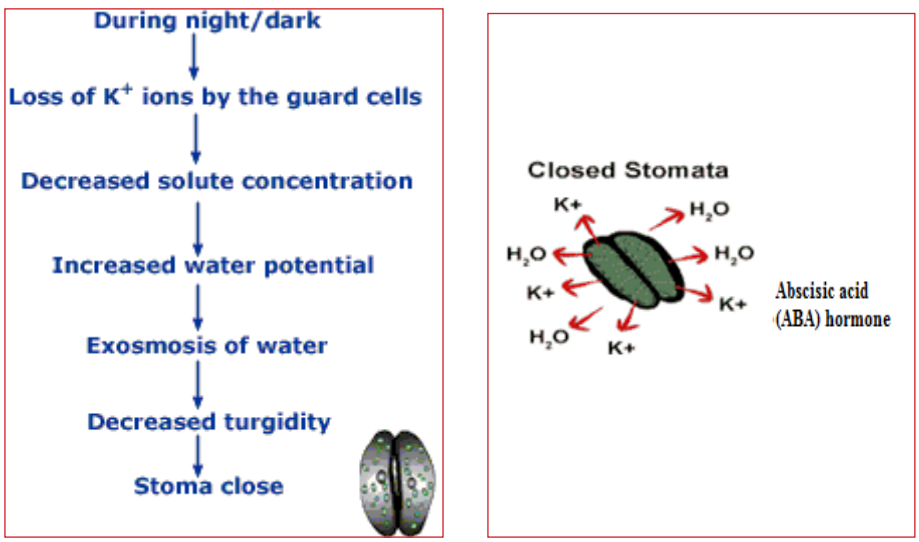
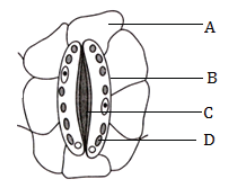


Figure 7.4: Drawing showing the mechanism of closing of stomata

Application activity 7.1

I. Analyze the diagram below and answer to the following questions .



1. What title fits better to this diagram:
   a. an open stoma
   b. a closed stoma
   c. Diagram of a guard cell and neighbouring cells
   d. Diagram of a stoma and neighbouring cells
5. 2. The part labelled C is:
   a. Vacuole
   b. Thick inner cell wall
   c. Chloroplast
   d. Thin outer cell wall
3. The part which better represents the neighbouring cell is:
   a. Part A
   b. Part B
   c. Part C
   d. Part D
4. If the guard cells become more turgid, what is more likely to happen?
   a. The cells A will swell
   b. The pore will increase its diameter
   c. The number of structures C will decrease
   d. The structure B will stretch in ward
5. Which of the following statements is false about that diagram?
   a. The stoma is closed
   b. The inner cell wall of guard is thicker than the outer cell wall
   c. There are many chloroplasts in neighboring cells
   d. The guard cells have many chloroplasts.

II. Draw one diagram showing the process of opening of a stoma including an involved hormone.

B. Structural adaptation and function of stomata, lenticels, breathing roots and leaves.

Activity 7.2

Aim: Observation of leaves of aquatic and terrestrial plants.

Materials: Microscope, prepared slides of leaves of aquatic and terrestrial plants, electrical current. You can also prepare your observation sample.

Procedure

1. Place your prepared slides leaves of aquatic and terrestrial plants on the stage of the microscope.
2. Adjust for observing the leaves of aquatic and terrestrial plants.
3. Draw the leaves of aquatic and terrestrial plants.
4. Differentiate between leaves of aquatic and terrestrial plants.

II. Observe the adaptations of these plants for gas exchange.

(a) Mangrove (b) Breathing roots (c) Pneumatophores

Explain how these plants are adapted for gas exchange.

The **guard cells** are located in the epidermal layer of the layer of the leaf. The 2 guard cells border a stoma thereby controlling its opening and closing. The adaptations of guard cells are:

i. Guard cells have chloroplasts, they therefore carry out photosynthesis. The sugar produced offers the osmotic pressure in the guard cells. This results in the stomata opening and closing.

ii. Guard cells are bean- shaped allowing for a space between the 2 cells. The stoma enables gases to diffuse in and out.

iii. The outer walls of the guard cells are thinner than inner walls. This allows guard cells to stretch outwards when they bulge, resulting into opening of the stoma.

A lenticel is a porous tissue consisting of cells with large intercellular spaces in the periderm of the secondarily thickened organs and the bark of woody stems and roots of dicotyledonous flowering plants. It functions as a pore, providing a pathway for the direct exchange of gases between the internal tissues and atmosphere through the bark, which is otherwise impermeable to gases. The shape of lenticels is one of the characteristics used for tree identification: Lenticels are found as raised circular, oval or elongated areas on stems and roots. Lenticels are also found in pneumatophorous roots (respiratory or breathing roots).

The exchange of atmospheric gases is essential to photosynthesis and cell respiration. In plants, the gas exchange takes place through stomata, breathing roots, lenticels and cuticles. Most stomata are on the lower epidermis of the leaves on plants.

Unlike other plant epidermal cells, the guard cells contain chlorophyll to carry out photosynthesis. This allows the cells to expand or contract to open or close the stomata.

Guard cells swells, through the process of osmosis, to allow opening of the stomata for CO_2 to enter and excess O_2 and H_2O to leave, and they shrink in order to force the stomata shut either partially or completely to prevent dehydration. The number of stomata on the epidermal surface depends on the ecology of plants. Usually, plants on wet climate have fast growth and a high concentration of stomata. Plants on dry weather have lower rates of photosynthesis, lower growth and lower concentrations of stomata.

C. Structural adaptation of leaves of aquatic and terrestrial plants to their habitats

Hydrophytes(aquatic plants)

Hydrophytes or water plants are plants that grow submerged or partially submerged in water. To thrive in this environment, hydrophytes have the following features:

i. Developed stomata on large upper surface of their leaves (rather than underside) making gas exchange more efficient.
ii. Large air space to facilitate evaporation from the mesophyll. This large air filled tissue is called aerenchyma. The air in the aerenchyma reduces density giving buoyancy (ability to float) to the plant and also assist in gaseous exchange.
iii. Little or no lignified supporting tissues on the submerged parts.

iv. Poorly developed transport tissue, stems and leaves have little or no lower cuticle but large continuous air spaces, forming reservoir of oxygen and CO_2 which also provides buoyancy to the plant tissues when submerged.

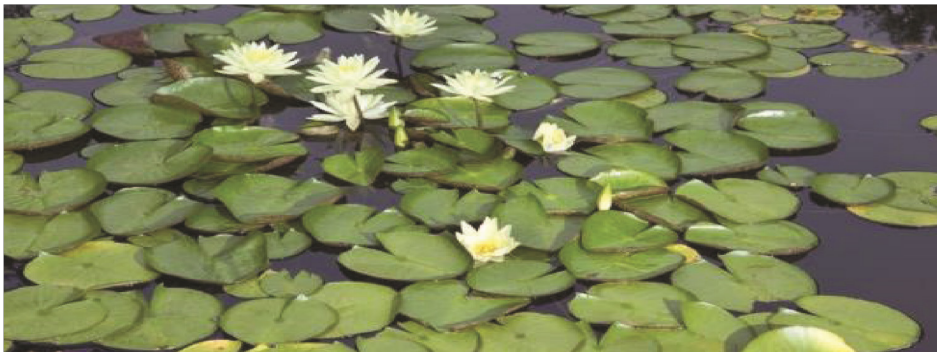


Figure 7.5: Water lily is a best example of hydrophytes

v. Emergent and floating types have broad leaves with maximum number of stomata on the upper surface to offer a large surface area for gaseous exchange and transpiration.

vi. Submerged hydrophytes have deeply dissected leaves to provide a large surface area for absorption of light energy.

Terrestrial plants

i. Mesophytes

Mesophytes are terrestrial plants plants that are adapted to grow in soil that is well supplied with water mineral salts. Such plants wilt easily when exposd to drought conditions as they are not adapted to conserve water.Th majority of flowering plants are mesophytes.The following are their adaptations :

2. Show leaf mosaic that minimizes overlapping hence each leaf canopy is able to receive light energy.
3. In areas with ample water, they possess broad leaves with thick cuticle and many stomata on both leaf surfaces to encourage high rate of transpiration.

- In dry/arid areas, they have more stomata on the lower side of the leaf surface to reduce water loss.

ii. Xerophytes

Xerophytic plants or xerophytes are plants that inhabit arid regions (such as a desert). They have the following adaptations:

1. They have few sunken stomata in grooves. The sunken stomata accumulate moisture in the sub-stomatal air spaces, leading to low diffusion gradient thus reducing the rate of transpiration.

2. They have ability to fix CO_2 at night, so the stomata are closed during the day.
3. Epidermis folded to reduce the surface area for transpiration.
4. Leaves reduced to scales or thorns to reduce the surface area for transpiration.
5. Leaves are reduced in size such as scale leaves of whispering pine to reduce water loss.
6. Leaves have thick waxy cuticles to minimize cuticular transpiration.
7. Leaves are folded to reduce transpiration, for example, in marram grass.
8. Others have reversed stomatal rhythm to prevent excessive water loss.

iv. Halophytes

A halophyte is a plant that grows in water of high salinity and they come into contact with saline water through its roots or by salt spray, such as in saline semi-deserts, mangrove swamps, and marshes. Halophytes are adapted in the flowing ways:

1. They store water in succulent tissues which have high concentration of salt. They can thus take up water from the sea water by osmosis.
2. They have extensive air spaces throughout the stem and roots making air available to all cells, and giving buoyancy to the stem and leaves at highest tides.
3. They develop breathing roots called pneumatophores which grow upward and protrude out of the ground. e.g. mangrove tress.
4. They have root cells that concentrate a lot of salt in them and this enables them to take in water by osmosis.
5. Some have salt glands that secrete excess salt.
6. They have pneumatophores (breathing roots) which are used to obtain atmospheric oxygen for respiration.
7. They have buttress roots for support and anchorage.

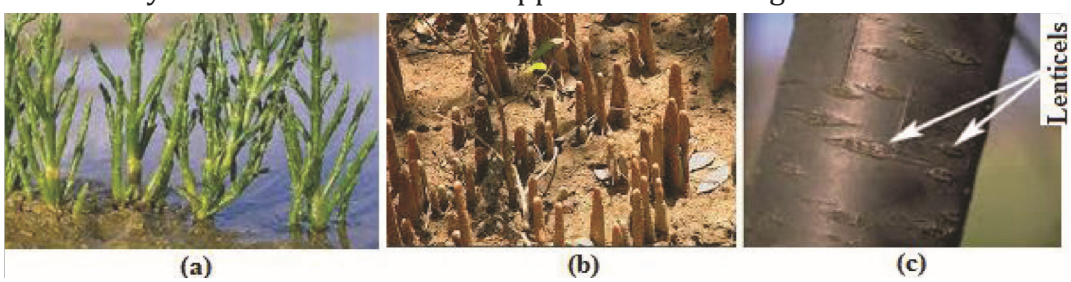


Figure 7.6: Adaptations for gas exchange in plants: (a) Salicornia europaea in a highly saline environment (b) Pneumatophores above the ground (c) Lenticels on stems

Application activity 7.2

1. Associate the terms of column A and B

column A	column B
1. Lenticel	a. are adapted to dry conditions
2. Pneumatophores	b. Porous tissue
3. Xerophytes	c. Respiratory roots

2. Salicornia europaea is adapted to a highly saline environment. Organize adaptations which prove this statement.

7.1.2 Gas exchange in animals

Mammals, reptiles, birds of all the shapes and size have lungs, but their lung are not always like each other, they have different shapes and structures. The lungs are made of "air filled paces and because of that they are moist and spongy". The air route through the body of most animals is similar to one another, in general after breathing; air moves to the "**naal cavity**" where it becomes moist, is warmed by the capillaries and is filtered next air moves into pharynx "**or the throat**" which is a tube, then larynx wchich is the " **voice box**" and is in front of the oesophagus, after that air enters the tgrachea also called :the windpipe" which like its name is pipe like structure, from there air goes into bronchi which are two smaller pipes to compared with trachea and they branch into even smaller structure called **bronchioles**; "because of the similarities between this branching and tree branching this is something referred to as the branchial tree.

A. Gaseous exchanges in insects, fish and amphibians

Activity 7.3

Aim: To dissect an insect (cockroach or grasshopper) and study its tracheal system.

Materials required Cockroach, dissecting microscope, surgical scissors, chloroform, forceps, scalpels, pins, dissecting tray etc.

Procedure

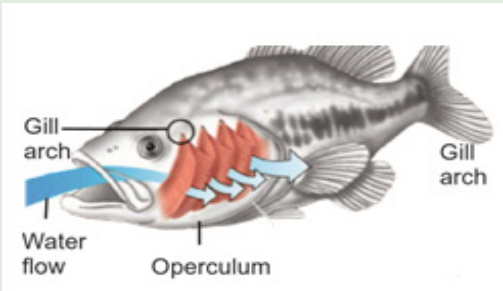
1. Obtain a live cockroach (Periplaneta americana) and anaesthesize it with chloroform.

2. Locate the position of spiracles on thorax and abdomen and record their position by making a rough sketch on the record book.
3. Pin the animal on the dorsal side with the ventral surface facing upwards on a dissecting tray.
4. Carefully remove the abdominal sterna (exoskeleton covering of the abdomen) without disturbing the internal tissues.
5. Remove the fat bodies and reproductive organs carefully to expose the tracheal system.

Observation

The tracheal system should be easily identified by its silvery appearance due to entrapped air in it. Can you locate the taenidia? Label the different parts of the tracheal system. Notice that in grasshopper, thoracic spiracles are used for inspiration while abdominal spiracles are used for expiration.

II. Observe the fish and answer the following questions.



1. Search using internet and textbooks to discover and draw the labelled structures of a fish involved in gaseous exchange.
2. Observe a fish in aquaria to monitor and sequence mouth and operculum movements during gas exchange.
3. Explain on counter and parallel flow in fish.

III. Observe the amphibian and answer the following questions.

Observe a live frog or toad in a glass tank and discuss its gas exchange surfaces.

B. Gaseous exchanges in insects

Trachea in insects

Air breathing animals (aerobic) require a continuous supply of oxygen for various metabolic activities. They also require continuous removal of carbon dioxide formed as a by-product of these metabolic activities. Insects do not breathe through their mouths as we do. The do not have lungs and, their blood which is a watery, yellowish liquid, does not carry oxygen and carbon dioxide around their bodies.

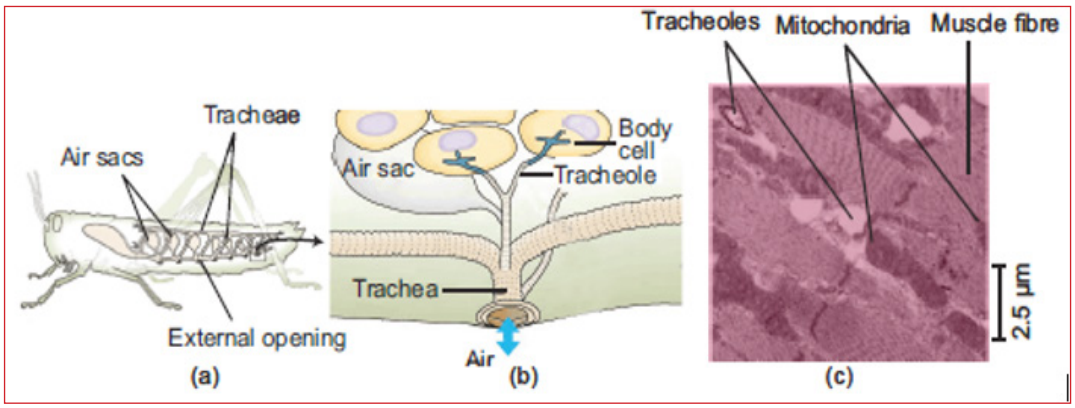


Figure 7.7: Tracheal system in insect (Grasshopper). Note that the fine tubes called bronchioles innervating at cellular level. (Source: Cambell Biology, 2011).

Insects have a system of tubes, called tracheae, instead of lungs. Sometimes larger tracheas have thickenings called taenidia. These are spiral cuticular layers which gives strength and elasticity. The trachea are tubes that are strengthened by rings of cuticle. These tracheae penetrate right through the insect's body. Air enters the tracheae by pores called spiracles. These spiracles are found on each side of the insect's abdomen.

Each segment of the abdomen has a pair of spiracles. Spiracles are respiratory openings found on the thorax and abdomen of insects. The spiracles are connected to trachea - tubes within the insect's body. Air enters the trachea via the spiracles and the oxygen then diffuses into the insect's body. This system consists of a vast network of cuticular (i.e., made of chitin, a long-chain polymer of an N-acetyl glucosamine) tubes penetrating to almost each individual cells of the body. This system serves two functions: it brings air into the body, and also distributes it to the cells. This pattern of tracheal system is very much similar to the system of blood vessels in higher animals.

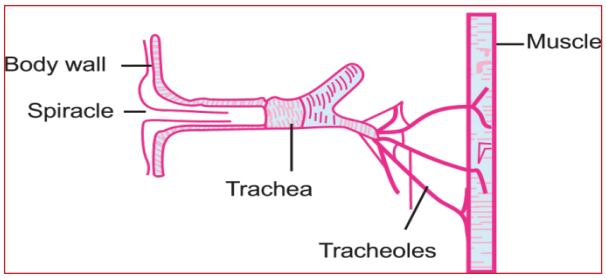


Figure 7.8: Detail structure of the tracheal system in insects

Mechanism of Ventilation in Insects

Normally there is no active ventilation in most tracheates (i.e., animals possessing trachea). Many of the tracheates (like onychophora, myriapoda, and insect larvae and pupae) depend on simple diffusion of gases in the air tubes. But ventilation and control of direction and volume of the air flowing through the system is present in adult insects. This is because adult insects are larger and so have higher metabolic rate which demands more oxygen. The spiracles and air sacs help the insect in ventilation and creating unidirectional flow of air. In grasshopper, thoraxic spiracles are used for inspiration while abdominal spiracles are used for expiration. This creates a unidirectional flow of air. Air sacs greatly increase the efficiency of ventilation. These are balloon-like structures of the trachea with a variety of size and shape. Active ventilation is brought about by rhythmic contraction and relaxation of body walls. This forces the air movement in and out of the tracheal system. Dorso-ventral flattening of abdomen is observed in grasshopper and beetles.

C. Gaseous exchanges in fish

Gills in fish

Gills are typical respiratory organs of aquatic animals, including fishes. Gills range in shape and size. It may be finger-like projections or simple epithelial extensions. The fish have evolved in the water, so their breathing organ is also made for that environment.

They use their gills for extracting oxygen from the water; there is very little water around “three to five percent of what is on the land”. This means fish can’t get that much energy from the oxygen they breathe but they do not need that much energy as they live in water, so their respiratory organ is constantly kept moist and also by being in water, fish are in a state of almost weightlessness and do not need to keep themselves upright and in balalnced position.

These together reduce the need for energy consumption. Fish breathe through their gills that are protected by flaps of operculum on each side of the head and are made of **filaments of lamellae**. **Lamellae** are flat plates and contain the capillaries, these are the places where the gas exchange takes place. Lamellae have surface and have thin walls, so diffusion of gasses happens with ease. There are some exceptions among fishes when it comes to breathing; lung fishes are the only fishes have lungs as well as gills and adapt from Australian lungfish rely heavily on their lungs lungs for breathing and cannot use their gills that much.

Gills are more developed in fishes. Fish gills consist of thousands of highly specialised **gill lamellae** enclosed in a gill cavity. The gill cavity is covered by an **operculum** and continuously ventilated by flowing water. Respiration through gills is also known as **branchial respiration**. All gill surfaces are provided with a dense network of thin capillary vessels and supported by skeletal elements called the **branchial arches**.

Types of gills

Gills can be of two types:

External gills: These gills are exposed to the environment and not enclosed within a pouch or cavity. They are found in the larvae of many vertebrates, including lungfishes, actinopterygians, and amphibians.

Internal gills: Gills are covered and protected laterally by soft skin folds, like the **interbranchial septum** in cartilaginous fishes, or by a firm operculum in many bony fishes. They are found within pharyngeal gills slits or pouches of most cartilaginous and bony fishes.

In cartilaginous fishes, the gills are found on the lateral side of the branchial arch . Gills are usually five pairs in number. They are located in vertical, anterioposteriorly compressed branchial chambers or gill pouches. Each branchial pouch is separated from each other by a stout interbranchial septum. This septum is made up of fibro-muscular tissue with blood vessels. A branchial pouch communicates to exterior with the help of narrow **external branchial aperture** or **gill slits**. Each gill has a central partition called the interbranchial septum. Within this septum, a stiff structure called **gill ray** gives support to the gills.

This septum is covered on each face by **primary lamellae** or **gill filaments**. Gill filaments are series of raised thin, highly vascular horizontal lamellar folds of

the interbranchial septum. The primary lamellae are again made up of standing rows of **secondary lamellae**. Water flows across their sides to irrigate the gills.

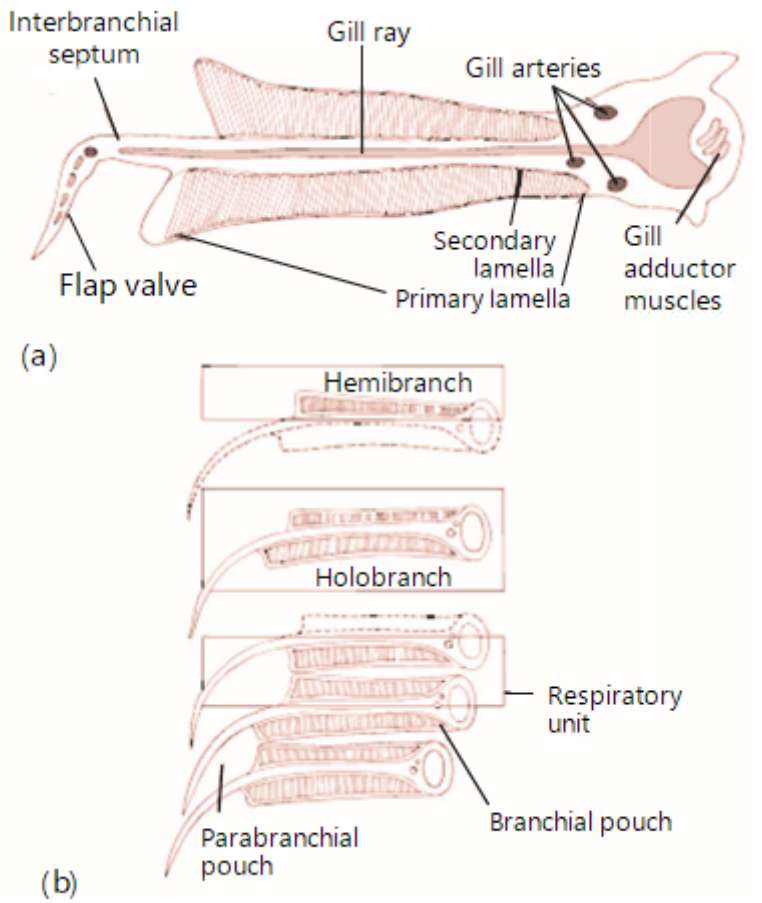


Figure 7.9: Structure of gills in shark. (Source: Kardong, Vertebrates: Comparative anatomy, Function, Evolution, 2012)

When gill lamellae are present on both anterior and posterior sides of a septum, it is called a **holobranch** or **complete gill**. However, when lamellae is present on only one face, it is called a **hemibranch**. Facing plates of lamellae on adjacent gills constitute a **respiratory unit**.

A branchial pouch therefore consists of posterior hemibranch of one gill and anterior hemibranch of the succeeding gill.

The pharyngeal structural region in bony fishes is almost similar to that of cartilaginous fishes.

The gill/branchial chamber on each side is covered by a fold of integument called the **operculum** (gill covering). It is supported by four opercular bones. The operculum protects the branchial arches and its gill lamellae and also helps in gill ventilation. There are five pair of gill pouches and four pairs of holobranchs or complete gills. In cross section, each gill is V-shaped and composed of primary lamellae (gill filaments) that are subdivided into secondary lamellae and supported on a branchial arch.

Mechanism of Gill Ventilation

Ventilation rate is much higher in aquatic animals than air breathing animals. This is because water has lower oxygen and greater density than air. So, more ventilation is required for oxygen uptake. This is achieved in gills by having a unidirectional flow of water. Ventilation of fish gills is achieved by rhythmic movement of various muscles. This generates a continuous current of water through the gills. The muscular pump of the buccal cavity actively drives water across the internal gills bringing about ventilation. First the mouth is opened, buccal floor drops and the pharyngeal floor lowered at the same time. This creates a vacuum inside pharyngeal cavity. At the same time, external branchial openings are closed. This results in water rushing into the pharyngeal cavity through mouth. Now mouth gets closed and the external aperture opens. This makes water flow out through the branchial apertures. As water passes through the gills, it washes the gill lamellae. Exchange of gases takes place between the blood flowing in the gill lamellae and the water current.

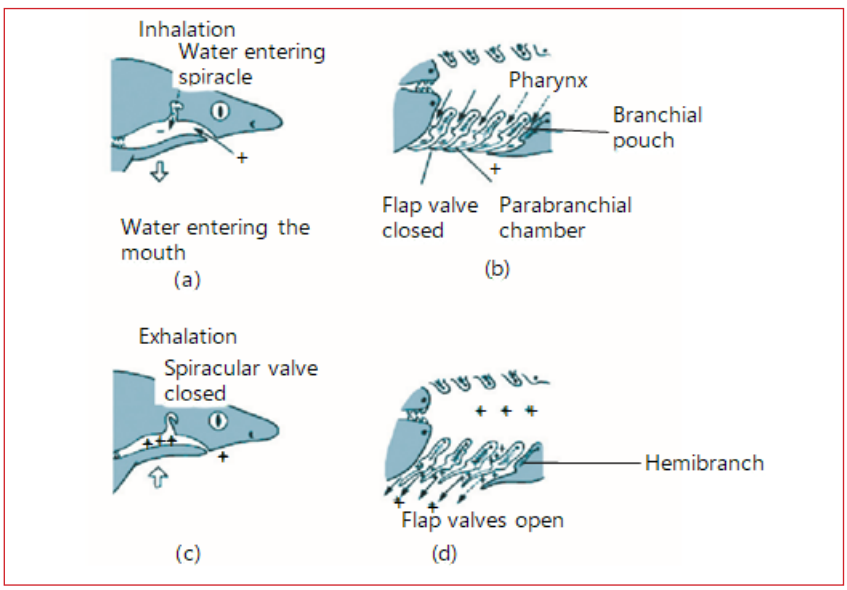


Figure 7.10: Gill ventilation in sharks. Lateral (a, c) and frontal view (b, d). Relative positive and negative pressures indicated by + and –, respectively (Source: Kardong, Vertebrates: Comparative anatomy*, Function, Evolution, 2012)*

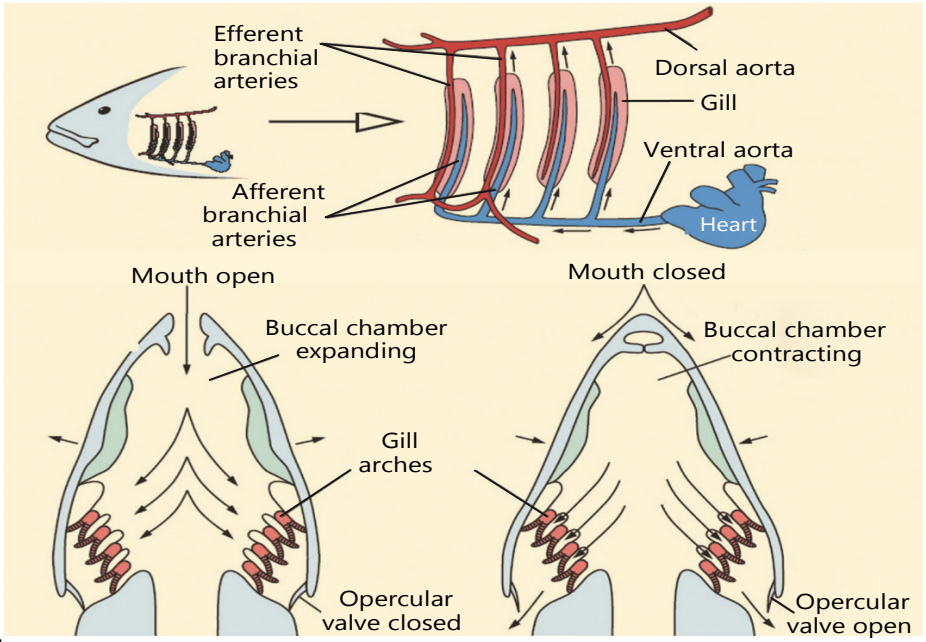


Figure 7.11: Mechanism of gill ventilation in Tilapi

Table 7.1: Difference between gaseous exchange of cartilaginous and bony fish

	Cartilaginous fish		Bony fish
1.	These have exposed gill slits for gaseous exchange	1.	These have operculum to vary pressure within the gill chamber.
2.	It is based on dual pump mechanism that creates alternating negative (suction) and positive pressures to draw water in and then drive it across the gills.	2.	It is mainatired by action of skeletal muscle pumps in the buccal and spereul defts.
3.	Inspiration occurs by contraction of muscles and expiration occurs by closing the month.	3.	Inspiration and expiration occurs by opening and closing of mouth and operculum valve.
4.	Example of cartilaginous fish is shark.	4.	Example of a bony fish is Tilapia.

Counter current mechanism

The high efficiency of fish gills, especially teleost in gas exchange is due to the presence of a counter current flow of blood and water through the system. In 'counter current' system, two channels in close proximity carry fluids in opposite directions. In such a system, equilibria will be established in the concentration of any permeable materials under two conditions i.e., if the channels walls are freely permeable to the particular materials and if the channels are long enough. The flow of blood in the gill lamellae and nearby water is a countercurrent type.

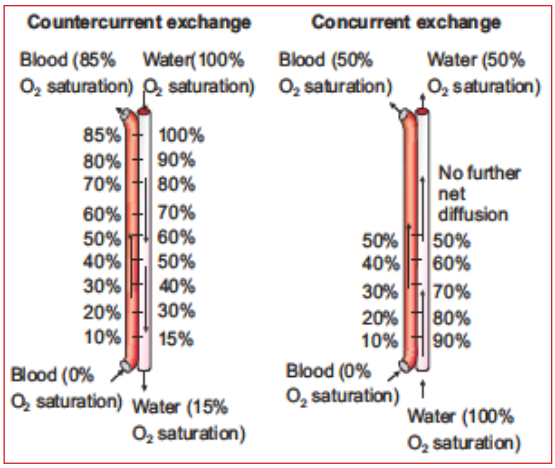


Figure 7.12: Current and counter current fluid flow.

In most fish gills, the blood in the secondary lamellae flows in one direction and water flows in the opposite direction. This establishes a countercurrent exchange system. The counter current system maintains a continuous gradient of oxygen concentration between blood and water which is not found in case of concurrent exchange system.

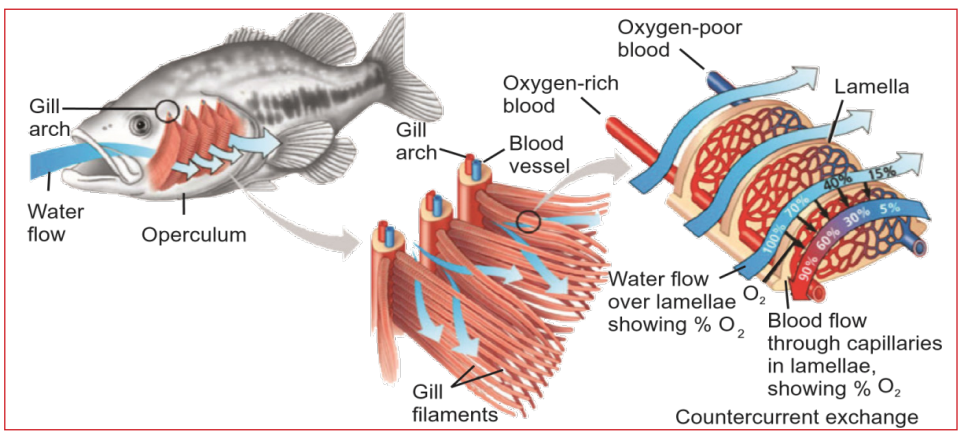


Figure 7.13: Countercurrent mechanism of gas exchange in bony fishes

This countercurrent flow maximizes difference in oxygen (and carbon dioxide) concentration between water and blood. Countercurrent exchange arrangement results in blood always being exposed to water with a higher oxygen concentration. A diffusion gradient is, therefore, maintained across the surface of gill. Blood in gill lamellae capillaries contains less oxygen and more carbon dioxide as it comes from different tissues after metabolism.

However, the water ventilating the gills has a greater concentration of oxygen compared to that of blood. Hence, oxygen diffuses readily from water to blood in capillaries of gill lamellae continuously till equilibrium is maintained. Due to the presence of a countercurrent exchanger system, a continuous difference in the concentration of the gases is maintained all throughout the length of the gill lamellae, and therefore, a continuous efficient gas exchanger system is obtained.

Significance of countercurrent mechanism in bony fishes

- A larger difference in pO_2 (i.e., partial pressure of O_2; the pressure of a specific gas in a mixture is called its partial pressure) can be maintained across the exchange surface.
- The larger the difference, the more the exchange of gases; thus, allowing more transfer of gas.
- The system is so efficient that in some teleost 85% of oxygen may be extracted from water passing over the gills using this system.
- This type of exchanger is also found in temperature control system of cold arctic animals, in air bladders of fish and even in the kidneys of vertebrates.
- A few fish have some warm tissues. For example, Tuna have warm muscles, eyes, and brains. This is only possible because of a countercurrent blood supply to selected tissues.

7.1. 3.Gaseous exchanges in amphibians.

Also note the continuous ventilation of the lungs when in land by alternate lowering and raising of the buccal chamber. Amphibians use the moist skin, gills or the lungs for gas exchange. Gas exchange occurring through the skin is known as cutaneous respiration. In some larval Salamanders and adult, external gills are also used for respiration. Modern amphibians rely heavily on cutaneous respiration. Sometimes, they develop accessory skin structures to increase the surface area available for gas exchange.

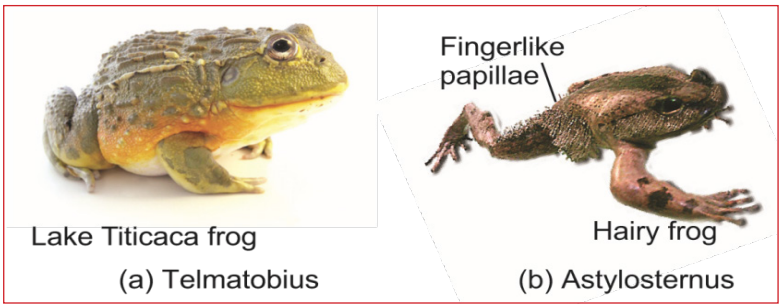


Figure 7.14: Cutaneous respiratory structures in some amphibians

In salamanders of the family Plethodontidae, adults do not have lungs and gills. They depend entirely on cutaneous respiration for metabolism. Lake Titicaca frog, Telmatobius culeus, has prominent loose skinfolds on its back and limbs for cutaneous respiration. In the male hairy frog, Astylosternus robustus, numerous papillae appear on its sides and hindlimbs during the breeding season, forming supplementary respiratory organ. The amphibian skin is thin, moist, and rich supplied with capillaries making it best suited for gas exchange by diffusion. In aquatic amphibians, pharyngeal slits often persist with internal gills. Feathery external gills are often present, especially among larval amphibians.

Amphibian larvae like Salamander larvae typically have both internal and external gills. Pumping action of the throat irrigates the internal gills with a unidirectional stream of water across their surfaces. Feathery external gills are held out in the passing current of water. In modern amphibians, ventilation depends not on ribs but on pumping movements of the throat to irrigate gills or fill lungs.

Most adult amphibians have lungs for breathing air . Normally, the respiratory surface within the lungs on the anterior region is more developed than the posterior along the inner walls. The inner surface of lungs forms partitions and divides to increase the surface area for gas exchange. Such a surface is called **septal**. The interconnecting septa divide the internal wall into compartments called **faveoli**. These faveoli open into the central chamber within each lung. Faveoli differ from the alveoli of mammalian lungs. Alveoli are found at the end of a highly branched tracheal system but faveoli are not. Faveoli are internal subdivisions of the lung wall that open into a common central chamber. Inspired air travels along the trachea into the central lumen of the lung and from here diffuses into the surrounding faveoli. Capillaries located within the thin septal walls of the faveoli take up oxygen and give up carbon dioxide.

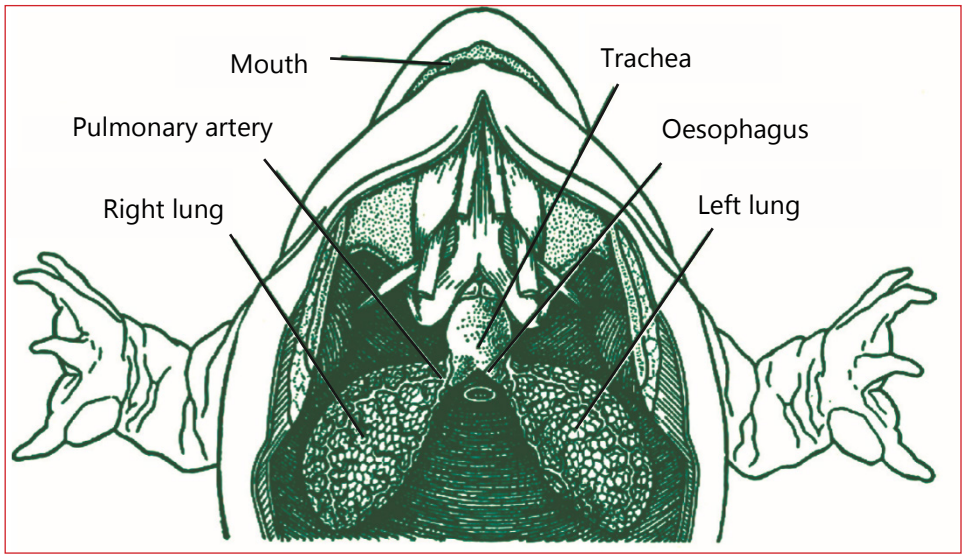


Figure 7.15: Structure of lungs in frog (amphibians).

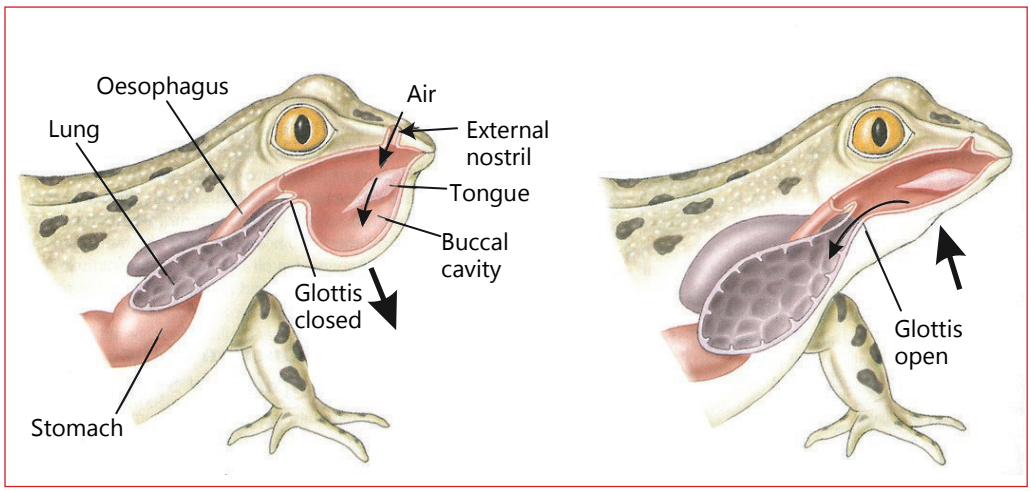
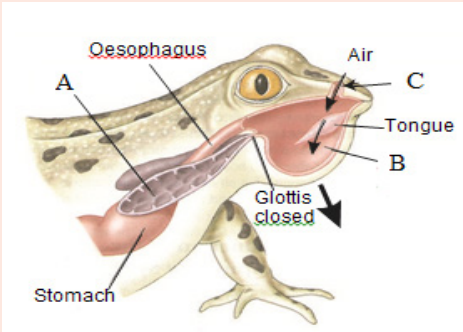


Figure 7.16: Mechanism of ventilation in frog (amphibians)

Application activity 7.3

1. Observe the following figure and answer the following questions.



   a. Identify the parts labeled A, B and C.
   b. Draw this figure illustrating the organ responsible of gaseous exchange inside the body.
2. You are provided with the list of organs: gill, spiracle, operculum, skin, tracheole, air sacs.

Select the organs contributing to the gaseous exchange in fish and insect.

D. Mechanism of ventilation and gas exchange in the alveoli of humans

Activity 7.4:Research

1. Make a computer model/simulation of the human respiratory system. This can also be downloaded from the internet. Use the internet to search videos, graphics and simulation or animations showing the different part and surface of the gas exchanges system in human. Also study the process of gas exchange and the mechanism of ventilation. Now, present your finding to your classmates. You can also clay models of the respiratory system in humans.
2. Design a model of the spirometer based on its main features.

Higher vertebrates including humans have specialized organs called lungs for gas exchange.

The process of gas exchange in the body, called respiration, has three basic steps:

1. Pulmonary ventilation or breathing is the inhalation (inflow) and exhalation (outflow) of air and involves the exchange of air between the atmosphere and the alveoli of the lungs.

2. External (pulmonary) respiration is the exchange of gases between the alveoli of the lungs and the blood in pulmonary capillaries across the respiratory membrane. In this process, pulmonary capillary blood gains O_2 and loses CO_2.
3. Internal (tissue) respiration is the exchange of gases between blood in systemic capillaries and tissue cells. In this step, the blood loses O_2 and gains CO_2. Within cells, the metabolic reactions that consume O_2 and give off CO_2 during the production of ATP are termed cellular respiration.

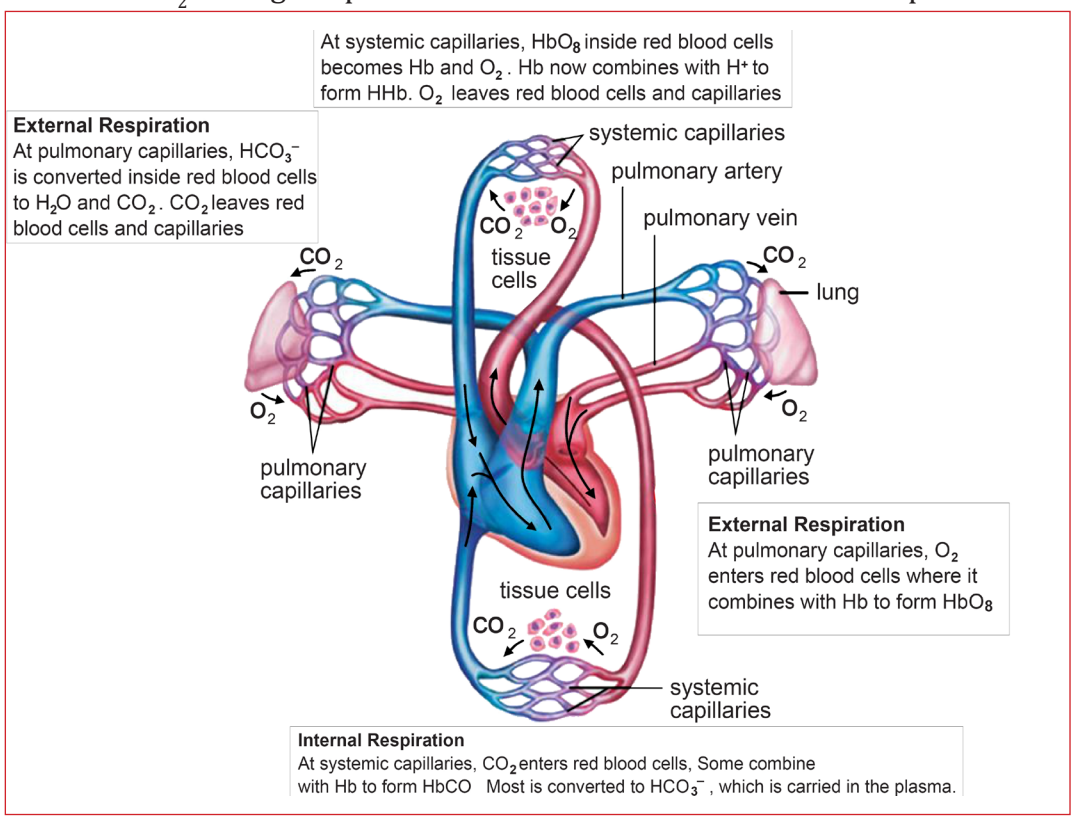


Figure7.17: Internal and external respiration.

a. Structure of gaseous exchange in humans

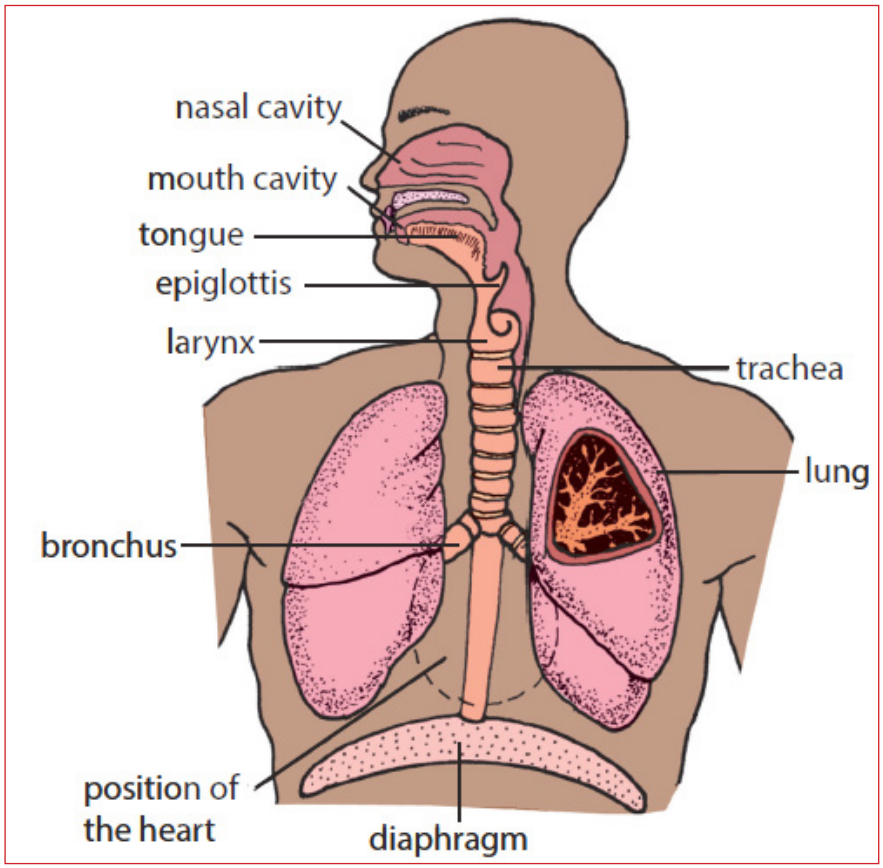


Figure 7.18: Human respiratory system

Air is inhaled through the nose into the **pharynx** (throat). Pharynx is a common passage for both air and food. The pharynx branches into two tubes, the **oesophagus** or **food pipe** and **the larynx**. The larynx is part of the airways and it houses the vocal cords. The nose, mouth, pharynx, and larynx are also called the **upper airways**. The larynx opens into a long tube, the **trachea**. The trachea then branches into two **bronchi**, the right primary bronchus enters the right lung and the left primary bronchus enters the left lung. The walls of the trachea and bronchi contain cartilage, which supports them and gives them their characteristic cylindrical shape. The right primary bronchus is more vertical, shorter, and wider than the left. Within each lung, the bronchi branch continuously into narrower, shorter, and more numerous tubes, more than 20 generations of branching

The primary bronchi divide to form smaller bronchi which are known as the **secondary (lobar) bronchi**, one for each lobe of the lung.

The secondary bronchi continue to branch, forming still smaller bronchi called **tertiary (segmental) bronchi**.

Tertiary bronchi divide to form smaller **bronchioles**. Bronchiole**s** are without cartilage. **Alveoli** (explained later) first begin to appear in them attached to their walls. Alveoli normally form grapelike clusters terminally. The airways are surrounded by smooth muscle whose contraction or relaxation can alter airway radius. Bronchioles in turn branch repeatedly, and the smallest ones branch into even smaller tubes called **terminal bronchioles**. This extensive branching from the trachea resembles an inverted tree and is sometimes commonly referred to as the **bronchial tree**.

The lung is a paired cone-shaped organ in the thoracic cavity. The lungs extend from the diaphragm to just slightly superior to the clavicles (collarbone). They are guarded by the ribs anteriorly and posteriorly. The mid region of left lung also has concavity called the **cardiac notch,** in which the heart lies. This makes the left lung about 10% smaller than the right lung. Each lung is divided into several lobes; three lobes in right and two in left lungs. Tiny air containing sacs called **alveoli** (singular, alveolus) arranged like bunch of grapes at the end of each bronchioles are the respiratory unit of the lungs. Alveoli are approximately 300 million in number in an adult and are the actual sites for gas exchange.

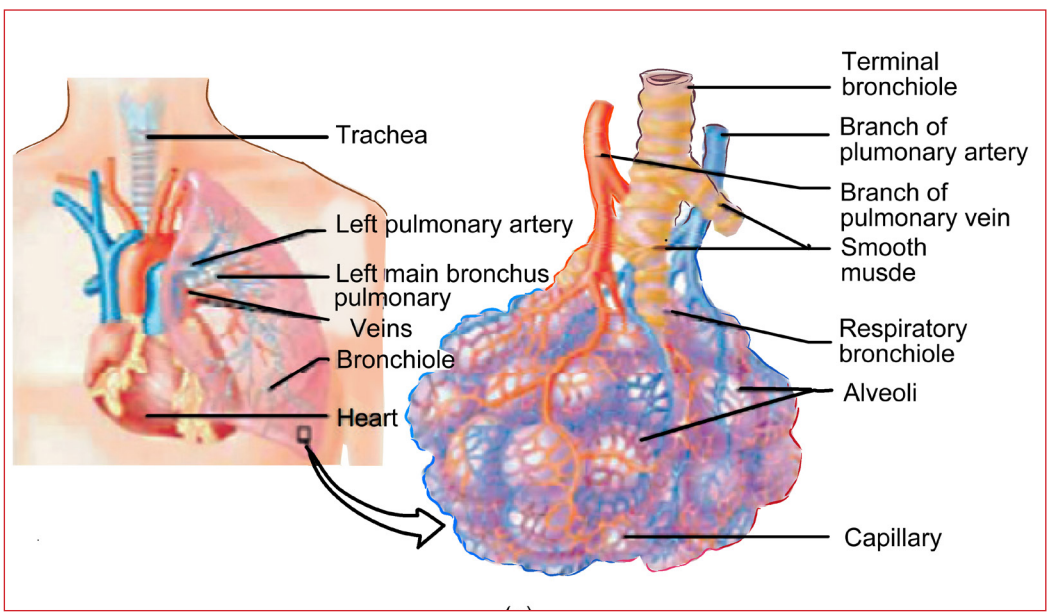


Figure 7.19: (a) Detail structure of human respiratory system: the lungs and the alveoli (Source: Vander et. al., Human Physiology, 2001)

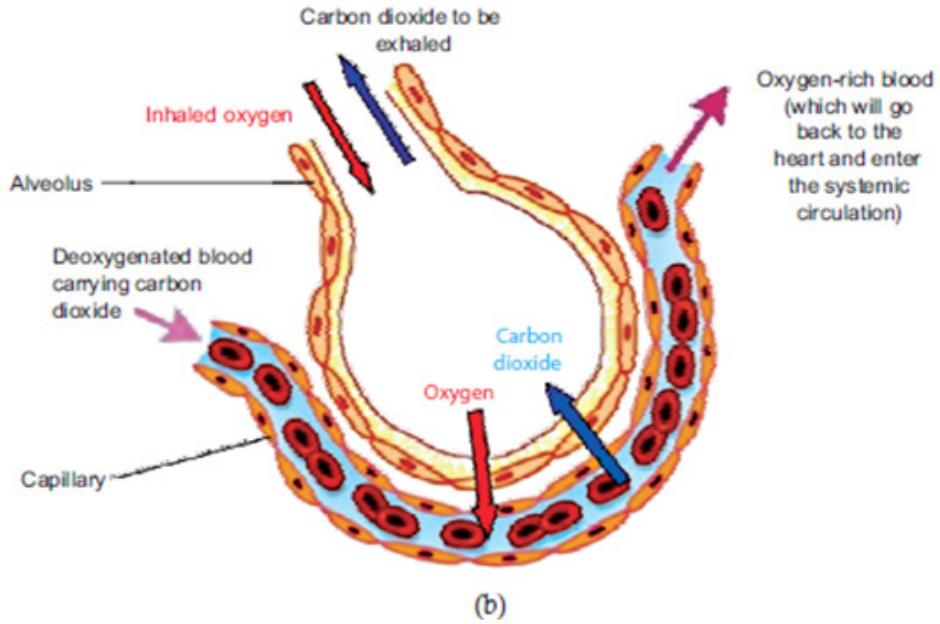


Figure 7.19: (b) gas exchange in the alveoli (Source: Vander et. al., Human Physiology, 2001)

Each lung is enclosed and protected by a double-layered serous membrane called the pleural membrane. It consists of two layers: the outer parietal pleura and the deeper visceral pleura. The space between the two is called the pleural cavity and contains a small amount of lubricating fluid secreted by the membranes. The important function of this pleural fluid is to reduce friction between the membranes during breathing movement.

b. Functions of tissues within the gas exchange system

The respiratory system consists of four main layers

i. The respiratory mucosa (epithelium and supporting lamina propria)
ii. Submuscosa
iii. Cartilage and/or muscle layer
iv. Adventitia

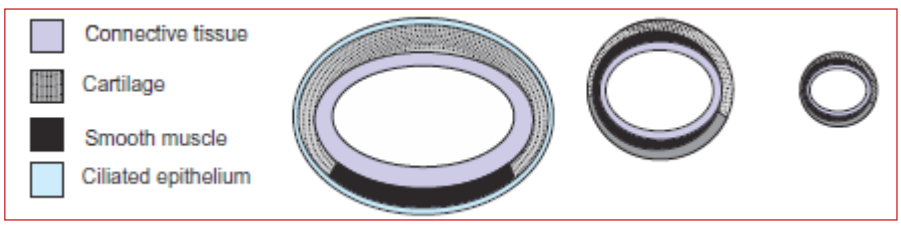


Figure 7.20: Diagrammatic representation of cross section of airways showing distribution of tissues (not to scale)

Trachea

The trachea is a wide flexible tube. The respiratory mucosa and submucosa are adapted to warm and moisten the air, and to trap particles in mucous. It consists of pseudostratifed columnar, ciliated epithelium with mucous secreting goblet cells. It has twenty C-shaped rings of hyaline tracheal cartilage which supports the trachea and keeps its lumen open. The gaps between the rings of cartilage are filled by a bundle of smooth muscle (trachealis muscle) and fibroelastic tissue. This structures together gives flexibility for ventilation. Adventitia is the outermost fibroelastic connective tissue layer.

The respiratory mucosa is made up of the epithelium and supporting lamina propria. The epithelium is tall columnar pseudostratified with cilia and goblet cells. Lamina propia lies underneath the epithelium. It contains elastin and has a supporting role. Blood vessels warm the air. The sub-mucosa contains mixed sero-mucous glands. The watery secretions from the serous glands humidify the inspired air. The mucous, together with mucous from the goblet cells traps particles from the air which are transported upwards towards the pharynx by the cilia on the epithlium. This helps to keep the lungs free of particles and bacteria. There are lots of seromucous glands in the submucosa layer.

The epithelial surfaces of the airways upto the end of the respiratory bronchioles have cilia that constantly beat toward the pharynx. They also contain m**ucous secreting glands** . This mucous keeps the lungs clear of particulate matter and the many bacteria that enter the body on dust particles. **Macrophage** present in the airways and alveoli also protect against infection.

Bronchi

Bronchi have the same basic structure as trachea. A few differences are respiratory epithelium are less tall than that of trachea and contains fewer goblet cells. Lamina propia has more elastic tissue. Muscularis mucosae begin to appear lamina propia and submucosa.

There are fewer submucosal glands and cartilage is in plates. There is less cartilage in the tertiary bronchi, It does not completely encircle the lumen.

Bronchioles

The tertiary bronchii branch into bronchioles. They have a diameter of 1mm or less, and the wall structure changes. There is no cartilage and no glands. The ring of smooth muscle is arranged in discrete bundles with a variety of organisations. The epithelium is made up of ciliated columnar cells in larger

bronchioles, or nonciliated in smaller bronchioles. There are no goblet cells, but there are cells called Clara cells. These are secretory cells and they secrete one of the components of surfactant.

Terminal bronchioles

The final branches of the bronchioles are called terminal bronchioles. These have a layer smooth muscle surrounding their lumens. Stimulation of the vagus nerve (parasympathetic) causes the smooth muscle to contract, and reduce the diameter of the terminal bronchioles. Small sacs are found extending from the walls of the terminal bronchi called respiratory bronchioles. These are lined by a ciliated cuboidal epithelium, and some non-ciliated cells called clara cells. The respiratory bronchii have a few single alveoli off their walls.

Tissue layers	Trachea	Bronchus	Tertiary Bronchus	Bronchiole	Respiratory bronchiole
Epithelium	Pseudo stratified	Pseudo stratified	Columnar	Columnar	Cuboidal
Clara cells	Absent	Absent	Absent	Present	Present
Goblet cells	Present	Present	Present	Present	Absent
Muscularis mucosa	Absent	Present	Present	Present	Present
Mucous glands	Present	Present	Present	Absent	Absent
Cartilage	Present	Present	Present	Absent	Absent

Alveoli

The alveoli are the sites of gas exchange with the blood. The wall of the air-facing surface(s) are lined by **type I alveolar** cells which is a one cell thick, continuous layer of flat epithelial cells. **Type II alveolar cells** are thicker specialized cells producing a detergent-like substance called **surfactant** and they are interspersed between type I cells.

In some of the alveolar walls, pores are present which permit the flow of air between alveoli.

The alveolar walls contain capillaries and a very small interstitial space, made of interstitial fluid and a loose meshwork of connective tissue. However, the interstitial space is absent altogether at most places and the basement membranes of the alveolar-surface epithelium and the capillary-wall endothelium fuse. As a result, the blood within an alveolar-wall capillary is separated from the air within the alveolus by an extremely thin barrier around 0.2 µm. The branching of bronchioles and the vast number of alveoli collectively increases the respiratory surface area to as much as 80 square metres. The extensive surface area of alveoli in contact with capillaries and the thin barrier results in the rapid exchange of large quantities of oxygen and carbon dioxide by diffusion.

Mechanism of ventilation (breathing)

Inspiration (inhalation or breathing in) is the movement of air from the external environment through the airways into the alveoli during breathing. Expiration (exhalation) is movement in the opposite direction. An inspiration and an expiration constitute a respiratory cycle.

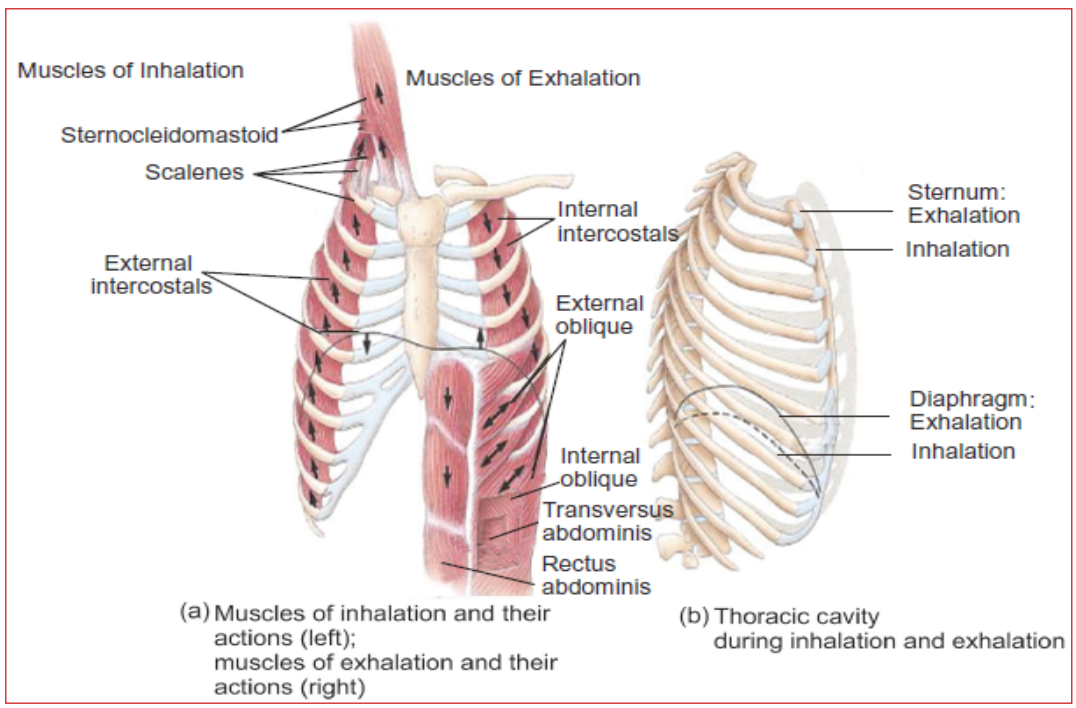


Figure 7.21: Structure and mechanism of lung ventilation in human

Inhalation: Air will move into the lungs when air pressure inside the lungs is less than that of outside (atmospheres). Expansion of the lungs increases the volume and so the pressure inside the lungs decreases. Expansion of the lungs

during normal quiet inhalation is achieved by contraction of the **diaphragm** and **external intercostals** which are the main muscles of inhalation The diaphragm is the dome-shaped skeletal muscle that forms the floor of the thoracic cavity. Contraction of the diaphragm causes it to flatten, lowering its dome. This increases the vertical diameter of the thoracic cavity. Around 75% of air enters the lungs by this action. Also contraction of the external intercostals elevates the ribs resulting in an increase in the volume of the chest cavity. About 25% of the air that enters the lungs during normal quiet breathing is due to this action. As the volume of the lungs increases and the pressure inside the lungs (**alveolar or intra-pulmonic pressure**) decreases and atmospheric air rushes into the lungs.

c. Exhalation

On the other hand if the volume of the lungs decreases, pressure inside the lungs increases. As a result, air rushes out of the lungs resulting in **exhalation** or **expiration.** However, normal exhalation during quiet breathing, unlike inhalation, is a passive process because no muscular contractions are involved. Exhalation results from **elastic recoil** of the chest wall and lungs. Elastic recoil is the natural tendency of the chest wall and the lungs to spring back after they have been stretched. The inspiratory muscles relax with the start of exhalation. Diaphragm and external intercostal muscles also relax resulting in decrease in volume of the lungs, causing air to move out of the lungs. Interestingly, exhalation becomes an active process (requiring energy supply) only during the time of forced exhalation (for example during heavy exercise etc). During these times, the muscles of exhalation are the abdominals and internal intercostals muscles which contract to increase pressure in the abdominal region and thorax. **Gas exchange in alveoli.**

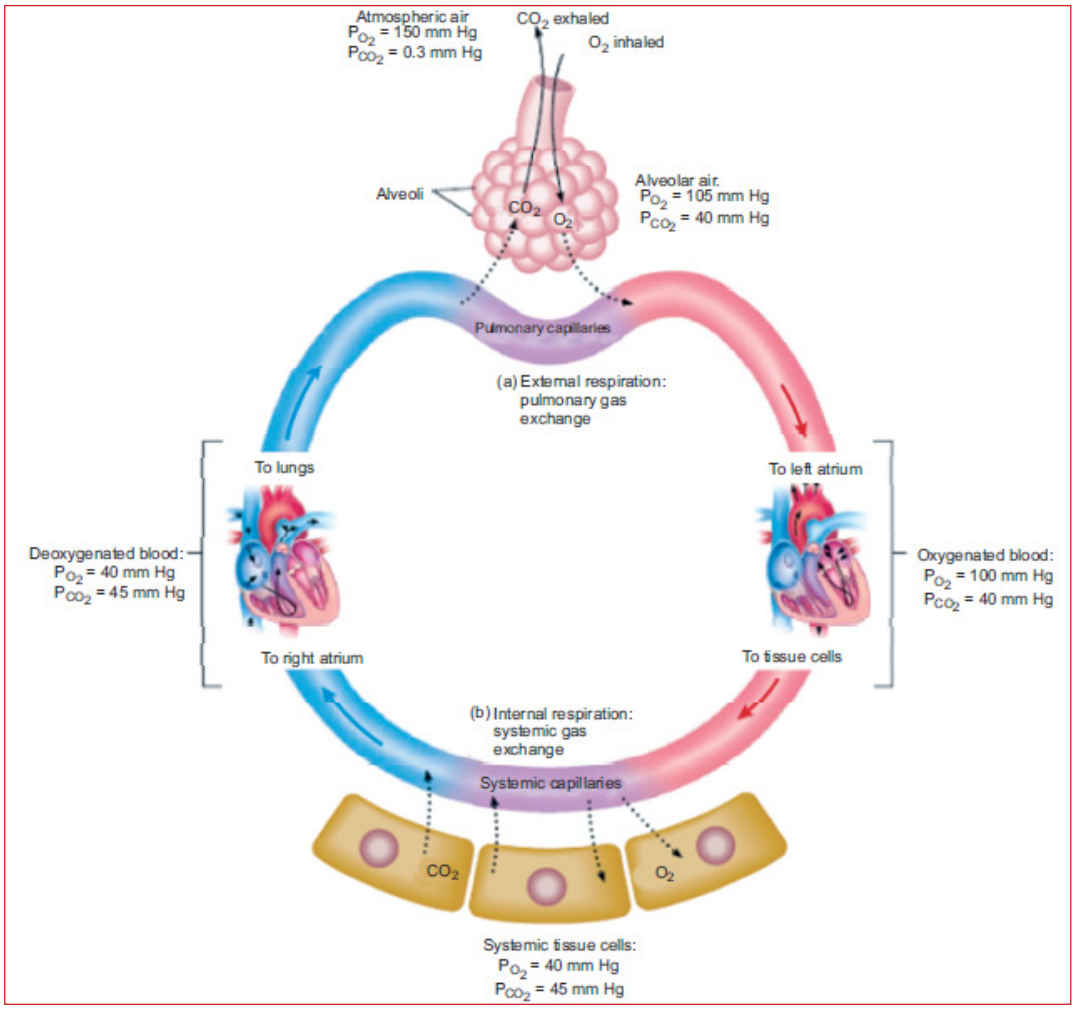


Figure 7.22: Drawing showing the gas exchange in the alveoli of human

Alveoli are the respiratory units of lungs. The alveolar and capillary walls together form the **respiratory membrane**. The exchange of gases in the alveoli and between the air spaces in the lungs and the blood takes place by diffusion across this respiratory membrane The pressure of a specific gas (x) in a mixture is called its **partial pressure** (Px). The difference in partial pressures determines the movement of O_2 and CO_2 between the atmosphere and lungs, between the lungs and blood, and between the blood and body cells. Gas diffuses across a permeable membrane from an area where its partial pressure is higher to the area where its partial pressure is low and the rate of diffusion is directly proportional to the difference in partial pressure.

As a result of this diffusion, the capillary blood pO_2 rises while its pCO_2 falls. This process of diffusion continues as long as there is difference in partial pressure

of the two gases between the two sides. An equilibrium is reached well before the end of the capillaries because blood flow in the capillaries is slow and gas exchange is rapid. Oxygenated blood now leaves the pulmonary capillaries to return to the heart from where it is pumped into the systemic arteries. The exchange of O_2 and CO_2 between systemic capillaries and tissue cells is called **internal respiration** or **systemic gas exchange.**

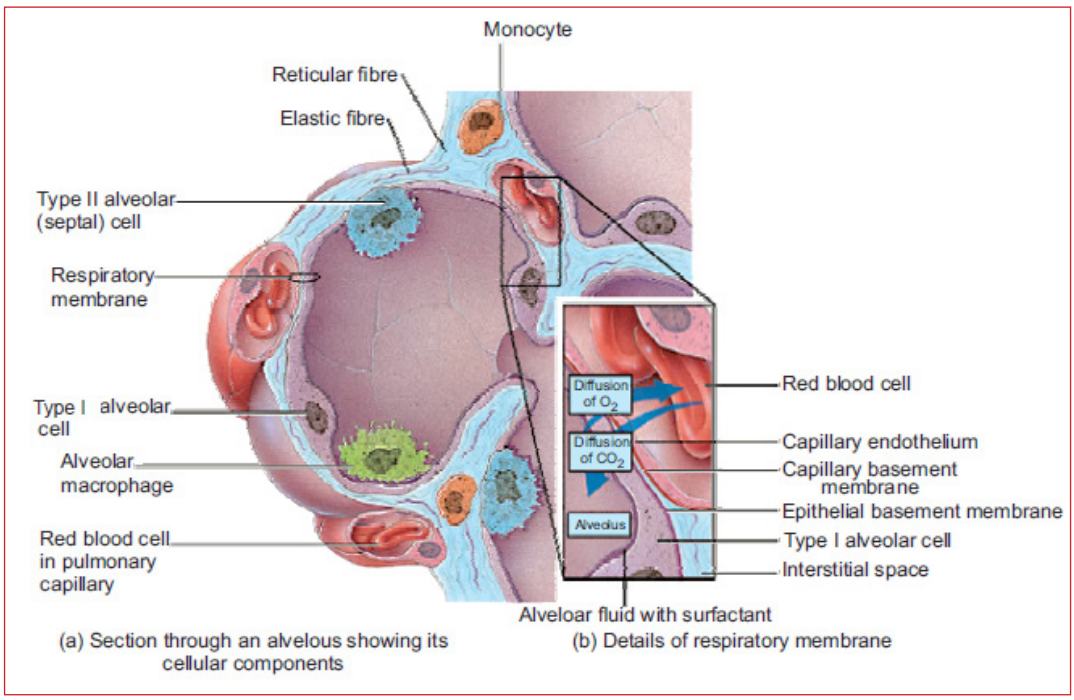


Figure 7.22: Detail structural components of an alveolus: (a) section through alveolus and (b) details of respiratory membrane

As stated earlier, **external respiration** or **pulmonary gas exchange** is the diffusion of O_2 from air in the alveoli of the lungs to blood in pulmonary capillaries and the diffusion of CO_2 in the opposite direction. In this process, blood picks up O_2 from alveolar air and unloads CO_2 into alveolar air as it flows through pulmonary capillaries. In a resting person, pO_2 is 105 mmHg in the alveolar air which is higher than that of blood in pulmonary capillaries, where it is only 40 mmHg. This results in diffusion of O_2 from alveolar air into pulmonary capillaries. However, CO_2 diffuses in the opposite direction because the pCO_2 of deoxygenated blood is 45 mmHg in a resting person, and the pCO_2 of alveolar air is 40 mmHg. Hence, carbon dioxide diffuses from deoxygenated blood into the alveoli until the pCO_2 of the blood decreases to 40 mmHg.

Application activity 7.4

1. Illustrate the diagram showing how the thoracic cavity appears during exhalation.
2. Associate the terms of column A and B

Column A	Column B
1. Nasal cavity	a. Stops food and liquids from going into the trachea during swallowing.
2. Epiglottis	b. Sound production
3. Larynx (voice box)	c. Filters, warms and moistens the air.

3. Show the process that occurs when oxygen moves from systemic capillary to the tissue cells for aerobic cell respiration.

7.2 Use of spirometer to measure ventilation rate and nervous control of breathing

Activity 7.5

Aim: Design a model of the spirometer based on its main features.

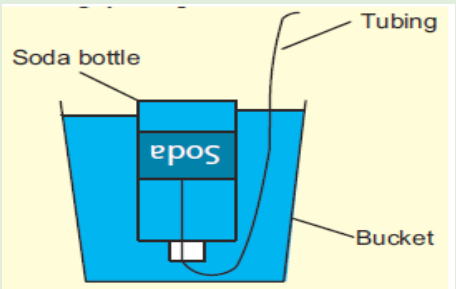
Materials Required

1. 2–3 litre empty soda/cold drink bottle with cap
2. One or two feet long piece of plastic tubing
3. One measuring cup with units in millilitres
4. One bucket or pan that can hold more than 3 litres of water
5. One permanent marker

Procedure

1. Marking measuring lines on the bottle: Add 500 ml of water to the soda/cold drink bottle using the measuring cup and mark a line with the marker at the top of the water level. Repeat this until the bottle is full. When the bottle is full, put the cap on the bottle.
2. Add sufficient water to the bucket or pan to submerge the soda bottle.
3. Invert the soda bottle and submerge it in the bucket, and remove the cap under the water. Open the bottle underwater to prevent any unwanted air from entering the bottle.

4. Place one end of the tubing into the soda bottle in the water, and leave the other end outside of the water.
5. Use the tubing to blow into, for determining lung capacity.
6. Remember to place the bottle in the water upside down before removing the cap.
7. 8. Don't forget to insert one end of the hose in the bottle after you open the cap underwater.
8. Before you exhale into the tubing, your spirometer should resemble the picture below.



9. Using the spirometer to obtain the readings:

i. One student holds the bottle to keep it from flipping over. Another student **inhales normally** and then exhales the air normally into the tubing connected to the spirometer. Note: Do not blow out all the "extra" air in your lungs.

ii. Note the amount of air you exhaled, remembering that each line on the bottle represents a half litre, starting from the top down.

iii. Record this volume, it is your "**tidal volume**." The tidal volume is the amount of air that you normally breathe in and out.

iv. Refill the bottle with water and reinsert the tubing. One student holds the bottle while another take a few normal breaths initially. This is to get a good reading in the next step. Then inhale as much air as you can and exhale this air into the end of the tubing outside of the water. II. Use illustrations or computer aided materials to observe the role of the brain in controlling gas exchange. Search, using internet and textbooks, the role of the brain in controlling gas exchange. Then, draw a diagram showing how the brain is involved in gas exchange.

7.2.1 Spirometry

The spirometer is an apparatus for measuring inspired and expired volumes during breathing and the respiratory rate The record is called a spirogram.

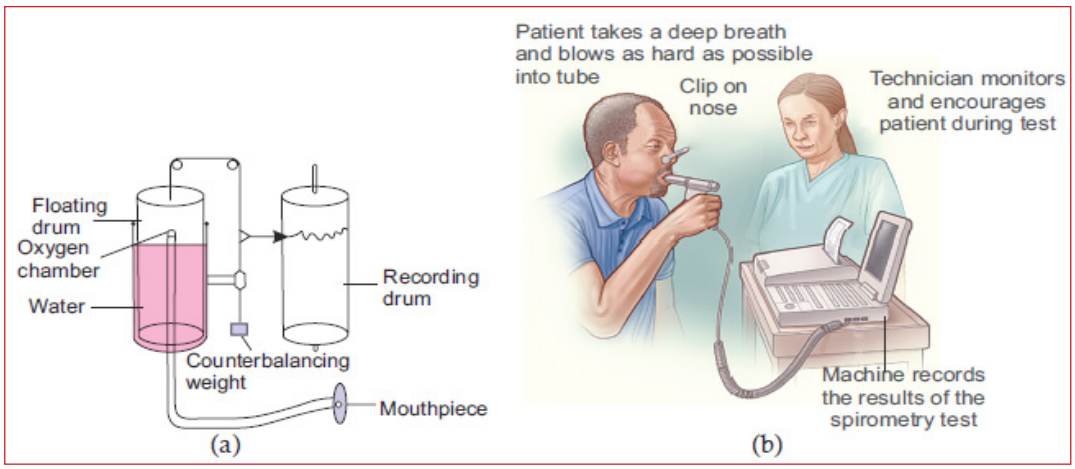


Figure 7.24: Spirometer

Use of spirometer to measure ventilation rate

The lung volumes and capacities can be measured by routine spirometry. A typical spirometer is a tube-like instrument with an open end called the mouthpiece. The spirometer consists usually of a water-filled tank with a bell shaped floating device. A tube connects the air space within the spirometer with the airways of the person whose lung volumes is being measured. A counterweight is placed on the bell. The position of the bell indicates how much air is in the spirometer and is calibrated in volume units. A person under the test blows air into it after deep breath. Usually, the airway through nose is shut or blocked using a clip so that air can only enter or leave through the mouth. Inhalation is recorded as an upward deflection, and exhalation is recorded as a downward deflection. The bell on the spirometer rises when the person blows into the device (expiration), and falls during inspiration. If the spirometer is equipped with a recording device (spirograph), it can also be used for graphic measurement of the total ventilation per unit time. Based upon the reading indicated corresponding to each breathing in or out, an expert physician can diagnose the health of the person's lungs and detect disorder if any.

Nowadays, the instrument is integrated with a computer system to accurately monitor the readings and give instant results.

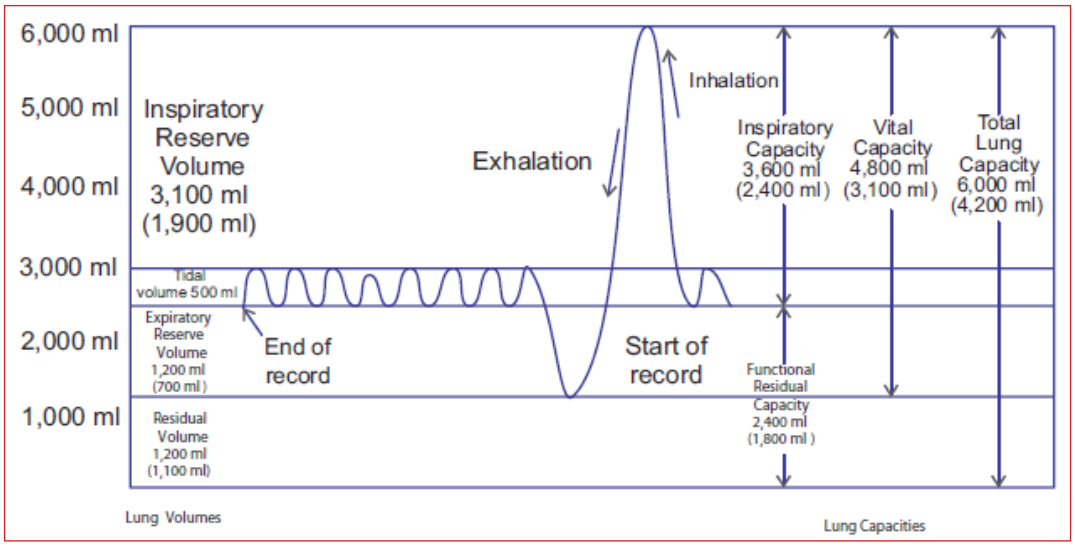


Figure 7.25: Spirogram of lung volumes and capacities in a healthy man and woman (within parentheses). The spirogram is read from the right (i.e., start of record) to the left (i.e., end of record)

7.2.2 Nervous control of breathing

Breathing depends entirely upon cyclical respiratory muscle excitation of the diaphragm and the intercostal muscles by their motor nerves as a result of nerve impulses transmitted to them from **centres** in the brain. When a burst of action potentials is initiated in the nerves to the inspiratory muscles, these muscle contracts and inspiration occurs. When these action potentials stop, the inspiratory muscles relax, and expiration occurs as the elastic lungs recoil. Similarly, in situations when expiration is facilitated by contraction of expiratory muscles, the nerves to these muscles, begin firing during expiration. This neural activity is primarily controlled by neurons in the **medulla oblongata**.

The **respiratory centre** is the cluster of neurons located bilaterally in the **medulla oblongata** and **pons** of the brain stem. It can be divided into three areas on the basis of their functions.

1. The **medullary rhythmicity area** in the medulla oblongata:
   - Controls the basic rhythm of respiration.
   - There are inspiratory and expiratory areas.
   - Nerve impulses generated in the **inspiratory area** establish the basic rhythm of breathingduring quiet breathing by causing contraction of external intercostal muscle.

- The neurons of the **expiratory area** remain inactive during quiet breathing. However, during forceful breathing nerve impulses from the inspiratory area activate the expiratory area.
- Impulses from the expiratory area cause contraction of the internal intercostal and abdominal muscles, which decrease the size of the thoracic cavity and causes forceful exhalation.

2. The **pneumotaxic area** in the pons:
   - Transmits inhibitory impulses to the inspiratory area.
   - The major effect of these nerve impulses is to help turn off the inspiratory area before the lungs become too full of air.
   - In other words, the impulses shorten the duration of inhalation. When the pneumotaxic area is more active, breathing rate is more rapid.
3. The **apneustic area** in the lower pons:
   - This area sends stimulatory impulses to the inspiratory area that activate it and prolong inhalation.
   - The result is a long, deep inhalation.
   - When the pneumotaxic area is active, it overrides signals from the apneustic area.

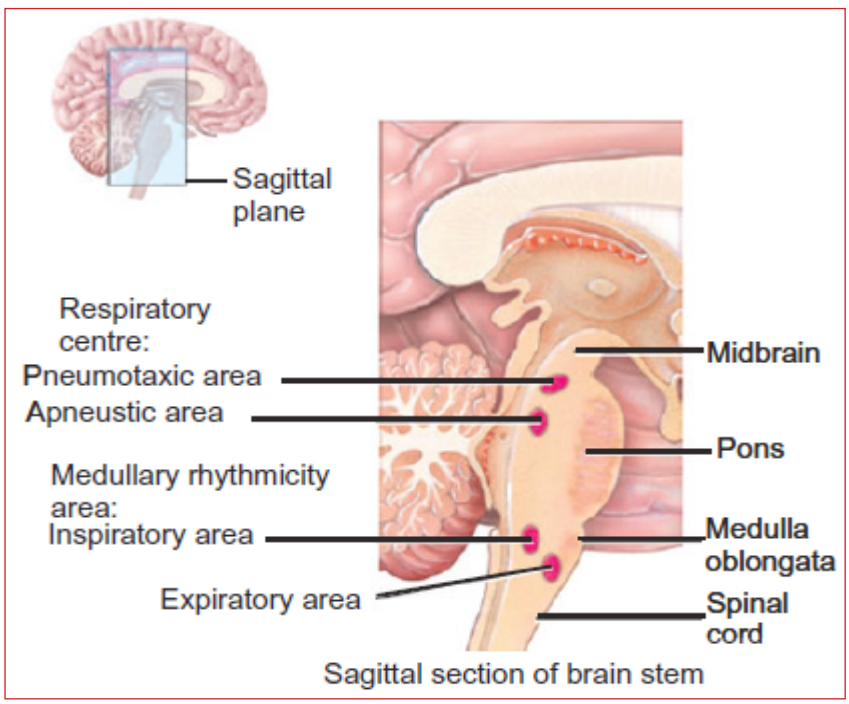


Figure 7.26: Respiratory centre in the human brain

In addition to the above, there are '**Pulmonary stretch receptors**' in the smooth-muscle layer of the airway. They respond to stretch stimulus on this muscle. Whenever there is large lung inflation, they are activated. Electric signals in the afferent nerve fibres from the stretch receptors travel to the brain and inhibit the medullary inspiratory neurons. This phenomenon is known as the **Hering-Breur inflation reflex**. Thus, inspiration is terminated by feedback from the lungs. However, this pulmonary stretch-receptor reflex plays a role in setting respiratory rhythm only under conditions of very large tidal volumes, for example in rigorous exercise.

Application activity 7.5

1. Select among the following terms, those which can complete these statements:

List of terms: Lung, Spirometer , medulla oblongata, pons , Apneustic area, gill.

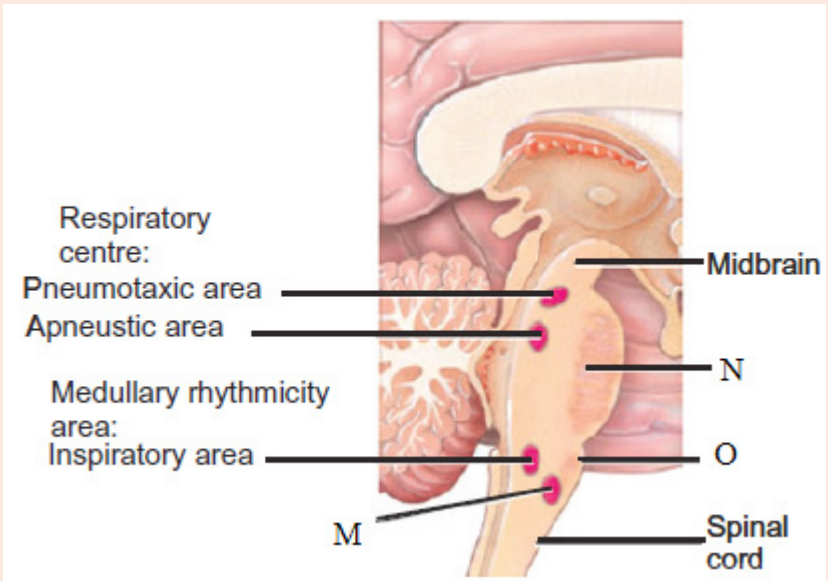
Statements

i. ..... is used to measure inspired and expired volumes of air.

ii. Respiratory centre is cluster of neurons located bilaterally in ..... and ..... of brain stem.

iii. ..... in brain prolongs inhalation.

2. You are provided with the sagittal section of the brain.



Identify the structures labeled M, N and O.

7.2.3 Lung volume and capacities

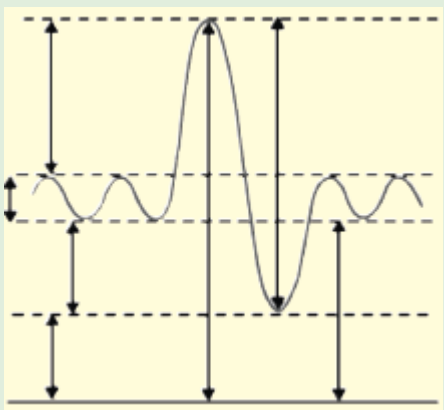
Activity 7.6

Aim: To use the illustrations of spirometer trace to define tidal volume, inspiratory reserve volume, expiratory reserve volume, vital capacity and residual volume.

Materials Required: Notebook, pen, pencil etc.

Procedure:

1. First write down the definitions of tidal volume, inspiratory reserve volume, expiratory reserve volume, vital capacity and residual volume.
2. Using a colour pencil/pen note try to locate the tidal volume in the spirometer trace provided.
3. Perform step 2 above for inspiratory reserve volume, expiratory reserve volume, vital capacity and residual volume.
4. Give a logical explanation for your labelling.
5. Show the labelled spirometer trace to your teacher and explain your results. Ask for corrections



Tidal volume: It is the volume of air entering the lungs during a single inspiration during normal quiet breathing. It is about 500 ml. It is approximately equal to the volume leaving on the subsequent expiration.

Inspiratory reserve volume: The maximal amount of air that can be increased above the resting tidal volume during deepest/forced inspiration is termed the inspiratory reserve volume. It is about 3000 ml in average adult males which is six fold greater than resting tidal volume and 1900 ml in average adult females.

Expiratory reserve volume: The 500 ml of air inspired with each resting breath adds to and mixes with the much larger volume of air already in the lungs, and then 500 ml of the total is expired. However, through maximal active contraction of the expiratory muscles i.e., forced expiration, it is possible to expire much more of the air remaining after the resting tidal volume has been expired; this additional expired volume is termed the **expiratory reserve volume** (about 1500 ml).

Residual volume: Even after a maximal active expiration, approximately 1000 ml of air still remains in the lungs. This is because the subatmospheric intrapleural pressure keeps the alveoli slightly inflated, and some air also remains in the non-collapsible airways. This volume, which cannot be measured by spirometry, is called the **residual volume** and amounts to about 1200 ml in males and 1100 ml in females.

Vital capacity: It is the maximal volume of air that a person can expire after a maximal inspiration. It is a useful clinical measurement for detecting various respiratory system related conditions. It is the sum of inspiratory reserve volume, tidal volume, and expiratory reserve volume (4800 ml in males and 3100 ml in females).

Inspiratory capacity is the sum of tidal volume and inspiratory reserve volume

(500 ml + 3100 ml = 3600 ml in males and 500 ml + 1900 ml = 2400 ml in females).

Total lung capacity is the sum of vital capacity and residual volume

(4800 ml + 1200 ml = 6000 ml in males and 3100 ml + 1100 ml + 4200 ml in females).

However, in a normal adult only 70% (=350 ml) of tidal volume reaches the respiratory zone because of the presence of **anatomical dead space**. Dead Space refers to the conducting airways which have a volume of about 150 ml. Exchanges of gases with the blood does not occur in this 150 ml of the airways. It occurs only in the alveoli. Since these airways do not permit gas exchange with the blood, the space within them is termed the **anatomic dead space**. Thus, the volume of fresh air entering the alveoli during each inspiration equals the tidal volume minus the volume of air in the anatomic dead space.

Alveolar ventilation: The total volume of fresh air entering the alveoli per minute is called the alveolar ventilation which is given by,

Alveolar ventilation (ml/min) = (Tidal volume – Dead space) × Respiratory rate

(ml/breath) (ml/breath) (breath/min)

= (500 – 150) ml/breath × 12 breath/min = 350 × 12 = 4200 ml/min.

Importance of Lung Capacities

These pulmonary function tests are useful diagnostic tools:

An examination of ventilation function of lungs is necessary for evaluation of functional properties of human respiratory system.

It is used for estimation of defects in respiratory system and also for consideration of fitness load in sports medicine.

Various respiratory disorders may be diagnosed by comparison of actual and predicted normal values for a patient's gender, height, and age.

Application activity 7.6

1. Use the given list, the appropriate terms to complete the following table.

- Inspiratory reserve volume (IRV)
- Tidal volume (TV)
- Expiratory reserve volume(ERV)
- Vital capacity
- Residual volume (RV)
- Functional Residual Capacity (FRC)
- Inspiratory Capacity (IC)
- Total Lung Capacity (TLC)

a. Pulmonary/ Lung volumes	**W**	**is a volume of air inhaled and exhaled without any noticeable effort (normal breathing).**
	X	is a volume of air that can be taken in by forced inspiration over and above the normal expiration.
B. Pulmonary/Lung Capacities .	Y	is a volume of air that can be maximally breathed out(exhaled) after a maximum inspiration (VC = IRV+TV+ERV).
	Z	is. the sum of tidal volume(TV) and inspiratory reserve volume(IRV)

2. Use the following data: 500 (tidal volume) ,150 (dead space volume, 12 breath/min).

Calculate the alveolar ventilation

7.3 Effects of tar and carcinogens in tobacco smoke on the gas exchange system and symptoms of lung cancer and chronic obstructive pulmonary diseases (COPD)

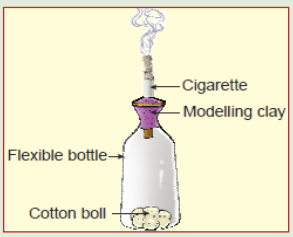
Activity 7.7

I. Aim : To observe the effect of tobacco on animals.

Collect some tobacco leaves or cigarette butts and boil them with water. Allow the solution to cool. Now filter it with a stainer. Pour the solution into a large squirt bottle. Spray the solution on a plant infested with aphids. Wait for a while. Do you find the aphids stay on the plant? If no, why? what are the possible tobacco effects on human life?

II. Aim: To observe the effect of cigarette smoking.

Put some cotton bolls inside a flexible plastic bottle. Wrap some modelling clay around the cigarette as shown.



Fit the cigarette on the mouth of the bottle with the filter end inside. Light the cigarette end outside the bottle. Squeeze and release the bottle to simulate smoking. When the cigarette is almost finished, remove it from the bottle. Take out the cotton bolls on a petri dish. Touch the bolls with your finger. Do you find some black colored tar on the bolls? Where does this tar come from? Research, from the internet or the library books, the effects of smoking that cigarette or tobacco, on the gas exchange system and present their findings to your classmate.

7.3.1 Effects of tar and carcinogens in tobacco smoke on the gas exchange system

Cigarette smoking harms nearly every organ of the body, causes many diseases, and reduces the health of smokers in general. Quitting smoking lowers the risk for smoking-related diseases and can increase the longevity.

Inhaling cigarette smoke is called passive smoking and presents a health hazard to people nearby who inhale it.

Of the thousands of chemicals in tobacco smoke three important ones are:

- **Carbon monoxide (CO)**, a poisonous gas form incomplete combustion carbon. CO in tobacco smoke combines easily, but irreversibly, with haemoglobin to form carboxyhaemoglobin and therefore reduces oxygen carrying capacity of the blood. This can lead to hypotension and heart failure.
- **Nicotine**, a poisonous alkaloid drug that is addictive. Nicotine in tobacco smoke stimulates the production of the hormone adrenaline by adrenal gland, leading to an increase in the heart rate and raised blood pressure. Nicotine also makes the red blood cell stickier and this leads to high risk of thrombosis and hence of the strokes.
- **Tar** is a sticky and brown substance. It appears in tobacco smoke minute droplets Tar in tobacco smoke is a mixture of chemicals that enter the respiratory tract. It is an irritant and causes inflammation of the mucous membranes lining the trachea, bronchi and bronchioles, resulting in producing more mucus. Tar also thickens the epithelium and paralyses the cilia on its surface. As a result, cilia cannot remove the mucus secreted by epithelium lining.
- **A carcinogen** is a substance capable of causing cancer in living tissue. Lung cancer is the uncontrolled growth (malignant tumor) of abnormal cells that start off in one or both lungs; usually in the cells that line the air passages. The abnormal cells do not develop into healthy lung tissue, they divide rapidly and form tumours. As tumours become larger and more numerous, they undermine the lung's ability to provide the bloodstream with oxygen. Tumours that remain in one place and do not appear to spread are known as "benign tumours". Malignant tumours, the more dangerous ones, spread to other parts of the body either through the bloodstream or the lymphatic system. Metastasis refers to cancer spreading beyond its site of origin to other parts of the body. When cancer spreads, it is much harder to treat successfully.

Table: List of carcinogens in cigarette smoke

Chemical	Amount (per cigarette)
Acetaldehyde	980 micrograms to 1.37 milligrams
Acrylonitrile	Formerly 1 to 2 milligrams .This product was used as fumigant in tobacco. Its use has since been discontinued.
4-Aminobiphenyl	0.2 to 23 nanograms
o-Anisidine hydrochloride	Unknown
Arsenic	Unknown
Benzene	5.9 to 75 micrograms
Beryllium	0.5 nanogram
1,3- Butadiene	152 to 400 micrograms
Cadmium	1.7 micrograms
1,1-Dimethylhydrazine	Unknown
Ethylene oxide	Unknown
Formaldehyde	Unknown

7.3.2 Signs and symptoms of lung cancer

The most common symptoms of lung cancer are:

i. A cough that does not go away or gets worse
ii. Chest pain that is often worse with deep breathing, coughing, or laughing
iii. Hoarseness
iv. Weight loss and loss of appetite
v. Coughing up blood or rust-coloured sputum (spit or phlegm)
vi. Shortness of breath
vii. Feeling tired or weak
viii. Infections such as bronchitis and pneumonia that don't go away or keep coming back
ix. New onset of wheezing

If lung cancer spreads to distant organs, it may cause:

Bone pain (like pain in the back or hips)

Nervous system changes (such as headache, weakness or numbness of an arm or leg, dizziness, balance problems, or seizures), from cancer spread to the brain or spinal cord. Yellowing of the skin and eyes (jaundice), from cancer spread to

the liver. Lumps near the surface of the body, due to cancer spreading to the skin or to lymph nodes (collections of immune system cells), such as those in the neck or above the collarbone.

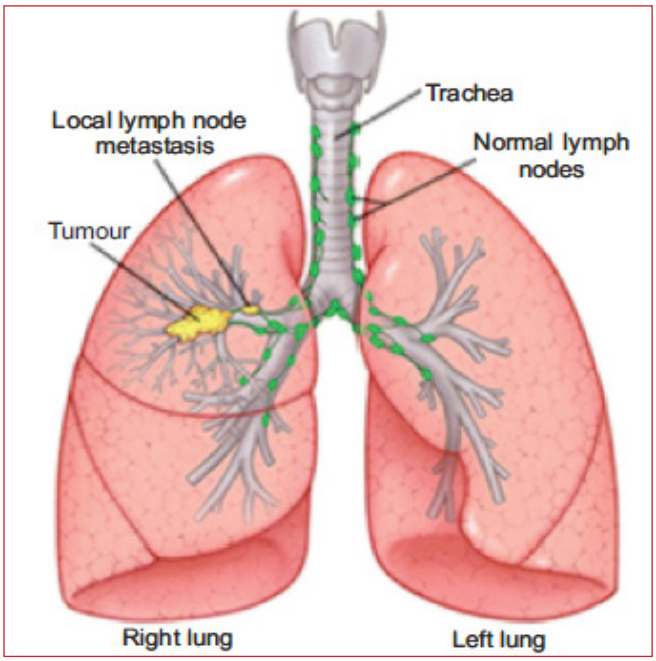


Figure 7.27: Showing tumour formation in lung (right) and healthy lung (left)

Effect of Lung Cancer on the Lung

Tobacco smoke contains over 4,000 chemical compounds, many of which have been shown to be cancer-causing, or carcinogenic. The two primary carcinogens in tobacco smoke are chemicals known as nitrosamines and polycyclic aromatic hydrocarbons.

7.3.3 Chronic obstructive pulmonary diseases (COPD) and smoking

Chronic Obstructive Pulmonary Disease (COPD) is a chronic inflammatory lung disease that causes obstructed airflow from the lungs. COPD is always caused by smoking. Over time, breathing tobacco smoke irritates the airways and destroys the stretchy fibres in the lungs. It usually takes many years for the lung damage to start causing symptoms, so COPD is most common in people who are older than 60.

Other things that may put you at risk include breathing chemical fumes, dust, or air pollution over a long period of time. Secondhand smoke also may damage the lungs.

The main symptoms are:

i. A long-lasting (chronic) cough.
ii. Breathing difficulty, especially during physical activities.
iii. Cough.
iv. Sputum production.
v. Wheezing.
vi. Blueness of the lips or fingernail beds (cyanosis).
vii. Frequent respiratory infections.
viii. Lack of energy.

As Chronic Obstructive Pulmonary Disease (COPD) gets worse, you may be short of breath even when you do simple things like get dressed or fix a meal. It gets harder to eat or exercise, and breathing takes much more energy. People often lose weight and get weaker. People with Chronic Obstructive Pulmonary Disease (COPD) are at increased risk of developing heart disease, lung cancer and a variety of other conditions.

Emphysema and Chronic bronchitis are the two most common conditions that contribute to Chronic Obstructive Pulmonary Disease (COPD). It causes airway obstruction in the lungs.

Table 7.2: Comparison between emphysema and chronic bronchitis

Emphysema	Chronic Bronchitis
It is a condition in which the air sacs (alveoli) at the end of the smallest air passages (bronchioles) of the lungs are destroyed as a result of damaging exposure.	Chronic bronchitis is inflammation of the lining of the bronchial tubes, which carry air to and from the air sacs (alveoli) of the lungs.
This causes destruction of the fragile walls and elastic fibres of the alveoli. Small airways collapse when you exhale, impairing airflow out of your lungs.	In this condition, bronchial tubes become inflamed and narrowed and your lungs produce more mucus, which can further block the narrowed tubes. It develops a chronic cough and sputum production.

People with Chronic Obstructive Pulmonary Disease COPD are also likely to experience episodes called exacerbations, during which their symptoms become worse than usual day-to-day variation and persist for at least several days.

- **Risk factors for COPD include**

i. **Exposure to tobacco smoke**: The most significant risk factor for COPD is long-term cigarette smoking. The pipe smokers, cigarette smokers and marijuana smokers are at risk, as are people exposed to large amounts of secondhand smoke.

ii. **People with asthma who smoke**: The combination of asthma, a chronic airway disease, and smoking increases the risk of COPD even more.

iii. **Occupational exposure to dusts and chemicals**: Long-term exposure to chemical fumes, vapours and dusts in the workplace can irritate and inflame your lungs.

iv. **Age**: COPD develops slowly over years, so most people are at least 35 to 40 years old when symptoms begin.

v. **Genetics**: As noted above, the uncommon genetic disorder alpha-1-antitrypsin deficiency is the cause of some cases of COPD. Other genetic factors are likely to make certain smokers more susceptible to the disease.

- **Complications of COPD include**

i. **Respiratory infections**: People with COPD are more susceptible to cold, the flu and pneumonia. Any respiratory infection can make it much more difficult to breathe and could cause further damage to lung tissue.

ii. **Heart problems**: COPD increases the risk of heart disease, including heart attack.

iii. **Lung cancer**: Smokers with chronic bronchitis have a greater risk of developing lung cancer than those smokers who don't have chronic bronchitis.

iv. **High blood pressure**: COPD may cause high blood pressure in the arteries that bring blood to your lungs (pulmonary hypertension).

v. **Depression**: Difficulty in breathing and dealing with serious illness can contribute to development of depression.

Application activity 7.7

Claudine's parents smoke tobacco at home when they are with her but she does not smoke. After 10 years, she has the following disease symptoms:

i. A cough that does not go away or gets worse
ii. Chest pain that is often worse with deep breathing, coughing, or laughing
iii. Hoarseness
iv. Weight loss and loss of appetite
v. Coughing up blood or rust-colored sputum (spit or phlegm)

vi. Coughing up blood or rust-colored sputum (spit or phlegm)
vii. Shortness of breath
viii. Feeling tired or weak

1. Identify the disease from which she is suffering.
2. Relate her parents's smoking and her disease.

7.3.4 Effects of nicotine and carbon monoxide on the cardiovascular system, contribution of tobacco smoking to atherosclerosis and coronary heart disease related to early death.

Activity 7.8

Describe the effects of nicotine and carbon monoxide on the cardiovascular system and contribution of tobacco smoking to atherosclerosis and coronary heart disease related to early death.

a. Effects of nicotine and carbon monoxide on the cardiovascular system

You have already studied that both carbon monoxide and Nicotine along with other carcinogens affect brain and heart. They too increase the risk of developing cardio vascular diseases, which includes coronary heart disease and stroke.

- The carbon monoxide in tobacco smoke reduces the amount of oxygen in blood. This means the heart has to pump harder to supply the body with the oxygen it needs.
- The nicotine in cigarettes stimulates body to produce adrenaline, which makes heartbeat faster and raises the blood pressure, making heart work harder.

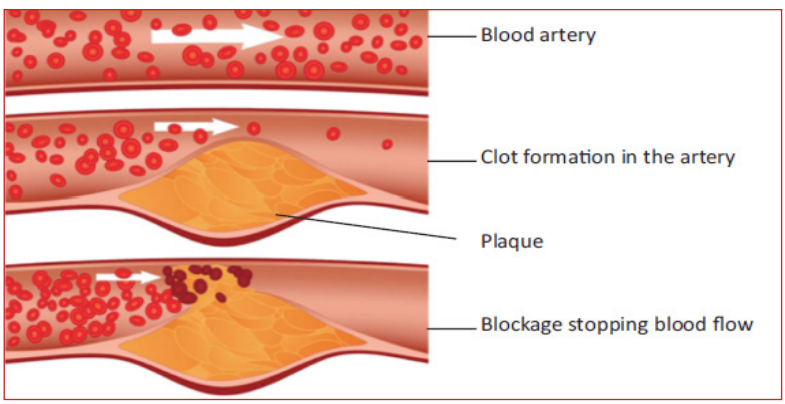


Figure 7.28: Showing the process of blocking arteries by plaque in coronary heart disease

b. Contribution of tobacco smoking to atherosclerosis and coronary heart disease

Those diseases include Atherosclerosis (Arthrosclerosis) and Coronary Heart Disease (C.H.D):

1. **Atherosclerosis (or arteriosclerotic vascular disease)** is a condition where the arteries become narrowed and hardened due to an excessive build up of plaque around the artery wall.

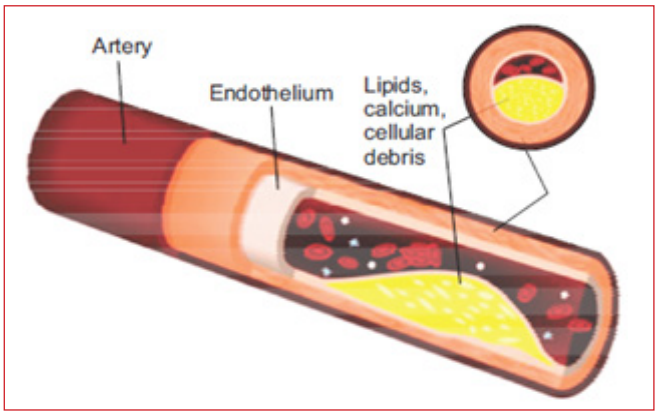


Figure 7.29: Showing plaque formation around the artery wall in Atherosclerosis

2. **Coronary Heart disease, where platelets**: components in the blood—stick together along with proteins to form clots which can then get stuck in the plaque in the walls of arteries and cause heart attacks. The most common symptoms of coronary artery disease are:

i. angina

ii. shortness of breath when exercising or doing other vigorous activity.

iii. Women are somewhat more likely than men to have other symptoms like nausea and back or jaw pain.

Smokers are more likely than non-smokers to develop heart disease, stroke, and lung cancer.

- Smoking is estimated to increase the risk:

i. For coronary heart disease by 2 to 4 times

ii. For stroke by 2 to 4 times

iii. Of men developing lung cancer by 25 times

iv. Of women developing lung cancer by 25.7 times

- Smoking causes diminished overall health, increased absenteeism from work, and increased health care utilization and cost.

- Smoking can make it harder for a woman to become pregnant and can affect her baby's health before and after birth.
- Smoking increases risks for:
- Preterm (early) delivery.
  i. Stillbirth (death of the baby before birth).
  ii. Low birth weight.
  iii. Sudden infant death syndrome (known as SIDS or crib death).
  iv. Ectopic pregnancy.
- Smoking can also affect men's sperm, which can reduce fertility and also increase risks for birth defects and miscarriage.
- Smoking can affect bone health.
- Smoking affects the health of your teeth and gums and can cause tooth loss.
- Smoking can increase your risk for cataracts (clouding of the eye's lens that makes it hard for you to see) and age-related macular degeneration (damage to a small spot near the centre of the retina, the part of the eye needed for central vision).

7.3.4 Evidence linking cigarette smoking to disease and early death

Cigarette smoking began en masse in the beginning of the twentieth century, and doctors started noticing a huge increase in cases of lung cancer from 1930 onwards, and by 1950s it was declared an epidemic.

For comparison, in 1912 there were 374 lung cancer cases, and now there are over 35,000 deaths a year, an increase of nearly 100 times.

The correlation between lung cancer and cigarette smoking is plain in the chart—it shows the 20 year 'lag' between the rise of cigarettes and the rise of lung cancer. Epidemiological data links smoking and cancer, and up to 50% of smokers may die of smoking-related diseases

One third of cancer deaths are as a result of cigarette smoking, and a quarter of smokers die of lung cancer. Chronic obstructive pulmonary disease is very rare in non-smokers, less than 10% of victims are non-smokers, and less than 2% of people with emphysema are non-smokers. One fifth of smokers suffer from emphysema, and as a result, deaths from pneumonia and influenza are twice as high amongst smokers.

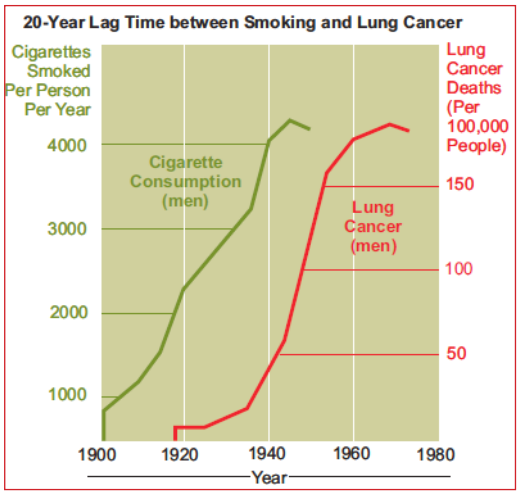


Figure 7.30: Lag time between smoking and lung cancer

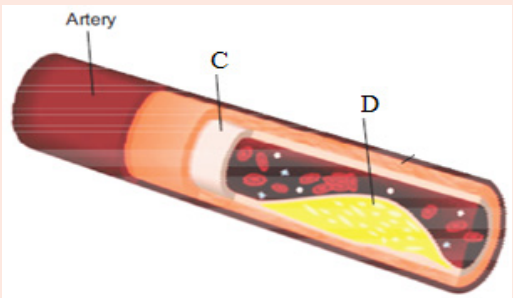
Anti-smoking campaigns

We will continue to run 'smoke-free' campaigns to encourage people to change their behaviour. The campaigns are aimed at:

i. Making people aware of the health dangers of smoking.
ii. Stopping young people from taking up smoking.
iii. Encouraging smokers to try and quit, and to do so in the most effective way.
iv. Encouraging people to stop smoking in their homes and family cars—emphasizing how it affects children.

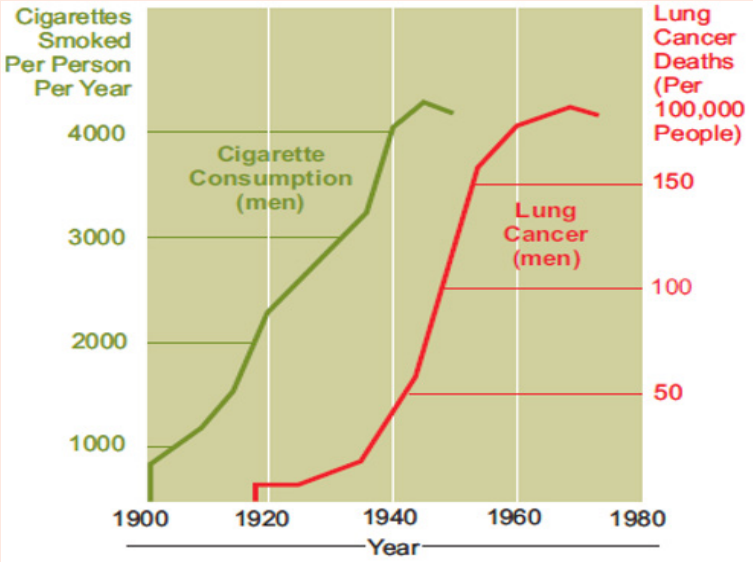
Application activity 7.8

I. Observe the following artery and answer the following questions.



1. Suggest the title of this diagram.
2. Identify C and D.
3. Interpret your observation focusing on what causes the artery to appear as it is.

II .Interpret the following graph (20-year lag time) between smoking and lung cancer graph focusing on relation of tobacco smoking and diseases.



a. Interpret this graph focusing on relation of tobacco smoking and diseases.

b. Apart from cancer, identify any 2 other diseases associated with smoking.

Skills lab 7

Aim: To fight against harmful drugs such as tobacco smokes.

Materials: Tobacco plant, cigarette , match-box, capital.

Procedure

i. After getting information about the harmful effects of harmful drugs such as tobacco smokes on human health, join /found a health and social club.

ii. Tell to the club members all harmful effects of consuming those chemicals focusing on a peson's health,family economy and country economy.

iii. Write a book or invent YouTube songs or films or comedies about all harmful drugs that particularly damage the nervous system and the body in general ; then sell them for earning money.

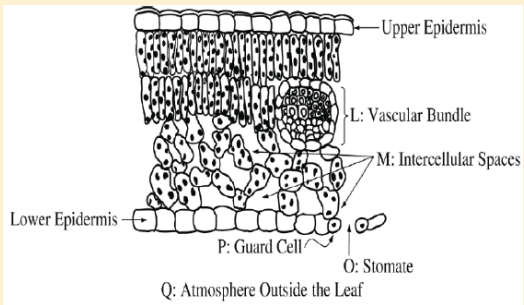
Portfolio Report:

i. Write your skills lab project implementation report focusing on how this skill lab has helped you to get much money and new biological skills, submit it to your teacher.

End unit assessment 7

Analyze the diagram and then choose the correct answer. Transpiration in the leaf depends on the transport of potassium ions into:

a. Into O
b. Into P
c. From M to L
d. From M to Q
e. From P to L.



2. The theory that says than during the light time, potassium pumps open and this brings about diffusion of CO2 from the atmosphere to the guard cells for photosynthesis is called:
   a. Theory of photosynthesis in guard cells
   b. Theory of starch sugar inter-conversion
   c. Theory of glycolate metabolism
   d. Theory of active Potassium Pump.
3. What is the main difference between the guard cells and the other epidermal cells?
   a. Guard cells have chloroplast while the remaining epidermal cells have no chloroplast
   b. Guard cells have oval shape while other cells have cubic shape
   c. Guard cells are beneath the spongy mesophyll
   d. Guard cells are covered by a transparent cuticle
4. Water lily is:
   a. Xerophytes
   b. Halophyte
   c. Hydrophyte
   d. Helophytes

5. Mangroves are plants adapted to estuaries or marine region with high salinity.

What statement does not describe the adaptations of mangroves?

a. The presence of lenticels that help in gas exchange and evaporation
b. Presence of large number of stomata on the upper side of the leaves
c. The presence of pneumatophores which are breathing roots.
d. Presence of succulent tissues that have high concentration of salt

6. Explain how gaseous exchange occurs in the leaf.
7. Describe the tracheal system of insects and relate to its function.
8. Describe the structure of the gills in relation to its function.
9. Describe the mode of gaseous exchange in amphibians.
10. Calculate vital capacity and alveolar ventilation from the data provided.

UNIT 8

TRANSPORT IN PLANTS AND ANIMALS

Key unit competence: Describe the structure of the transport tissues in plants, the mechanisms by which substances are moved within the plant and relate the structures of the circulatory and lymphatic systems to their functions in human.

Introductory activity 8

1. Have you ever seen how plants get water and minerals from roots or how does food prepared by leaves reach other parts of plants? What kind of transport system allows the passage of water and food to various parts of plants? Research using, internet and library books, about these questions and discuss your findings in the class.
2. Have you once seen an injured person bleeding? Write what you think about the origin and pathway of that blood before exiting the body.

8.1 Need for a transport system and the structure of transport tissues

Activity 8.1

1. Discuss the needs of transport systems in plants and animals.
2. **Aim**: To observe prepared slides of cross-sections showing transport structures in stem and roots and how leaves of xerophytes have adapted to reduce water loss by transpiration.

Requirements: Electrical source, Microscope, Prepared slides of transport structures in stem, roots and leaves. You can prepare your sample to be observed using the onion or Commelina .

Procedure

1. Place the prepared slide on the stage of a microscope.
2. Adjust to observe the specimen.
3. Draw the specimen observed.

8.1.1 Need for a transport system

Water is the most abundant constituent of all living things on this earth. Plant tissues contain more than **70 per cent water.** Water content in cells affects many metabolic activities inside the plant systems. Quantity of water in plant cells is maintained because these have evolved various mechanisms to take up water from the soil through efficient conducting systems. The water content in different plant parts is variable for example the amount of water in root cells has been found to be different from that of fruits, stem and seed in sunflower plants. Different plant species also have different water content expressed as percentage of fresh weight in their plant parts. Plants suffer continuous water loss through the aerial parts by transpiration and evaporation. However, these sustain continuous water loss from aerial parts by maintaining an efficient transport system and uptake of water from the soil. It is interesting to study how plants take up water from the soil and transport it to the aerial parts.

Plants have unique mechanism for transport of water, nutrients and food. Water is taken up by the roots and transported along with minerals to other parts of the plant. Along with water, many nutrient elements that are essential for the growth of the plants are also taken up from the soil. The food manufactured in leaves is similarly translocated from the source to the other parts of the plant. The transport of food is also carried out by the conducting tissue. The unit dwells on various aspects of the transport in plants.

The transport system in animals has 3 main roles which are:

a. **Transport** of respiratory gases, nutrients, hormones, metabolic wastes etc .
b. **Protection** against some diseases thanks to antibodies, against permanent bleeding thanks to thrombocytes etc.
c. **Regulation** (homeostasis)such as thermoregulation.

Physical activities can make individuals including students to be stronger and healthier by:

i. Lowering obesity rate.
ii. Lowering body mass indexes, benefit from developing muscles and burning calories.
iii. Lowering the rates of diabetes and high blood pressure.
iv. Bettering heart and lung function.
v. Enabling lymph as one of the body fluids to quickly reach in different part of the organisms.

8.1.2 Structure of transport tissues in plants

a. Structure of xylem tissue

Xylem is involved in uptake of water and mineral elements and phloem is involved in transport of food material from source to the sink. The stem appeared coloured in the activity because the water is rising through the specialized conducting tissues called the xylem.

Xylem: forms a continuous system running from the tips of the roots to the above ground parts and also to the branches and leaves. It forms the long-distance transport systems within the plants. It is a complex tissue forming a part of vascular tissue. Xylem tissue is composed of four types of cells: Tracheids, Vessels, Xylem fibres and Xylem parenchyma.

a. **Tracheids:** Tracheids are elongated cells with blunt ends, present along the long axis of the plant system. Tracheids are imperforate cells with bordered pits on their end walls. They are arranged one above the other. These have broader lumen and lignified walls that offer mechanical support to the plants. Sometimes an intermediate type of cell element is also found in vascular system known as fibre-tracheids.
b. **Vessels:** Vessels are main transporting elements in xylem. These are long cylindrical tube-like structures made up of many cells called vessel members. These vessels are joined end to end forming a continuous column. Sides of xylem vessels are lignified. These do not have protoplasm and have perforations in their end walls.
c. **Xylem parenchyma:** These are thin walled cells that act as storage cells and their walls are made up of cellulose. Radial conduction of water takes place by ray parenchyma cells in thick tall trees.
d. **Xylem fibres:** These are cells with thick obliterated walls. These have narrow lumen and their function is to attribute mechanical strength to the plants.

Xylem elements can be observed and studied well by using maceration technique. The slivers of stem are cut and put into maceration mixture.

These are separated from the mixture, washed, stained and mounted in glycerine and observed under microscope. Xylem elements in macerated plant material as seen under microscope (Figures 8.1 and 8.2).

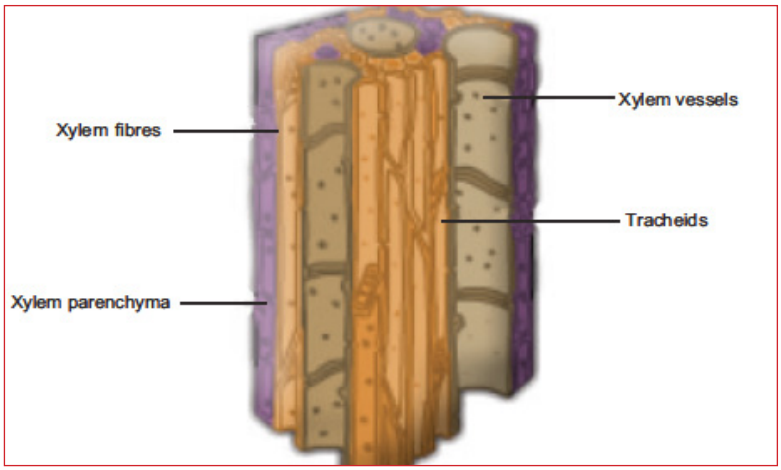


Figure 8.1: Diagram showing xylem elements fibres, parenchyma cells, trachieds and vessels

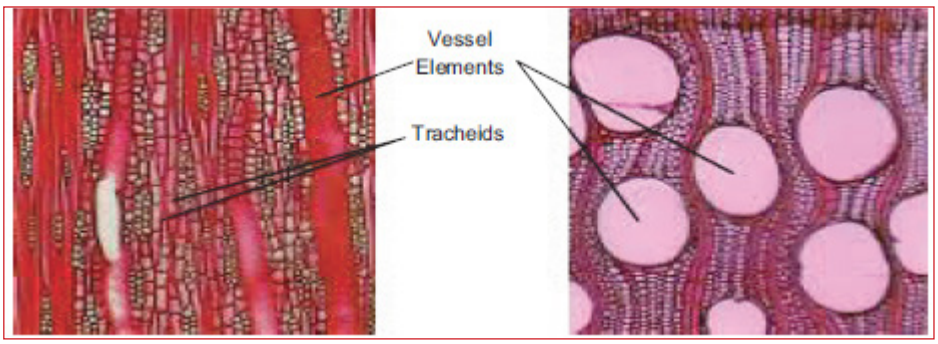


Figure 8.2: R.LS of stem showing tracheids and vessels elements

b. Structure of phloem

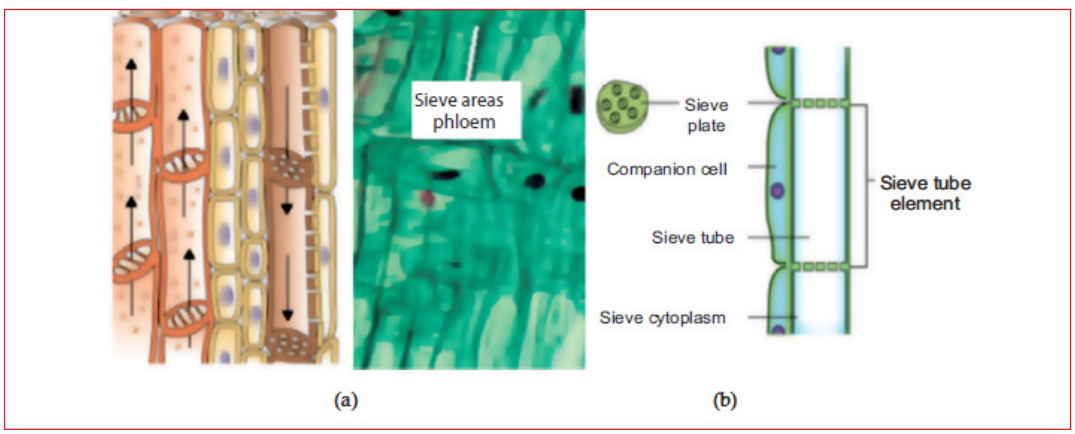


Figure 8.3: (a) and (b) A Structure of phloem: RLS of the stem showing various parts of phloem

An analysis of the phloem exudate obtained by making an incision into the phloem tissue provides evidence that photoassimilates are transported through phloem.

The phloem collects photoassimilates in green leaves, distributes them in the plant and supplies it to the other heterotrophic plant organs. Phloem is composed of various specialized cells called sieve tubes, companion cells, phloem fibres, and phloem -parenchyma.

1. **Sieve tubes:** Sieve tubes are series of cells joined end to end. The cross walls between successive sieve elements become perforated forming sieve plates. The cell walls are thin. Although the cell contents are living, the nucleus disintegrates and disappears. The lumen is filled with a slimy sap which is composed mainly of protein. The function of sieve tubes is transport of organic compounds.
2. **Companion cells:** These are specialized parenchyma cells which always appear with the sieve tube elements. They are also elongated, thin-walled and have distinct nucleus in the cytoplasm of the companion cell. Their function is to regulate the metabolic activities of the sieve tube elements.
3. **Phloem fibres:** These cells are elongated and tapering. They have thickened walls. Phloem fibres give mechanical strength to the plants.
4. **Phloem parenchyma:** These are living cells with thin walls. Phloem parenchyma stores compounds such as starch.

Application activity 8.1

1. You are provided with a list of terms; choose among them those which can complete the following statements:

Terms list: Phloem, tracheids, vessels, parenchyma and fibres, absorb, companion cell, transport, active and passive.

Statements:

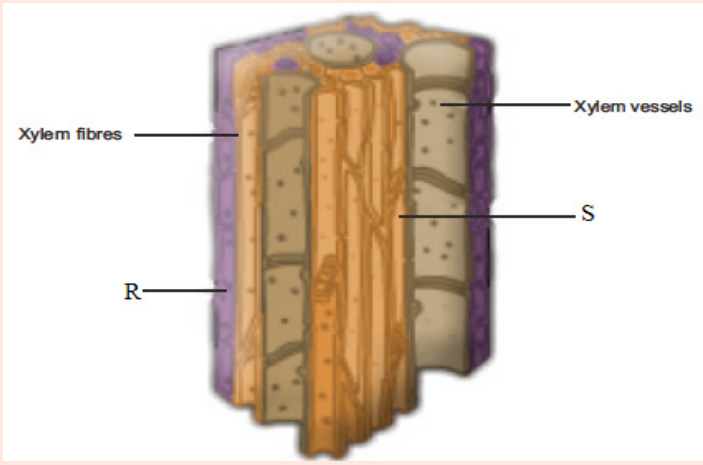
i. Xylem tissue is composed of four types of cells:

ii. ....., ..., ... and ..... .

iii. Plants ..... water from soil and ..... it to aerial parts.

iv. Two pathways regulating uptake of water from roots are ..... and ..... .

2. Observe the figure below and answer the following questions



8.2 Transport mechanisms of plants and the process of transpiration

Activity 8.2

I) Aim: To investigate how plants transport water and minerals.

Requirements: A fresh green plant, a glass of water, natural food colour, a razor, slide and a microscope.

Procedure

i. Take a fresh green plant.

ii. Give a cut at the basal end.

iii. Put the cut segment in water with natural food colours.

iv. Cut a transverse section of the stem and observe it under the microscope.

Discussion: What do you think the stem will look like?

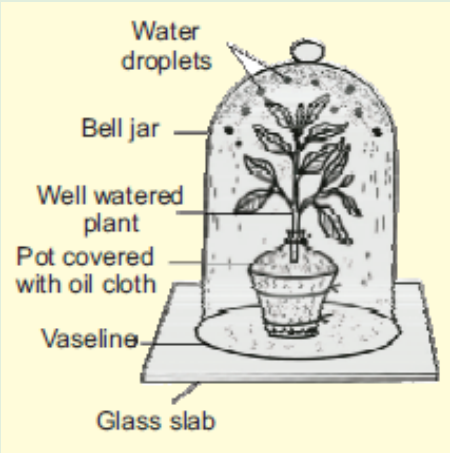
Could you see that some part of the stem appears colored? Explain why.

II) Aim: To demonstrate the phenomenon of transpiration by bell jar method.

Requirement: A potted plant, glass plate, bell jar, oilcloth, grease and thread.

Procedure

1. Take a watered healthy plant. Cover the soil by cloth to avoid evaporation.
2. Place the pot on a glass plate and cover with a bell jar.
3. Leave the apparatus for some time and observe.
4. What do you see at the inner side of the bell jar? Where do these come from?
5. Discuss reasons for the fact that transpiration is an inevitable consequence of gas exchange in plants.



Results: Small drops of water start appearing on the inner side of bell jar due to condensation of water vapour transpired from the plant.

III) Aim: To study the effect of different light intensities on rate of transpiration using potometer.

Requirements: Twig of Dracaena. Potometer, Luxmeter, Table lamp.

Procedure: Place a twig of plant in one end of the potometer and seal it air-tight. Fill the entire apparatus with water so that there are no air spaces in between. The plant is exposed to different light intensities.

Do you see any changes in the level of water at the other end of the tube? Explain why.

Results: With the increase in light intensity, the level of the water drops indicating increase in rate of transpiration.

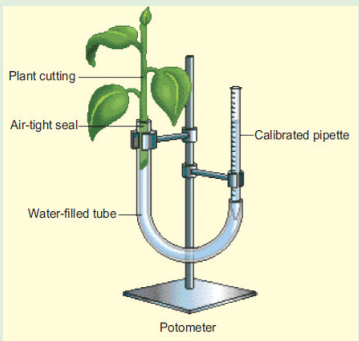


Figure 8.12: Study the effect of light intensities on rate of transpiration using potometer

8.2.1 Transport of mineral sap through xylem

a. Absorption of water through roots

Soil is the main source of water for the plants. The principal source of soil water is the water that is stored in the spaces between the soil particles after precipitation or rainfall. From the root hair cells the water enters into the **epidermis, cortex** and finally **endodermis**

Endodermis is impregnated with fatty substances along the wall called **casparian strips**. These strips form networks and these seal off the spaces between the endodermal cells. From the endodermis water enters into the **vascular tissue**.

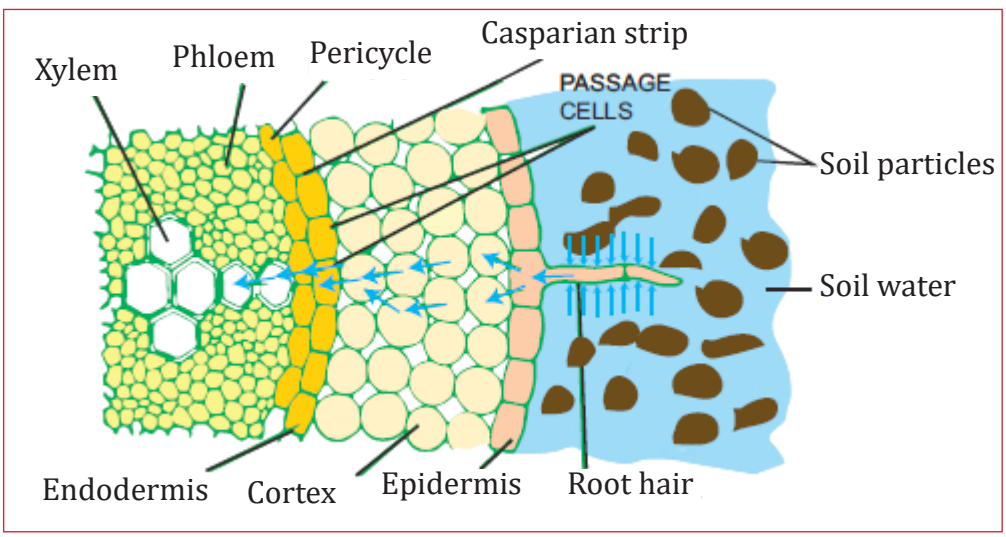


Figure 8.4: Diagram showing entry of water in the root system

The movement of water into the roots can take place by various pathways. The first pathway is referred to as **apoplast.** It means that water is moving along the interconnecting cell walls and spaces between the walls. Water moves through apoplast because of capillary action or free diffusion along the gradient. It is also called non-living continuum .The other pathway is the **symplast,** in which water moves across the root hair membrane and through the cells themselves. Plamsodesmata act as channels to transport water between the cells

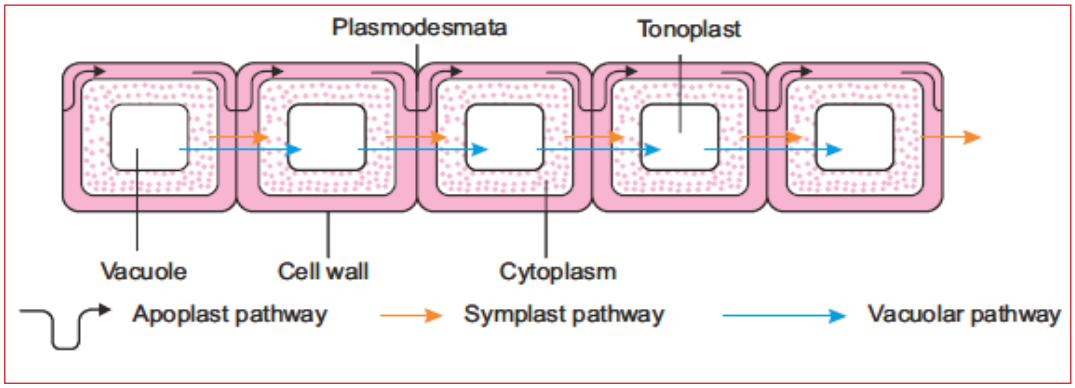


Figure 8.5: Path of water through apoplast, symplast and vacuolar

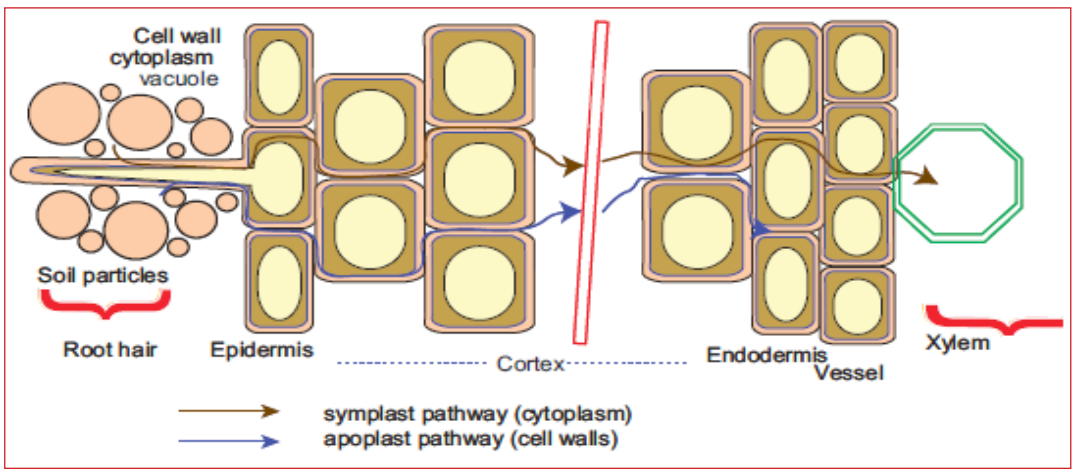


Figure 8.6: Diagram showing the movement of water through various pathways and through various cell layers in the roots

In natural conditions, the apoplastic and symplastic pathway do not separate and are operating simultaneously within the system. The absorption of water through roots is affected by various abiotic and biotic factors. When the **soil temperature** is high, movement is fast. Low temperature reduces water uptake in plants. The **branching pattern of the roots** also affects the uptake of water.

Water is a polar molecule. When two water molecules approach one another, the slightly negative charged oxygen atom of one forms a hydrogen bond with a slightly positively charged hydrogen atom in the other. This attractive force, along with other intermolecular forces, is one of the principle factors responsible for the occurrence of surface tension in liquid water. It also allows plants to draw water from the root through the xylem to the leaf.

b. Anatomy of root

In most of the herbaceous plants, the roots show various layers of cells through which the water travels inside the root systems. The outer layer that is protective is termed as epidermis and is followed by ground tissue consisting of multiple layers of cortex, endodermis and pericycle. Two to six exarch xylem bundles are found. Phloem tissue is alternate with the xylem tissue

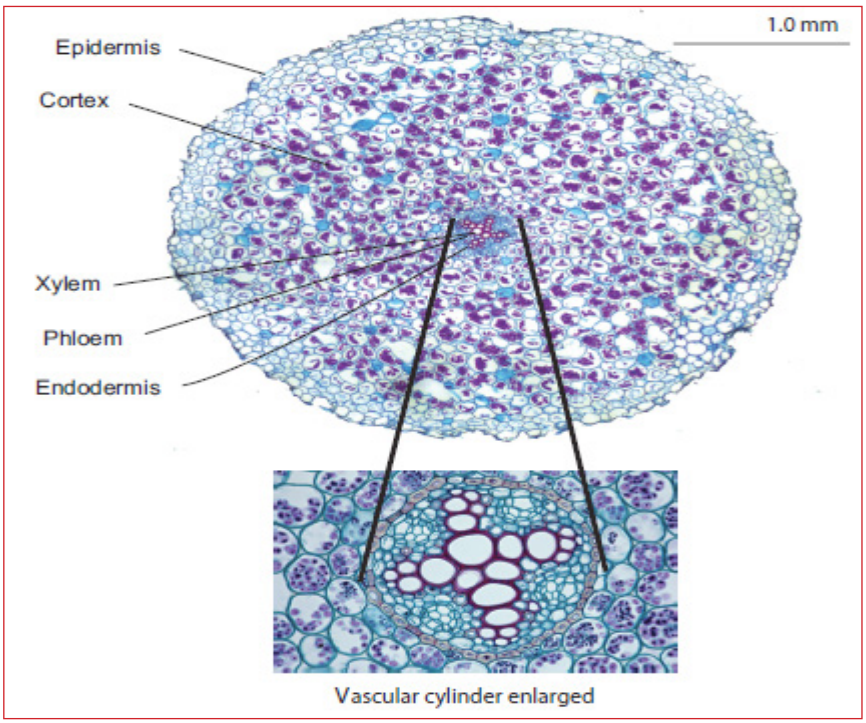


Figure 8.7: Anatomy of ranunculus root

c. Rise of water/ascent of sap

Cohesive and adhesive forces are important for the transport of water from the roots to the leaves in plants. Various processes are operating inside the plant system and cells to facilitate the movement of water from soil to roots and from one cell to another. Absorption of water by root hairs from the soil and movement of water from one living cell to another within the plant is brought about by osmosis. The most important factor that affects the uptake

is the **mineral concentration of salts** in soil. Before we discuss other things, we should understand that solutions are classified on the basis of mineral concentrations present in them. On the basis of mineral concentration in these, various types of solutions are Hypotonic solutions,

Hypertonic solutions and Isotonic solutions. You have already studied about them in Unit 2.

d. Mechanism of uptake of water and mineral salts

It is quite clear that various mineral elements are present in the water and these are carried along with water to the aerial parts of the plants. This is possible because water is a polar solvent and many mineral ions are highly soluble in it. Many viewpoints have been put forward to help in understanding of water and mineral ions in the plants. Different factors affect this uptake of water and mineral salts. They include the **root pressure**, **transpiration pull**, **cohesion** (ability of water molecules to be linked to one another) , **adhesion** (ability of water molecules to be attached to a surface of an objet) and **capillarity action** (the ability of a liquid to flow in narrow spaces without the assistance of, or even in opposition to, external forces like gravity) .

i. Root pressure

As various ions from the soil are actively transported into the vascular tissues of the roots, water follows (its potential gradient) and increases the pressure inside the xylem. This positive pressure is called root pressure and can be responsible for pushing up water to small heights in the stem. How can we see that root pressure exists? Choose a small soft-stemmed plant and on a day, when there is plenty of atmospheric moisture, cut the stem horizontally near the base with a sharp blade, early in the morning. You will soon see the drops of solution ooze out of the cut stem; this comes out due to the positive root pressure. If you fix a rubber tube to the cut stem as a sleeve you can actually collect and measure the rate of exudation, and also determine the composition of the exudates. Effects of root pressure is also observable at night and early morning when evaporation is low, and excess water collects in the form of droplets around special openings of veins near the tip of grass blades, and leaves of many herbaceous parts. Such water loss in its liquid phase is known as **guttation**.

Root pressure can, at best, only provide a modest push in the overall process of water transport. It obviously does not play a major role in water movement up tall trees. The greatest contribution of root pressure may be to re-establish the continuous chains of water molecules in the xylem which often break under the enormous tensions created by transpiration. Root pressure does not account for

the majority of water transport; most plants meet their need by transpiratory pull.

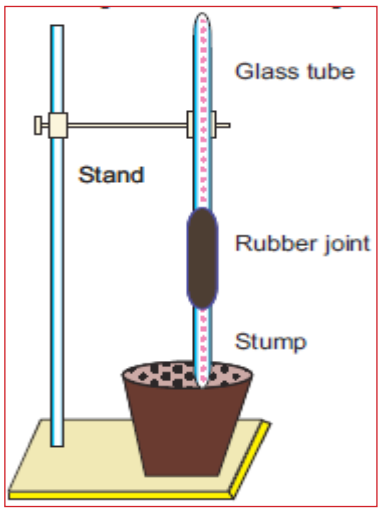


Figure 8.8: Root pressure

ii. Transpiration pull

Despite the absence of a heart or a circulatory system in plants, the flow of water upward through the xylem in plants can achieve fairly high rates, up to 15 metres per hour. How is this movement accomplished? A longstanding question is, whether water is 'pushed' or 'pulled' through the plant. Most researchers agree that water is mainly 'pulled' through the plant, and that the driving force for this process is transpiration from the leaves. This is referred to as the cohesion-tension-transpiration pull model of water transport . But, what generates this transpirational pull?

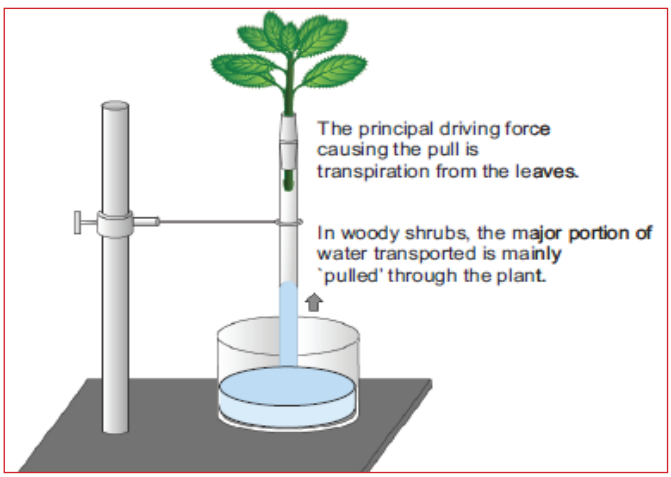


Figure 8.9: Transpiration pull

Water is transient in plants. Less than 1 per cent of the water reaching the leaves is used in photosynthesis and plant growth. Most of it is lost through the stomata in the leaves. This water loss is known as transpiration.

You have studied transpiration in an earlier class by enclosing a healthy plant in polythene bag and observing the droplets of water formed inside the bag. You could also study water loss from a leaf using cobalt chloride paper, which turns colour on absorbing water.

1 MPa = 10 atmospheres or 14.5 pounds/inch^2.

The root hairs are not developed in some of conifer plants; thus, water is absorbed with the help of mycorrhizal associations. Mycorrhizal fungi also called vesicular arbuscular mycorrhizae (VAM) also play an important role in absorption of water. Mycellia absorb water and minerals and transfers to the roots. These fungal mycelia obtain their food from the roots.

Velamen is a specialized tissue present on the outer side of cortex found in epiphytes such as orchid that absorb water through the hanging roots.

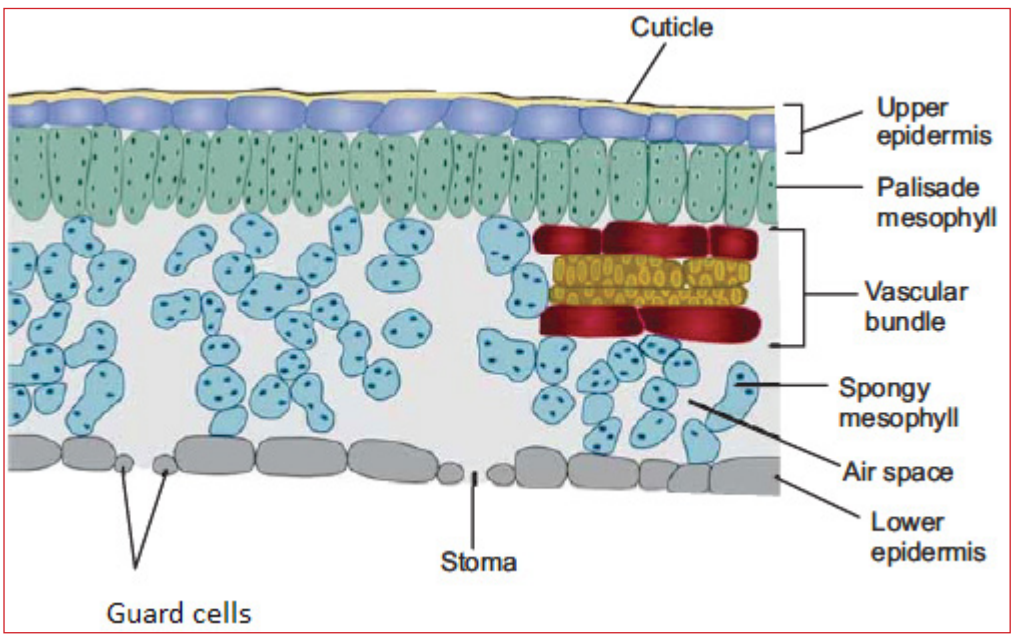


Figure 8.10: V.S leaf showing various parts

The outer layer of the leaf is epidermis surrounded by palisade parenchyma cells. The epidermis has stomata composed of guard cells. Stomata can be present on both the leaf surfaces. In many plants, stomata are present only on the lower leaf surface. The epidermis is protective in function.

The palisade layer is made up of columnar epithelial cells joined end-to-end having many chloroplasts. Below the palisade layer are round spongy parenchyma cells that have conspicuous intercellular spaces. The conducting tissue system consists of tissues present near or at the centre of midrib region. The xylem is composed of vessels and trachieds and phloem has fibres and parenchyma. Larger vascular bundles are surrounded by bundle sheaths .

Plants do not have systems for transporting oxygen and carbon dioxide. Instead, these gases diffuse through air space within stems, roots and leaves.

e. Transpiration in plants

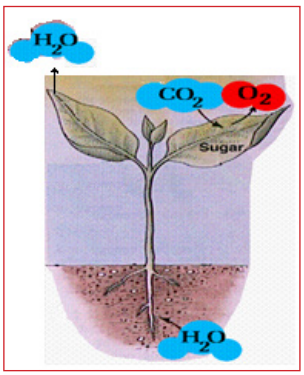


Figure 8.11: Process of transpiration in plants

Transpiration is a physical process responsible for uptake of water in the form of water vapours from the plants. Most of the transpiration takes place from the leaves through stomata, cuticles and lenticels. Transpiration through stomata is called **stomatal transpiration**. It accounts to 90-95% of the total transpiration. Small quantity of water is also lost through cuticle. Stomatal opening and closing affects the rate of transpiration in plants. Changes in turgor pressure of the guard cells cause stomata to open or close. Both the upper and lower leaf surfaces have a flattened layer of cells called epidermis. Epidermis is covered by a waxy layer called cuticle. In many plants, the lower epidermis has a pair of bean shaped cells called guard cells which along with the subsidiary cells and other guard cells form stomatal complex. Guard cells in dicots are kidney shaped and in monocots are dumbbell shaped. Guard cells have thickenings in inner walls. The guard cells together form a stomatal pore or aperture. Of the total water taken up by the plant most of it is lost in the form of water vapour. This type is **cuticular transpiration**.

Stomata are also meant for gaseous exchange of oxygen and carbon-dioxide, but transpiration also occurs when they are open .

There is a trade off during the gas-exchange that is important for respiration and photosynthesis in the plant systems.

About less than 0.5% is lost through the lenticels, tissues on stem and fruits. This is called **lenticular transpiration**.

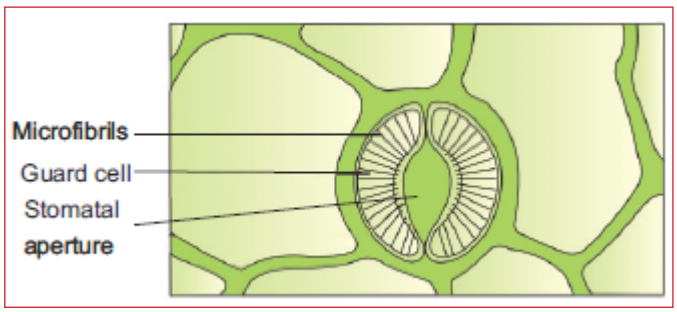


Figure 8.12: Transpiration occurs through stomatal aperture

f. Factors affecting transpiration

The absorption of water from the roots is affected by many physico-chemical properties of soil such as soil temperature, soil air, amount of water available in the soil and concentration of mineral salts in the soil . Atmospheric humidity, temperature, wind velocity, light and water availability in the soil affect the rate of transpiration in the plants. Study of various temperature treatments on plants can be studied by using simple potometers**.** In increased light intensity stomata open wider to allow more carbon dioxide into the leaf for photosynthesis.

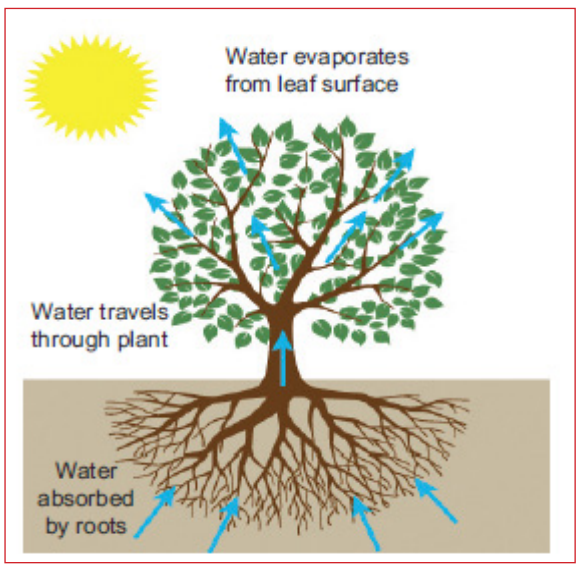


Figure 8.13: Process of transpiration on a sunny day

With the increase in wind velocity, there is also increase in the rate of transpiration as water evaporates fast.

Temperature affects transpiration indirectly through its effect on water vapour present in the air. An increase in temperature brings about decrease in relative humidity of the air thus increasing rate of transpiration.

g. Significance of transpiration

Transpiration helps the plants in many ways. It has been considered as a necessary evil. This is because plants lose lot of water due to the process but it is vital for many other physiological processes. The reasons why this process is advantageous to plants are:

1. It maintains and regulates temperature by evaporative cooling.
2. It helps in absorption and transportation of mineral ions in plants.
3. It provides water to keep cells turgid in order to support the plant.
4. It makes water available to leaf cells for photosynthesis.

8.2.2 Transport of organic sap through phloem

Process of the movement of food synthesized during photosynthesis from the leaves to the roots and other parts of a plant through the phloem is called **translocation**. This is carried out by another conducting tissue phloem.

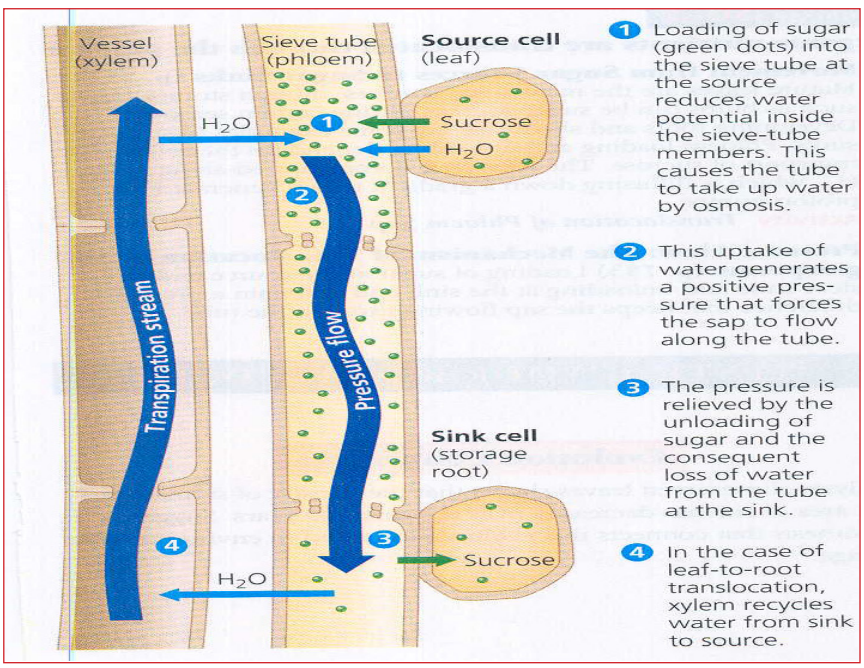


Figure 8.14: Transport of organic matter in a plant.

The organic sap transport requires the 3 main steps which are :

i. **Loading**: movement of solutes such as carbohydrates from leaf photosynthetic cells/source to the sieve tube of the phloem .

ii. **Translocation** : step in which the pressure inside the sieve tube pushes the sucrose and other substances from the source to the sink such as root or flower, stem or fruit or young leaf unable to photosynthesize.

iii. **Unloading**: movement of solutes (such as **sucrose**)followed by water from the sieve tube to the sink cell .

a. Movement of sugar in plants

As sugar is synthesized in the leaves by the process of photosynthesis its high concentration inside the phloem cells of the leaf creates a diffusion gradient by which more water is transported into the cells. Translocation takes place in the sieve tubes, with the help of adjacent companion cells. Food is translocated in the form of sucrose. The movement of water and dissolved minerals in xylem is always upward from soil to leaves against the gravitational pull. However, the movement of food can be upward as well as downward depending upon the needs of the plants.

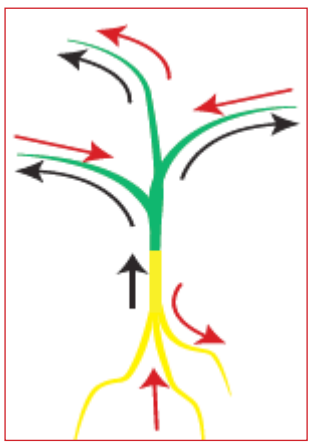


Figure 8.15: Phloem Transport can be bidirectional represented by red arrows

b. Mechanism of uptake of food in plants

As explained earlier, leaves manufacture food by the process of photosynthesis and transport it to other parts of the plants. Part of plants where food is formed more than requirement is known as **source**. Leaves act as a source and where these are stored and sent is the **sink**. Roots act as sinks for food. Movement of food takes place from source to the sink. Leaves prepare food in the form of glucose that is converted into sucrose. Sucrose enters into the phloem at the expense of energy in the form of ATP.

It is noteworthy that in plants, roots, fruits and other organs also act as storage organs for food and from here the food is translocated to other parts. So, the direction of movement of the phloem can be both upwards and downwards and hence the movement is bidirectional. Sugars, hormones and amino-acids are also transported or translocated through phloem. Transport of food involves 3 steps: Phloem loading, translocation and phloem unloading. Sucrose and other carbohydrates are **actively loaded** into the sieve tubes at the source by a **chemiosmotic mechanism.** It requires ATP.

ATP supplies energy to pump protons out of the sieve tube members into the apoplast.

Creates proton gradient.

The gradient drives the uptake of sucrose into the symplast through channels by the **cotransport** of protons back into the sieve tube members.

Osmotic concentration of phloem increases due to presence of sucrose. Therefore, water enters into sieve tubes by osmosis, due to which the hydrostatic pressure is created in phloem. High pressure in the phloem allows the movement of food to all parts of the plants having low pressure in their tissues. The *pressure-flow hypothesis* proposed by Munch is the simplest model and continues to earn widespread support among plant physiologists. The pressure-flow mechanism.

is based on the mass transfer of solute from source to sink along a hydrostatic (turgor) pressure gradient. Translocation of solute in the phloem is closely linked to the flow of water in the transpiration stream and a continuous recirculation of water in the plant.

Theory proposes that food molecules flow under pressure through the phloem. The food is mixed with water. The pressure is created by the difference in water concentration of the solution in the phloem and the relatively pure water in the nearby xylem. Sugars manufactured in mesophyll cells are driven by energy into the companion cells and sieve tube elements of the phloem. After accumulation into the phloem, water enters in cells by osmosis. A pressure is built up in sieve tubes called turgor pressure. Due to this pressure, sugars are removed by the cortex of both stem and root and consumed or converted into storage products such as starch. Starch does not exert any osmotic effect. Hence, osmotic pressure of phloem cells decreases. Thus, the pressure gradient created between leaves and shoot and root drives the contents of the phloem up and down through the sieve tubes .

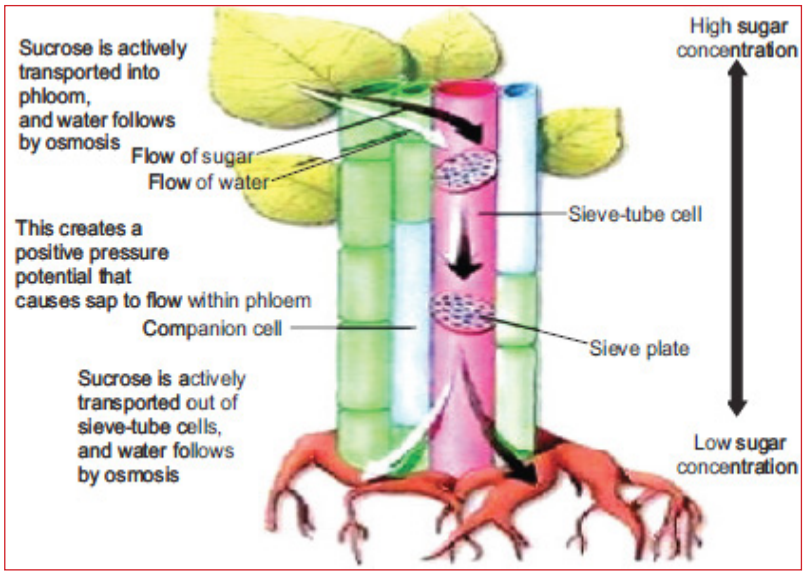


Figure 8.16: Illustrated account of the phloem transport in plants

Assimilates including sucrose, amino acids and nutrients are transferred into sieve elements of fully expanded leaves against significant concentration and electrochemical gradients. This process is referred to as phloem loading. The cellular pathways of phloem loading, and hence transport mechanisms and controls, vary between plant species. Longitudinal transport of assimilates through sieve elements is achieved by mass flow and is termed phloem translocation. Mass flow is driven by a pressure gradient generated osmotically at either end of the phloem pathway, with a high concentration of solutes at the source end and a lower concentration at the sink end. At the sink, assimilates exit the sieve elements and move into recipient sink cells where they are used in growth or storage processes. Movement from sieve elements to recipient sink cells is called phloem unloading. The cellular pathway of phloem unloading, and hence transport mechanisms and controls, vary depending upon sink function.

Figure 8.17: *(a) Girdling in trees*

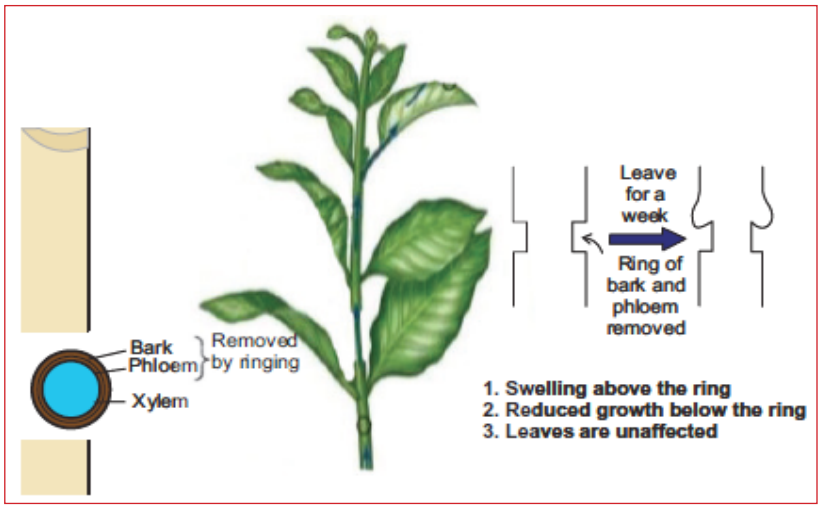


Figure 8.17: (b) Picture showing the role of phloem in translocation of food

A simple experiment, called girdling, was used to identify the tissues through which food is transported .On the trunk of a tree a ring of bark up to a depth of the phloem layer, can be carefully removed. In the absence of downstream movement of food, the portion of the bark above the ring on the stem becomes swollen after a few weeks . This simple experiment shows that phloem is the tissue responsible for translocation of food : and that transport takes place in one direction, i.e., towards the roots.

c. To Investigate Mass Flow Hypothesis

In mass flow, Munch's model demonstrates that fluid flows from the region of high hydrostatic pressure to the region of low hydrostatic pressure.

As fluid flows, it carries the whole mass of different substances.

In osmometer A, concentrated sucrose solution (leaf) has lower water potential. Water flows into it from a high water potential region (xylem vessel) to a low water potential region (leaf cells) by osmosis.

This create high hydrostatic pressure in A and forces sucrose solution to enter into the connecting tube (sieve tube) and pass to B (root cell).

As the flow of mass from osmometer A to osmometer B continues, the sucrose solution is pushed along and finally appears in B.

In B, contain water/dilute sugar solution, water moves out from a higher water potential region by the hydrostatic pressure gradient produced and redistributed through connecting tube (xylem vessels) between the two containers.

Mass flow continues until the concentration of sugar solution in A and B are equal (balanced).

In nature, equilibrium is not reached because solutes are constantly synthesized at source A and utilized at the sink B.

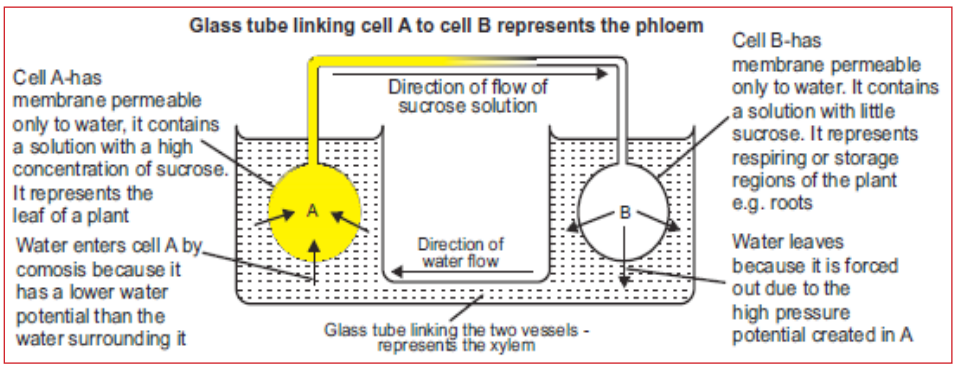


Figure 8.18: Model of mass flow hypothesis

8.2.3 Adaptations of Xerophytes to reduce water loss by transpiration.

Many plants show various morphological features that help them survive in regions with low water availability. The morphological variations are observed in root, stem, branching pattern, types of leaves and other parameters. These variations are manifestations of changes taking place in the plants at various other levels such as anatomical and biochemical level. These variations are termed as adaptations and help plants to survive in a particular environment. Plants that grow in environments that have plenty of water have stomata on both upper and lower epidermal cells of the leaves. These have isobilateral leaves, aerenchyma in stems and undeveloped vascular bundles.

However, the plants growing in low water availability show various xeromorphic and xerophytic characters. Xerophytic plants exhibit a variety of specialized adaptations to survive in such conditions. Xerophytes may use water from their own storage, allocate water specifically to sites of new tissue growth, or lose less water to the atmosphere and so convert a greater proportion of water in the soil to growth.

Xerophytic adaptation of reducing water loss by transpiration:

1. Xerophytes have thick waxy cuticle which reduces evaporation as it acts as a barrier. The shiny surface also reflects heat and so lowers temperatures reducing water loss.

2. They have rolled leaves or leaves reduced to spines to reduce water loss.
3. Stomata are present in pits. They are sunken. They open at night to reduce the amount of water lost by transpiration.
4. Roots are deep and/or spreading to maximize the absorption of underground water.
5. They exhibit crassulacean acid metabolism, i.e., CAM Physiology.
6. They have fleshy stems or leaves—some cells in stems or leaves have very large vacuoles that acts as water storage areas. These stems are also called succulent stems.

Application activity 8.2

1. Choose among the following terms , those which can complete these statements.

List of terms: Root pressure,Transpiration, Potometer , potassium ion, sunken ,CAM

Statements

i. …….. is the loss of water from plants.
ii. …….. is used to study the rate of transpiration.
iii. Xerophytes have …….. stomata.
iv. Xerophytes exhibit …….. metabolism.

2. Draw and describe the mass flow hypothesis in the translocation of phloem sap.

8.3 Circulatory system in insects, annelids, fish and mammals

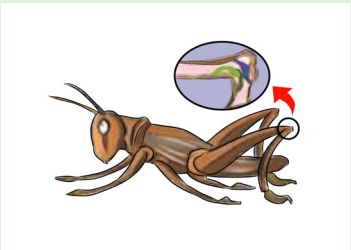
Activity 8.3

Observe the illustrations of animals below and answer the following questions


Earthworm


Lion


Fish



Grasshopper

Do the above animals have the same circulatory system? Justify your reasoning by distinguishing the type of circulatory system(s) found in each animals?

8.3. 1 Open circulatory system

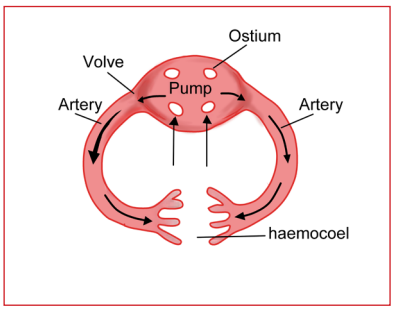


Figure 8.19: Drawing showing the open circulatory system.

The open circulatory system is common to **mollusks** and **arthropods**. Open circulatory systems evolved in **crustaceans**, **insects**, **mollusks** and **other invertebrates**.

In animals, circulatory system is either open or closed.

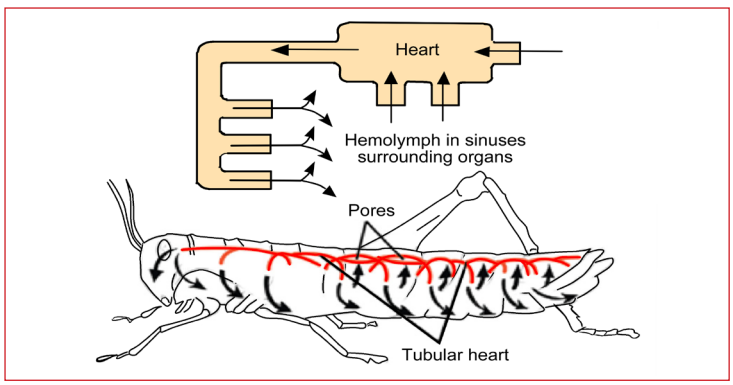


Figure 8.20: Open circulation in insect (Adapted from Campbell Biology 11th Edition)

Insects and other arthropods have a heart which is an elongated tube located dorsally. The internal organs are suspended in a network of blood-filled sinuses which collectively form the haemocoel. Blood from the heart mixes with the interstitial fluid in the haemocoel to form haemolymph. The **advantage** of this system the direct exchange of materials between body cells and haemolymph.

8.3. 2 Closed circulatory system

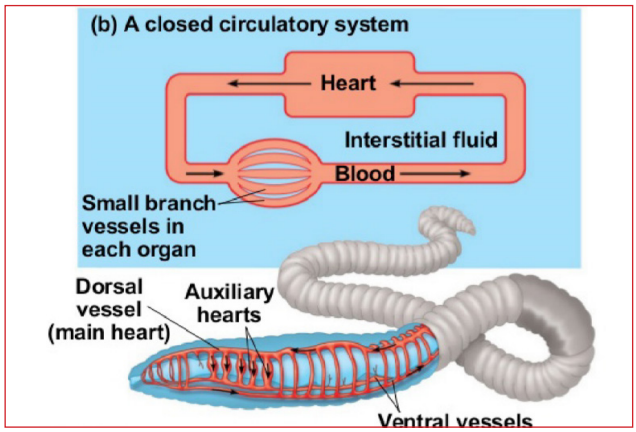


Figure 8.21: Closed circulation in annelids (adapted from Campbell Biology 11th edition)

The earthworm possesses a closed circulation system whereby the blood is confined to a series of blood vessels and not permitted to mix with the body tissues. Blood is pumped around the system by muscular longitudinal and ventral vessels and five pairs of lateral pseudo-hearts in segments 7 to 11. Backflow of blood is prevented by valves. The blood itself contains haemoglobin dissolved in the plasma and some phagocyte cells. It is **advantageous** for an organism to have closed circulatory system because:

- It helps in control of distribution of blood to different parts of the body.
- Muscular walls of vessels can constrict and dilate to vary the amount of flow through specific vessels
- Blood pressures are fairly high and the circulation can be vigorous
- It is more efficient hence the blood can reach further distances
- Allows for more control over oxygen delivery

All vertebrates including; fish, amphibians, reptiles, birds and mammals possess a prominent muscular heart which pumps blood around the body. The closed circulatory system can be single, partial and double.

Table 8.1: A comparison between open and closed circulatory systems

Closed circulation	Open circulation
Present in annelids and vertebrates	In invertebrates mainly arthropods
Blood does not bath the cells	Blood directly bathes the cells
Blood flows into vessels	Blood flows into haemocoel
There is a muscular heart	There is not muscular heart but nodes as simple heart
Higher blood pressure	Lower blood pressure
Blood contains hemoglobin	There is no hemoglobin
Examples: Earthworms, fish, frog, human	Examples: insect, arachnids

The closed circulatory system can be single or double.

1. Single circulation in fish

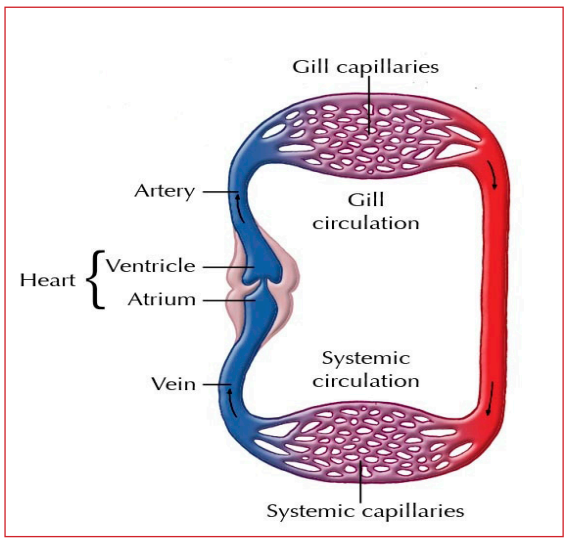


Figure 8.22: Single circulation in fish.

Fish have a two-chambered heart made of one atrium and one ventricle. Deoxygenated blood from the body is pumped by the heart to the gills. Here blood is oxygenated before passing around the body and ultimately returning to the heart. Blood has to pass through two capillary systems, the capillaries of the gills and then those of the body before returning to the heart. Capillaries offer considerable resistance to the flow of blood. This means that, in fish , there is a marked drop in blood pressure before the blood completes a circuit. In this type of circulation, it is an advantage that the blood circulating in the body has already been oxygenated in the gills.

2. Complete double circulation in mammals and birds

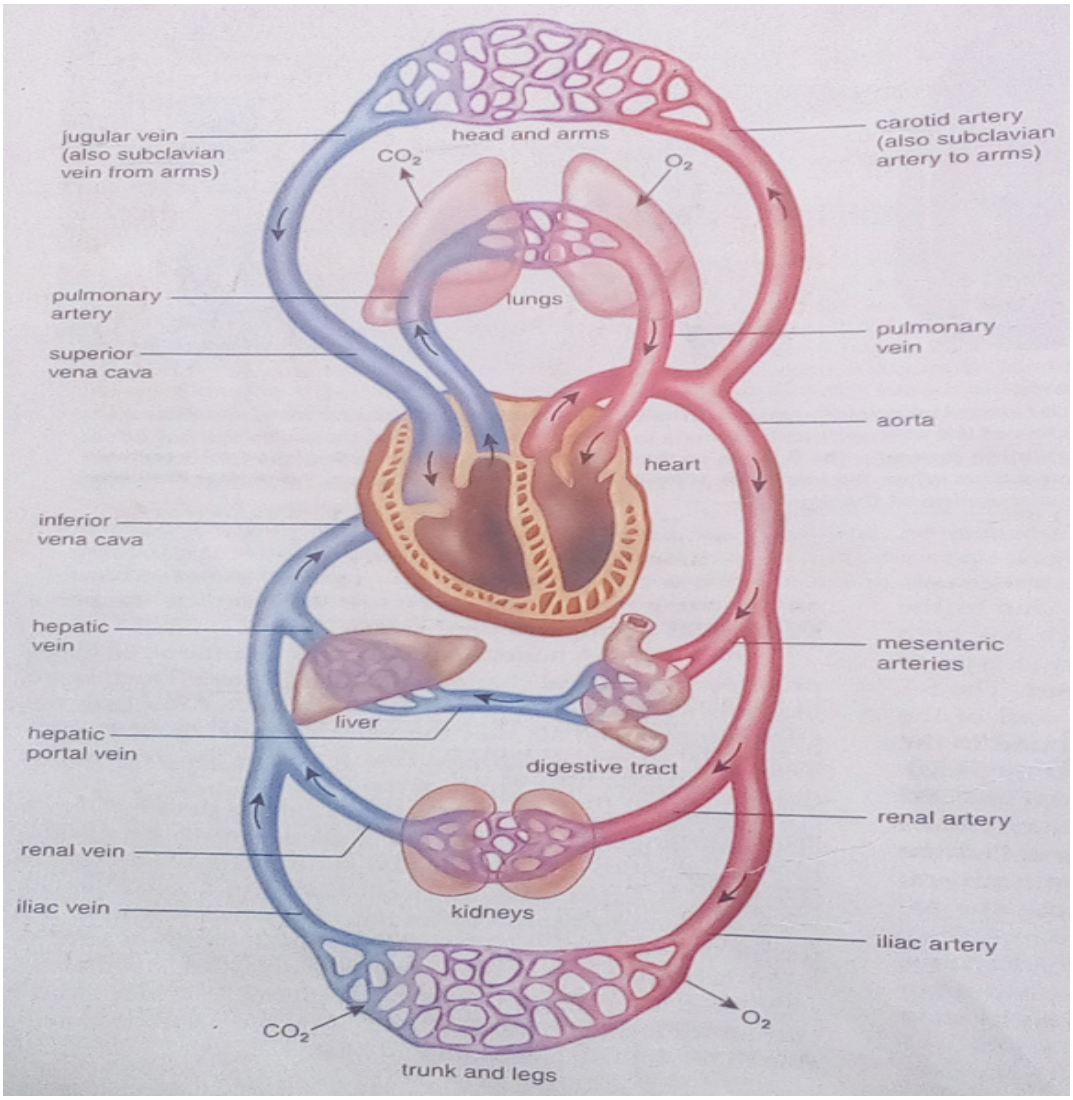


Figure 8.23: Closed double circulation in mammals and birds

The right side of the heart delivers oxygen - poor blood to the capillary beds of the gas exchange tissue in lungs, where there is a net movement of O2 into the blood and of CO2 out of the blood. This part of the circulation is called *a* **pulmonary circuit** or **pulmonary circulation** .After the oxygen- enriched blood leaves the gas exchange tissues, the lungs, it enters the left side of the heart. Contraction of the left part of the heart propels this blood to the capillary beds in organs and tissues throughout of the body. Following the exchange of O2 and CO2 as well as nutrient and waste products, then the oxygen poor blood returns to the right part of the heart, completing the **systemic circuit** or the **systemic circulation**.

This circulation is called double circulation because blood must pass twice in the heart for one complete circuit. Mammals and birds have a four-chambered heart and a complete double circulation. The following are some of the advantages of double circulation:

- The heart can increase the pressure of the blood after it has passed through the lungs, so the blood flows more quickly to the body tissues.
- The systemic circulation can carry blood at a higher pressure than the pulmonary circulation.
- The blood pressure must not be too high in the pulmonary circulation, otherwise it may damage the delicate capillaries in the lungs.

Partial double circulation in amphibians

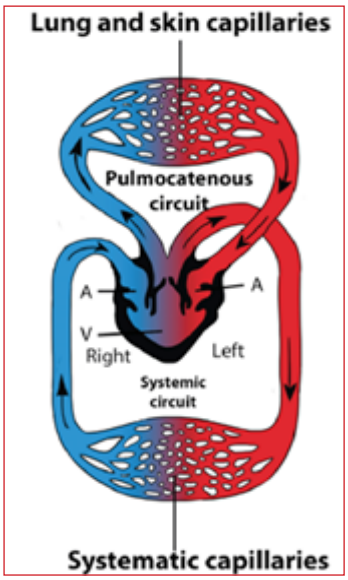


Figure 8.24: Closed circulation amphibian

Frogs and other amphibians have three-chambered hearts, with two atriums and one ventricle. Blood pumped from the ventricle enters a forked artery. One fork, the pulmonary circulation, leads to the lung. The other fork, the systemic circulation, leads to the rest of the body. Blood returning from the pulmonary circulation enters the left atrium, while blood from the systemic circulation enters the right atrium. Although there is **some mixing** of oxygenated and deoxygenated blood in the ventricle, a ridge within the ventricle assures that most of the oxygenated blood is diverted to the systemic circulation and most of the deoxygenated blood goes to the pulmonary circulation. In reptiles, this ridge is more developed, forming a partial wall.

In crocodiles, the wall is complete, forming a four-chambered heart like that found in mammals and birds. All amphibians and most of the reptiles possess a heart with two atria and one ventricle. This circulation is called partial because the only one ventricle received oxygenated and non-oxygenated blood which can be mixed as illustrated below:

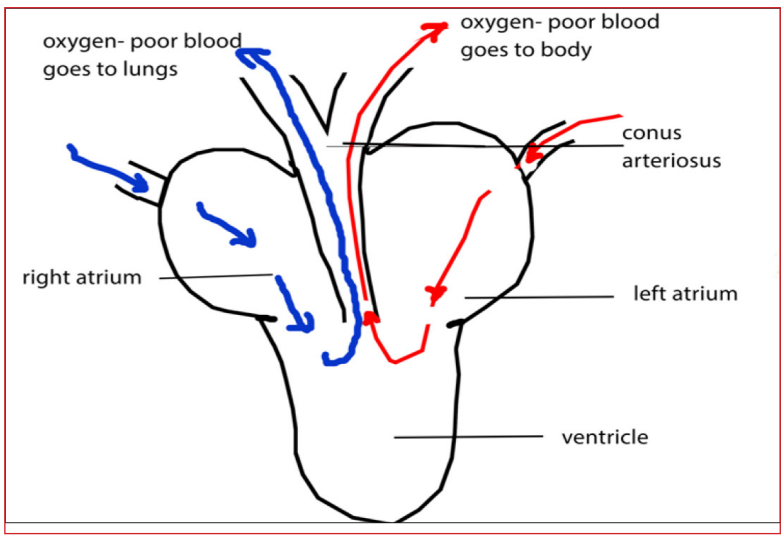


Figure 8.25: Illustration of partial double circulation in amphibians

A spiral valve called conus arteriosus helps to keep deoxygenated and oxygenated blood separate to some extent. The figures below distinguish how closed circulation occurs in fishes and in amphibians.

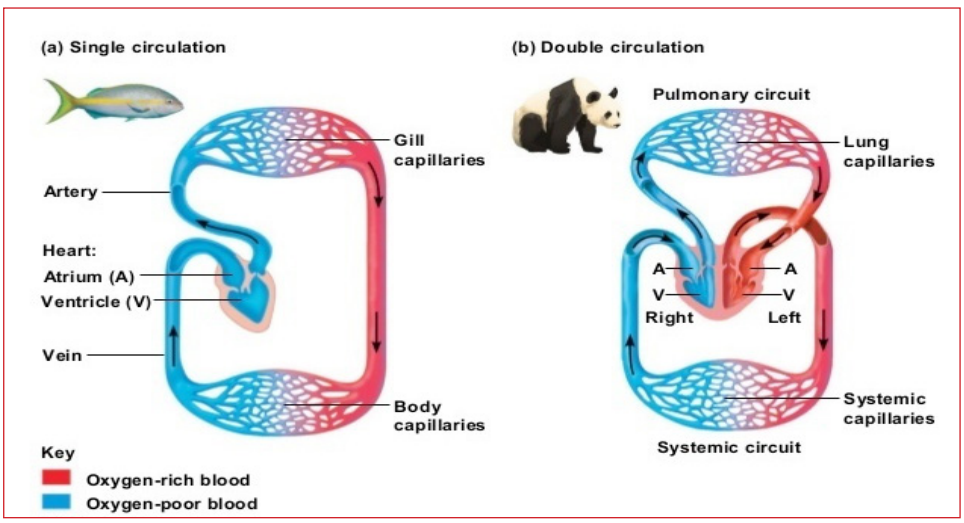


Figure 8.26: Illustration of single and double circulation

Table 8.2: Comparison between single and double circulation

Single circulation	Double circulation
Blood passes through the heart once during one complete circuit of the body	Blood passes through the heart twice during one complete circuit of the body
Lower blood pressure	Higher blood pressure
Present in fish.	Present in amphibians, reptiles, birds and mammals

Application activity 8.3

1. Choose the statement which is incorrect about the need of transport system in animals:

a. It transports respiratory gases, nutrients, hormones, metabolic wastes etc .

b. It protects against some diseases thanks to antibodies, against permanent bleeding thanks to thrombocytes etc.

c. It contributes to regulation (homeostasis) such as thermoregulation.

d. It contains neurons that conduct the nerve impulses.

2. Show how the open and closed circulatory systems differ.
3. Draw the human double circulation

8.4 Structure of the mammalian heart

Activity 8.4

Aim: To investigate the structure of human heart

Materials: Mammalian heart, dissecting kit.

Procedure

i. Obtain an intact heart of sheep or goat from a butcher's shop or slaughterhouse

ii. Rinse it under a tap to remove excess blood

iii. Observe the surface of the heart and identify the main visible features

iv. The blood vessels may have been cut off, but it is possible to identify where

v. These would have been attached later in the dissection

The heart is a striated muscle located between the two lungs and behind the sternum in the thorax and which contracts in order to propel blood throughout the body

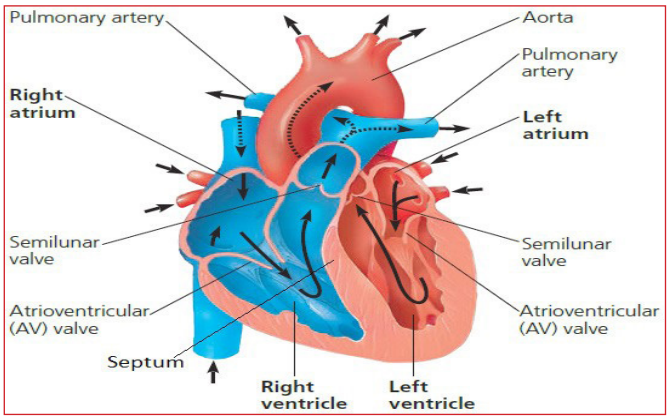


Figure 8.27: Structure of human heart (From Campbell 11th Edition)

The walls of the heart are composed of interconnected cardiac muscle fibers, connective tissue and tiny blood vessels. Each fiber possesses one or two nuclei and many large mitochondria. The heart is surrounded by a tough sac called **pericardium**. A **pericardial fluid** is secreted between the membranes allowing them to move easily over each other. The pericardium protects the heart from overexpansion caused by elastic recoil when it is beating very fast. The walls of the heart consist mainly of a special type of muscles called **cardiac muscle**.

The heart is divided into a left and a right side separated by the **septum**. The heart of mammals and birds is composed of 4 chambers including 2 upper thin-walled atria and 2 lower thick-walled ventricles. The right side of the heart is completely separated from the left. The right-side deals with deoxygenated blood and the left side with oxygenated blood. The muscular wall of the left ventricle is thicker than that of the right ventricle because the left ventricle has to pump blood to all round the body with much higher pressure.The left atrium is separated from the left ventricle by a *bicuspid* or *mitral* valve, whilst a *tricuspid* valve separates the right atrium from the right ventricle. Jointly, these two valves are known as *atrioventricular valves*. Atrioventricular valves are pushed open when atria contract but, when ventricles contract, they close and produce the *first sound* of the cardiac cycle, the second being that of the closing *semi-lunar valves* (aortic and pulmonary valves).

Application activity 8.4

1. Justify this statement: The right atrium is larger than the left atrium.
2. Associate the column A and B

Column A	Column B
1. The valve located between right atrium and right ventricle	a. Pulmonary
2. Sac surrounding the heart	b. Tricuspid
3. Artery linked to lungs	c. Pericardium

8.5 Heartbeat and the mammalian cardiac cycle

Activity 8.5: research activity

Use a computer simulation or a chart to observe the initiation of a heart and cardiac cycle. Then, draw the cardiac cycle that you have seen.

8.5.1 Initiation of a heartbeat

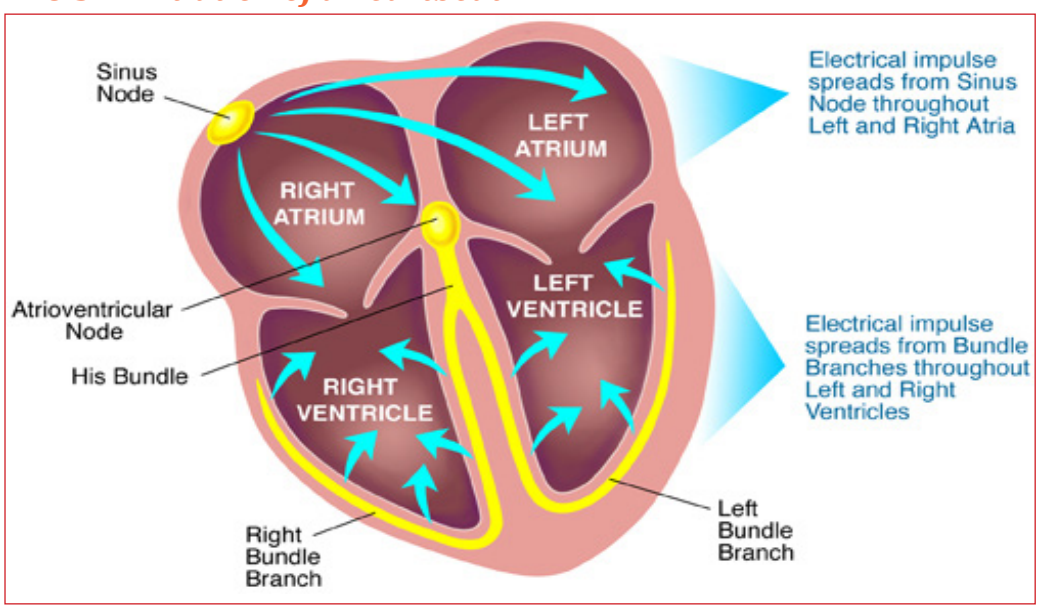


Figure 8.28: Initiation (origin) of heart- beat.

- Heartbeat is a rhythmic sequence of contractions of the heart. It is coordinated by *two small groups of cardiac muscle cells* called the *sinoatrial (SA)* and *atrioventricular (AV) nodes*. The *sinoatrial node*, often known

as the *cardiac pacemaker*, is found in the upper wall of the right atrium and is responsible for the wave of electrical stimulation that starts atrial contraction by creating an action potential. The action potential causes the cardiac cells to contract. This wave of contraction spreads across the cells of the atrium, reaching the atrioventricular node (AV node) which is found in the lower right atrium.

- The atrioventricular node conducts the electrical impulses that come from the SA node through the atria to the ventricles. The impulse is delayed there before being conducted through special bundles of heart muscle cells called the *bundle of His*. There is a collection of heart muscle cells (fibers) specialized for electrical conduction that transmits the electrical impulses from the AV node and the *Purkinje fibers*, which leads to a contraction of the ventricles. This delay allows for the ventricles to fill with blood before the ventricles contract. Heartbeat is also controlled by nerve messages originating from the autonomic nervous system.
- The bundle of His branches into Purkinje fibers. Purkinje fibers, specialized cardiac muscle cells, conduct action potentials into the ventricles and cause the cardiac muscle of the ventricles to contract in a controlled way.

8.5.2 Mammalian cardiac cycle and cardiac sounds

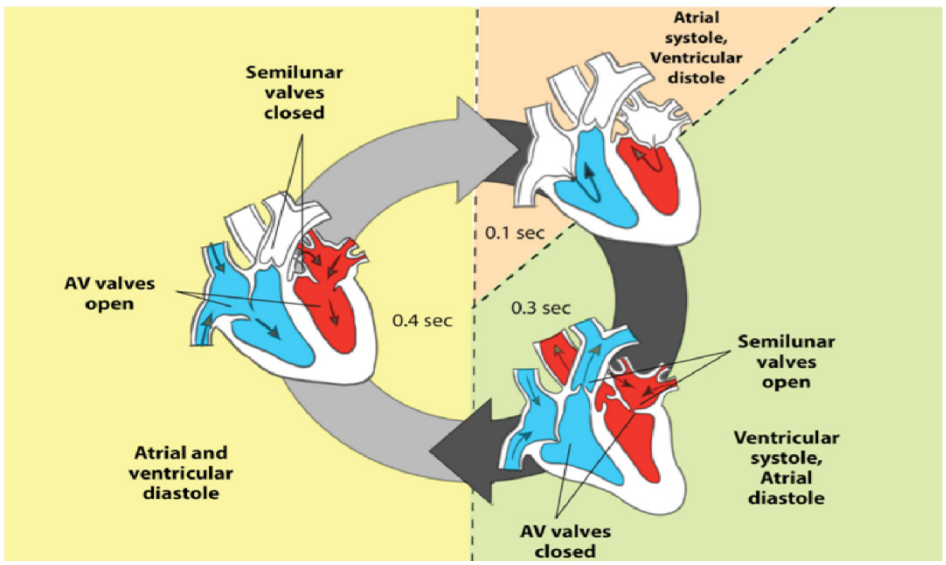


Figure 8.29: Cardiac cycle

The cardiac cycle is the sequence of events which take place during the completion of one heartbeat. It involves repeated contraction (*systole*) and relaxation (*diastole*) of the heart muscle.

Table 8.3: Cardiac cycle (heartbeat) time.

Cardiac cycle (heartbeat)		
Time	Atria	Ventricles
0.15 second	Systole	Diastole
0.30 sec	Diastole	Systole
0.40 sec	Diastole	Diastole
Total: 0.85 second / heartbeat		

The steps in cardiac cycle are the followings:

1. **Atrial and ventricular systoles**

- When atria diastole ends, the two atria contract simultaneously, and it results in blood being pumped into the ventricles. The ventricles contract almost immediately after the atria, about 0.1 to 0.2 seconds later. When this occurs, the pressure in the ventricles rises and closes the atrioventricular valves, preventing blood from returning to the atria.
- The pressure forces open the semilunar valves and blood enters aorta and pulmonary artery. Arterial blood pressure is the highest when the heart contracts during ventricular systole. The pressure at this time is called **systolic pressure.** The high blood pressure caused by the powerful contractions of the ventricles stretch the arteries.

2. **Atrial and ventricle diastoles**

- During the time when the atria and ventricles are both relaxed, blood returns to the heart under low pressure in the veins and enters the two atria. At first the atrioventricular valves are closed but, as the atria fill with blood, pressure in them rises. Eventually it becomes greater than that in the relaxed ventricles and valves are pushed open.
- The higher pressure developed in the aorta and pulmonary artery during the ventricular systole tends to force some blood back towards the ventricles and this closes the semilunar valves. Hence backflow into the heart is prevented. The ventricular diastole ends the cardiac cycles and is followed by the atrial diastole. Hence the cycle restarts. When the heart rate is 75/min, which means 75 heartbeats per minute, the period of one cardiac cycle is 0.8 sec. During diastole, the elastic walls of the arteries snap back. As a consequence, there is a lower but still substantial blood pressure when the ventricles are relaxed (**diastolic pressure**).
- In healthy adults, there are two normal heart sounds often described as a **lub** and a **dub** that occur with each heart- beat (lub-dub, lub-dub). In addition to these normal sounds, a variety of other sounds may be

heard including ***heart murmurs*** or ***clicks***. A medical practitioner uses a *stethoscope* to listen for these sounds, which gives him or her important information about the condition of the heart.

- The **closing of atrioventricular valves**, mitral (bicuspid) and tricuspid, during **ventricular systole** produces the first heart sound, described as **lub**.
- the **closing of the semilunar valves** during **ventricular diastole** causes the second heart sound described as **dub**.

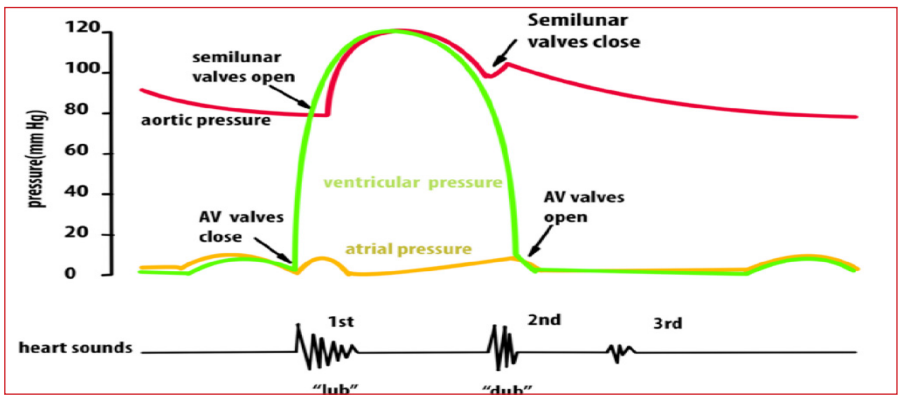


Figure 8.30: Relationship between heart sounds and key events in cardiac cycle

- The electrical activity of the heart can be monitored using an *Electrocardiogram (ECG)*. This involves attaching of sensors to the skin. Some of the electrical activity generated by the heart spreads through the tissue next to the heart and onwards to the skin. The sensors on the skin pick up the electrical excitation created by the heart and convert this into a trace.
- The trace of a health person has particular shape. It consists of a series of waves that are labeled *P, Q, R,* S and *T.* Wave *P* shows the excitation of the atria, while *QRS* indicates the excitation of the ventricles and *T* shows **diastole**.

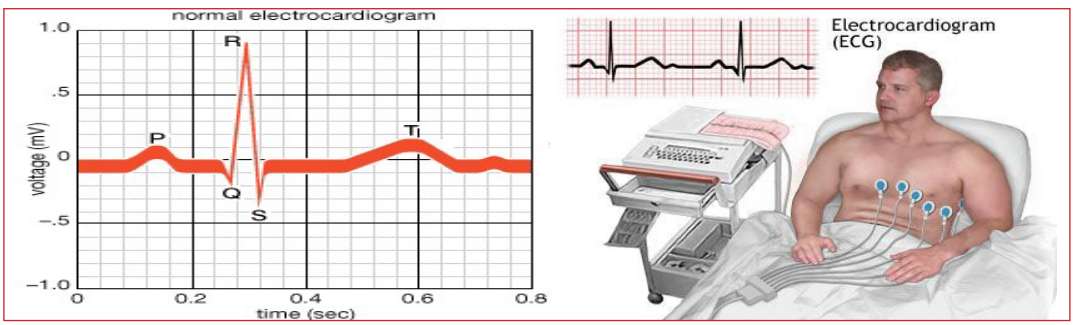


Figure 8.31.Electrocardiogram normal wave and electrocardiogram machine.

1. P: P wave- indicates that the atria are electrically stimulated (depolarized) to pump blood into the ventricles: contraction of atria.
2. QRS: QRS complex- indicates that the ventricles are electrically stimulated (depolarized) to pump blood out: in pulmonary artery and in aorta.
3. ST: ST segment- indicates the amount of time from the end of the contraction of the ventricles to the beginning of the T wave.
4. T: T wave- indicates the recovery period (repolarization) of the ventricles.
5. U: U wave- rarely seen, and thought to possibly be the repolarization of the papillary muscles.

Application activity 8.5

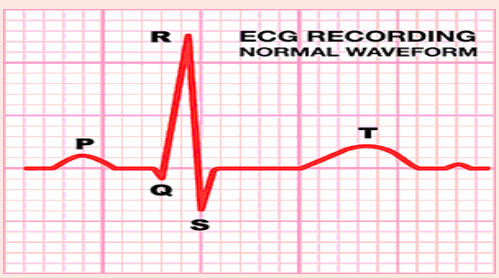
1. During the mass sports, the doctor made a medical check-up and found the following data from three participants A, B and C.

	Participant A	Participant B	Participant C
Number of heartbeat /min	92	72	52
Systolic pressure / mmHg	180	120	80
Diastolic pressure/ mmHg	120	80	60

   a. Among three participants, who has the cardiovascular problem? Why?

   b. Differentiate between systolic and diastolic pressure

2. Observe the illustration below and answer to the following questions:



   a. Interpret the shape of the electrocardiogram trace above.

   b. Explain why the QRS complex has a larger peak than the P wave.

8.6 Control of the heart rate and the factors controlling heart rate

Activity 8.6

Aim: Investigate and state the effect of physical activity on the pulse rate and blood pressure.

Material: Watch, or stop clok.

Procedure:

a. Place your middle finger on the artery found near the opening of the ear then determine the number of pulses during resting. Repeat this 3 time then calculate the average of heart- beat per minute.

b. Do some warm-up exercises within 2 minutes, again place your middle finger on the artery found near the ear then determine the number of pulses during resting. Repeat this 3 time then calculate the average of heart -beat per minute. Just use the stop clock or a watch to count the number of pulse (beatings) within one minute.

i. How does your heart rate immediately after a warm -up exercises differ from resting rate?

ii. How would you explain the differences?

8.6. 1 Control of the heart rate

a. Nervous and hormonal control of heart rate

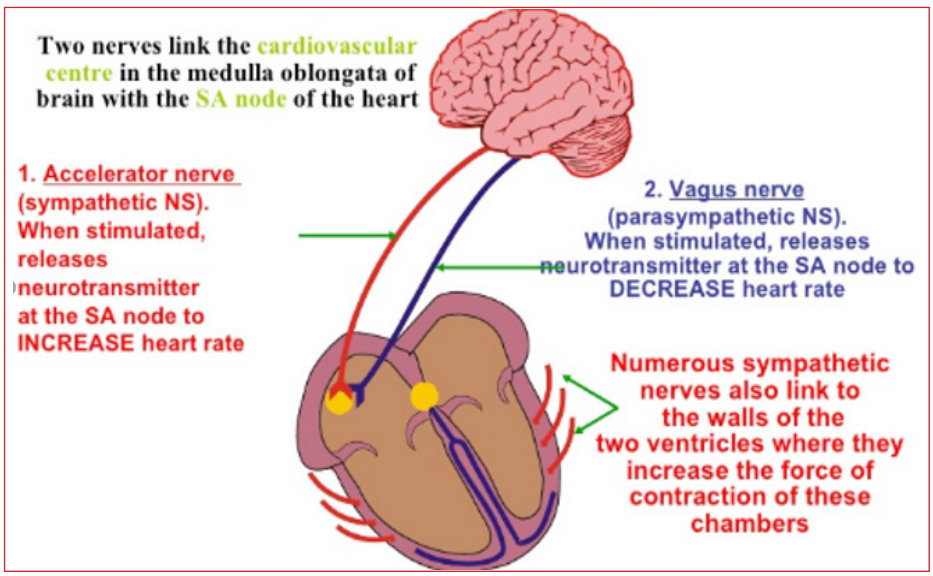


Figure 8.32: Nervous control of the heart-beat .

Heart muscle is **myogenic** because it has the **ability to initiate its own contractions**. The initiation of an action potential to travel along the atrial walls as a wave of excitation causing the contraction is initiated by the **sinoatrial node (SAN)** or **pacemaker.** This is where one heartbeat originates, then the signal spreads through the **atrioventricular node (AVN***)* and down the **Purkinje tissue** to the ventricular apex, and finally through the ventricles, causing them to contract. The signals are sent from brain to the SAN through two nerves from the autonomic nervous system specifically **sympathetic nerve** and **vagus nerve** from the brain to the heart. The **cardiovascular center** that sends impulses to the SAN is located in the **medulla oblongata** of the hindbrain. The medulla oblongata receives various signals itself, so that it can communicate with the SAN how to coordinate an appropriate response to the external changes. If the vagus nerve is stimulated, it causes a release of **acetylcholine** (neurotransmitter**)** , which slows down the rate of heartbeat but does not affect the force of ventricular contraction. **Baroreceptors** located in the aorta and carotid arteries detect the pressure of blood from the left ventricle. When the pressure is low, the baroreceptors stimulate the **vasomotor center (VMC)** of the hindbrain to send impulse via sympathetic nerve fibers. This induces **vasoconstriction** which causes increased resistance to blood flow and a corresponding rise in blood pressure. Conversely, when blood pressure is high, the impulses from VMC pass along parasympathetic fibers and stimulate **vasodilation** which causes reduction in blood pressure.

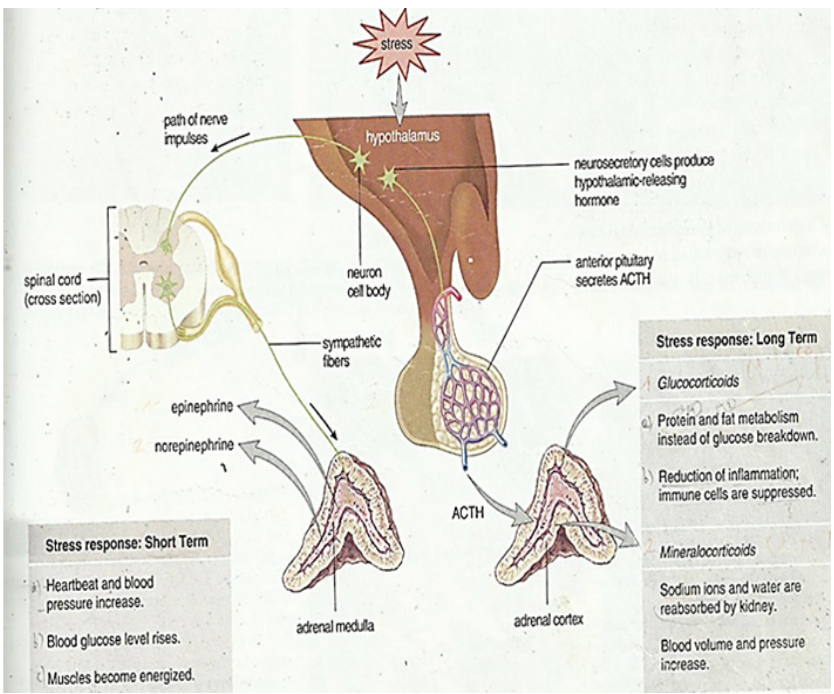


Figure 8.33: Hormonal control of heartbeat by adrenal hormones.

- The hormone called **adrenaline (epinephrine)** also affects the heart rate. In conditions of excitement, activity or stress, the **adrenaline** is released into the blood circulation from the adrenal glands (specifically adrenal medulla). Reaching the heart, it causes an increase in the rate and strength of the heartbeat.
- Epinephrine is also called adrenaline; norepinephrine is also called noradrenaline.

b. Other factors controlling heart rate

i. Carbon dioxide

Chemically, high CO_2 levels stimulate the vasomotor Centre (VMC) to vasoconstrict arterioles. The resulting high blood pressure transports CO_2 more rapidly to the lungs for expulsion and exchange with O_2. Where tissues suddenly become active, they produce more CO_2. This causes vasodilation of local blood vessels, thus increasing their blood supply and allowing more oxygen and glucose to reach them for respiratory purposes.

ii. Body temperature change

This is one of the thermoregulatory changes that occur to prevent the body's core temperature of 37^0C from increasing or decreasing. Heart rate increases when heat is gained by the body such as in hot climates and during physical exercise in order to transfer more heat away from the body. When the body loses heat such as in cold weather or a cold shower, heart rate decreases to preserve core temperature.

iii.pH and Mineral ions

A significant heart rate increase was obtained after a decrease of potassium and calcium and an increase in pH levels and with no significant variations in indices of autonomic activity. The analysis revealed that changes in physiological range of potassium, calcium, and pH could cause large heart rate variations from 60 to 90 bpm.

c. Effect of drugs and physical activity on cardiac frequency

i. Physical exercise

The heart rate and *blood pressure* both rise during physical *exercise.* Over time, regular physical *exercise* can help lower the resting *blood pressure* and heart rate. This is because physical *exercise* training improves the health of the heart and blood vessels, allowing the cardiovascular system to function more efficiently. This enables increased blood flow to muscles without putting excess pressure on blood vessel walls.

While blood pressure rises during exercise, it is too much smaller degree than the increase in heart rate.

ii. Caffeine and other drugs

Caffeine found in coffee, tea and soda is a stimulant drug that influences the nervous system to **increase heart rate.** It mimics the effect of adrenaline, a natural hormone in the body responsible for elevating heart rate. Other stimulants such as **cocaine** and ephedrine work in a similar manner.

There are specific drugs used in *lowering heart rate* such as beta- and calcium channel blockers. Beta-blockers work by interfering with the receptors that *adrenaline* binds to, subsequently decreasing hormonal influence on heart rate. Calcium channel blockers reduce the amount of calcium that enters the heart muscle. Because calcium is needed for muscle to contract, the heart beats at a slower rate when this drug is taken.

Application activity 8.6

1. The following is a list of hormones : oestrogen, progesterone, adrenaline, cortisol.

i. Identify the main hormone that immediately affects the heartbeat during stress.

ii. Relate that hormone to the heartbeat rate.

2. Some drugs like caffeine affect the heartbeat rate. Justify this statement.

8.7 Structure of blood vessels

Activity 8.7

Aim: To observe prepared slides of blood vessels.

Materials: Microscope, prepared slides of blood vessels and electrical current.

Procedure

i. Place the prepared slides of blood vessels on the microscope slide.

ii. Adjust to observe the blood vessels

Questions

1. Draw and label the observed blood vessels.
2. Compare those blood vessels.
3. Explain the relationship between each blood vessel and its function.

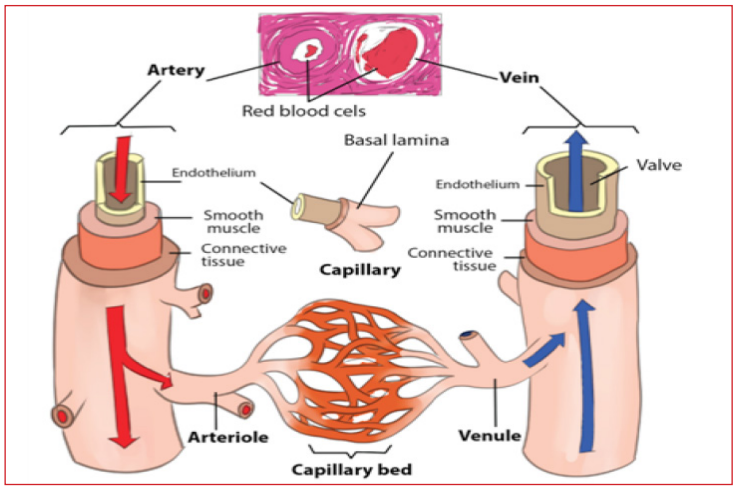
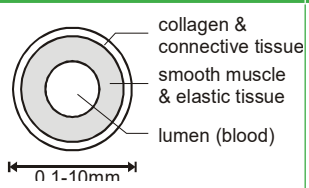
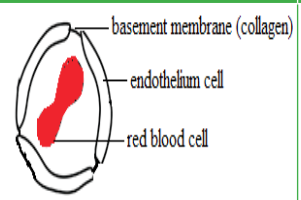
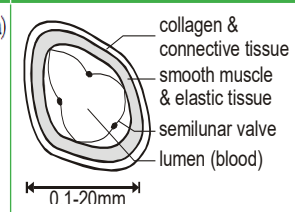


Figure 8.34: Illustration of blood vessels.

Table 8.4. Comparison between arteries, capillaries and veins.

	Arteries	Capillaries	Veins
Diagram			
Structure of wall	Thick and strong. Contain muscles, elastic fibers and fibrous tissue.	Very thin, only one cell thick.	Thin, mainly fibrous tissue. Contains far less muscle and elastic tissue than arteries
Lumen	Narrow and varies with heartbeat (increases as a pulse of blood passes through)	Very narrow and just wide enough for a red blood cell to pass through.	Wide
Valves	Absent, except in the aorta and pulmonary artery.	Absent	Present and prevent backflow of blood.
Branching	Branched into arterioles	No branch	Branched into venules

How a structure fits its function	Strength and elasticity needed to withstand the pulsing of the blood, prevent bursting and maintain pressure wave. It helps to maintain high blood pressure, preventing blood flowing backwards.	No need for strong walls, as most of the blood pressure has been lost. Thin walls and narrow lumen bring blood into close contact with body tissue, allowing diffusion of materials between capillary and surrounding tissues. White blood cells can squeeze between cells of the wall.	No need for strong walls, as most of the blood pressure has been lost. Wide lumen offers less resistance to blood flow
Function	Carry blood away from the heart at high pressure and transport oxygenated blood, exception for pulmonary artery	Supply all cells with their requirements. So, they provide large area for exchange of materials between blood and body cells, and take away waste products	Return blood to the heart at low pressure, and transport deoxygenated blood ,exception for pulmonary vein

Application activity 8.7

1. Associate the following vessels with their functions

Vessels	Functions
Blood artery	Carry carbonated blood from organs to heart.
Blood capillary	Carries oxygenated blood from heart to organs.
Blood veins	It is the site of exchange of materials between blood and tissue cells.

2. Link the adaptations of blood vessels to their functions.

8.8 Blood composition, its functions and cardiovascular diseases.

Activity 8.8

Aim: To examine the blood sample composition

Materials : Blood collected from the bucher, sharp material such as blade or knife, test tube or other container, microscope, slide, coverslip, stain (such as methylene blue) and cleaning tissue.

Procedure:

a. Visit a bucher and collect blood of animals (such goat, cow,…)
b. Place the blood in the container.
c. Use a microscope to observe a blood smear:
i. Place 3 drops of blood on the slide.
ii. Add 2 drops of stain (such as methylene blue).
iii. Cover with a coverslip
iv. Place the prepared sample on the microscope stage.
v. Adjust for observation.

1. Draw the structure of blood cells.
2. Identify body fluids composition.
3. Discribe cardiovascular diseases.
4. Discuss the relationship between blood, tissue fluid and lymph.

8.8.1 Main types of body fluids and their compositions

Body fluids are *liquids* originating from inside the body of living humans.

Table 8.5: Body fluids and their composition

Name	Composition
Blood	Blood is composed of plasma and different types of cells including red blood cells (erythrocytes), white blood cells (leukocytes), and thrombocytes (platelets).
Plasma	Plasma is a liquid yellowish portion of blood. It is composed of all the components of blood except the red and white blood cells and thrombocytes. Plasma contains water (90%), proteins (albumin, fibrinogen and globulins), nutrients (glucose, fatty acids, amino acids), waste products (urea, uric acid, lactic acid, creatinine), clotting factors, minerals, immunoglobulins, hormones and carbon dioxide,
Serum	Plasma minus fibrinogen.
tissue fluid (interstitial fluid)	Plasma minus most proteins
Lymph	Tissue fluid within lymphatic vessels

8.8.2 Composition and functions of blood

The main blood components are formed elements and plasma. Formed elements are erythrocytes (red blood cells), leukocytes (white blood cells) and thrombocytes (platelets).

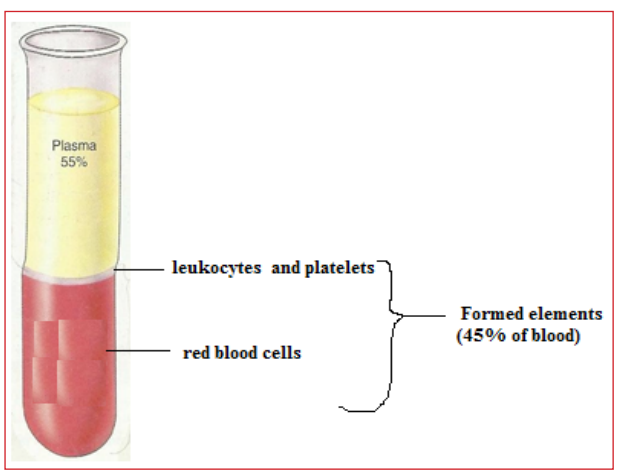
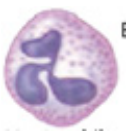
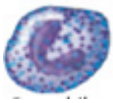
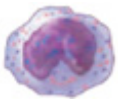


Figure 8.35: Blood sample in a test tube.

Table 8.6: Blood composition

Formed elements			
Blood component	**Origin (source)**	**Structure**	**Function**
Red blood cells (erythrocytes)	Bone marrow	 They have 7-8 μm in diameter and are bright-red to dark- purple biconcave cells without nuclei	Transport of oxygen and carbon dioxide.
White blood cells (leukocytes)	Bone marrow	Different structures	Fight infection
Granulocytes (granular leukocytes / **polymorphonuclear cells**)	Bone marrow	Different structures commonly including the granules in cytoplasm, hence their name	Different functions related to fighting infection
Neutrophils	Bone marrow	 They have 10-14μm in diameter, and they are spherical cells with multi-lobed nuclei, fine, and pink granules in cytoplasm.	Phagocytize pathogens
Eosinophils	Bone marrow	 They have 10-14μm in diameter. They are spherical cells with bi-lobed nuclei, coarse, deep-red, and uniformly sized granules in cytoplasm.	Phagocytize antigen-antibody complexes and allergens

Basophils	Red bone marrow	 They have 10-12µm in diameter. They are spherical cells with lobed nuclei, large, irregularly shaped and deep-blue granules in cytoplasm.	Release histamine which promotes blood flow to injured tissues, and produce heparin (anticoagulant)
Agranulocytes (agranular leukocytes/ **monomor-phonuclear cells**)	Bone marrow	Different structures commonly lacking granules in cytoplasm, hence their name	Different functions related to fighting infection
Lymphocytes	Bone marrow, lymphoid tissue and spleen	 . They have 5-17µm in diameter (average 9-10µm). They are spherical cells with large round nuclei.	**1. B-lymphocytes They** are responsible for humoral immunity, which are antibody secretion that recognize and bind to bacteria, allow their phagocytosis and destruction). Granulocytes and monocytes can better recognize and destroy bacteria when antibodies are attached to them (**opsonisation**). Cells are also responsible for the production of some components of blood serum, called immunoglobulin. **2. T-lymphocytes** recognize the infected cells and destroy virus using macrophages. These cells amplify or suppress the overall immune response by regulating the other components of the immune system, and secrete many cytokines.

Monocytes	Bone marrow	 They have 10-24µm in diameter. They are large spherical cells with kidney-shaped, round or lobed nuclei.	Become macrophages that phagocytize pathogens and cellular debris.
Platelets (thrombocytes)	Bone marrow	 They have 2-4µm in diameter. They are disk-shaped cell fragments, without nuclei; purple granules in cytoplasm.	Blood clotting (coagulation)

Plasma

	Different sources	**Different chemical molecular formulae**	**Different functions**
Water	Absorbed from small intestine	H_2O	Maintains blood volume and transport of molecules
Plasma proteins	Liver	Different chemical molecular formulae	Maintain blood osmotic pressure and pH
Albumin	Liver	$C_{123}H_{193}N_{35}O_{37}$	Maintain blood volume and pressure
Globulins	Liver	$C_{36}H_{61}N_7O_{19}$ (globulin G)	Transport and fight infection
Fibrinogen	Liver	$C_5H_{11}N_3O_2$	Blood clotting
Salts	Absorbed from small intestine	Different chemical molecular formulae	Maintain blood osmotic pressure and pH aid metabolism
Gases	Different sources	Different chemical molecular formulae	Different functions
Oxygen	Lungs	O_2	Cellular respiration
Carbon dioxide	Tissues	CO_2	End product of metabolism

Nutrients (Lipids, glucose, amino acids)	Absorbed from small intestine C6H12O6 (glucose) C6H14N4O2 (arginine)	$C_{27}H_{460}$ (cholesterol) $C_6H_{12}O_6$ (glucose) $C_6H_{14}N_4O_2$ (arginine)	Food for cells
2.6.Nitrogenous wastes (urea, uric acid)	Liver uric acid: C5H4N4O3	Urea : CH_4N_2O uric acid: $C_5H_4N_4O_3$	Excretion by kidneys
Others (Hormones, vitamins…	Varied	$C_{257}H_{383}N_{65}O_{77}S_6$ (insulin hormone)	Aid in metabolism

Application activity 8.8

1. Choose the cells contributing to phagocytosis of pathogens :

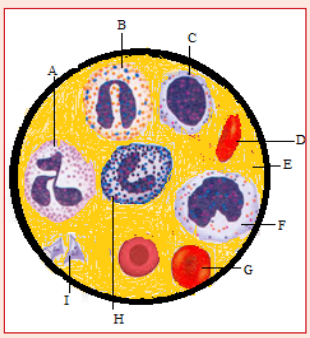
a. Macrophage.

b. T-lymphocytes.

c. Erythrocytes

2. Relate the blood to tissue fluid.

3. Look at the figure below and answer the questions that follow.



a. Identify the blood components represented by the letters A, B, C, D, E, F, G, H, I.

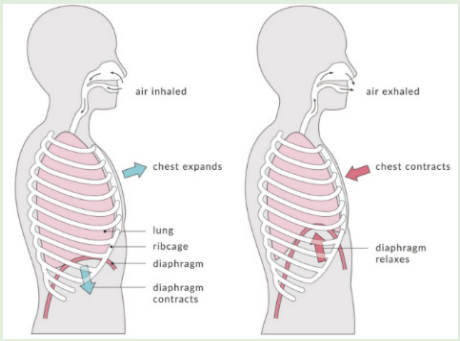
b. Identify the origin of each blood component.

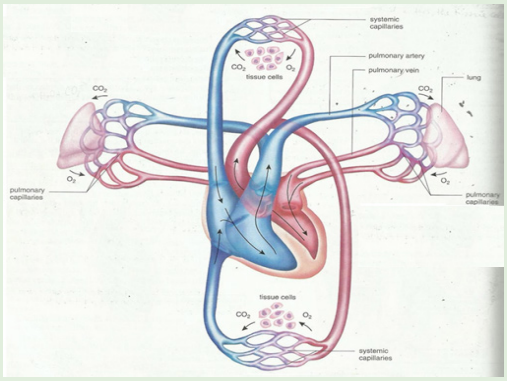
c. Show the functions of each of those blood components.

8.9 Transport of respiratory gases

Activity 8.9: research

1. **Observe the following illustrations and answer the following questions.**





Use illustrations, internet and library books to discover the origin and transport mechanism of respiratory gases.

The respiratory gases are oxygen (O_2) and carbon dioxide (CO_2) transported by haemoglobin.

a. Structure of haemoglobin of red blood cells

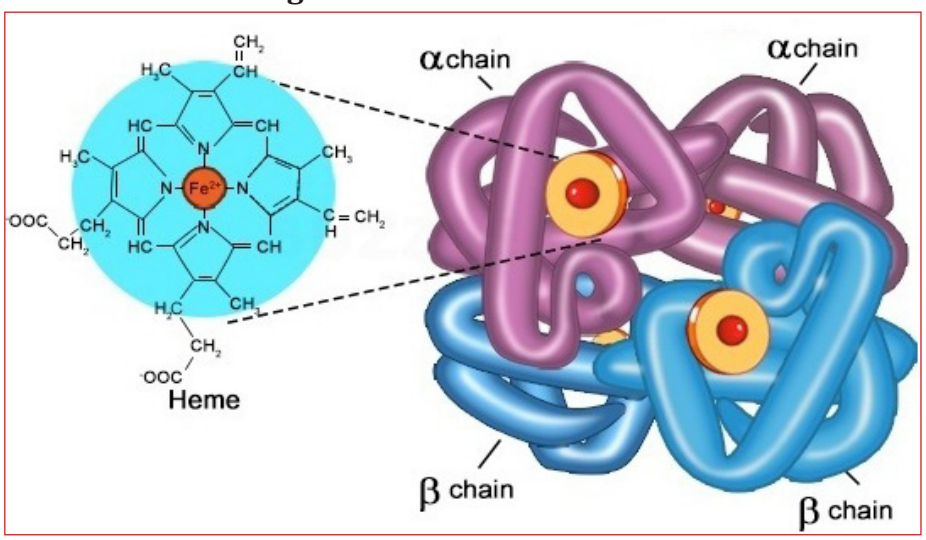


Figure8.36: Structure of haemoglobin (Hb).

Hemoglobin is a red protein responsible for transporting oxygen in the blood of vertebrates. It is also involved in the transport of carbon dioxide.

Hemoglobin is composed of heme and globin (polypeptide chains). Heme is iron porphyrin compound. Ferrous iron occupies the center of the porphyrin ring and establishes linkages with all the four nitrogen of all the pyrrole rings. It is also linked to nitrogen of imidazole ring of histidine present in globin part.

Globin part is made of **four polypeptide chains**, two identical α-chains and two identical β-chains in normal adult hemoglobin. Each chain contains a "heme" in the so called '**heme pocket'** and **one hemoglobin molecule possess four heme units**. Hemoglobin molecule contains hydrophobic amino acids inside and hydrophilic ones on the surface. Heme pockets of α-subunits are of just adequate size to give entry to an O2 molecule. Entry of O2 into heme pockets of β-subunits is blocked by a valine residue.

b. Transport of carbon dioxide (CO_2)

At **systemic capillaries**, CO_2 enters red blood cells. Some CO_2 combine with Hb to form $HbCO_2$ (Carbaminohemoglobin)

$Hb + CO_2 \rightarrow HbCO_2$ (Carbaminohemoglobin).

Most CO_2 is converted to HCO_3^-(bicarbonate ion), which is carried in the plasma.

Hemoglobin is in relation with **chloride shift**, also known as the **Hamburger shift** named after Hartog Jakob Hamburger. It is a process which occurs in a cardiovascular system and refers to the exchange of bicarbonate (HCO_3^-) and chloride (Cl^-) across the membrane of red blood cells (RBCs). The **chloride shift** occurs in this way:

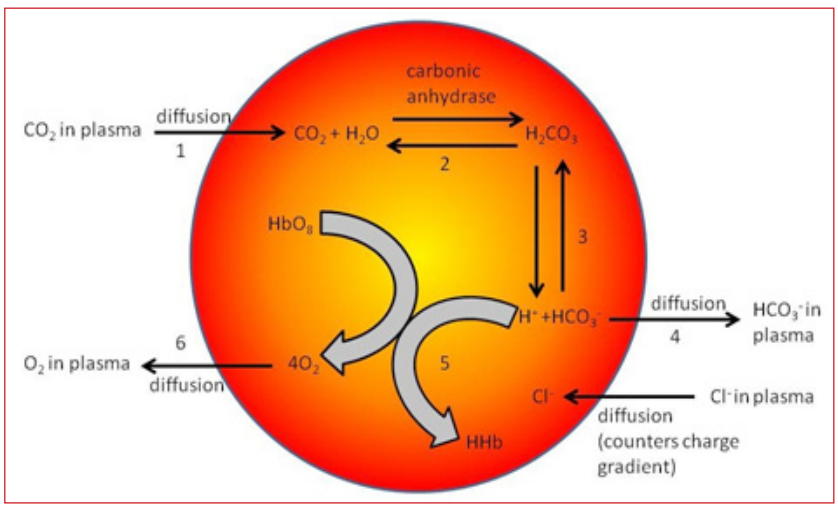


Figure 8.37: Chloride shift and transport of carbon dioxide by hemoglobin of erythrocyte.

HHb is reduced hemoglobin which is hemoglobin combined with hydrogen ion (H^+).

c. Transport of oxygen

Hemoglobin (Hb) gets oxygen in lungs from external environment to alveoli to **pulmonary capillaries**; Hb transports it, via the **circulatory system**, until it reaches the **systemic capillaries** from which it diffuses toward the tissue fluid and tissues cells. In tissue cells, oxygen is involved in aerobic cell respiration. The reaction between oxygen and hemoglobin is summarized as follows:

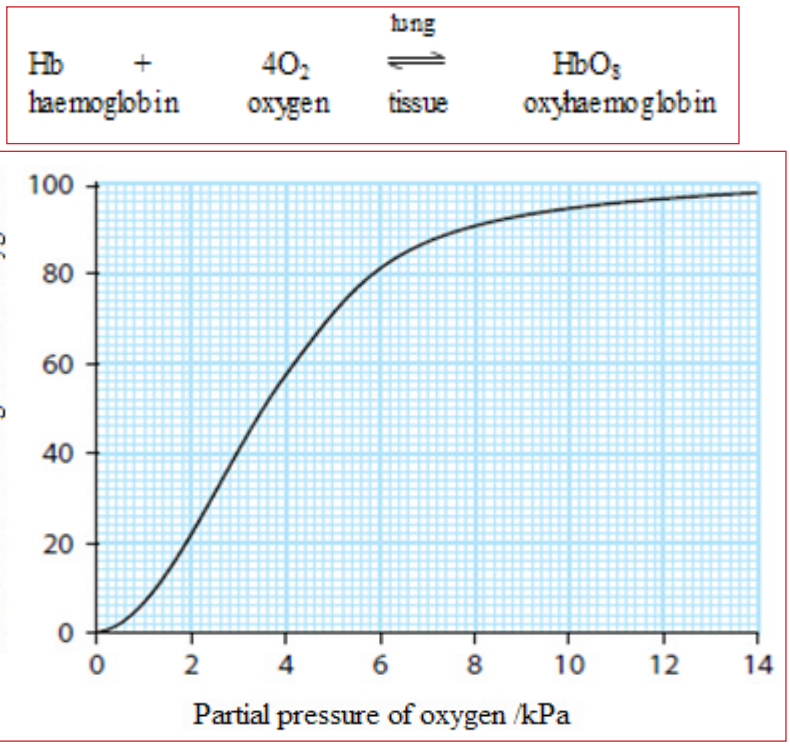


Figure 8.38: Oxygen dissociation curve

- Oxygen dissociation curve is determined by plotting the partial pressure of oxygen in blood as the **abscissa** and the percentage of hemoglobin combined with oxygen in the form of oxyhemoglobin as the **ordinate**.
- The s-shape of the oxygen dissociation curve can be explained by the behavior of a hemoglobin molecule as it combines with or loses oxygen molecules. When an oxygen molecule combines with one haeme group, the whole haemoglobin molecule is slightly distorted. The distortion makes it easier for a second oxygen molecule to combine with a second haeme group. This in turn makes it easier for a third oxygen molecule to combine with a third haeme group. It is then still easier for the fourth and final oxygen molecule to combine.

- Once oxygen molecule is combined with hemoglobin, it becomes successively easier for the second and third oxygen molecules to combine, so the curve rises very steeply. Over this part of the curve, a small change in the partial pressure of oxygen (2 kPa) causes a very large change in the amount of oxygen which is carried by the hemoglobin.
- The oxygen saturation can be calculated at this stage. It is a measurement of the percentage of oxygen binding sites. If all the oxygen binding sites contain oxygen, then the oxygen saturation is 100%. Oxygen saturation is defined as the ratio of oxyhemoglobin to the total concentration of hemoglobin present in the blood (Oxyhemoglobin + Reduced hemoglobin). *Haemoglobin concentration* is *expressed* as **g/dl** and the **normal range for hemoglobin is 13.5 to 17.5 grams** per deciliter for **men, and 12.0 to 15.5 grams** per deciliter for women.

Oxygen saturation

Where: c (Hb) = concentration of deoxygenated hemoglobin,

C (HbO_2) = concentration of oxygenated hemoglobin**.**

- The **Bohr effect** is a physiological phenomenon in which a raise of carbon dioxide in the blood and a decrease in pH results in a reduction of the affinity of hemoglobin for oxygen. This causes the oxygen dissociation curve for hemoglobin to shift to the right. The Bohr Effect occurs in this way:

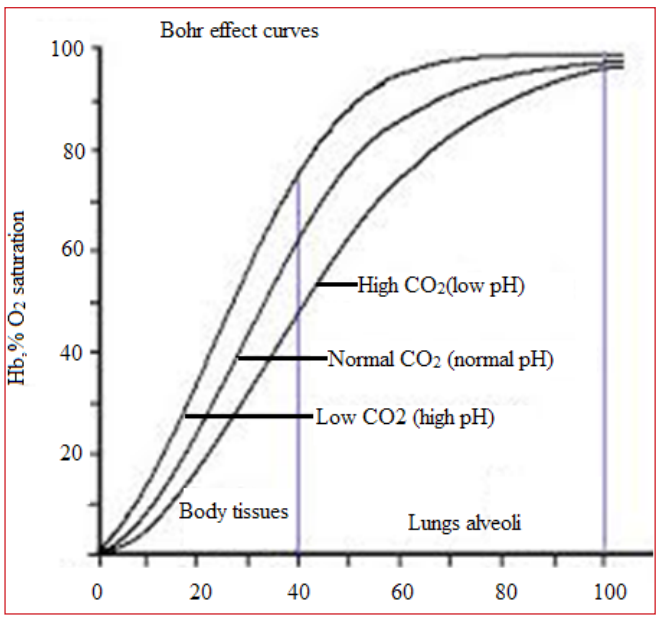


Figure 8.39: Drawing showing the Bohr effect curve

Application activity 8.9

1. Table below shows data.

Partial pressure of oxygen/ kPa	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Percentage saturation haemo-globin	8.5	24.0	43	57.5	71.5	80	85.5	88	92	94	95.5	95.5	97.5	98

a. Plot those data on a graph and interpret it.

b. Suggest the name which must be given to such a graph.

2.)In a healthy adult human, the amount of haemoglobin in 1 dm3 of blood is about 150 g. Given that 1 g of pure haemoglobin can combine with 1.3 cm3 of oxygen at body temperature, how much oxygen can be carried in 1 dm3 of blood?

8.10 Blood clotting and common cardiovascular diseases

Activity 8.10: research

Research, using internet and library books:

1. The process of blood clotting.
2. The cardiovascular diseases and possible risk factors; then, present your findings to your classmates.

a. Blood clotting

Blood clotting also known as **blood coagulation** is the process by which blood becomes thick and stops flowing, forming a solid cover over any place where the skin has been cut or broken. Blood that has been converted from a liquid to a solid state is called **blood clot**. A blood clot called **thrombus** is stationary within a vessel or the heart. If a blood clot moves from that location through the bloodstream, it is referred to as an **embolus.**

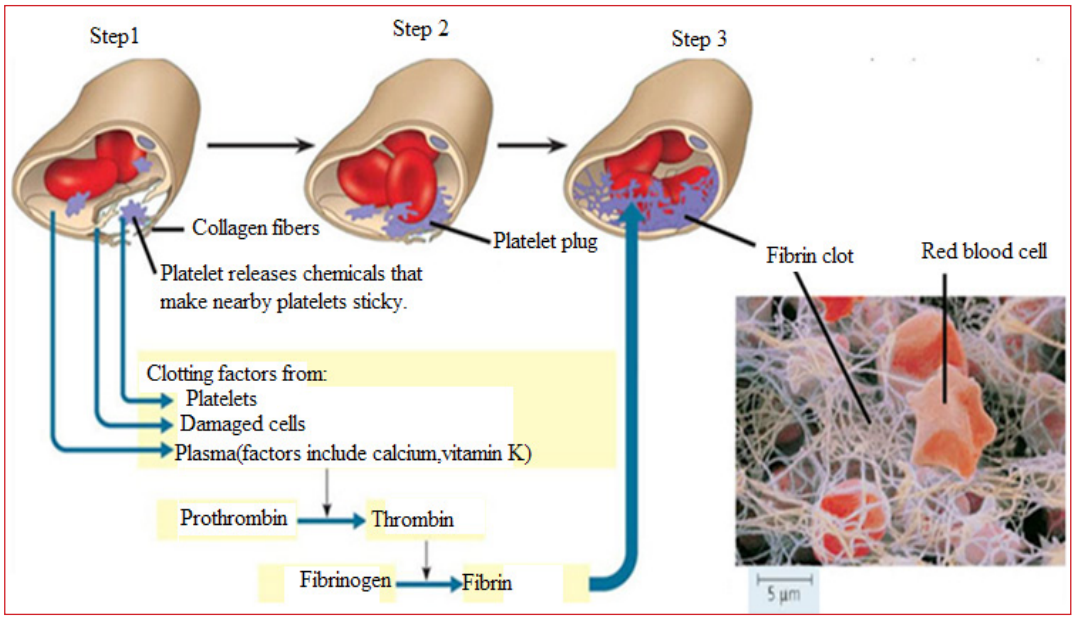


Figure 8.40: Drawing showing the blood clotting process

Blood clotting is a series of different processes:

Step1: The blood coagulation process begins when the endothelium of a vessel is damaged, exposing the connective in the vessel wall to blood. Platelets adhere to collagen fibers in the connective tissue and release a substance that makes nearby platelets sticky.

Step2: The thrombocytes form a plug that provides emergency protection against blood loss.

Step3: This seal is reinforced by a clot of fibrin when vessel damage is severe. Fibrin is formed via a multistep process where clotting factors released from the clumped platelets or damaged cells mix with clotting factors in the plasma, forming an activation that converts a plasma protein called **prothrombin** to its active form, called **thrombin**. This is facilitated by calcium ions and vitamin K. Thrombin itself is an enzyme that catalyzes the final step of the clotting process. This final step is the conversion of **fibrinogen** to **fibrin**. The threads of fibrin become interwoven into a patch. And the blood clot is formed. These threads trap red blood cells and other blood components, preventing the continuous bleeding.

b. Common cardiovascular diseases

1. Stroke

Stroke is a cardiovascular disease due to the **lack of oxygen to the brain** which may lead to reversible or irreversible **paralysis**. The damage to a group of nerve cells in the brain is often due to interrupted blood flow, caused by a **blood clot** or **blood vessel bursting**.

2. Atherosclerosis

Atherosclerosis is a cardiovascular disease characterized by the progressive **narrowing and hardening of the arteries** over time. Atherosclerosis normally begins in later childhood, and is usually found in most major arteries. It does not usually have any early symptoms. **Causes** of atherosclerosis include a **high-fat diet, high cholesterol, smoking, obesity, and diabetes.**

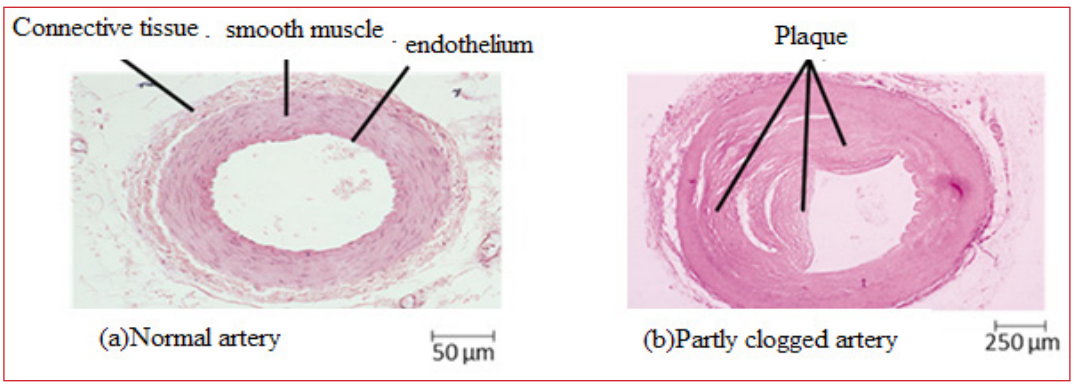


Figure 8.41: Plaque formation in blood vessels

3. Coronary heart disease

Coronary heart disease (CHD) is a disease in which a **waxy** substance called **plaque** builds up inside the coronary arteries.

c. Risk factors associated with cardiovascular diseases

1. Uncontrollable factors include the:
   i. gender (males are at greater risk),
   ii. age (old people have higher risk)/senescence
   iii. family/ genetic history in relation to heart diseases
   iv. post-menopausal stages for females. Making some changes in lifestyle can reduce chance of having heart disease.

2. Controllable risk factors include:
   i. smoking,
   ii. high blood pressure,
   iii. physical inactivity,
   iv. obesity,
   v. diabetes,
   vi. stress anger

Application activity 8.10

1. Relate smoking and much lipids consumption to the cardiovascular system diseases.
2. A woman liked to cook most food with oil. Then after 10 years most of members of her family including herself become obese and undergo hypertension; once her husband suddenly fell down and died.

a. Identify 2 suspected cardiovascular diseases associated with his death.
b. Demonstrate how one of those diseases develops.

8.11 Lymphatic system

Activity 8.11

Describe the structure and function of the lymphatic system.

8.11.1 Structure of a lymphatic system

A lymphatic system is system composed of tissues and organs, including the bone marrow, spleen, thymus and lymph nodes that produce and store cells that fight infection and disease. The channels that carry lymph are also part of this system. So, the lymphatic system is part of the circulatory system and an important part of the immune system.

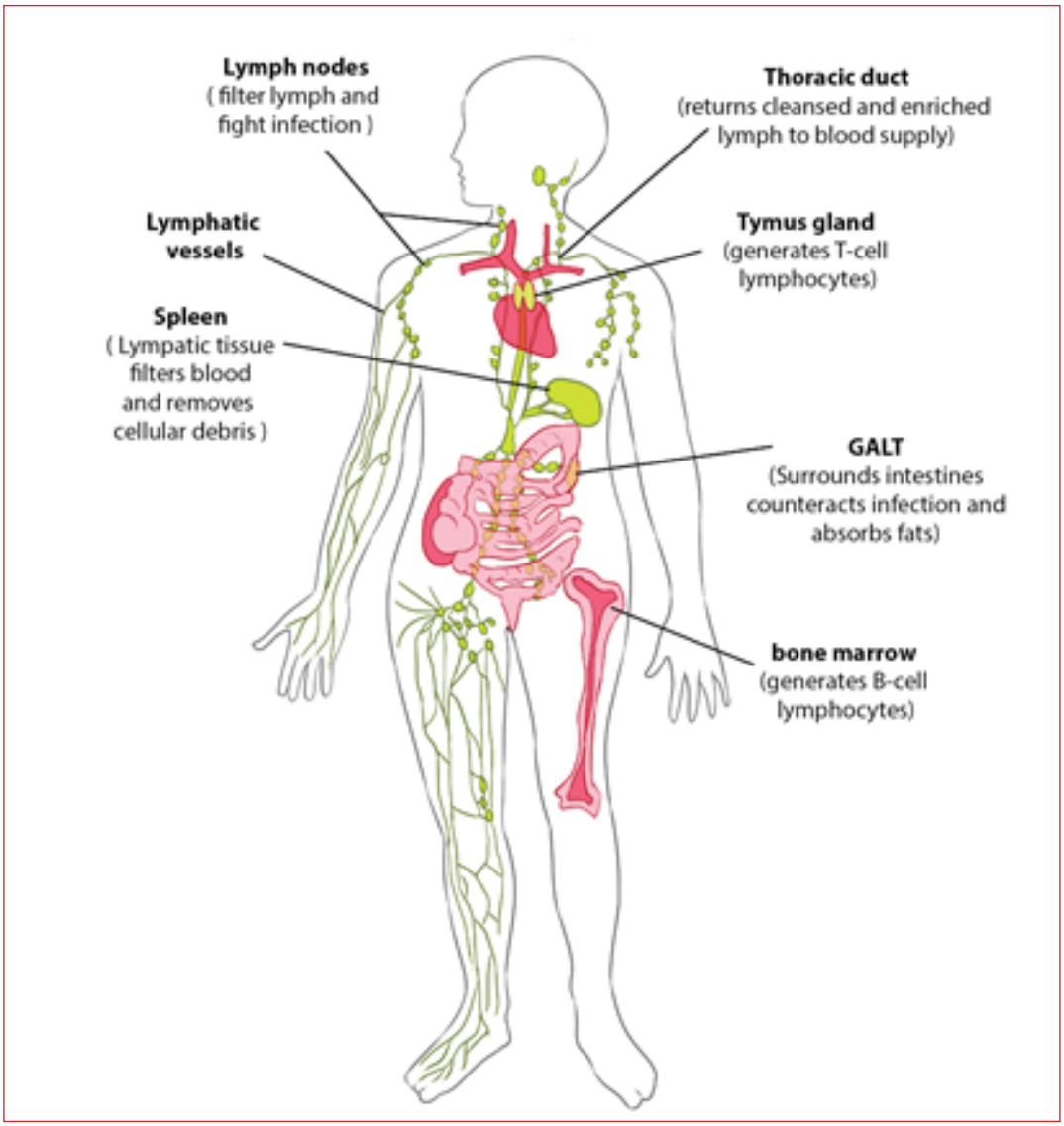


Figure 8.42: Drawing showing the structure of human lymphatic system.

8.11.2 Functions of a lymphatic system

iii. **Drainage of fluid from blood stream into the tissues:** The circulating blood through narrow vessels leads to leakage of fluid or plasma into the tissues carrying oxygen and nutrients to the tissues and taking waste materials from the tissues into the lymph channels. The leaked fluid drains into the lymph vessels.

iv. **Filtration of the lymph at the lymph nodes:** The nodes contain white blood cells that can attack any bacteria or viruses they find in the lymph as it flows through the lymph nodes.

The cancer cells may also get trapped similarly at the lymph nodes and thus lymph nodes act as indicators of how far the cancer has already spread.

v. **Filtering blood**: This is done by the spleen which filters out bacteria, viruses and other foreign particles.

vi. **Raises an immune reaction and fights infections**: The lymphatic system especially the lymph nodes are over active in case of an infection; the lymph nodes or glands often swell up in case of a local infection.

8.11.3 Formation of tissue (interstitial) fluid

Fluids and proteins leak from the blood capillaries into the interstitial fluid that bathes the cells of tissues. This occurs due to the arterial end of capillary, where the blood pressure is greater than osmotic pressure so that fluid flows out of capillary into the interstitial fluid. This process is called **pressure filtration** or **ultrafiltration**.

Formation of lymph

The lymph is the tissue fluid that moves within the lymphatic vessels. The lymphatic vessels recover some leaked fluid and proteins, and carry them to large veins at the base of the neck.

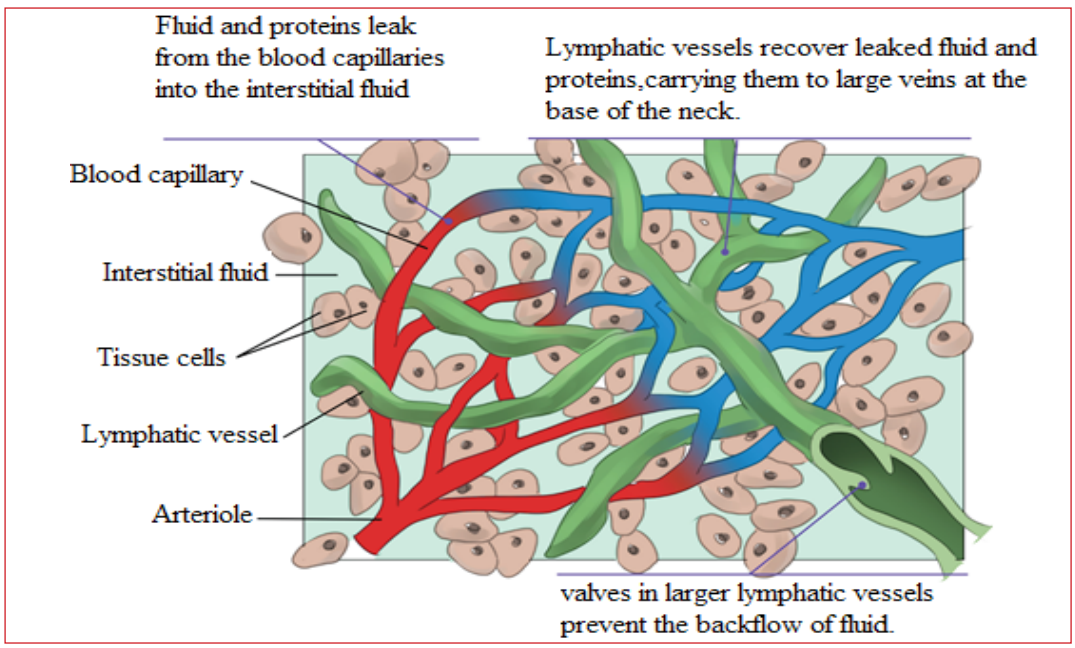


Figure 8.43: Close association of lymphatic vessels and blood capillaries.

8.11.4 Comparison between lymphatic and circulatory systems

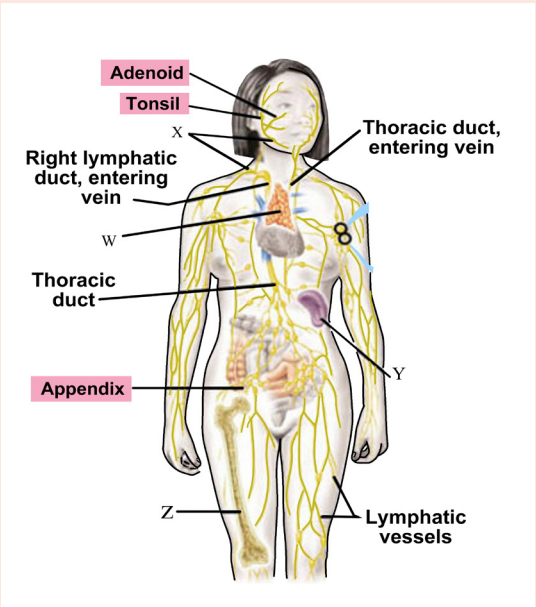
Both cardiovascular and lymphatic systems are vascular networks carrying body fluids.

Table 8.7. Differences between lymphatic and circulatory system

Criteria	Circulatory system	Lymphatic system
Main function	Blood collect and distribute O2, nutrients and hormones to tissues of the body.	Lymph collect and remove waste products left behind by tissues of the body.
Fluid flow	Blood flows in a continuous loop throughout the body by arteries, capillaries and veins	Lymph flows in an open circuit from tissues to lymphatic vessels. It is unidirectional, and it has valves to stop from flowing backwards.
Type of fluid	Blood	Lymph
Type of vessels involved	Blood vessels	Lymphatic vessels

Application activity 8.11

Observe the figure below and respond to the following questions.



1. Identify the organs W, X, Y, Z shown on this figure
2. Explain why the organs W, X, Y, Z are important to the body.

Skills lab 8

Aim: Acquire dissection skills and money.

Materials: Small capital, rabbit, breeding site of rabbits.

Procedure

1. Using your pocket money, buy two rabbit (male female).
2. Breed those rabbits and allow them to produce offspring.
3. Among the produced young ones, dissect one mature rabbit to investigate its circulatory system (heart, blood vessels and blood) structure.
4. Sell some of the young ones to get money.

Portfolio Report

i. Write your skills lab project implementation report focusing on how this skill lab has helped you to get much money and new biological skills, submit it to your teacher.

ii. Invite your classmate to visit your bleeding places at home

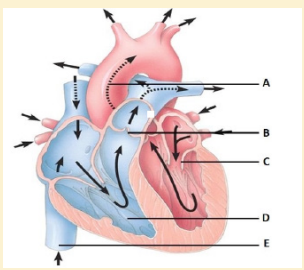
Note: Invent or discover other skill labs related to this unit.

End unit assessment 8

1. Blood returning to the mammalian heart in a pulmonary vein drains first into the:
   a. Vena cava b. Left ventricle, c. Right ventricle, d.Left atrium
2. Pulse is a direct measure of:
   a. Blood pressure, b. Breathing rate, c. cardiac output, d . Heart rate. e. stroke volume
3. Complete the following paragraph by filling in the blank spaces.

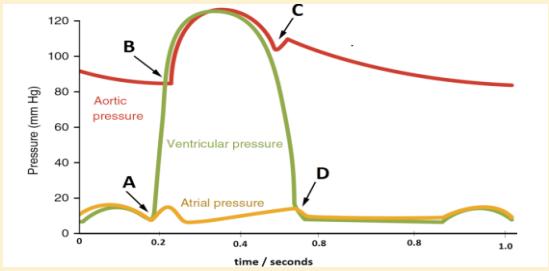
Blood is ……in the lungs. The red pigment ……has a high affinity for oxygen. The pumping action of the……creates pressure which pushes the blood around the body. In the tissues the partial pressure of……is low. This causes the ……of the oxyhaemoglobin. In the tissues, the oxygen is used in the process of…….. Most of the carbon dioxide produced in this process enters the…….. cells. Here it is converted to carbonic acid by the action of the enzyme carbonic anhydrase. The carbon dioxide is transported as …….. back to the lungs.

4. How many oxygen molecules can each haemoglobin molecule transport?
5. Explain the function of fibrinogen.
6. Distinguish between plasma and serum.
7. a. Explain why haemoglobin is called conjugated protein.
   b) Describe the effect of high carbon dioxide concentrations on the oxygen dissociation curve of haemoglobin.
8) a) By which process does fluid leave the blood and enter the tissue fluid?
   b) Which component of the blood does not enter the tissue fluid?
9 The figure below shows a cross section through the human heart



a. Label the structure A-E
b. What are the functions of the structures A and B

10. The figure below shows pressure changes to the left side of the heart and the aorta during the cardiac cycle



a. State what is happening at point A-D on the graph. Explain your answer.

b. If the time taken for one complete cardiac cycle is 0.8 seconds, how many cardiac cycles are there in one minute?

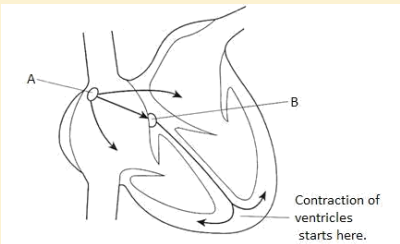
11 Explain any two advantages of closed double circulatory system and two disadvantages of open circulatory system.

12 a) Where is the radial pulse taken?

b) Suggest what will happen to the heart rate if the vagus nerve is cut off.

13 The diagram shows a vertical section through a human heart. The arrows represent the direction of movement of the electrical activity which starts muscle contraction

Carefully, observe the following and answer the questions that follow.



a. Name the structure denoted by the letter A

b. Explain why each of the following is important in then pumping of blood through the heart.

i. There is a slight delay in the passage of electrical activity that takes place at the point A

ii. The contraction of the ventricles starts at the base

c. Describe how stimulation of the cardiovascular centre in the medulla may result in an increase in heart rate

14. Read the following passage and answer the questions that follow.

The human heart is a double pump adapted to forcing blood, at the same rate but at different pressures, along the two systems of double circulation. High pressure in the systemic circulation has evolved with lower pressure in the pulmonary circulation and low pressure lymphatic circulation. Each heart beat is controlled by a wave of electrical excitation. In turn, the cardiac output of the heart adapts to meet the body needs and is influenced by nervous and hormonal control.

a. Based on the statement: "The human heart is a double pump adapted to forcing blood, at the same rate but at different pressures, along the two systems of double circulation". Explain how the mechanism that controls each heartbeat, and the structure of the heart, enable it to do this.

b. Describe the role played by hormones and the nervous system in controlling heart rate.

c. Describe the formation of how lymph fluid.

15. Draw this picture in your exercise book. It shows various internal parts of a leaf. These are marked us A, B, C, D, E and F. Identify and name these parts.

UNIT 9

GENERAL PRINCIPLES OF HOMEOSTASIS, EXCRETION AND OSMOREGULATION

Key unit competence: Explain general principles of homeostatic mechanisms, excretion and osmoregulation.

Introductory activity 9

Analyze the following water treatment plant and answer the questions that follow:

The photo above shows a water treatment plant located in Kigali in Kimisagara. The water in the river that supplies the water treatment plant may become polluted with sediments, animal waste, urine of people, but the water treatment plant removes these wastes. In an analogous way, the cells of all body systems produce waste products, and these wastes end up in the blood.

a. Which system in our body could be compared to a water treatment plant?
b. Which organs make the system that you have named above?
c. Which fluid produced by the body that contains the metabolic waste products?
d. Compare the process of removing the waste products from the water to the process by which our body removes the metabolic waste products from the blood. Are there any similarities?

9.1 Significance of constant internal environment and factors kept constant in the body

Activity 9.1

Use your biological knowledge to the answer the questions that follow:

1. Define the following biological terms

a. Homeostasis

b. Internal environment

2. State ant three factors that need to be maintained constant in the human body?

3. Explain why our body temperature is kept constant independently of the external environment.

All living organisms have an ability to maintain stable internal conditions. It requires continuous adjustments to the changes occurring in both internal and external environment. This self-regulating property of living beings to maintain a constant internal environment is termed as 'homeostasis' ('homeo', "similar," and 'stasis', "stable"). Homeostasis is a key concept in the understanding of biological mechanisms that play an important role in survival of individual cells, to an entire body.

Homeostasis is the property of a system that regulates its internal environment and tends to **maintain a stable, constant condition** of properties such as **temperature** or **pH**. It was defined by Claude Bernard and later by Walter Bradford Cannon in 1926, 1929 and 1932. Typically used to refer to a living organism, the concept came from that of milieu interieur that was created by Claude Bernard and published in 1865. Multiple dynamic equilibrium adjustment and regulation mechanisms make homeostasis possible.

9.1.1 Meaning of internal environment

Internal environment or interstitial fluid (or tissue fluid) is a solution that bathes and surrounds the cells of multicellular animals. It is the main component of the extracellular fluid, which also includes plasma and transcellular fluid. The interstitial fluid is found in the interstitial spaces, also known as the tissue spaces. On average, a person has about 11 liters of interstitial fluid, providing the cells of the body with nutrients and a means of waste removal.

9.1.2 Factors of homeostasis to be kept constant in the body

To function efficiently, organisms have control systems to keep internal conditions near constant, a feature known as homeostasis. This requires information about conditions inside the body and the surroundings, which are detected by sensory cells. Some of the physiological factors controlled in homeostasis in mammals are:

- **Core body temperature**: The maintenance of a steady body temperature involves mechanisms such as sweating or shivering. These mechanisms occur whenever the internal body temperature becomes high or low.
- **Blood glucose concentration**: When glucose levels are high, a hormone called insulin is released by beta cells of the pancreas. Insulin stimulates the conversion of glucose as insoluble glycogen by the body cells. This lowers the glucose concentration in the blood. A condition called as diabetes occurs due to the deficiency of insulin in the body, due to which glucose level of blood increases. When the blood glucose levels are low, another hormone known as glucagon is released by the alpha cells of pancreas. Glucagon breaks down stored glycogen in the form of glucose. The addition of glucose in blood returns the body glucose levels to normal.
- **Metabolic wastes**, particularly carbon dioxide and urea
- **Blood pH**: The pH of the blood is regulated at 7.365 (a measure of alkalinity and acidity). The tolerable lower and upper limit for a human body is about pH 7.0 and pH 7.8, respectively. To prevent a change in the pH, all body fluids, including cell cytoplasm are buffered (buffer is a chemical or a combination of chemicals) absorbing either hydrogen ions (H^+) or hydroxide ions.
- **Water potential of the blood**: Whenever the water content of the blood and lymph fluid gets low, it is restored initially by extracting water from the cells. Also, the throat and mouth become dry. These symptoms of thirst motivate humans to drink water.
- **The concentrations in the blood of the respiratory gases, oxygen and carbon dioxide**: A change in breathing and heart rate occurs in humans due to various activities like exercise. As a result, the amount of carbon dioxide produced and oxygen demand in the body increases. The heart rate increases so that the blood flows rapidly to the tissues to fulfil the oxygen requirement and remove the carbon dioxide from the cells. Also, the speed and depth of breathing increases. The body works to normalize breathing and heart rate when activity stops.

Application activity 9.1

1. In your own words, explain the significance of a constant internal environment by giving suitable examples.
2. State four factors that must be kept constant in the internal environment of the body.
3. What are the main internal and external causes of change in the internal environment?

9.2 Feedback mechanisms

Activity 9.2

The temperature in the house can be maintained constant using a thermostat. The thermostat sends a message to the furnace to produce heat. Heat returns to the thermostat. The heat will cause the thermostat to stop stimulating the furnace. If temperature drops below the set point of the thermostat then the furnace will be stimulated again. The furnace will turn on and off several times a day to keep the temperature constant. How can this heating system be compared to our body temperature regulation?

All homeostatic control mechanisms have at least three interdependent components for the variable being regulated: The receptor is the sensing component that monitors and responds to changes in the environment. When the receptor senses a stimulus, it sends information to a "control center", the component that sets the range at which a variable is maintained. The control center determines an appropriate response to the stimulus. In most homeostatic mechanisms, the control center is the brain. The control center then sends signals to an effector, which can be muscles, organs or other structures that receive signals from the control center. After receiving the signal, a change occurs to correct the deviation by either enhancing it with positive feedback or depressing it with negative feedback. (https://biologydictionary.net/positive-and-negative-feedback-homeostasis/)

The homeostatic mechanisms in mammals require information to be transferred between different parts of the body. There are two coordination systems in mammals that do this: the **nervous system** and the **endocrine system**.

- In the nervous system, information in the form of electrical impulses is transmitted along nerve cells (neurons).
- The endocrine system uses chemical messengers called hormones that travel in the blood, in a form of long-distance cell signaling.

Positive feedback mechanisms are designed to accelerate or enhance the output created by a stimulus that has already been activated. Unlike negative feedback mechanisms that initiate to maintain or regulate physiological functions within a set and narrow range, the positive feedback mechanisms are designed to push levels out of normal ranges. To achieve this purpose, a series of events initiates a cascading process that builds to increase the effect of the stimulus. This process can be beneficial but is rarely used by the body due to risks of the acceleration's becoming uncontrollable. One positive feedback example event in the body is blood platelet accumulation, which, in turn, causes blood clotting in response to a break or tear in the lining of blood vessels. Another example is the release of oxytocin to intensify the contractions that take place during childbirth. Another example of a positive feedback mechanism is milk production by a mother for her baby. As the baby suckles, nerve messages from the mammary glands cause the hormone prolactin, to be secreted by the mother's pituitary gland. The more the baby suckles, the more prolactin is released, which stimulates further milk production by the mother's mammary glands. In this case, a negative feedback loop would be unhelpful because the more the baby nursed, the less milk would be produced.

Table 9.1: Negative and positive feedback compared

Negative feedback	Positive feedback
Shuts off the original stimulus, or reduces its intensity	Increases the original stimulus to push the variable farther.
In this feedback loop, the values remain within a range	Values go out of range
Common in the body	Very uncommon
This feedback loop is initiated by a stimulus that disturbs the homeostasis of a body system	Positive feedback is also initiated by a stimulus.
Examples: body temperature, sugar metabolism…	Examples: lactation, labor contractions, blood clotting

Application activity 9.2

a. State any to examples of a negative feedback and two examples of positive feedback in our body.
b. What are the main differences between positive feedback and negative feedback?
c. Explain why a positive feedback cannot be effective in homeostatic regulation?

9.3 Negative feedback mechanisms related to the endocrine and nervous systems in homeostatic activities

Activity 9.3: Research activity

Have you ever thought about how your body maintains the same blood calcium level independently of whether you have eaten or not? Do you know about homeostasis and why it is required? Use library and Internet sources to collect information about the regulation of blood calcium level.

In the human body, all the organs and organ systems are controlled by nervous and endocrine systems. The nervous system controls the activities of body parts by reacting quickly to external and internal stimuli. The endocrine system regulates those activities slowly but its effects are long lasting. The hypothalamus is a part of the brain (nervous control center) located just above the brain stem and consists of a group of neurons that forms the primary link between the nervous system and the endocrine system. This small part of the brain is responsible for regulating many key body processes, including internal body temperature, hunger, thirst, blood pressure, and daily body rhythms.

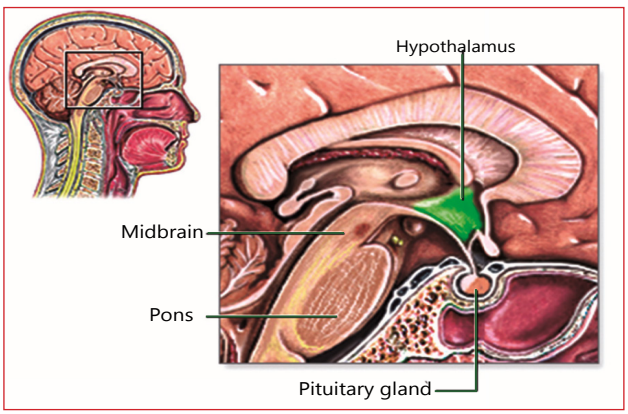


Figure 9.1: Hypothalamus and Pituitary gland

Nervous system consists of receptive nerve cells which transmit the signal to the brain, which in turn, command the effector nerve cells, muscles and glands to respond. For instance, humans maintain a constant body temperature, usually about 37.4°C. It increases during the day by about 0.8°C and decreases slightly during sleeping. The core body temperature is usually about 0.7-1.0°C higher than skin or axillary temperature. A change in temperature is sensed by receptors found in the skin, veins, abdominal organs and hypothalamus. The receptors in the skin provide the sensation of cold and transmit this information to brain. The brain process and commands for the vasoconstriction of blood vessels in the skin and limb. This drops the surface temperature, providing an insulating

layer (fat cell) between the core temperature and the external environment. The major adjustment in cold is shivering to increase the metabolic heat production. On the contrary, if the body temperature rises, blood flow to the skin increases, maximizing the potential for heat loss by radiation and evaporation.

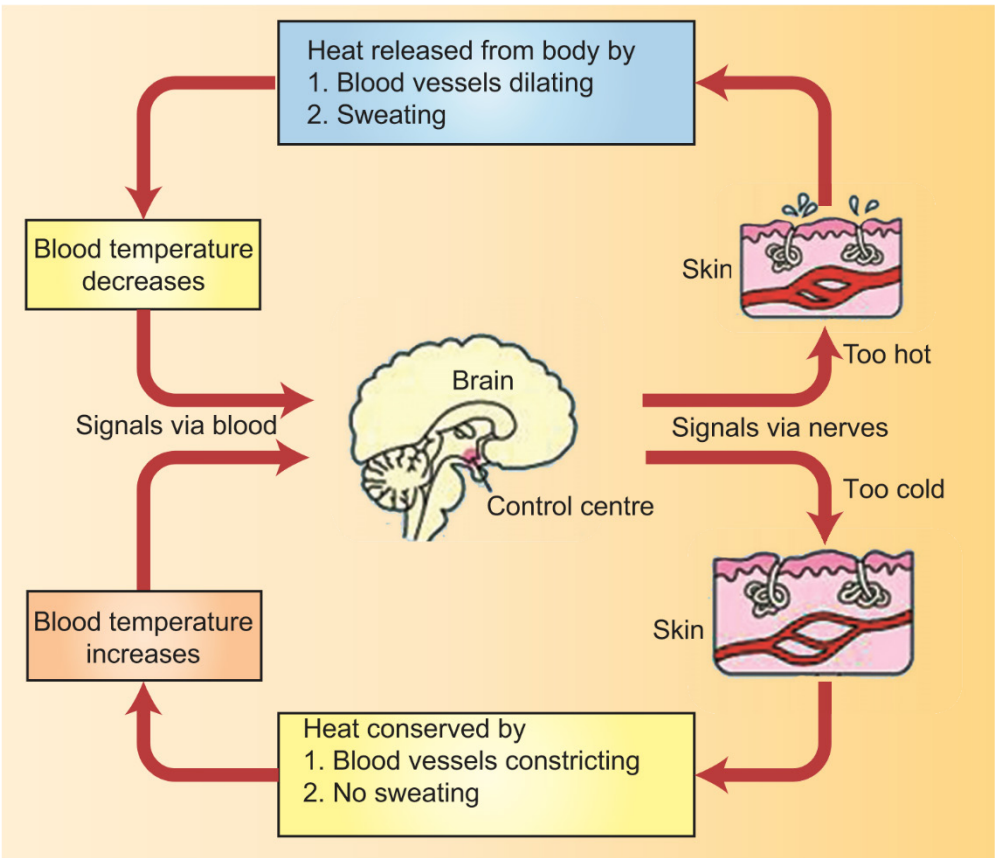


Figure 9.2: Homeostatic regulation of body temperature

The endocrine system consists of glands which secrete hormones into the bloodstream. Each hormone has an effect on one or more target tissues.

In this way, it regulates the metabolism and development of most body cells and its systems through feedback mechanisms, mostly negative. For example, when blood calcium becomes too low, calcium-sensing receptors in the parathyroid gland become activated. This results in the release of Parathyroid Hormone (PTH), which acts to increase blood calcium by release from the bones. This hormone also causes calcium to be re-absorbed from urine and the gastrointestinal tract. Calcitonin, released from the thyroid gland functions in reverse manner, i.e., decreasing calcium levels in the blood by causing more calcium to be fixed in bones.

Application activity 9.3

a. Which part of the body is involved in temperature regulation?
b. Which hormones are involved in blood calcium regulation?
c. What are the functions of the nervous system and the nervous system in homeostatic regulation?

9.4 Causes of changes in the internal environment

Activity 9.4: Research activity

Nowadays there are many people suffering from different disorders such as diabetes mellitus and diabetes insipidus. Make a search on the internet and in the library in order to know the cause of these disorders.

Homeostasis is maintained through a series of control mechanisms. When homeostatic process is interrupted, the body can correct or worsen the problem, based on certain influences. There are internal and external causes influencing the body's ability to maintain homeostatic balance.

9.4.1 Internal causes: heredity

Genetic/Reproductive: A variety of diseases and disorders occur due to the change in the structure and function of genes. For example, cancer can be genetically inherited or can be induced due to a gene mutation from an external source such as UV radiation or harmful drugs. Another disorder, Type 1 diabetes, occurs due to the lack or inadequate production of insulin by the pancreas to respond to changes in a person's blood glucose level.

9.4.2 External causes: lifestyle

Nutrition: A diet lacking specific vitamin or mineral leads to the cellular malfunction. A menstruating woman with iron deficiency will become anaemic. As iron is required for haemoglobin, an oxygen transport protein present in red blood cells, the blood of an anaemic woman will have reduced oxygen-carrying capacity.

Physical Activity: Physical activity is essential for proper functioning of our cells and bodies. Adequate rest and exercise are examples of activities that influence homeostasis. Lack of sleep causes ailments such as irregular cardiac (heart) rhythms, fatigue, anxiety that and headaches. Overweight and obesity are related to poor nutrition and lack of physical activity that greatly affects many organ systems and their homeostatic mechanisms. It increases a person's risk of developing heart disease, Type 2 diabetes, and certain forms of cancer.

Mental Health: Both the physical and mental health is inseparable. Negative stress (also called distress) leads to thoughts and emotions harmful for homeostatic mechanisms in the body.

9.4.3 Environmental exposure

Many substances act as toxins, including pollutants, pesticides, natural and synthetic drugs, plants and animal products interfering at cellular levels. Modern medicines practice can also be potentially harmful in case of wrong or over dosage. For instance, drug overdose affects the central nervous system, disrupts breathing and heartbeat in human body. It can further result in coma, brain damage, and even death. Therefore, alterations or interruption of beneficial pathways, whether caused by an internal or external factor will result in harmful change in homeostasis. Therefore, adequate positive health influences are to be taken into consideration in order to maintain homeostasis.

Application activity 9.4

What are the causes of the changes in the internal environment? State any two genetic causes and two environmental causes.

9.5 Formation, composition and movement of tissue fluid and its relationship to the blood and lymph

Activity 9.5

You may have observed a clear fluid after having an injury. This fluid does not have a red color. This fluid is not blood because it does not have a red color. What is the name of this fluid? What is the composition of this fluid? What are some similarities and differences between this fluid and blood?

The blood supplies nutrients and essential metabolites to the cells of a tissue and collects back the waste products. This exchange of respective constituents between the blood and tissue cells occurs through **interstitial fluid** or **tissue fluid** formed by the blood. The fluid occupies the spaces between the cells known as tissue spaces. It is the main component of the extracellular fluid, which also includes plasma and transcellular fluid. On an average, a person has about 10 liters of interstitial fluid making 16% of the total body weight.

9.5.1 Formation

The formation of the tissue fluid is based on the difference in pressure of flowing of blood through capillaries. A hydrostatic pressure is produced at the arterial end of blood capillaries which is generated by the heart. This results in expulsion of water and other solutes (known as plasma) from capillaries except blood proteins (like serum albumin). This retention of solutes in capillaries creates water potential. The osmotic pressure (water moves from a region of high to low concentration) tends to drives water back into the capillaries in an attempt to reach equilibrium. At the arterial end, the hydrostatic pressure is greater than the osmotic pressure, so the net movement favours water along with solutes being passed into the tissue fluid. At the venous end, the osmotic pressure is greater, so the net movement favours tissue fluid being passed back into the capillary. The equilibrium is never attained because of the difference in the direction of the flow of blood and the solutes imbalance created by the net movement of water (Figure 11.6).

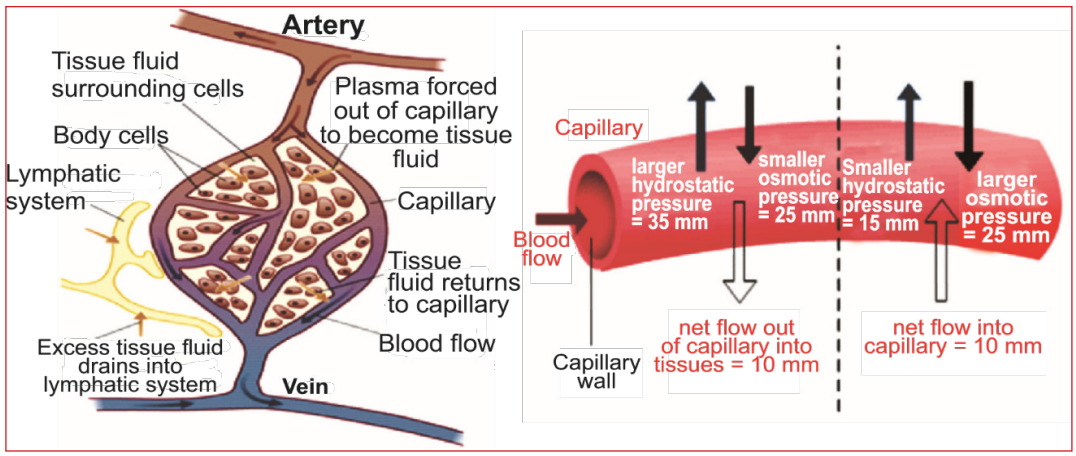


Figure 9.3: Formation of interstitial fluid from blood

9.5.2 Composition

As the blood and the surrounding cells continually add and remove substances from the interstitial fluid, its composition continually changes.

Water and solutes can pass between the interstitial fluid and blood via diffusion across gaps in capillary walls called intercellular clefts; thus, the blood and interstitial fluid are in dynamic equilibrium with each other. Generally, tissue fluid consists of a water solvent containing sugars, salts, fatty acids, amino acids, coenzymes, hormones, neurotransmitters, as well as metabolic waste products from the cells.

Not all of the contents of the blood pass into the tissue, which means that tissue fluid and blood are not the same. Red blood cells, platelets, and plasma proteins cannot pass through the walls of the capillaries. The resulting mixture that does pass through is, in essence, blood plasma without the plasma proteins. Tissue fluid also contains some types of white blood cells, which help to combat infection.

9.5.3 Movement

To prevent a buildup of tissue fluid surrounding the cells in the tissue, the lymphatic system plays an important role in its transport. Tissue fluid can pass into the surrounding lymph vessels where it is then considered as lymph. The lymphatic system returns protein and excess interstitial fluid to the blood circulation. Thus, it is transported through the lymph vessels to lymph nodes and ultimately with blood in the venous system, and tends to accumulate more cells (particularly, lymphocytes) and proteins.

Application activity 9.5

a. What are the main components of lymph?
b. What are the main differences between blood and lymph?
c. How does lymph differ from tissue fluid?

9.6 Structure and functions of excretory organs in mammals

Activity 9.6

a. What are the main excretory organs of humans?
b. What are the main excretory waste products of mammals?
c. Identify the organs of the human excretory organs and their functions.

Excretion the removal of toxic waste products of metabolism from the body. The term is generally taken to mean nitrogenous wastes such as; urea, ammonia and uric acid but other materials like carbon dioxide and the bile pigments are also waste products of metabolism, and their removal is as much a part of excretion as the elimination of urea.

Excretion is an essential process in all forms of life. When cells metabolize or break down nutrients, waste products are produced. For example, when cells metabolize amino acids, nitrogen wastes such as ammonia are produced. Ammonia is a toxic substance and must be removed from the blood and excreted from the body.

Although the kidneys are the main organs of excretion of wastes from the blood, several other organs are also involved in the excretion, including the; liver, skin, and lungs.

- The large intestine eliminates waste products from the bile synthesis.
- The liver breaks down excess amino acids in the blood to form ammonia, and then converts the ammonia to urea, a less toxic substance. The liver also breaks down other toxic substances in the blood, including alcohol and drugs.
- The skin eliminates water and salts in sweat.
- The lungs exhale water vapor and carbon dioxide.

Importance of excreting wastes

i. To maintain life processes, the body must eliminate waste products, many of these which can be harmful. The lungs eliminate carbon dioxide, one of the products of cellular respiration. The large intestine removes toxic wastes from the digestive system.

ii. The liver transforms ingested toxins, such as alcohol and heavy metals, into soluble compounds that can be eliminated by the kidneys.

Waste	Origin of waste	Organ of excretion
Ammonia	Deamination of amino acids by the liver	Kidneys
Urea	Deamination of amino acids by the liver Ammonia combined with carbon dioxide	Kidneys
Uric acid	Products of the breakdown of nucleic acids, such as DNA	Kidneys
Carbon dioxide	Waste product of cellular respiration	Lungs
Bile pigments	Breakdown of red blood cell pigment, hemoglobin	Liver
Lactic acid	Product of anaerobic respiration	Liver

9.6.1 Kidneys and excretion

The kidneys are part of the urinary system (Figure 9.4). The kidneys work together with other urinary system organs in the function of excretion

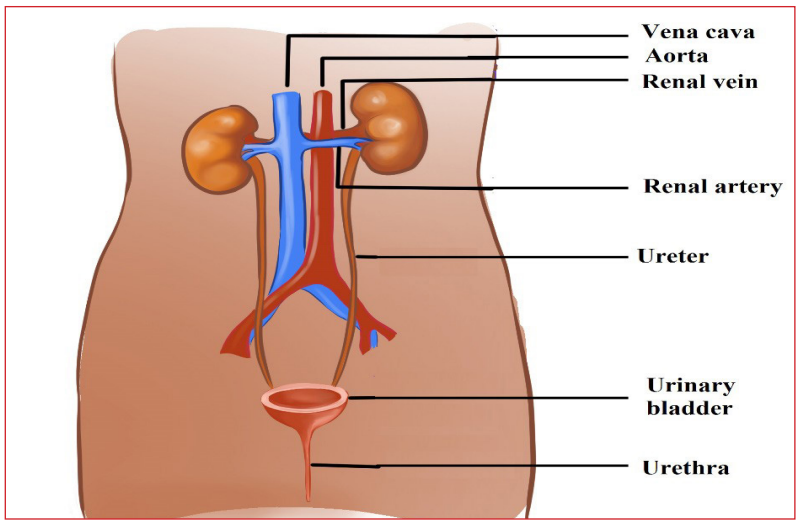


Figure 9.4: Human urinary system

a. Urinary system

In addition to the kidneys, the urinary system includes the; ureters, bladder, and urethra. The main functions of the urinary system are to; filter waste products and excess water from the blood and remove them from the body.

From the kidneys, urine enters the ureters. Each ureter is a muscular tube about 25 centimetres long. Peristaltic movements of the muscles of the ureter send urine to the bladder in small amount. Ureters carry urine to the bladder. The bladder is a hollow organ that stores urine. It can stretch to hold up to 500 millilitres. When the bladder is about half full, the stretching of the bladder sends a nerve impulse to the sphincter that controls the opening to the urethra. In response to the impulse, the sphincter relaxes and lets urine flow into the urethra.

The urethra is a muscular tube that carries urine out of the body. Urine leaves the body through another sphincter in the process of urination. This sphincter and the process of urination are normally under conscious control/voluntary system.

b. Kidneys

The kidneys are a pair of bean-shaped, reddish brown organs about the size of a fist. They are located just above the waist at the back of the abdominal cavity, on

either side of the spine. The kidneys are protected by the ribcage. They are also protected by a covering of tough connective tissues and two layers of fat, which help cushion them. Located on top of each kidney is an adrenal gland. The two adrenal glands secrete several hormones. Hormones are chemical messengers in the body that regulate many body functions. The adrenal hormone aldosterone helps regulate kidney functions. The functional unit of a kidney is a nephron.

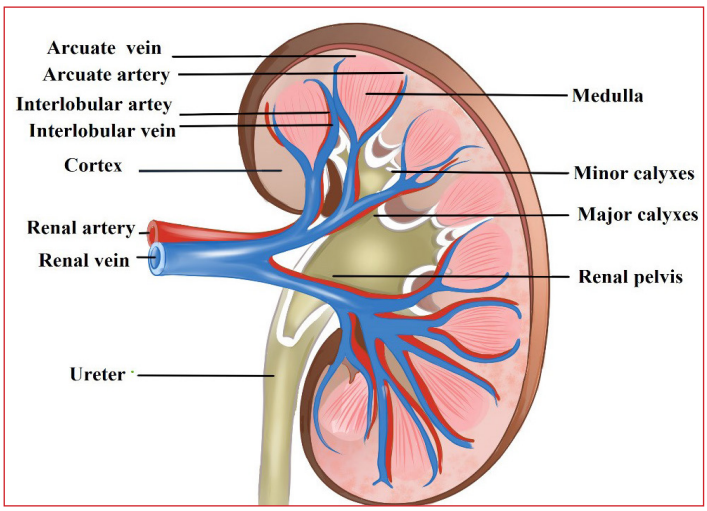


Figure 9.5: Human kidney

9.6.2 Structure and the functions of the nephron

Nephrons are the structural and functional units of the kidneys. A single kidney may have more than a million nephrons. An individual nephron (Figure 9.6) includes a glomerulus, Bowman's capsule, and renal tubule.

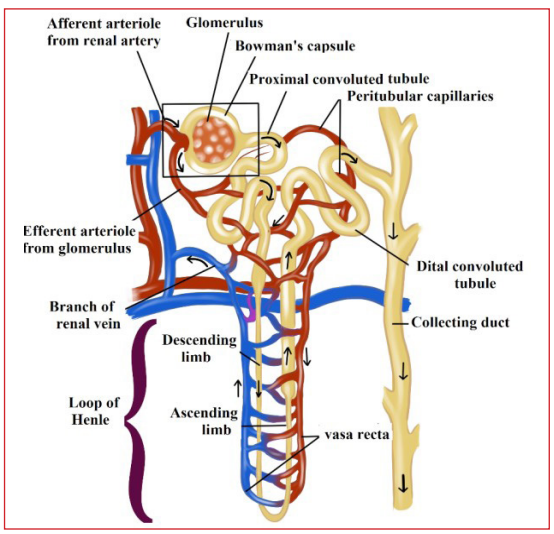


Figure 9.6: Sructure of a nephron

a. Parts of the nephron and their functions

- **The glomerulus** is a cluster of arteries that filters substances out of the blood.
- **Bowman's capsule** is a cup-shaped structure around the glomerulus that collects the filtered substances.
- **The renal tubule** is a long, narrow tube surrounded by capillaries that reabsorbs many of the filtered substances and secretes other substances.

b. Ultra-filtration, selective reabsorption and tubular secretion

The renal arteries, which carry blood into the kidneys, branch into the capillaries of the glomerulus of each nephron. The pressure of blood moving through these capillaries forces some of the water and dissolved substances in the blood through the capillary walls and into Bowman's capsule. Bowman's capsule is composed of layers. The space between the layers, called Bowman's space, fills with the filtered substances.

The process of filtering substances from blood under pressure in the glomerulus is called ultra-filtration, while the fluid that collects in Bowman's space is called glomerular filtrate. The filtrate is mainly composed of; water, salts, glucose, amino acids, hormones and urea. Larger structures in the blood including; the protein molecules, blood cells, and platelets do not pass into Bowman's space. Instead, they remain in the main circulation.

From Bowman's space, the filtrate passes into the renal tubule whose main function is reabsorption. Reabsorption is the return of needed substances in the glomerular filtrate back to the bloodstream. It is necessary because some of the substances removed from the blood by filtration including; water, salts, glucose, and amino acids which are useful and needed by the body. About 75 % of these substances are reabsorbed in the renal tubule.

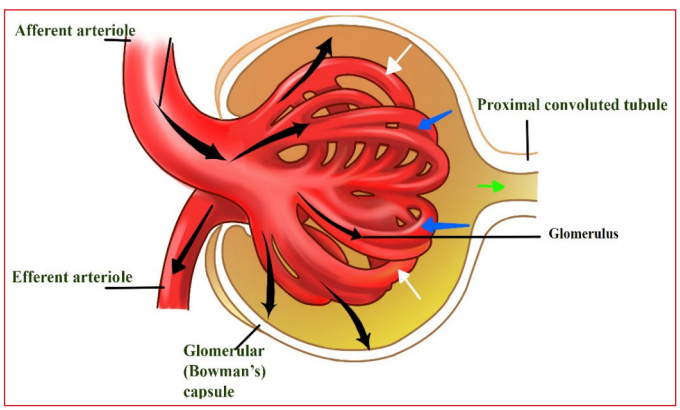


Figure 9.7: Glomerulus

Under conditions in which the kidney conserves as much water as possible, urine can reach an osmolality of about 1200 milliosmoles (mOsm/L), considerably hypertonic to blood (about 300 mosm/L). Osmolarity is the solute concentration expressed as molarity. This ability to excrete nitrogenous wastes with a minimal loss of water is a key terrestrial adaptation of mammals. The loop of Henle is known as a countercurrent multiplier. The term counter-current refers to the fact that the fluid flows in opposite directions in the two sides of the loop, down one side and up in the other. The multiplier effect is seen by comparing the osmolality of the fluid in the cortex and that in the renal medulla at the hairpin end of the loop.

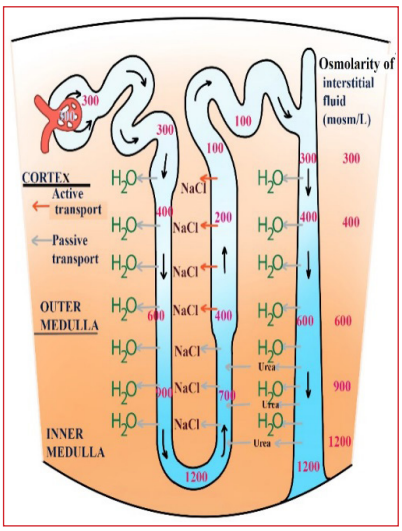


Figure 9.8: Transport of substances across the loop of Henle

The remaining fluid enters the distal tubule. The distal tubule carries the fluid, now called tubular fluid, from the loop of Henle to a collecting duct. As it transports the fluid, the distal tubule also reabsorbs or secretes substances such as calcium and sodium following the influence of hormones (e.g. aldosterone). The process of secreting substances into the tubular fluid is called secretion.

Application activity 9.6

1. What are the main parts of a nephron?
2. In which part of the nephron does each of the following processes takes place?

a. Ultrafiltration

b. Reabsorption

c. Secretion

3. What is the function of the loop of Henle?

9.7 Formation of urea and urine

Activity 9.7

a. Where is urea produced?
b. Where is urea excreted?
c. What the main steps involved in the formation of urine?
d. What is the importance of the ornithine cycle?

Urine formation depends on three processes including **ultrafiltration, selective reabsorption** and **secretion/tubular secretion**.

a. Ultra-filtration

Each nephron of the kidney has an independent blood supply, which moves through the afferent arteriole into the glomerulus, a high-pressure filter. Normally, pressure in a capillary bed is about 25 mm Hg. The pressure in the glomerulus is about 65 mm Hg. Dissolved solutes pass through the walls of the glomerulus into the Bowman's capsule. Although materials move from areas of high pressure to areas of low pressure, not all materials enter the capsule.

b. Selective reabsorption

The importance of reabsorption is emphasized by examining changes in the concentrations of fluids as they move through the kidneys. On average, about 600 mL of fluid flows through the kidneys every minute. Approximately 20% of the fluid, or about 120 mL, is filtered into the nephrons. This means that if none of the filtrate were reabsorbed the quantity of around 120 mL of urine each minute would be formed and the amount of at least 1 L of fluids would be consumed every 10 minutes to maintain homeostasis.

c. Secretion

Secretion is the movement of wastes from the blood back into the nephron. Nitrogen containing wastes, excess H+ ions, and minerals such as K+ ions are examples of substances secreted. Even drugs such as penicillin can be secreted. Cells loaded with mitochondria line the distal tubule. Like reabsorption, tubular secretion occurs by active transport, but, unlike reabsorption, molecules are shuttled from the blood into the nephron.

Formation of urea

The body is unable to store proteins or amino acids, and any surplus is destroyed in the liver. Excess amino acids which are brought to the liver by the hepatic portal vein, are deaminated by the liver cells.

In this process the amino (NH_2) group is removed from the amino acid, with the formation of ammonia. The amino acid residue is then fed into carbohydrate metabolism and oxidized with the release of energy. Meanwhile the ammonia must not be allowed to accumulate because it is highly toxic even in small quantities. Under the influence of specific enzymes in the liver cells, the ammonia enters a cyclical series of reactions called the ornithine cycle, in which it reacts with carbon dioxide to form the less toxic nitrogenous compound urea. The urea is then shed from the liver into the bloodstream, and taken to the kidney which eliminates it from the body.

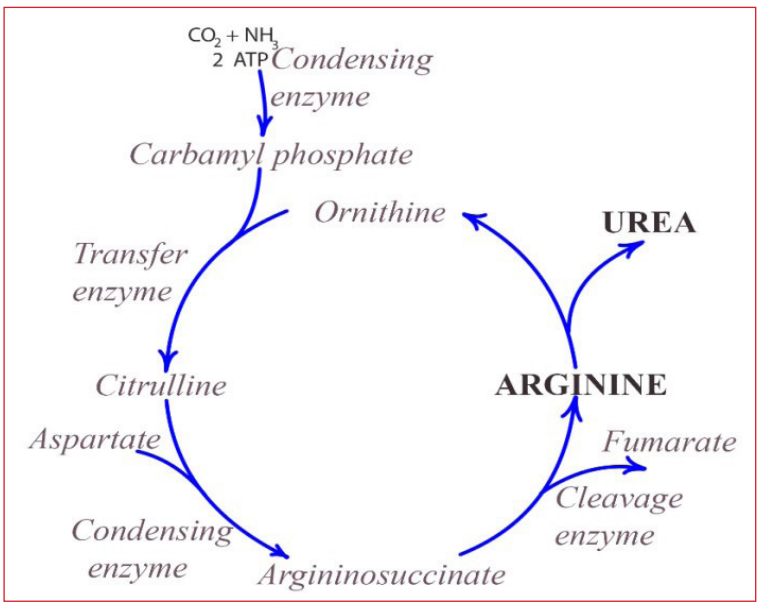


Figure 9.9: Ornithine cycle

Application activity 9.7

1. What are the main components of urine?
2. The table below shows the percentage of various components in the blood plasma in the part labelled A, the fluid in the part labelled B and in the urine of a human

Waste	Origin of waste	Organ of excretion
Ammonia	Deamination of amino acids by the liver	Kidneys
Urea	Deamination of amino acids by the liver Ammonia combined with carbon dioxide	Kidneys
Uric acid	Products of the breakdown of nucleic acids, such as DNA	Kidneys
Carbon dioxide	Waste product of cellular respiration	Lungs
Bile pigments	Breakdown of red blood cell pigment, hemoglobin	Liver
Lactic acid	Product of anaerobic respiration	Liver

9.8 Kidney transplants and dialysis machines

Activity 9.8

a. Explain why some people need to have their kidney replaced?
b. What is the use of a dialysis machine?

Dialysis is a medical procedure in which blood is filtered with the help of a machine. Blood from the patient's vein enters the dialysis machine through a tube. Inside the machine, excess water, wastes, and other unneeded substances are filtered from the blood. The filtered blood is then returned to the patient's vein through another tube. A dialysis treatment usually lasts three to four hours and must be repeated three times a week. Dialysis is generally performed on patients who have kidney failure. Dialysis helps them stay alive, but does not cure their failing kidneys.

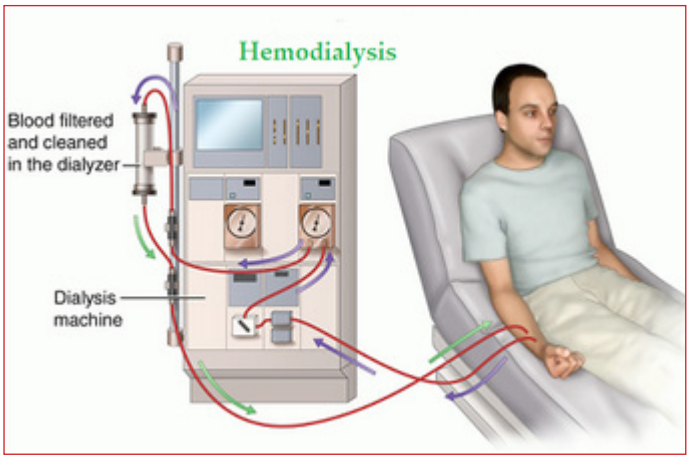


Figure 9.10: The process of dialysis

Kidney transplantation or renal transplantation is the organ transplant of a kidney into a patient with end-stage renal disease. Organ transplantation is a medical procedure in which an organ is removed from one body and placed in the body of a recipient, to replace a damaged or missing organ. Kidney transplants are sometimes performed on people who suffer from severe renal failure. Usually, the donor has suffered an accidental death and had granted permission to have his or her kidneys used for transplantation. An attempt is made to match the immune characteristics of the donor and recipient to reduce the tendency for the recipient's immune system to reject the transplanted kidney. Even with careful matching, however, recipients have to take medication for the rest of their lives to suppress their immune systems so that rejection is less likely. The major cause of kidney transplant failure is rejection by the recipient's immune system.

Application activity 9.8

What is the difference between dialysis and kidney transplantation?

9.9 Role of the hypothalamus, pituitary gland, adrenal gland and nephron in varying the osmotic pressure of blood

Activity 9.10

a. Which hormone are involved in the regulation of the osmotic pressure of the blood?
b. Where are those hormones produced?
c. What are the function of these hormones?

The body adjusts for increased water intake by increasing urine output. Conversely, it adjusts for increased exercise or decreased water intake by reducing urine output. These adjustments involve nervous system and the endocrine system.

9.9.1 Regulation by antidiuretic hormone (ADH)

A hormone called antidiuretic hormone (ADH) helps to regulate the osmotic pressure of body fluids by causing the kidneys to increase water reabsorption. When ADH is released, more concentrated urine is produced, thereby conserving body water. ADH is produced by specialized nerve cells in the hypothalamus, and it moves along specialized fibres from the hypothalamus to the pituitary gland, which stores and releases ADH into the blood. Specialized nerve receptors, called osmoreceptors, located in the hypothalamus detect changes in osmotic pressure when there is a decrease in water intake or increase in water loss by sweating, causing blood solutes to become more concentrated. This increases the blood's osmotic pressure. Consequently, water moves into the bloodstream, causing the cells of the hypothalamus to shrink. When this happens, a nerve message is sent to the pituitary, signaling the release of ADH, which is carried by the bloodstream to the kidneys. By reabsorbing more water, the kidneys produce more concentrated urine, preventing the osmotic pressure of the body fluids from increasing any further.

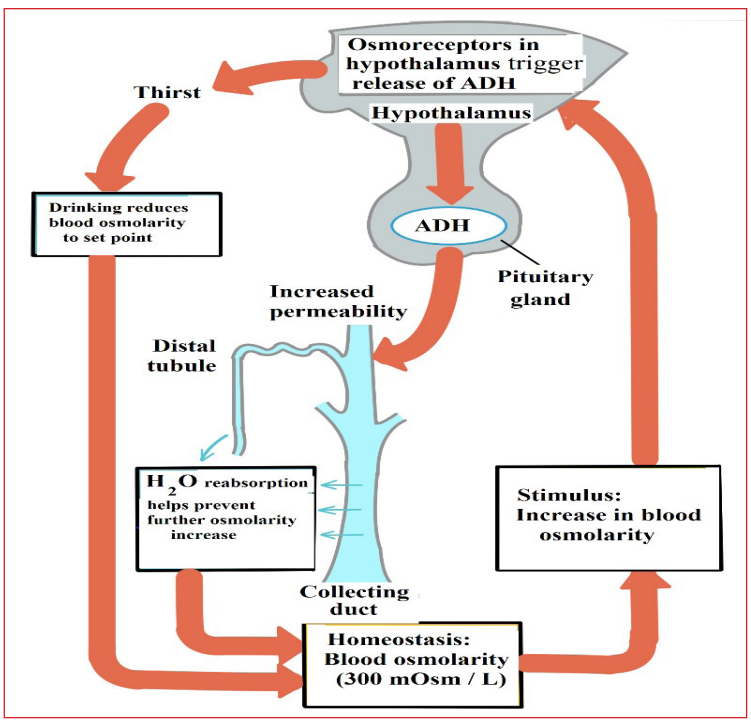


Figure 9.11: Water balance by ADH

9.9.2 Kidneys and blood pressure

The kidneys play a role in the regulation of blood pressure by adjusting for blood volumes. A hormone called aldosterone acts on the nephrons to increase Na^+ reabsorption. The hormone is produced in the cortex of the adrenal glands which lies above the kidneys. Not surprisingly, as NaCl reabsorption increases, the osmotic gradient increases and more water move out of the nephron by osmosis.

Aldosterone is secreted by the adrenal cortex in response to a high blood potassium levels, to a low blood sodium levels, or to a decreased blood pressure. When aldosterone stimulates the reabsorption of Na^+ ions, water follows from the filtrate back to the blood. This helps maintain normal blood volume and blood pressure. In the kidneys, aldosterone increases reabsorption of Na^+ and water so that less is lost in the urine. Aldosterone also stimulates the kidneys to increase secretion of K^+ and H^+ into the urine. With increased water reabsorption by the kidneys, blood volume increases.

Application activity 9.9

What is the effect of drinking a lot of water on the production of the following hormones?

a. ADH
b. Aldosterone

9.10 Excretion and osmoregulation in protists, insects, fish, amphibians and birds

Activity 9.11

1. What are the excretory organs in the following animals?
   a. Amoeba
   b. Housefly
   c. Tilapia
2. Explain the osmoregulation in fresh water fishes

a. Osmoregulation in protists such as Amoeba

Amoeba makes use of **contractile vacuoles** to collect excretory wastes, such as ammonia, from the intracellular fluid by diffusion and active transport. As osmotic action pushes water from the environment into the cytoplasm, the vacuole moves to the surface and disposes the contents into the environment.

b. Excretion in insects

Insects and other terrestrial arthropods have organs called **Malpighian tubules** that remove nitrogenous wastes and also function in water balance. The Malpighian tubules extend from dead-end tips immersed in **haemolymph** (circulatory fluid) to openings into the digestive tract. The filtration steps which are common to other excretory systems are absent. Instead, the transport epithelium that lines the tubules secretes certain solutes, including nitrogenous wastes, from the haemolymph into the lumen of the tubule.

Water follows the solutes into the tubule by osmosis, and the fluid then passes into the rectum. There, most solutes are pumped back into the haemolymph and water reabsorption by osmosis follows. The nitrogenous wastes mainly insoluble uric acid, are eliminated as nearly dry matter along with the faeces. Capable of conserving water very effectively, the insect excretory system is a key adaptation contributing to their success on land.

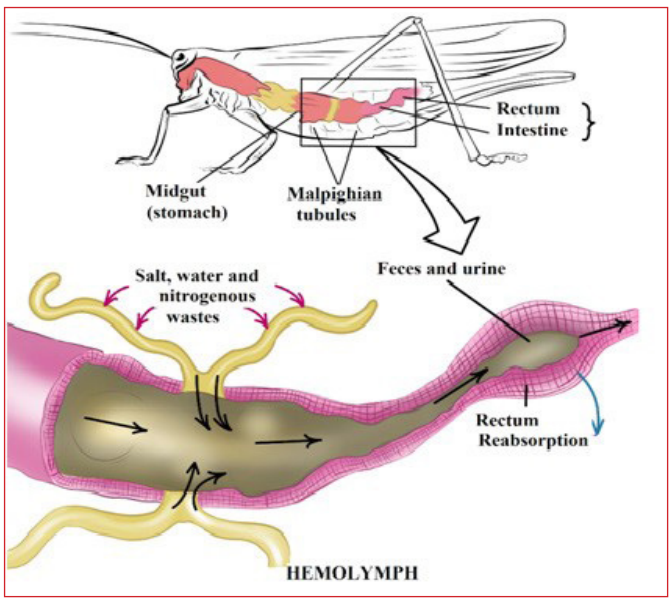


Figure 9.12: Malpighian tubules of insects

c. Excretion in birds and reptiles

Most birds live in environments that are dehydrated. Like mammals, birds have kidneys with juxtamedullary nephrons that specialize in conserving water. However, the nephrons of birds have loops of Henle that extend less far into the medulla than those of mammals. Thus, bird kidneys cannot concentrate urine to the high osmolarities achieved by mammalian kidneys. Although birds can produce hyperosmotic urine, their main water conservation adaptation is

having uric acid as the nitrogen waste molecule. Since uric acid can be excreted as a paste, it reduces urine volume.

The kidneys of reptiles having only cortical nephrons, produce urine that is osmotic or hypo-osmotic to body fluids. However, the epithelium of the chamber called the cloaca helps conserve fluid by reabsorbing some of the water present in urine and feces. Also like birds, most reptiles excrete their nitrogenous wastes as uric acid.

Freshwater fishes and amphibians

Freshwater fishes are hyperosmotic to their surroundings, so they must excrete excess water continuously. In contrast to mammals and birds, freshwater fishes produce large volumes of very dilute urine. Their kidneys, which contain many nephrons, produce filtrate at a high rate. Freshwater fishes conserve salts by reabsorbing ions from the filtrate in their distal tubules, leaving water behind.

Amphibian kidneys function much like those of freshwater fishes. When in fresh water, the kidneys of frogs excrete dilute urine while the skin accumulates certain salts from the water by active transport. On land, where dehydration is the most pressing problem of osmoregulation, frogs conserve body fluid by reabsorbing water across the epithelium of the urinary bladder.

Marine bony fishes

The tissues of marine bony fishes gain excess salts from their surroundings and lose water. These environmental challenges are opposite to those faced by their freshwater relatives. Compared with freshwater fishes, marine fishes have fewer and smaller nephrons, and their nephrons lack a distal tubule. In addition, their kidneys have small glomeruli, and some lack glomeruli entirely. In keeping with these features, filtration rates are low and very little urine is excreted.

Application activity 9.10

Compare the osmoregulation in unicellular organisms such as amoeba and insects.

9.11 Principles of osmoregulation in marine, freshwater and terrestrial organisms

Activity 9.12

Obtain a live fish from an aquarium or a lake in a bucket. Increase the concentration of salts in the water to see what happens to the fish and record your observation. Why does the fish die? You can use another animal that lives in fresh water such as tadpoles.

Organisms in aquatic and terrestrial environments must maintain the right concentration of solutes and amount of water in their body fluids. This involves excretion through the skin and the kidneys.

a. Marine animals

Marine bony fishes, such as the salmon, constantly lose water by osmosis. Such fishes balance the water loss by drinking large amounts of seawater. They then make use of both their gills and kidneys to rid themselves of salts. In the gills, specialized chloride cells actively transport chloride ions (Cl-) out, and sodium ions (Na+) follow passively. In the kidneys, excess calcium, magnesium, and sulphate ions are excreted with the loss of only small amounts of water.

b. Freshwater animals

The body fluids of fresh water animals **must be hypertonic** because animal cells **cannot tolerate salt concentrations as low as those of lake or river water**. Having internal fluids with an osmolality higher than that of their surroundings, freshwater animals face the problem of gaining water by osmosis and losing salts by diffusion through their gills. Many freshwater animals, including fishes, solve the problem of water balance **by drinking almost no water and excreting large amounts of very dilute urine**. At the same time, salts lost by diffusion and in the urine are replaced by those found in the food they eat.

c. Land animals

The threat of dehydration is a major regulatory problem for terrestrial plants and animals. Humans, for example, die if they lose as little as 12% of their body water. Adaptations that reduce water loss are key to survival on land. Much as a waxy cuticle contributes to the success of land plants, the body coverings of most terrestrial animals help prevent dehydration.

Examples are the waxy layers of insect exoskeletons, the shells of land snails, and the layers of dead, keratinized skin cells covering most terrestrial vertebrates,

including humans. Despite these and other adaptations, most terrestrial animals lose water through many routes: in urine and feces, across their skin, and from moist surfaces in gas exchange organs. **Land animals maintain water balance by drinking and eating moist foods and by producing water metabolically through cellular respiration**. A number of desert animals, including many insect-eating birds and other reptiles, are well enough adapted for minimizing water loss that they can survive without drinking water. A noteworthy example is the kangaroo rat loses so little water that 90% replaced by water generated metabolically; the remaining 10% comes from the small amount of water in its diet of seeds.

Application activity 9.11

Compare the osmoregulation in fresh water fishes with the excretion in salt water fishes.

9.12 Excretion in plants

Activity 9.13

a. Name three excretory waste products of plants.
b. Plants do not have complex excretory organs. State three reasons.
c. What are hydathodes? What is their importance in the excretion in plants?

Compared to animals, plants do not have a well-developed excretory system to throw out nitrogenous waste materials. This is because of the differences in their physiology. Therefore, plants use different strategies for excretion.

The gaseous waste materials produced during respiration (carbon dioxide) and photosynthesis (oxygen) diffuse out through stomata in the leaves and through lenticels in other parts of the plant. Excess water evaporates mostly from stomata and also from the outer surface of the stem, fruits, etc., throughout the day. This process of getting rid of excess water is called transpiration. The waste products, like oxygen, carbon dioxide and water, are the raw materials for other cellular reactions such as photosynthesis and cellular respiration. The excess of carbon dioxide and water are used up in this way. The only major gaseous excretory product of plants is oxygen.

Many plants store organic waste products in their permanent tissues that have dead cells, for example in heartwood. Plants also store wastes within their leaves or barks, and these wastes are periodically removed as the leaves and barks fall off. Some of the waste products are stored in special cells or cellular

vacuoles. Organic acids, which might prove harmful to plants, often combine with excess cations and precipitate out as insoluble crystals that can be safely stored in plant cells. Calcium oxalate crystals accumulate in some tubers like yam.

Aquatic plants lose most of their metabolic wastes by direct diffusion into the water surrounding them. Terrestrial plants excrete some wastes into the soil around them. Plants do not have complex excretory systems. This is because of the following reasons:

- There is very little accumulation of toxic wastes. Often the plant wastes are utilized by the plant. For example, carbon dioxide is used for photosynthesis and oxygen for respiration.
- The extra gaseous waste is removed from the plant by simple diffusion through the stomata and the lenticels.
- Most of the waste substances formed in plants are not harmful and can be stored in the plant tissues.
- Some plants store other waste such as resins in their tissues in a non-toxic form. These tissues or organs later fall off the plant.
- Excess water and dissolved gases are removed by the process of transpiration through the stomata.
- Some plants remove waste products by exudation, for example gums, resins, latex and rubber.
- In some plants water with dissolved salts oozes out through hydathodes. This is called guttation.

Note that hydathodes are specialized structures and they are mainly responsible for secreting water in liquid form. They are generally restricted to the apex or the serrated edges of the margins of leaves.

Application activity 9.12

Most of the waste products produced by plants are useful to humans. Name any three waste products produced by plants that humans may benefit.

9.13 Adaptations of organisms to different environmental conditions

Activity 9.14

a. Name any three animals adapted to live in very cold areas.
b. List the adaptations that these animals have in common.
c. The camels are animals adapted to live in deserts. What are the adaptations of these animals that help them to survive in the deserts?

Every organism has certain features or characteristics which enables it to live successfully in its particular habitat. These features are called adaptations, and the organism is said to be adapted to its habitat. Organisms living in various habitats need different adaptations in order to maintain homeostasis. The animals adapt to such changes in their environment which threatens their chances of survival. The main threats are temperature, lack of water and food. Besides the environmental threats, many animals also need to be able to defend themselves from predators and pathogens.

Different organisms have adapted to the great diversity of habitats and distinct conditions in the environment. Although, the adaptations are many and varied, they can be categorized into mainly three types: Structural, physiological and behavioural.

9.13.1 Structural Adaptations

Structural (or morphological) adaptations are the physical features of the organism. It includes shapes or body covering as well as its internal organisation. Microscopic organisms which includes protozoans and bacteria employ encystment (a state of suspended form, separated by the outside world by a solid cell wall) to surpass hostile conditions for long periods of time, even millions of years. Larger animals like polar bears are well adapted for survival in the cold climate of Arctic region. They have a white appearance to camouflage from prey on the snow and ice. Also, polar bear have thick layers of fat and fur, for insulation against the cold and a greasy coat which sheds water after swimming.

Figure 9.13: Polar bear in cold climate

Dolphins are fish-like mammals which have streamlined shape and fins instead of legs. They also have blowholes on the tops of their heads for breathing, rather than their mouth and nose. Desert animals like camels have many adaptations that allow them to live successfully in hot and dry conditions. They have long eyelashes and nostrils that can close and open to prevent entry of sand. Thick eyebrows shield the eyes from the desert sun. Camels store fat in the hump which can be metabolised for energy. A camel can go a week or more without water, and they can last for several months without food. Their huge feet help them walk on sand without sinking into it.

(a) (b)

Figure 9.14: Camel's adaptations in desert environment: (a) Nostrils and (b) Hump

9.13.2 Physiological Adaptations

Physiological adaptations are related to the working of an organism's metabolism.

These adaptations enable the organism to regulate their bodily functions, such as breathing and temperature, and perform special functions like excreting chemicals as a defence mechanism (Sea stars). Chameleon (a reptile) changes colour or body markings in order to blend into its surroundings. Marine mammals such as whales are endothermic/warm blooded (able to maintain a constant body temperature). They cope with the temperature changes during migration over large distances and can spend time in arctic, tropical and temperate waters.

9.13.3 Behavioural Adaptations

Behavioural adaptations are learned adaptations that help organisms to survive. The whales produce sounds that allow them to communicate, navigate and hunt prey. Bears hibernate or 'sleep' through the coldest part of the year. Bryozoans are water dwelling small individual animals found in colonies in high numbers on the continental shelf in New Zealand. These animals band together for collecting food and survive predation. Penguins are the flightless birds found in the oceans around Antarctica. During extreme winter, Emperor penguins show social behaviour by huddling together in groups comprising several thousand penguins to stay warm.

Application activity 9.13

Describe two structural adaptations, two physiological adaptations and two behavioral adaptations.

Skills lab 9

Dissection of the rabbit to study the urinary system

Materials required: A mature rabbit, dissecting tray, and dissecting kit, chloroform.

- Place the rabbit in the dissecting tray, ventral side up.
- Tie the legs securely to the corners of the tray by passing a string or rubber bands (2 bands together) under the tray from front leg to front leg and hind leg to hind leg.
- Be sure that the specimen is held firmly before you begin dissecting.
- Find the lower edge of the sternum (breastbone) and make an incision through the skin from that point to the pelvis. This will expose the layers of the abdominal muscles.
- Strip the skin well back to the sides and examine the muscle layer.
- Using the scissors or the scalpel, make another incision through the muscle layer. This will expose a thin membrane, the peritoneum, which lines the abdominal cavity.
- Cut through the peritoneum to expose the abdominal organs.
- Open the abdominal cavity wide by making several lateral cuts and pulling the skin and muscle layer well to the side.
- Use pins to pin back the cut sections of skin and muscle.
- Discard the digestive organs and examine the kidneys.
- Cut under each kidney and remove it along with the ureter tube.
- Cut a kidney laterally and examine its internal structure.
- You should find a spongy cortex on the other curved side and a hollow pelvis on the inner concave side. See if you can find the renal blood vessels which lead to and from the kidneys. Discard the kidneys.

Identify the functions of each part of the urinary system.

End unit assessment 9

1. The most important function of the kidney is:

a. Removal of water from the body.

b. Regulating blood composition.

c. Storage of salts in the body.

d. Elimination of urea from the blood.

2. Glucose is small enough to be filtered from the blood in glomeruli in the kidney, but is not normally found in the urine. This is because glucose is:

a. Reabsorbed in distal convoluted tubules

b. Reabsorbed in proximal convoluted tubules

c. Reabsorbed along the whole length of the nephrons

d. Respired by cells in the kidney

3. Which of these does not contribute to the process of filtration in the kidney?

a. High hydrostatic blood pressure in glomerular capillaries.

b. Large surface area for filtration.

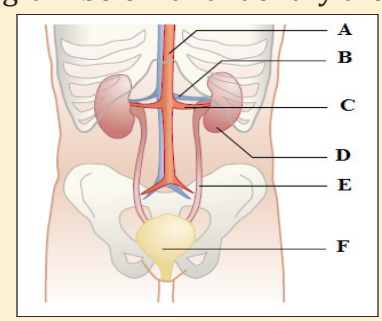
c. Permeability of glomerular capillaries.

d. Active transport by epithelial cells lining renal tubules.

4. a. Name the nitrogenous waste substances excreted by mammals.

b. Explain why it is important that carbon dioxide and nitrogenous wastes are excreted and not allowed to accumulate in the body.

5. Observe the diagram below and identify the following structures:



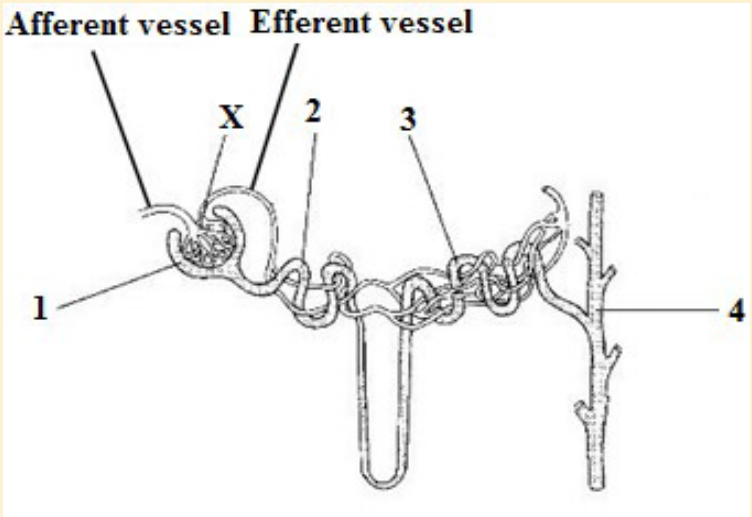
a. The structure that filters blood

b. The structure that carries urine from the kidney

c. The structure that carries blood containing urea into the kidney

d. The structure that stores urine

6. The following diagram shows the nephron.



a From the diagram above write the number that represents the:
   i. Collecting duct
   ii. Bowman's Capsule

b On the diagram above label the loop of Henle.

c Name structure X.

d Compare the blood pressure in the afferent and efferent arterioles and explain the cause of this difference.

e Proteins are not present in the glomerular filtrate but amino acids are absent. Explain.

f Compare the urea concentration in the renal artery with that in the renal vein.

Name TWO organs that excrete urea.

UNIT 10

CHARACTERISTICS OF DIFFERENT GROUPS OF MICROORGANISMS, CULTURING AND FACTORS AFFECTING THEIR POPULATION GROWTH

Key unit competence: Describe the structure, characteristics of microorganisms and explain the process of culturing microorganisms and the factors affecting their population growth.

Introductory activity 10

It was Saturday when Gakwaya and his friends ate bread in the breakfast. Some bread was left in the cupboard and when Gakwaya woke up on Monday to eat the bread before going to school, he found that the bread had turned into a black and whitish color with a fuzzy appearance and its odor was changed.



Photo: Normal bread and bread with lack and whitish color*. (Source: https://www.kingarthurflour.com/recipes/walter-sands-basic-white-bread-recipe and http://craves.everybodyshops.com/is-it-safe-to-tear-off-the-mold-and-eat-the-rest-of-the-bread/)*

a. What do you observe from the pictures?
b. Look up in a dictionary the meaning of the words: Micro, organism, micro-organism, yeast, germ, virus, bacteria, mould, fungi, algae, microbe, microbiologist, nucleus, parasite, viral, decomposer.
c. What do you think may have happened on the bread?
d. What is the nature of those substances on the bread? Are these living or nonliving thigs?
e. What do you think may happen to Gakwaya if he eats such a bread?

10.1 Types of microorganisms

Activity 10.1

1. what do you understand about?
   a. Microbiology
   b. Prokaryotic
2. State any two beneficial effects of microbes.
3. What are the main differences between archaebacterial and eubacteria?

The term "**microbiology**" comes Greek words: '**micros**' which means **small**, '**bios**' which means **life** and '**logos**' which means **science**. Microbiology **is the study of microorganisms or microbes which are too small organisms that can be only seen under microscope**. They include bacteria, fungi, algae, protozoa and viruses. They play positive role in the life of living organisms and are also harmful to the other living organisms.

Micro-organisms are everywhere: in the air, water soil, in intestine and the skin of animals, on plants, on rock surfaces in very hot and cold places (ice). Before the invention of the microscope, microbes were unknown and thousands of people died in devastating epidemics because, vaccines and antibiotics were not available to fight against infectious diseases. Nowadays, microorganisms can be grown in the laboratory and studied.

Microorganisms can be classified on the basis of cell structure (morphology), cellular metabolism, or on differences in cell molecular components such as DNA, fatty acids, pigments, antigens, and quinones. In genarl, the microbes are categorized into five groups which are **bacteria, archaea, fungi, algae, protozoa** and **viruses**.

Prokaryotes include several kinds of microorganisms, such as bacteria and cyanobacteria while eukaryotes include such microorganisms as fungi, protozoa, and simple algae. Viruses are considered neither prokaryotes nor eukaryotes because they lack the characteristics of living things, except the ability to replicate (which they accomplish only in living cells) and studied under microscope.

10.2 Effects of microorganisms on environment and human activities

Microbes are everywhere in the biosphere, and their presence invariably affects the environment that they are growing in. The effects of microorganisms on their environment can be beneficial or harmful or inapparent with regard to human measure or observation where they can perform a variety of functions, such as photosynthesis, breaking down waste, and infecting (agents of disease) other organisms.

The beneficial effects of microbes are derived from their metabolic activities in the environment, their associations with plants and animals, and from their use in food production and biotechnological processes. The beneficial effects are:

1. **Nutrient cycling and the cycles of elements that make up living systems**

Microorganisms have the ability to recycle the primary elements that make up all living systems, especially carbon (C), oxygen (O) and nitrogen (N) which are in different molecular forms that must be shared among all types of life.

In **primary production**, the photosynthetic microorganisms such as algae and cyanobacteria are involving in CO_2 fixation

Decomposition or **biodegradation** results in the breakdown of complex organic materials to forms of carbon that can be used by other organisms

Nitrogen fixation is a process found only in some bacteria which removes N_2 from the atmosphere and converts it to ammonia (NH_3), for use by plants and animals. Nitrogen fixation also results in replenishment of soil nitrogen removed by agricultural processes. Some bacteria fix nitrogen in symbiotic associations in plants.

Oxygenic photosynthesis occurs in plants, algae and cyanobacteria. It is the type of photosynthesis that results in the production of O_2 in the atmosphere.

2. **Associations with animals and plants**

Microbes invariably enter into beneficial associations with all higher forms of organisms. For example, bacteria and other microbes in the intestines of animals and insects digest nutrients and produce vitamins and growth factors. In the plants, leguminous plants (peas, beans, clover, alfalfa, etc.) live in intimate associations with bacteria that extract nitrogen from the atmosphere and supply it to the plant for growth. The microbes that normally live in associations with humans on the various surfaces of the body (called the normal flora)

3. Production of foods and fuels

In the home and in industry, microbes are used in the production of fermented foods. Yeasts (like Saccharomyces) are used in the manufacture of beer and wine and for the leavening of breads, while some bacteria (lactic acid bacteria) are used to make yogurt, cheese, sour cream, buttermilk and other fermented milk products. Vinegars are produced by bacterial acetic acid fermentation. Other fermented foods include soy sauce, sauerkraut, dill pickles, olives, salami, cocoa and black teas. Bacteria are the agents of most other food fermentations.

4. Medical, pharmaceutical and biotechnological applications

In human and veterinary medicine, for the treatment and prevention of infectious diseases, microbes are a source of antibiotics and vaccines.

Antibiotics are substances produced by microorganisms that kill or inhibit other microbes which are used in the treatment of infectious disease. Antibiotics are produced in nature by molds such as Penicillium and bacteria such as Streptomyces and Bacillus.

Vaccines are substances derived from microorganisms used to immunize against disease. The microbes that are the cause of infectious disease are usually the ultimate source of vaccines.

Biotechnology

Microbiology makes an important contribution to biotechnology, an area of science that applies microbial genetics to biological processes for the production of useful substances. Important tools of biotechnology are microbial cells, microbial genes and microbial enzymes.

5. Basic research

Microorganisms, in particular the bacterium, Escherichia coli and the yeast, Saccharomyces, have been used as model organisms for basic research and the study of cellular life. Because of cell theory and the unity of biological processes in all organisms, this information provides us with insight and understanding of life at all levels, including human.

Application activity 10.2

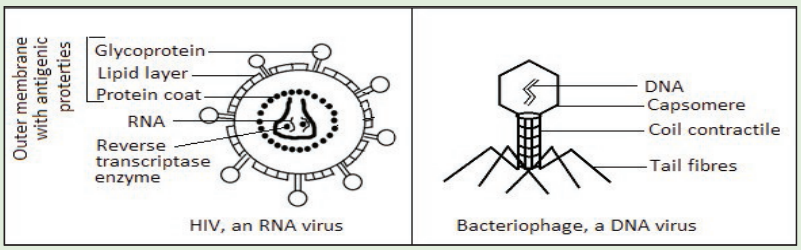
1. What are the basic shapes of bacteria?
2. Name any two examples of archaebacteria.
3. What are the similarities and differences between protozoa and animals?

10.3 Characteristics of microorganisms

10.3.1 Characteristics and structure of viruses

Activity 10.3

The figure below shows two types of viruses (HIV virus and a bacteriophage)



1. Use the figure to identify the main parts of a virus?
2. Analyze the figure and identify the main differences between a virus and a eukaryotic cell.
3. The HIV virus on the figure has an enzyme called reverse transcriptase or RT. What is its

The term "**virus**" was first used in the 1890s to describe agents smaller than bacteria that cause diseases. The existence of viruses was established in 1892, when, Russian scientist, Dmitry Ivanovsky discovered later microscopic particles known as the tobacco mosaic virus

There are at least 3,600 types of virus. Hundreds of which are known to cause diseases in animals, bacteria, and plants. Viruses consist of an inner core of either **ribonucleic acid (RNA)** or **deoxyribonucleic acid (DNA)** plus a **protein protective coat** called **capsid** made of protein or of protein combined with lipid or carbohydrate components.

The core confers infectivity, and the capsid provides specificity to the virus. In some virions, the capsid is further enveloped by a fatty membrane. The later may cause virion inactivation by exposure to fat solvents such as ether and chloroform.

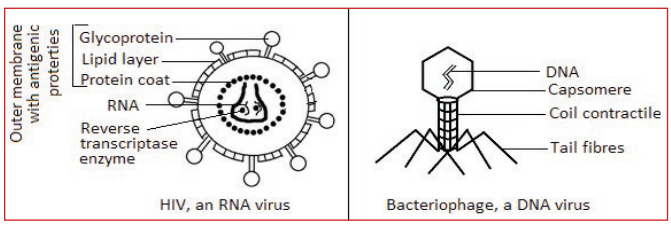


Figure 10.1: Structure of viruses

- Viruses are complex biochemical molecules having the following characteristics:
- Viruses are not visible under light microscope because they are very small than bacteria.
- They possess a single type of nucleic acid either DNA or RNA enclosed in a protein coat.
- They can reproduce and grow inside the host cell.
- They have no cell and no cell organelles. They are accellular
- They are obligate parasite i.e. cannot survive outside a host cell.
- They do not feed, respire and excrete.
- They are neither prokaryotes nor eukaryotes

10.3.2 Virus types

DNA and RNA viruses differ in the way they use the host cell's mechanisms to produce new viruses. For example, a DNA virus may act in one of the two ways:

The virus may directly produce RNA that is used to make more viral proteins or it may join with the host cell's DNA to direct the synthesis of new viruses. RNA viruses replicate differently from DNA viruses. Upon entering the host cell, a viral RNA is released into the host cell's cytoplasm. There, it uses the host cell's ribosomes. Some RNA viruses known as retroviruses contain an enzyme called reverse transcriptase in addition to RNA. Reverse transcriptase uses RNA as a template to make DNA. The DNA then makes an RNA transcript of itself. This RNA is then translated into proteins that become part of new viruses. Reverse transcriptase is so named because it reverses the normal process of transcription, in which DNA serves as a template for producing RNA.

Application activity 10.3

1. Explain why viruses are called obligate intracellular parasites?
2. What are the main differences between viruses and cells?
3. What is a temperate virus?

10.4 Protozoans, algae, molds and eubacteria.

Activity 10.4: Research activity

Using library textbook or search engine,

a. identify the characteristics of each of the following organisms
i. Protozoa
ii. Molds
iii. Eubacteria
b. Explain the life cycle of Plasmodium

10.4.1 Moulds

Moulds pervade our world, living wherever moisture is present. Some are of great benefit to humans, providing antibiotics, acting as decomposers so that nutrients can be recycled, or taking part industrial processes. Other moulds cause diseases which lead to serious damage.

Moulds have cells arranged in long thread-like filaments, the hyphae, that form a mass called Mycelium. Moulds are usually considered as fungi, but mould may also be formed by filamentous bacteria, slime moulds, and water moulds. Therefore, there are two main types of moulds: fungal moulds and non-fungal moulds.

10.4.2 Fungal moulds

All fungi that produce mycelia can be called moulds, but the term is usually used for an organism in which the mycelium forms the main body of the fungus. In the black bread mould Rhizopus and the pin mould Mucor, the mycelium consists of a tangled mass of hyphae with many nuclei. These hyphae are called coenocytic because the fungal tissue is not separated by cell walls.

Fungal hyphae have an outer cell wall made of chitin and inner lumen which contains the cytoplasm and organelles. A cell surface membrane surrounds the cytoplasm and sticks tightly to the cell wall.

Rhizopus and Mucor are Saprotrophic, obtaining their nutrients from dead organic material. Rhizopus nigricans and Mucor mucedo can live on bread but some species of Rhizopus feed on living plants, and Mucor commonly grows on rotting fruits and vegetables, in the soil or on dung.

Rhizopus and Mucor secrete hydrolytic enzymes onto their food source and digest the food outside the organism and then absorb the soluble digestion products and assimilate them.

10.4.3 Penicillium and saccharomyces

a. Penicillium and antibiotics

Penicillium is highly known for producing penicillin, the first antibiotic discovered in 1928 by a scientist Alexander Fleming when he was culturing some Staphylococcus bacteria during his medical research.

After leaving some Petri dishes for many days, he found a mouldy growth of Penicillium notatum contaminating a corner of one of dishes. Then Fleming

realized that Staphylococcus next to the mould has been destroyed. After studying Staphylococcus closely, Fleming concluded that the Penicillium mould was producing a substance that killed the Staphylococcus. He carried on with finding out if the broth of Penicillium mould contained penicillin which could destroy pathogenic bacteria.

In 1931, Fleming dropped his research. Howard Florey and Ernst Chain went on to produce purified penicillin. A successful work was reported 1940, and penicillin has been used to treat wounded soldiers in Second World War. In 1945, Fleming, Florey and Chain received the Nobel Prize for the discovery of penicillin.

b. Saccharomyces

Definition and characteristics

- Saccharomyces is a genus of yeasts which include all unicellular fungi that reproduce asexually by budding.
- They occur commonly on feces, in the soil, and on the surfaces of plants and animals.
- The most familiar and industrial important yeast is Saccharomyces cerevisiae.
- The tiny cells of this yeast are very active metabolically. They are usually aerobic but in the absence of oxygen they use anaerobic metabolism, producing carbon dioxide and ethanol (alcohol) as waste products which are industrially useful
- Each cell of Saccharomyces cerevisiae has a single nucleus and is usually egg shaped.
- Cells contain most of organelles of a typical eukaryote.

10.4.4 Protozoa

Protozoa are single celled microscopic organisms that are noted for their ability to move independently. Protists live in many different environments; they can drift in the ocean, creep across vegetation in fresh water rivers and ponds, crawl in deep soil and even reproduce in the bodies of other organisms. Most protozoans are heterotrophic obtaining their nutrients by ingesting small molecules of cells. These particles are usually broken in food vacuoles, membrane-bound chambers that contain digestive enzymes.

Many species of protozoa are free-living, while others are parasitic. Free-living protozoa live in any habitat where water is available at some time during the year. Many species make up the zooplankton, a population of organisms that

constitutes one of the primary sources of energy in aquatic ecosystems. Other free-living protozoa live in the soil. Parasitic protozoa usually have complex life cycles that take place in the cells, tissues, and blood stream of their hosts. Several species cause a variety of serious human diseases, including malaria, amebic dysentery and giardiasis. Protozoa that cause diseases

Entamoeba histolytica

a. Characteristics of *Entamoeba* histolytica

Entamoeba histolytica is a protozoan parasite responsible for a disease called amoebiasis. It occurs usually in the large intestine and causes internal inflammation as its name suggests (histo which means tissue, lytic which means destroying). 50 million people are infected worldwide, mostly in tropical countries in areas of poor sanitation. Inside humans Entamoeba histolytica lives and multiplies as Trophozoites. Trophozoites are oblong and about 15–20 μm in length. In order to infect other humans, they encyst and exit the body.

b. Life cycle *Entamoeba* histolytica

Entamoeba histolytica life cycle does not require any intermediate host. Mature cysts (spherical, 12–15 μm in diameter) are passed in the feces of an infected human. Another human can get infected by ingesting them in fecally contaminated water and food. If the cysts survive the acidic stomach, they transform back into trophozoites in the small intestine. Trophozoites migrate to the large intestine where they live and multiply by binary fission.

Both cysts and Trophozoites are sometimes present in the feces. Cysts are usually found in firm stool, whereas Trophozoites are found in loose stool. Only cysts can survive longer periods (up too many weeks outside the host) and infect other humans. If trophozoites are ingested, they are killed by the gastric acid of the stomach. Occasionally trophozoites might be transmitted during sexual intercourse.

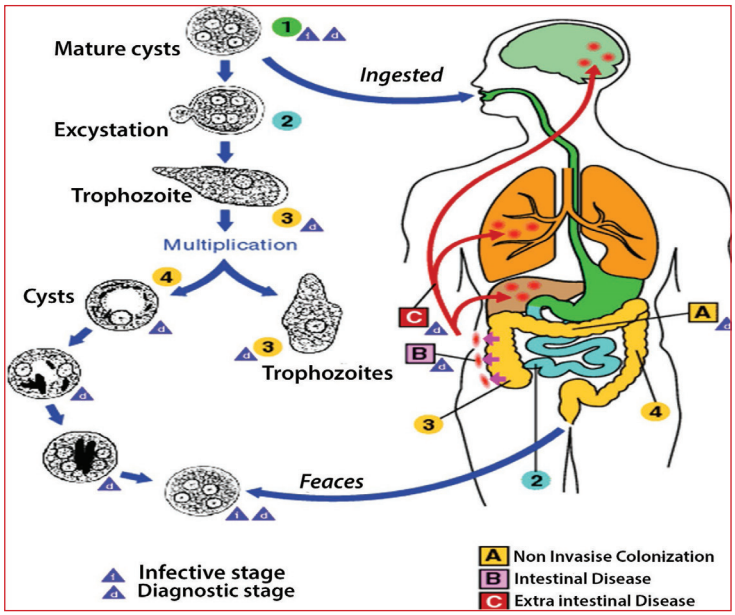


Figure10.2. Life cycle Entamoeba histolytica

c. Symptoms

Many Entamoeba histolytica infections are asymptomatic and Trophozoites remain in the intestinal lumen feeding on surrounding nutrients. About 10–20 % of the infections develop into amoebiasis which causes 70 000 deaths each year. Minor infections (luminal amoebiasis) can cause symptoms that include:

- Gas (flatulence) intermittent
- constipation loose stools
- stomach ache
- Stomach cramping.

Severe infections inflame the mucosa of the large intestine causing amoebic dysentery. The parasites can also penetrate the intestinal wall and travel to organs such as the liver via bloodstream causing extra-intestinal amoebiasis. Symptoms of these more severe infections include: Anemia, Appendicitis (inflammation of the appendix), bloody diarrhea, fatigue, fever, gas (flatulence), genital and skin lesions, intermittent constipation, liver abscesses (can lead to death, if not treated), malnutrition, painful defecation (passage of the stool), peritonitis (inflammation of the peritoneum which is the thin membrane that lines the abdominal wall), pleurapulmonary abscesses, stomach ache, stomach cramping, toxic mega-colon (dilated colon), Weight loss.

d. Prevention

To prevent spreading the infection to others, one should take care of personal hygiene. Always wash your hands with soap and water after using the toilet and before eating or preparing food. Amoebiasis is common in developing countries. Some good practices, when visiting areas of poor sanitation:

- Wash your hands often.
- Avoid eating raw food.
- Avoid eating raw vegetables or fruit that you did not wash and peel.
- Avoid consuming milk or other dairy products that have not been pasteurized.
- Drink only bottled or boiled water or carbonated (bubbly) drinks in cans or bottles.

Natural water can be made safe by filtering it through an "absolute 1 micron or less" filter and dissolving iodine tablets in the filtered water.

***Plasmodium spp*.**

a. Characteristics

- Plasmodium is the genus of the class of Sporozoa that includes the parasite that causes malaria. Plasmodium is a type of protozoa, a single-celled organism that is able to divide only within a host cell.
- The main types of Plasmodium spp are P.falciparum, the species that causes falciparum malaria, the most dangerous type of malaria; P. malariae, the species that causes quartan malaria; P. ovale, a species found primarily in east and central Africa that causes ovale malaria; and P. vivax, the species that causes vivax malaria, which tends to be milder than falciparum malaria.

b. Life cycle of Plasmodium

Plasmodium species exhibit three life-cycle stages gametocytes, sporozoites, and merozoites.

Gametocytes within a mosquito develop into sporozoites. The sporozoites are transmitted via the saliva of a feeding mosquito to the human blood stream. From there, they enter liver parenchyma cells, where they divide and form merozoites. Inside the host's liver cell, the Plasmodium cell undergoes asexual replication. The products of this replication, called merozoites, are released into the circulatory system. The merozoites invade erythrocytes and become enlarged ring-shaped Trophozoites.

More erythrocytes are invaded, and the cycle is reinitiated. The merozoites are released into the bloodstream and infect red blood cells. Rapid division of the merozoites results in the destruction of the red blood cells, and the newly multiplied merozoites then infect new red blood cells. Some merozoites may develop into gametocytes, which can be ingested by a feeding mosquito, starting the life cycle over again.

The red blood cells destroyed by the merozoites liberate toxins that cause the periodic chill-and-fever cycles that are the typical symptoms of malaria. P. vivax, P. ovale, and P. falciparum repeat this chill-fever cycle every 48 hours (tertian malaria), and P. malariae repeats it every 72 hours (quartan malaria). P. knowlesi has a 24-hour life cycle and thus can cause daily spikes in fever.

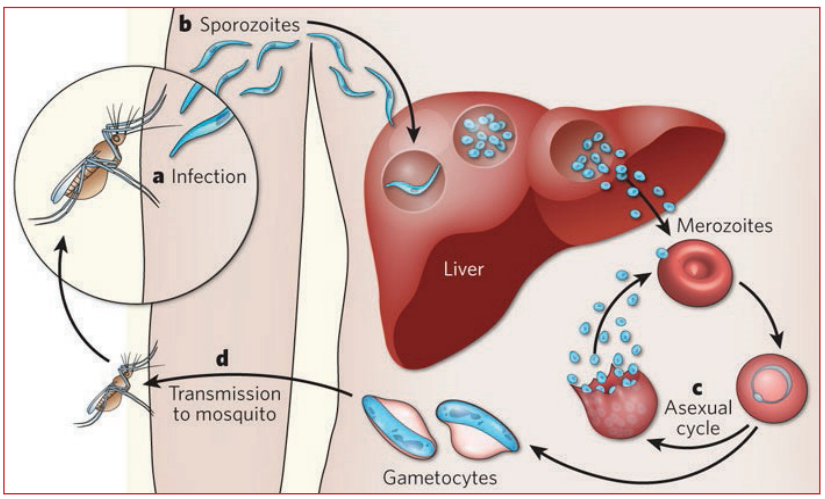


Figure10.3. Cycle of Plasmodium

10.4.5. Trypanosoma spp.

a. Characteristics

- Trypanosoma is the genus containing a large number of parasitic species which infect wild and domesticated animals and humans in Africa.
- Commonly known as African sleeping sickness, human trypanosomiasis is caused by the species Trypanosoma brucei and is transmitted to humans through either a vector or the blood of ingested animals.
- The most common vector of Trypanosoma brucei is the tsetse fly, which may spread the parasite to humans and animals through bites.
- Through a process called antigenic variation, some trypanosomes are able to evade the host's immune system by modifying their surface membrane, essentially multiplying with every surface change. Trypanosoma brucei gradually infiltrates the host's central nervous system.

b. Symptoms

Symptoms include: Headache, weakness, and joint pain in the initial stages; anaemia, cardiovascular problems, and kidney disorders as the disease progresses; in its final stages, the disease may lead to extreme exhaustion and fatigue during the day, insomnia at night, coma, and ultimately death.

c. Occurrence

Human trypanosomiasis affects as many as 66 million people in sub-Saharan Africa. Trypanosomes are also found in the Americas in the form of Trypanosoma cruzi, which causes American human trypanosomiasis, or Chagas' disease. This disease is found in humans in two forms: as an amastigote in the cells, and as a trymastigote in the blood.

d. Mode of transmission

- The vectors for Trypanosoma cruzi include members of the order Hemiptera, such as assassin flies, which ingest the amastigote or trymastigote and carry them to animals or humans.
- The parasites enter the human host through mucus membranes in the nose, eye, or mouth upon release from the insect vectors. Left untreated, Chagas' disease may cause dementia, megacolon and damage to the heart muscle, and may result in death.

e. Life cycle of Trypanosoma

Trypanosoma's cell structure plays a vital role in allowing the cell to morph into three forms (trypomastigote, epimastigote, and amastigote) during its life cycle, depending on where the cell is located in the host's anatomy. The location of the kinetoplast in relation to the nucleus and the flagellum emergence dictate in which stage the trypanosome cell is found.

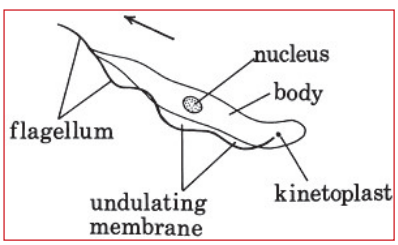


Figure 10.4: Cell structure of Trypanosoma

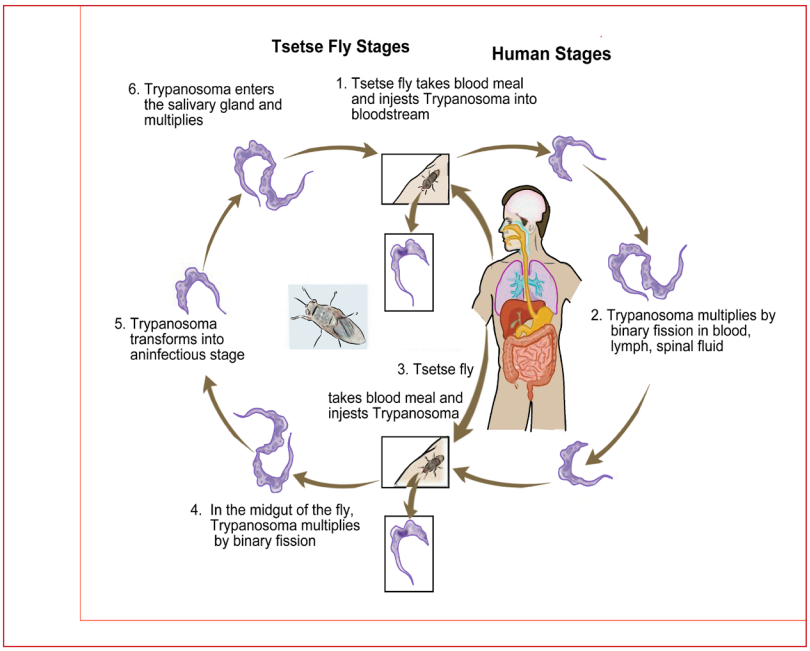


Figure 10.5. Life cycle of Trypanosoma

10.4.6. Eubacteria

They occur in many shapes and sizes and have distinct biochemical and genetic characteristics. Eubacteria that are rod-shaped are called bacilli, sphere-shaped are called cocci (sing. Coccus) and spiral-shaped are called spirilla (sing. Spirillum).

1. **Bbacilli**: bacteria with rod-shape. Ex: Clostridium tetani, Bacillus subtilis
2. **Vibrios**: comma-shaped with a single flagellum. eg: Vibrio cholera
3. **Cocci**: group of bacteria with spherical shape such as Streptococci. Cocci that occur in chains are Staphylococci which are grapelike clusters of cocci and Diplococci which is sphere shaped that are grouped two by two.
4. **Spirilla**: bacteria with spiral shape. e.g.: Spirillum volutans.

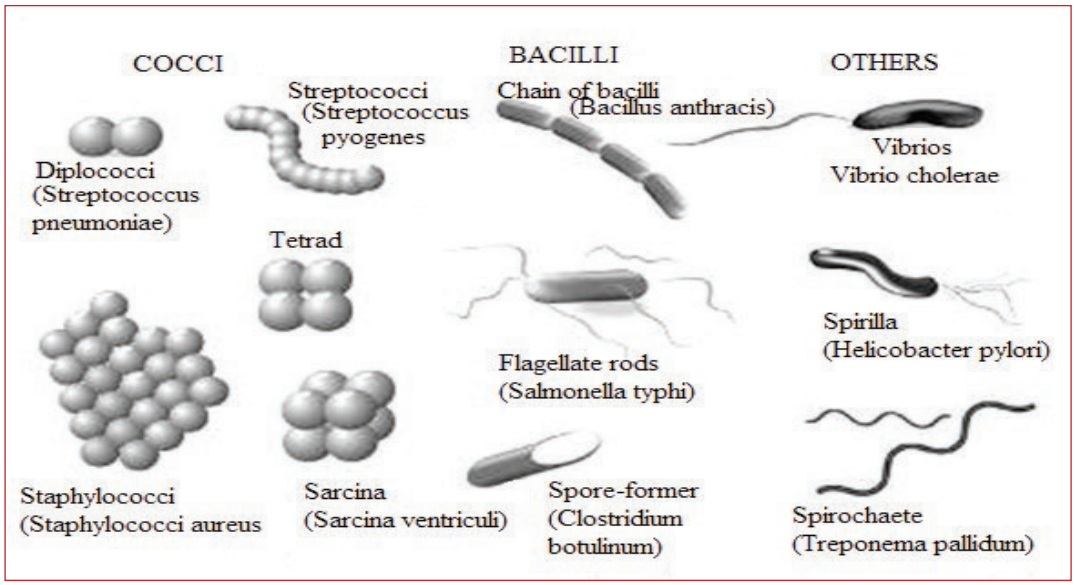


Figure 10.6: Shapes of bacteria cells

10.4.7. Algae

Algae are plantlike organisms that belong to the kingdom protista. Although most of algae are unicellular, some such as the macrocysts are large multicellular organisms. Algae differ from protozoa, which are also classified in the kingdom protista in that they manufacture their food through the process of photosynthesis.

Characteristics of algae

Algae are a diverse group of protists. They range in size from microscopic single-celled organisms to large seaweeds that may be many meters long. Unlike protozoa which are heterotrophic, algae are autotrophic protists; they have chloroplasts and produce their own carbohydrates by photosynthesis.

In the past, some classification systems placed the algae in the plant kingdom. However, algae lack tissue differentiation and thus have no true roots, stems or leaves. The reproductive structures of algae also differ from those of plants; they produce gametes in single-celled gametangia or gamete chambers. Plants by contrast, form gametes in multicellular gametangia. For these reasons, algae are classified as protists.

Despite their diversity, different kinds of algae have several features in common. For example, most algae are aquatic and have flagella at some stages of their life cycle.

In addition, algae cells often contain pyrenoids, organelles that synthesize and store starch.

Structure

The body portion of an alga is called a thallus. The thallus of an alga is usually haploid. A variety of thallus formats characterize algae. In some species, the thallus consists of a single cell. In other species, it is made of many cells in varying arrangements. Four types of algae are recognized based on the following body structures: unicellular, colonial, filamentous and multicellular.

- **Unicellur algae**: have a structure that consists of a single cell. Most unicellular algae are aquatic organisms that compose the phytoplankton, a population of photosynthetic organisms that forms the foundation of aquatic food chains. Through photosynthesis, phytoplankton produces almost half of the world's carbohydrates, thereby providing important nutrients for numerous aquatic organisms. Such unicellular algae are also among the major producers of oxygen in the atmosphere. The chlamydomonas is an example of a unicellular alga.
- **Colonial algae**: such as volvoxes have a structure that consists of a group of cells acting in a coordinated manner. Some of these cells become specialized. This division of labor allows colonial algae to move, feed and reproduce efficiently.
- **Filamentous algae**: such as spirogyra, have a slender, rod shaped thallus composed of rows of cells joined end to end. Other species of filamentous algae have specialized structures that anchor the thallus to the ocean bottom. This adaptation secures the alga in one place as it grows toward the sunlight at the water's surface.
- **Multicellular algae**: often have a large complex thallus. For instance, Ulva has a leaf like thallus that may be several centimeters wide but two cells thick.

Application activity 10.4

1. Complete the table below

Disease	Causative agent	Vector
Malaria		
Trypanosomiasis		

2. List any three symptoms of amoebiasis.
3. What is the cause of anemia for people suffering from malaria?

10.5 E. coli, food poisoning and evolution of harmful strains

ACTIVITY 10.5

You may have understood different people who have had problems after eating different kinds of food. These situations may happen after eating food at home, in a restaurant and even in the hotel. Make a search to know the possible reasons of such cases. What can be done in order to prevent these problems?

10.5.1 E. coli and food poisoning

E. coli is a rod-shaped bacterium measuring about 2.5µm by 0.5µm. I t is mainly found in guts of vertebrates. It is chemoheterotrophic, capable of thriving on a variety of the organic molecules. Its presence in water indicates contamination by feces. E. coli reproduces asexually by binary fission. It can also take part in a primitive form of sexual activity called conjugation where genetic material is passed in one direction from bacterium to another through a pilus. Although conjugation does not in itself produce new offspring, after the process has finished, the bacteria reproduce asexually, passing on their new genetic make-up to their offspring.

10.5.2 Evolution of harmful strains

E. coli was thought to be a relatively harmless resident of the human gut which might linked to the occasional upset stomach and mild diarrhea. When massive colonies of mutualistic bacteria are present in the gut, including most strains of E. coli, they help to keep harmful bacteria away from starving them of food. They also help make vitamin K. But in 1982, it became clear that a new strain of E. coli had evolved into a much more troublesome organism. The strain had acquired a gene that enabled it to produce a powerful toxin which damages the intestinal wall, causing severe diarrhoea and internal bleeding.

This may lead to internal serious dehydration in young children and elderly people, and may result into death. In majority of the cases, infections of pathogenic strain of E. coli are not fatal and the disease clears without treatment.

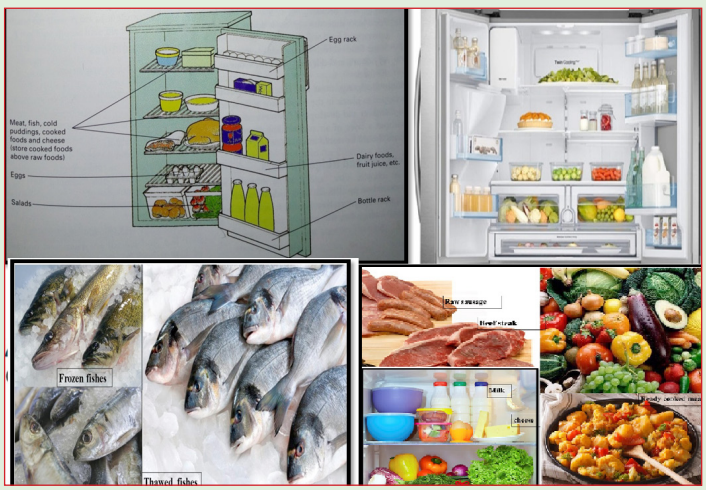
Application activity 10.5

Nowadays we are taking drugs to treat malaria. These drugs are different from those that people have been taking in the 1990s. Make a search to know the possible reasons of this. Do you know any other drug that it is not treating any disease that it used to treat? Why?

10.6 Food conservation and water purification

Activity 10.6

The figure below shows different ways of conserving and preserving food



a. Name any three food seen on the photo and show how they can be conserved.

b. Which one of the methods stated above on the figure can be used to conserve food for long periods of time?

10.6.1 Food conservation

The term food conservation refers to any one of a number of techniques used to prevent food from spoiling. It includes methods such as canning, pickling, drying and freeze-drying, irradiation, pasteurization, smoking, and the addition of chemical additives.

The optimum storage conditions differ; raw meat and poultry are kept at around 00c, meat products at 1oC - 40oC.

Canned foods and many vegetables in dry conditions at 10oc - 150oc, and dried foods such as flour are stored, in air tight containers at10oc – 150oc. For long term storage, meat and fish are vacuum-sealed or can be vacuum packed in laminated plastic containers. For pasteurization, food and drinks such as milk are heated to a temperature that kills disease causing microorganisms. Example: Mycobacterium tuberculosis. (https://www.britannica.com/topic/food-preservation)

The most frequent and traditional conservation systems used are:

- **By cooling**: refrigeration (Between 0º and 5ºC), freezing (less than -18ºC). It consists of maintaining the cold (refrigeration or freezing) throughout the entire process through which the food passes: production, transport, reception, storage, sale to the consumer.

  If the correct temperature is not maintained during the whole process, the food will suffer IRREVERSIBLE consequences.

- **By heating**: microorganisms are destroyed by heat. The most popular methods are: pasteurization, cooking, sterilization and ultra-pasteurization.
- Removing part of the water from the food: **drying, salting, sugaring, smoking**.
- Others: **pickling**, use of preservatives.

10.6.2 Water purification

Water purification is the process by which undesired chemical compounds, organic and inorganic materials, and biological contaminants are removed from water. That process also includes distillation (the conversion of a liquid into vapor to condense it back to liquid form) and deionization (ion removal through the extraction of dissolved salts). One major purpose of water purification is to provide clean drinking water. Water purification also meets the needs of medical, pharmacological, chemical, and industrial applications for clean and potable water. The purification procedure reduces the concentration of contaminants such as suspended particles, parasites, bacteria, algae, viruses, and fungi. Water purification takes place on scales from the large (e.g., for an entire city) to the small (e.g., for individual households).

Most drinking water in Rwanda is obtained is obtained from the lakes and rivers where pollution levels are low. The process of water treatment involves both filtration and chlorination. The process of water purification is summarized below:

- Impure water is first passed through screens to filter out floating debris.
- Filtration through coarse sand traps larger and insoluble particles. The sand also contains specially grown microbes which remove some of the bacteria.
- A sedimentation tank has chemicals known as flocculants, for example alum, added to it to make the smaller particles, which remain in the water, stick together and sink to the bottom of the tank.

- These particles are removed by further filtration through fine sand.
- Finally. A little chlorine gas is added, which kills any remaining bacteria. This sterilizes the water.

Application activity 10.6

Place pieces of meat in air-tight storage jars (or plastic storage bags), making sure to fully cover the meat with salt. Alternate layers of meat and salt to ensure all parts of the meat are covered in salt. Keep the jars/bags in a cool place for two weeks. Do not allow to freeze.

10.7 Fermentation

Activity 10.7

Banana beer can be produced from banana juice.

a. How can banana juice be converted to banana beer?
b. What are the ingredients necessary to produce banana juice?

Fermentation refers to the metabolic process by which organic molecules (normally glucose) are converted into acids, gases, or alcohol in the absence of oxygen.

Types of fermentation

There are many types of fermentation that are distinguished by the end products formed from pyruvate or its derivatives. The two fermentations most commonly used by humans to produce commercial foods are ethanol fermentation (used in beer and bread) and lactic acid fermentation (used to flavor and preserve dairy and vegetables).

a. Alcoholic fermentation

Yeast releases digestive enzymes which allow the transformation of glucose into ethanol as result of anaerobic fermentation. The presence of bubbles is the evidence that carbon dioxide is released as waste product of the alcoholic fermentation. Making Beer depends on a process called malting. You soak and keep barley grains in water. As germination begins, enzymes break down the starch in the barley grains into a sugary solution. You then extract a solution produced by malting and use it as an energy source for the yeast. The mixture of yeast and sugar solution is then fermented to produce alcohol. Hops are added at this stage to give flavor. The beer is given time to clear and develops its flavor before putting it in bottles or to be sold. Interestingly, alcohol in large quantities is toxic to yeast as well as to people. This is why the alcohol content of wine is rarely more than 14%. Once it gets much higher, it kills all the yeast and stops fermentation.

b. Lactic acid fermentation

Lactic acid fermentation is the production of lactic acid. Fermentation occurs in mammalian muscle during periods of intense exercise where oxygen supply becomes limited, resulting in the creation of lactic acid. This type of fermentation is used routinely in mammalian red blood cells and in skeletal muscle that has an insufficient oxygen supply to allow aerobic respiration to continue (that is, in muscles used to the point of fatigue). In muscles, lactic acid accumulation must be removed by the blood circulation and the lactate brought to the liver for further metabolism.

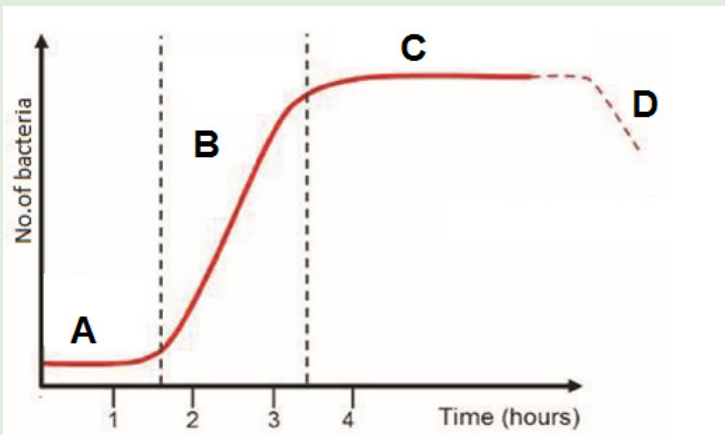
Application activity 10.7

Make a research on the use of fermentation in the production of bread.

10.8 Measuring population growth of bacteria and fungi

Activity 10.8

The figure below shows the growth curve of bacteria. Observe it and answer the questions that follow:



Indicate on the figure the letter that shows when

a. The population of bacteria is increasing
b. The population of bacteria is decreasing
c. There is no population growth
d. What are the causes of the increase of the bacteria population?

When bacteria or any other microorganisms are incubated in a suitable culturing medium, they reproduce by binary fissions and the number of individuals increases.

The ordinary growth of population is described as sigmoid curve or S-shaped curve made of 4 main phases:

- The lag phase: period of adaptation of microorganisms to the new habitat (new environment)
- The log or exponential phase: period of high rate of reproduction. Bacteria are sensitive to the limiting factors of the growth or anti-microbial agents
- The stationary phase: Stationary phase of plateau-growth slows down. The population remains constant because the rate of dividing/growth is equal to the rate of death within the population. The maximum number that a habitat can accommodate for a long period is known as the carrying capacity.
- The decline or death phase: period of high rate of death than the rate of dividing/growth due to the scarcity of food, the abundance of metabolic waste products, presence of antibiotics or any other drugs killing the germs. Figure 19.5 shows the phases explained above.

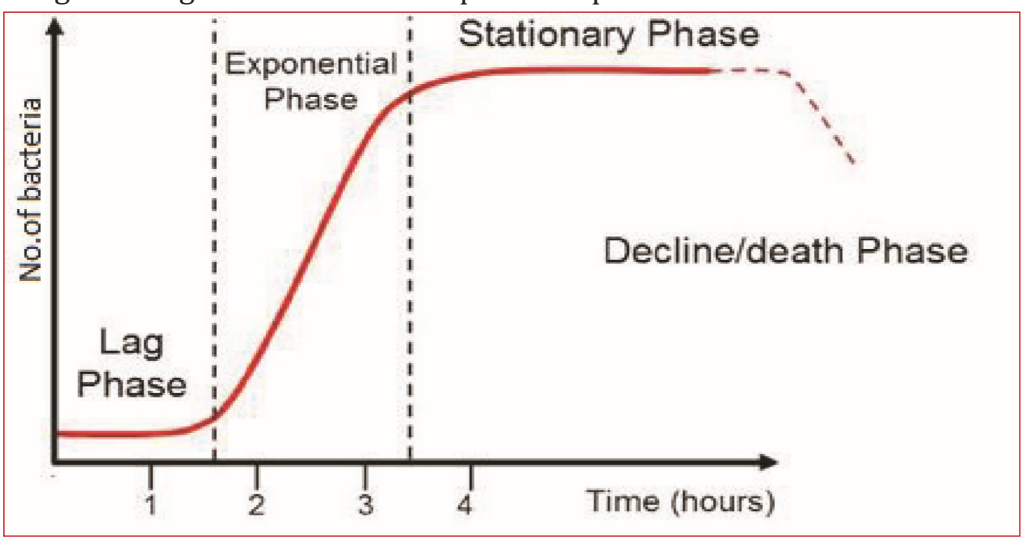


Figure 10.7: Graph of population growth of bacteria

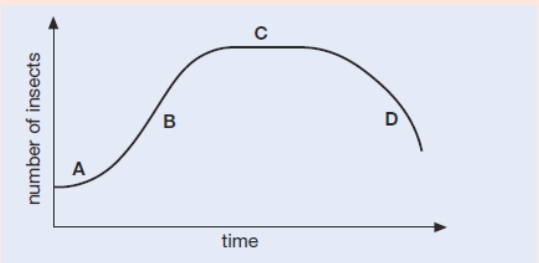
10.8.1 Measuring population growth of bacteria

The typical growth curve of a population of bacteria is similar to the growth curve expected for yeast, a unicellular fungus or the growth of any population. When measuring the growth of a population of bacteria or yeast, we can carry out direct counting of the numbers of cells or indirectly by measuring some indication of the number of cells such as the coldness of a solution, or production of a gas.

It is usual to inoculate a small sample of the microorganisms in a sterilized nutrient medium and to place the culture in an incubator at the optimum temperature for growth. Other conditions are pH, oxygen concentration and ionic and osmotic balance. Growth can be measured from the time of inoculation. Two types of cell count are possible, namely viable count and total count. The viable count is the total of living cells only and total count is the total number of both living and dead cells and is easier to measure.

Application activity 10.8

1. The graph shows a population growth graph for bacteria.



b. Which of the four phases, labelled **A, B, C** and **D**, represents the stationary phase and which the lag phase?

c. During which phases will some of the bacteria die?

d. State **two** factors that could affect the rate of population growth during phase ***C***.

10.9 Culturing microorganisms

Activity 10.9: Research activity

Make a search in different books or on the internet on the following elements.

a. What is a culture medium?

b. What is the importance of culturing microorganism?

c. What are the ingredients necessary to make a culture medium?

d. What are the possible apparatus necessary to make a culture medium?

Many microorganisms can be grown in the laboratory. This allows scientists to learn a lot about them. We can find out which nutrients they need to survive and which chemicals will kill them. We can also discover which microorganisms can be useful to us and which cause deadly disease.

To find out more about microorganisms, you need to culture them. Culturing microorganisms involves growing very large numbers of them so that you can see the colony as a whole.

To culture microorganisms, you must provide them with everything they need. This usually involves providing a culture medium containing carbohydrates to act as an energy source.

A long with this, various mineral ions some supplement of proteins and vitamins are included.

The nutrients are often contained in an agar medium. Agar is a substance which dissolves in hot water and sets to form a jelly. You pour hot agar containing all the necessary nutrients into a Petri dish. Microorganisms are living organisms. Therefore, they have requirements for their growth, maintenance and multiplication. These include:

- Optimum temperature (30-40°C) for enzymes to work better.
- Source of energy such as glucose, maltose, juice.
- Source of other nutrients (minerals such are as potassium, sodium, iron, magnesium and calcium, vitamins, proteins
- Air for aerobic microbes or complete absence of air for anaerobic microorganisms.

The medium for culture of microbes can be the dead organic matters (food, fruits, remaining of organism, juice, milk) or a prepared medium such as Agar agar (universal medium for any germ)... Different types of media are used culture microorganisms.

10.9.1 Types of media

There are many different types of media described by their components or ingredients.

Universal media: this allow the growth of every type of bacteria e.g. agar-agar Differential/selective media: are specific to some types of bacteria for example Lowenstein for tuberculosis bacteria. Their ingredients will favour growth of certain types of bacteria.

A pure culture: this contains only one kind of microorganism. The pure cultures are important for scientific method as they are free from other types of microorganisms.

10.9.2 Principles of sterile culturing

- Wash hands before touching a sterile Petri-dish
- Open the Petri-dish as little as possible, and replace the lid quickly
- Never cough or sneeze near the dish
- Never touch the infected jiffy with fingers
- When culturing is no longer required, they should be flooded with strong disinfectant
- After cleaning out the nutrient from Petri-dish, they should be washed and disinfected, and then if they are glass, heat sterilize.
- Wash your hands thoroughly after all operation by using soap.
- Never push hands near the mouth during experimental work.

Safety precautions

Bacteria grow and reproduce more quickly when they are warm than when they are cold. It would be dangerous to incubate cultures at temperatures close to body temperature (37°C) because doing so might allow the growth of pathogens harmful to health. So the maximum temperature used in school and college labs is 25°C. However, higher temperatures can be used industrially, and these produce faster growth.

10.9.3 Culture media

A medium is a solid or liquid preparation containing nutrients for the culture of microorganisms. A pure microbial culture undergoes the following steps namely:

- Choice of the culture medium.
- Sterilization of the culture medium.
- A culture with a collection of microbial cells growing on or, in a medium.
- Selection of a pure colony from a collection of microbial cells growing – Introduction of a microorganism into a suitable growth medium – Streaking to carrying out a pure culture.

Microorganisms may be cultured in a solid medium or a liquid medium or broth. When there is not a culture with a collection of microbial cells growing on or, in a medium. A source of microorganisms is spread on the surface of an agar to produce individual colonies. Once individual colonies are obtained, this collection of microorganisms can then use to carry out a pure microbial culture.

a. Solid medium

Solid media are particularly suitable for bacteria and fungi and are prepared by mixing the liquid nutrient solution with a gelling agent, usually agar, at a concentration of about 1-5%, thus, producing nutrient agar that allows the growth of colonies.

b. Liquid media

The liquid media are water – based solutions that are generally termed as broths, milks and infusions.

Liquid media are often useful for measuring population growth. They may be placed in a test tube, stopped by a plug of cotton wool or a metal cap, or in a glass, screwcrapped bottle such as a universal bottle which holds about 25cm2 enough for one agar plate.

The medium must be sterilized and after, adding a small quantity of cells to the medium is called inoculation.

c. Enrichment media

An enrichment medium is a medium in which substances are added to meet the requirements of certain microorganisms in preference to others. As a result, certain microorganisms grow better than others.

d. A selective medium

It is a medium in which one or more substances are added to favor the grown of specific microorganisms and to inhibit the growth of others. Example, the addition of penicillin to a culture to select for those organisms resisting to it, or the selection of hybridizes cells during the production of monoclonal antibodies.

10.9.4 Aseptic technique

Aseptic technique is using sterilized equipment and solutions and preventing their contamination. Sterilization is the removal or destruction of all living microorganisms, including spores (inactive structures that enable some microorganisms to survive unfavorable periods). Bacterial and fungal spores are abundant in most environments including laboratories. A range of special techniques and apparatus are designed to prevent contamination of nutrients media. Autoclaves are used to sterilize equipment and culture media before experiments and also to sterilize equipment and specimens before disposal. In addition, after sterilization, a great care is taken during experiments to ensure that there is no infection.

Application activity 10.9

Make a list of materials and products necessary to make a culture medium and the importance of each one.

10.10 Staining bacteria and growing viruses

Activity 10.10

Discuss the following questions

a. What is the importance of staining bacteria?
b. How is the Gram stain performed?
c. Which colors do bacteria take after Gram staining?

10.10.1 Staining bacteria

Bacteria have a peptidoglycan or murein cell wall that maintains cell shape, provides protection and prevents the cell from lysis. Based on the composition of the cell wall, bacteria can be classified as Gram-positive and Gram-negative. During the process of Gram staining , some bacteria without a lipid layer along with their peptidoglycan cell wall take the gram stain and appear violet (purple) and are therefore called gram positive. Example streptococcus and staphylococcus. Bacteria having a lipid layer along with their peptidoglycan cell wall do not take up the gram stain and are therefore called gram negative.

Example: Escherichia coli, Azotobacter, Salmonella.

Gram-positive bacteria retain the gram stain and appear purple under the technique. Gram- negative bacteria do not retain the purple stain and take up a second pink stain instead. Because gram-positive bacteria have a thicker layer of peptidoglycan in their cell wall than gram-negative bacteria do, they are able to retain the gram stain.

Gram-positive and gram-negative bacteria also differ in several other ways: for example, they have different susceptibilities to antibacterial drugs, they produce different toxic materials and they react differently to disinfectants. For these reasons the gram stain is useful for identifying and grouping bacteria.

Procedure of the gram stain

- In the gram stain procedure, bacteria that have been placed on a slide are stained with a purple dye solution called crystal violet.

- The purple dye is washed off with water, and then a solution of iodine is added to the slide.
- The bacteria are rinsed with alcohol.
- And then re-stained with a pink dye solution called safranin.
- Gram-positive bacteria will retain the purple dye and appear purple, while gram-negative bacteria will appear pink.

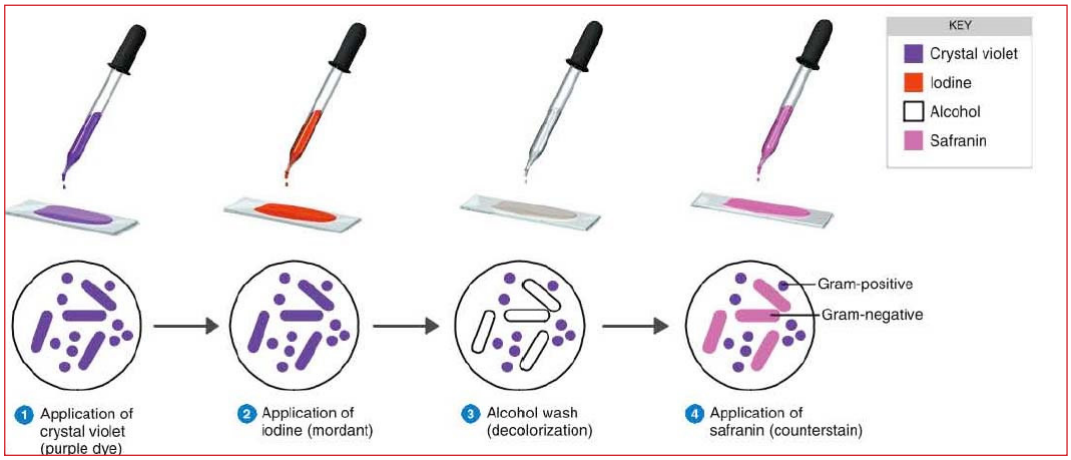


Fig 10.8: The gram stain technique

10.10.2 Growing viruses

The culture of viruses is made more difficult than the culture of bacteria or fungi because viruses can only grow and multiply inside living cells. This can be done by infecting whole organisms such as plants or animals but, where possible, cell, tissue cultures are now used. An early technique was to grow certain viruses in chick embryos while the embryo was still growing inside the egg.

Application activity 10.10

Identifying bacteria by using the Gram stain technique The Gram s

The Gram stain technique

- Place bacteria on a slide
- Stained the bacteria with a purple dye solution called crystal violet.
- The purple dye is washed off with water,
- Add a solution of iodine to the slide.
- The bacteria are rinsed with alcohol.
- And then re-stained with a pink dye solution called safranin.
- Gram-positive bacteria will retain the purple dye and appear purple, while gram-negative bacteria will appear pink.

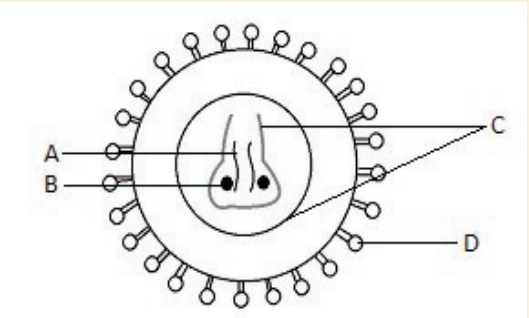
Skills lab 10

Production of alcohol using banana juice

Knead the bananas until they are soft and pulpy. Use a stiff grass to help knead and squash the banana pulp and to extract the juice. The pulp residue will remain in the grass. Pour off the extracted juice into a large clean bucket or similar container. This banana juice is non-alcoholic and can be diluted and drunk at this stage if desired. Add clean boiled water to the extracted juice (one volume of water for three volumes of banana juice). It is necessary to dilute the banana juice so that the concentration of soluble solids is low enough for the yeast to ferment the juice. Grind the cereal (sorghum or millet) and lightly roast it over an open fire. Add the roast cereal (1 part cereal to 12 parts juice) to the diluted banana juice. Cover the bucket with a clean lid and leave in a warm place to ferment for 18 to 24 hours. The ground cereal improves the color and flavor of the beer. After fermentation the beer is filtered through a sterilized cotton cloth.

End unit assessment 10

1. State any TWO diseases caused by:
   a. Bacteria
   b. Protozoa
   c. Microscopic fungi
2. What is the main feature of moulds?
3. Why viruses are not generally considered to be living things?
4. The diagram below represents the structure of the human immunodeficiency virus (HIV/AIDS).



   i. Name A, B, C, and D.
   ii. HIV/AIDS is under retroviruses. What is meant by retroviruses?
   iii. What type of leucocytes (white blood cells) are destroyed by HIV/AIDS?
5. What are different types of media used in the laboratories for culturing microorganisms?
6. How do biologists differentiate between Gram –positive and Gram – negative bacteria?
7. Describe the three methods of preventing bacterial growth in food.
8. How does temperature affect the growth of bacteria in culture media?
9. Assuming that you have a bacterial infection, would you ask for vaccination against the bacteria? Why or why not?
10. How do bacteria maintain the balance in the environment?
11. Identify the following groups of bacteria

UNIT 11

BIOTECHNOLOGY AND ITS APPLICATIONS

Key unit competence: Explain the biotechnology involved in the production of ethanol, biogas, and agriculture product other chemicals and bread making.

Introductory activity 11

Analyze the figure below and answer the questions that follow:

a. What does the figure A show? What is its importance?

b. What are the letters do you read from the figure D? What does the letters mean in full?

c. What is the difference between the two types of rice shown on the figure C?

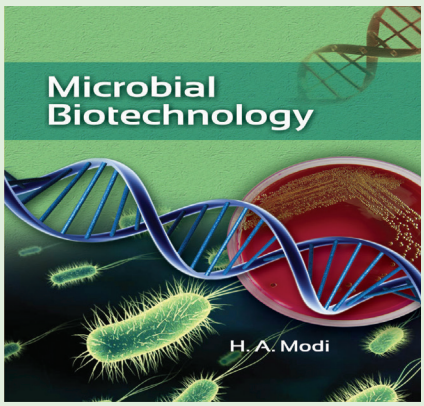
d. The figure B shows an organic and a GMO tomato? What are the differences between the two types of tomatoes?

e. Suggest how a GMO tomato such as that shown in the figure B could be produced?

11.1 Role of microbes in biotechnology and genetic engineering

Activity 11.1

Based on the figure below, answer the following questions:.



1. What are the roles of microbes in our daily life?
2. How microbes are used in production genetically modified

Biotechnology is a broad discipline that concerning to the use of biology to develop **technologies** and **products** for the welfare of human beings. It has various applications in different fields such as Therapeutics, Diagnostics, Processed Food, Waste Management, Energy Production, Genetically Modified Organisms by using living cells and microorganisms (like bacteria, yeast, algae, protozoa and viruses).

Those microbes and other living cells are tools used for achieving the role of biotechnology through traditional and genetic engineering (the manipulation of genes) approaches.

In genetic engineering, the genetic information for many biological products and biological processes can be introduced into microbes in order to genetically engineer them to produce a substance or conduct a process. The genes can come from any biological source: human, animal, plant or microbes where the pieces of DNA (genes) are introduced into a host by means of a carrier (vector) system. The foreign DNA becomes a permanent feature of the host, being replicated and passed on to daughter cells along with the rest of its DNA.

Application activity 11.1

Explain the importance of using microbial biotechnology crop agriculture and health care

11.2 Applications of biotechnology

Biotechnology has application in four major industrial areas, including health care (medical), crop production and agriculture, non food (industrial) uses of crops and other products (e.g. biodegradable plastics, vegetable oil, biofuels), and environmental uses.

Applications of biotechnology in medicine

Biotechnology techniques are used in medicine for diagnosis, vaccines and treating different diseases. It gives opportunities for the people to protect themselves from dangerous diseases. The field of Biotechnology, genetic engineering has introduced techniques like gene therapy, development of vaccines and antibiotics, monoclonal antibodies recombinant DNA (rDNA) technology and polymerase chain reaction (PCR) which use genes and DNA molecules to diagnose diseases and insert new and healthy genes in the body which replace the damaged cells.

Application of biotechnoliogy in environment

Cleaning up and managing the environment: Cleaning up the environment using living organismsis called **bioremediation**. Naturally occurring, as well as genetically modified microorganisms, such as bacteria and fungi, and enzymes are used tovbreak down toxic and hazardous substances present in the environment.

The environmental Biotechnology is defined as “an environment that helps to develop, efficiently use and regulate the biological systems and prevent the environment from pollution or from contamination of land, air and water”.

There are five major different types of Applications of Environmental Biotechnology. They are as follows:

Bio-marker: This type of Application of environmental Biotechnology gives response to a chemical that helps to measure the level of damage caused or the exposure of the toxic or the pollution effect caused. In other word, Biomarker can also be called as the Biological markers the major use of this applications helps to relate the connection between the oils and its sources.

Bio-energy: The collective purport of Biogas, biomass, fuels, and hydrogen are called the Bioenergy. The use of this application of Environment Biotechnology is in the industrial, domestic and space sectors. As per the recent need it is concluded that the need of clean energy out of these fuels and alternative ways of finding clean energy is the need of the hour. One of the pioneer examples of green energy are the wastes collected from the organic and biomass wastes; these wastes help use to over the pollution issues caused in the environment. The Biomass energy supply has become a prominent importance in every country.

Bioremediation: The process of cleaning up the hazardous substances into non-toxic compounds is called the Bioremediation process. This process is majorly used for any kind of technology clean up that uses the natural microorganisms.

Biotransformation: The changes that take place in the biology of the environment which are changes of the complex compound to simple non-toxic to toxic or the other way round is called the biotransformation process. It is used in the Manufacturing sector where toxic substances are converted to Bi-products.

Benefits

- The major benefits of environmental biotechnology are it helps to keep our environment safe and clean for the use of the future generations. It helps the organisms and the engineers to find useful ways of getting adapted to the changes in the environment and keep the environment clean and green.
- The benefit of environmental biotechnology helps us to avoid the use of hazardous pollutants and wastes that affect the natural resources and the environment. The development of the society should be done in such a way that it helps to protect our environment and also helps us to develop it.
- The environmental biotechnology has a role to play in the removal of the pollutants. It is becoming an advantage for the scientists and the environmentalists to find ways to convert the waste to re-useable products.

- The applications of environmental biotechnology are becoming a benefiting factor for the environment; the applications includes â€" genomics, proteomics, bioinformatics, sequencing and imaging processes are providing large amounts of information and new ways to improvise the environment and protect the environment.

Application of biotchnology in agriculture

It is known as Green Biotechnology; it has helped in production of crops with improved disease resistance; herbicide-tolerance and insecticide-resistance. Plants with improved nutritional value for livestock etc. have also been bred through biotechnology.

Control of pests: One application of biotechnology is in the control of insect pests. The genetic make-up of the pest is changed by causing some mutations. These pests become sterile and cannot produce next generation.

Manufacturing and bio-processing: With the help of new biological techniques it has become possible to grow on large scale, the plants that produce compounds for use in detergents, paints, lubricants and plastics etc.

Food and drinks: With biotechnology, it has now become easy to process foods and their products. Preservation and storing of food for consumption later has become easy and cheap with the help of biotechnology. Seedless grapes and seedless citrus fruits have been developed using biotechnology

Application of biotechnology in industry

Biotechnology has been used in the industry to produce new products for human welfare. Food additives have been developed which help in the preservation of food. Microorganisms are used in the mass production of items such as cheese, yoghurt, alcohol, enzymes, biofuel, etc.

Application activity 11.2

Why microbes are used in genetic engineering?

11.3 Application of enzyme technology

Activity 11.3

Visit a nearby bakery and verify how bread is prepared. Write a short report on the raw materials and procedures used in making bread up to the final product.

11.3.1 Enzymes in brewing

Enzymes increase processing capacity and improve economy in the fruit juice and wine industries. The most commonly used enzymes in these industries are pectinase. Pectinase increase juice yields and accelerate juice clarification. They produce clear and stable single-strength juices, juice concentrates and wines, from not only core fruits such as apples and pears, but also stone fruits, berries, grapes, citrus-fruits, tropical fruits and vegetables like carrots, beets and green peppers. Future aspects focus on a wider application of enzymes to brew with high amounts of inexpensive raw materials like barley. Barley contains starch that has to be broken down to fermentable sugars before the yeast can make alcohol. Therefore, traditional brewing contains an extra step compared with wine-making, namely malting in which enzymes needed for the degradation of starch into fermentable sugars are produced.

11.3.2 Enzymes perform many functions in beverages

The most important field of application for enzymes in the beverage industry is the extraction of fruit juice and vegetable juice. Pectinases, in particular, are employed for apple and pear juice and for juices made from berries and tropical fruits. They break down pectins found in the plant cell walls as supporting substances. This increases the quality of juice extracted and reduces fruit waste. Enzymes can be used in winemaking to increase the preliminary juice extraction and to obtain more high-quality wine. Pectinase not only increase juice yields, but also increase the colour and health-promoting antioxidants in fruit and vegetable juices. They also increase colour extraction and juice volume by reducing fruit and vegetable mash viscosity and improving solid/liquid separation, Pectinase and Amylase enzyme solutions speed up filtration and prevent storage or post-packaging haze formation by depectinizing and reducing starch in raw juices.

11.3.3 Medical applications of enzymes

Development of medical applications for enzymes has been at least as extensive as those for industrial applications, reflecting the magnitude of the potential rewards: for example, pancreatic enzymes have been in use since the nineteenth century for the treatment of digestive disorders. The variety of enzymes and their potential therapeutic applications are considerable. At present, the most successful applications are extracellular: purely topical uses, the removal of toxic substances and the treatment of life-threatening disorders within the blood circulation.

11.3.4 Applications of enzymes in baking

Bread is a staple food prepared from a dough of flour and water, usually by baking. Throughout recorded history it has been a prominent food in large parts of the world and is one of the oldest man-made foods, having been of significant importance since the dawn of agriculture.

Bread may be leavened by processes such as reliance on naturally occurring sourdough microbes, chemicals, industrially produced yeast, or high-pressure aeration. Commercial bread commonly contains additives to improve flavor, texture, color, shelf life, nutrition, and ease of manufacturing.

For decades, enzymes such as maltase and fungal amylases have been used in bread-making. Rapid advances in biotechnology have made a number of exciting new enzymes available for the baking industry. The importance of enzymes is likely to increase as consumers' demand more natural products free of chemical additives.

Application activity 11.3

Explain the use of enzymes in baking of bread

11.4 Fermentation, fermenters and the antibiotics production

Activity 11.4

Recall the fermentation of beer by using banana juice and make short notes to present to in the class. Search also the other uses of fermentation in our everyday life.

11.4.1 Fermentation and fermenters

Fermentation is anaerobic breakdown of organic compounds by living cells (microorganisms) that produces ethanol and carbon dioxide or lactate (lactic acid). It occurs in yeast and bacteria, but also in oxygen-starved muscle cells, as in the case of lactic acid. Fermentation is also used more broadly to refer to the bulk growth of microorganisms on a growth medium, often with the goal of producing a specific chemical product. French microbiologist Louis Pasteur is often remembered for his insights into fermentation and its microbial causes. The science of fermentation is known as zymology. To many people, fermentation simply means the production of alcohol: grains and fruits are fermented to produce beer and wine.

If a food soured, one might say it was 'off' or fermented. Fermentation react NADH with an endogenous, organic electron acceptor. Usually this is pyruvate formed from the sugar during the glycolysis step. During fermentation, pyruvate is metabolized to various compounds through several processes:

c. **Ethanol fermentation** or **alcoholic fermentation**, is the production of ethanol and carbon dioxide.
d. **Lactic acid fermentation** refers to two means of producing lactic acid: Homolactic fermentation is the production of lactic acid exclusively. Heterolactic fermentation is the production of lactic acid as well as other acids and alcohols.

Sugars are the most common substrate of fermentation, and typical examples of fermentation products are ethanol, lactic acid, Carbon dioxide, and hydrogen gas (H2). However, more exotic compounds can be produced by fermentation, such as butyric acid and acetone. Yeast carries out fermentation in the production of ethanol in beers, wines, and other alcoholic drinks, along with the production of large quantities of Carbon dioxide. Fermentation occurs in mammalian muscle during periods of intense exercise where oxygen supply becomes limited, resulting in the creation of lactic acid.

A fermenter also known as bioreactors are an apparatus that maintains optimal conditions for culture and growth of microorganisms (on liquid or solid media) to be used in large-scale fermentation and in the commercial production of antibiotics and hormones. The processes that take place in fermenters refers as fermentation which includes aerobic and anaerobic processes.

Application of enzymes in breads making

Bread production involves harvesting the wheat, separating the grain from the husk, crushing the grain to make flour, mixing the flour with water and then finally baking it. The main difference between unleavened and leavened bread is that leavened or risen bread uses leavened dough, and unleavened bread does not. If the leavened bread is desired, then one adds yeast and allowing the bread to sit for a specific amount of time, depending on the type of bread being made.

11.5 Antibiotics

Activity 11.5

Read the following passage on the production of penicillin by Alexander Fleming

Dr Alexander Fleming, the bacteriologist on duty at St Mary's Hospital, returned from a summer vacation in Scotland to find a messy lab bench and a good deal more. Upon examining some colonies of Staphylococcus aureus, Dr Fleming noted that a mold called Penicillium notatum had contaminated his Petri dishes. After carefully placing the dishes under his microscope, he was amazed to find that the mold prevented the normal growth of staphylococci, it took Fleming a few more weeks to grow enough of the mold so that he was able to confirm his findings. His conclusion turned out to be phenomenal: there was some factor in the Penicillium mold that not only inhibited the growth of the bacteria but, more important, might be harnessed to combat infectious disease. That substance that inhibited the growth of bacteria was called antibiotics.

From the passage, answer the questions that follow:

a. What is the importance of antibiotics?
b. What may be the uses of penicillin?

11.5.1 Uses of antibiotics

Antibiotics are powerful medicines that fight certain infections by either stopping bacteria from reproducing or by destroying them. Before bacteria can multiply and cause symptoms, the body's immune system can usually kill them. The word antibiotic means "against life." Any drug that kills germs in your body is technically an antibiotic.

Penicillin, an important part of our anti-microbial armament, had a significant impact on the second half of the twentieth century. Deep-fermentation methods, which were primarily developed for the production of penicillin during the war, gave rise to the development of antibiotics and contributed to the nascent biotechnology industry which appeared in the 1970s.

How do antibiotics work?

Antibiotics are used to treat bacterial infections. Some are highly specialized and are only effective against certain bacteria. Others, known as broad-spectrum antibiotics, attack a wide range of bacteria, including ones that are beneficial to us.

There are two main ways in which antibiotics target bacteria. They either prevent the reproduction of bacteria, or they kill the bacteria, for example by stopping the mechanism responsible for building their cell walls. There are now hundreds of different types of antibiotics, but most of them can be broadly classified into six groups. These are outlined below.

Penicillin – widely used to treat a variety of infections, including skin infections, chest infections and urinary tract infections.

Tetracyclines – can be used to treat a wide range of infections; commonly used to treat moderate to severe acne and rosacea, which causes flushing of the skin and spots.

11.5.2 Antibiotic resistance

Antibiotic resistance occurs when an antibiotic has lost its ability to effectively control or kill bacterial growth; in other words, the bacteria are "resistant" and continue to multiply in the presence of therapeutic levels of an antibiotic.

a. Why do microbes become resistant to antibiotics?

Antibiotic resistance is a natural phenomenon. When an antibiotic is used, microbes that can resist that antibiotic have a greater chance of survival than those that are "susceptible." Susceptible microbes are killed or inhibited by an antibiotic, resulting in a selective pressure for the survival of resistant strains of microbes.

Some resistance occurs without human action, as microbes can produce and use antibiotics against other microbes, leading to a low-level of natural selection for resistance to antibiotics. However, the current higher-levels of antibiotic-resistant microbes are attributed to the overuse and abuse of antibiotics.

In some countries and over the Internet, antibiotics can be purchased without a doctor's prescription. Patients sometimes take antibiotics unnecessarily, to treat viral illnesses like the common cold.

b. How do microbes become resistant?

Some microbes are naturally resistant to certain types of antibiotics. However, microbes may also become resistant in two ways: by a genetic mutation or by acquiring resistance from another bacterium.

Mutations, rare spontaneous changes of the microbes's genetic material, are thought to occur in about one in one million to one in ten million cells. Different genetic mutations yield different types of resistance. Some mutations enable

the microbes to produce potent chemicals (enzymes) that inactivate antibiotics, while other mutations eliminate the cell target that the antibiotic attacks. Still others close up the entry ports that allow antibiotics into the cell, and others manufacture pumping mechanisms that export the antibiotic back outside so it never reaches its target.

Microbes can acquire antibiotic resistance genes from other microbes in several ways.

By undergoing a simple mating process called "conjugation," microbes can transfer genetic material, including genes encoding resistance to antibiotics (found on plasmids and transposons) from one bacterium to another. Viruses are another mechanism for passing resistance traits between microbes. The resistance traits from one bacterium are packaged into the head portion of the virus. The virus then injects the resistance traits into any new microbes it attacks. Microbes also have the ability to acquire naked, "free" DNA from their environment. Any microbes that acquire resistance genes, whether by spontaneous mutation or genetic exchange with other microbes, have the ability to resist one or more antibiotics. Because microbes can collect multiple resistance traits over time, they can become resistant to many different families of antibiotics.

11.5.3 Implications of antibiotic use

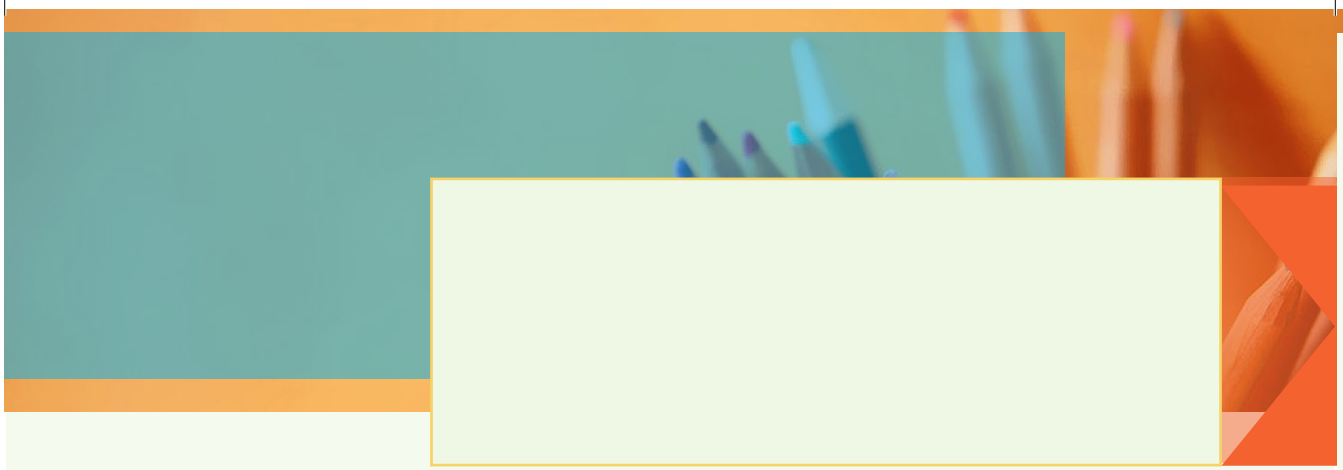
Antibiotics are considered the keystone of modern medicine, but their excessive use continues to generate unwanted side effects. While specialists are making strides to preserve the effectiveness of antibiotics and to slow potential infections through better policy, the overuse of antibiotics continues to have severe health consequences around the world.

Application activity 11.5

Nowadays some antibiotics are not treating the diseases that they used to treat. Explain why.

End unit assessment 11

1. Summarize the advantages of using enzymes
2. Explain the medical applications of enzymes
3. Explain how bacteria become resistant.
4. What do you understand by antibiotic resistance?
5. What are the main ingredients of bread?
6. Explain why microorganisms are particularly suitable for industrial use.
7. Explain the application of biotechnology
8. Describe the role of genetic engineering in area of medicine and veterinary



UNIT 12

HUMAN REPRODUCTIVE SYSTEM, GAMETOGENESIS, PREGNANCY AND METHODS OF BIRTH CONTROL.

Key unit competence: Relate the structures of the human reproductive system to their functions and describe gamete formation and explain the role of hormones in human reproduction, stages of pregnancy, contraceptive methods and fetal development.

Introductory activity 12

Observe the photo below and answer the questions that follow:

a. The woman on the left side is pregnant. What do you think about the origin of the fetus in the womb of the pregnant woman?

b. Use the photo on the right side to make short notes on the embryonic development.

c. Use the photo and try to identify the parts of the female reproductive system and their functions.

d. The child on the photo is a boy. Can you identify the parts of the male reproductive system and their functions?

e. What do you think are the causes to the changes observed on the woman on the right side of the photo?

12.1 Male and female human reproductive systems

Activity 12.1

Aim: To dissect and identify structures of male and female reproductive system of rat.

Theory: The sex of the rat can be determined by looking for external testes and teats. Large testes are visible at the ventro-posterior side of the male rat and 6 pairs of teats ventrally in females. The major male reproductive organs of the male rat are the testes (singular: testis) which are located in the scrotal sac, along with internally placed duct systems and associated glands. Female reproductive system consists of a pair of ovaries, duct system and glands.

Procedure

- Obtain and sacrifice a rat. Place it in your dissecting tray with ventral side facing up so as to observe the external features and determine the sex of the rate you have taken.
- Examine the anal opening just posterior to the tail. Insert the scissor blades through the anus along the midline lifting the skin carefully so as not to damage the underlying organs.

  In male rat, cut through the scrotum carefully to reveal the testis and also observe other internal structures: epididymis, vas deferens, seminal vesicles, prostate gland and seminiferous tubules.

  In female rat, locate the urethral and vaginal openings on the ventro-posterior side of the body, under the tail, just posterior to the last pair of teats. Also, observe other reproductive organs: uterus, ovaries, oviducts and vagina.

Precautions

1. Be careful not to cut too deeply. Keep the tip of your scissors pointed upwards.
2. Always wear gloves and safety goggles when handling the rat to protect your hands and eye from chemical splattering or debris.
3. Once an incision is made, allow the rat to be drained off the fluid.
4. Handling and dissection of animals should be done in the presence of experts, following ethical guidelines.

Human beings reproduce by sexual means where the male and female involve in sexual intercourse, resulting in fertilization. During sexual intercourse, the interaction between the male and female reproductive systems results in fertilization of the woman's ovum by the man's sperm. The ovum and sperm are specialized reproductive cells called gametes, generated by a process called gametogenesis (i.e., spermatogenesis in males and oogenesis in females). The gametes are haploid in nature and it is when these two cells merge into one zygote cell that genetic recombination occurs and diploid condition is achieved back. After a gestation period, i.e., nine months in humans, childbirth takes place.

12.1.1 Sexual development in males

The main visible differences between boys and girls at birth are their reproductive organs. Of course, there are other differences between boys and girls at birth, but in this chapter, the focus is on their reproductive systems. As different as the male and female reproductive systems are at birth, they start out relatively similar. Before birth, the expression of genes on the male Y-chromosome brings about the differences.

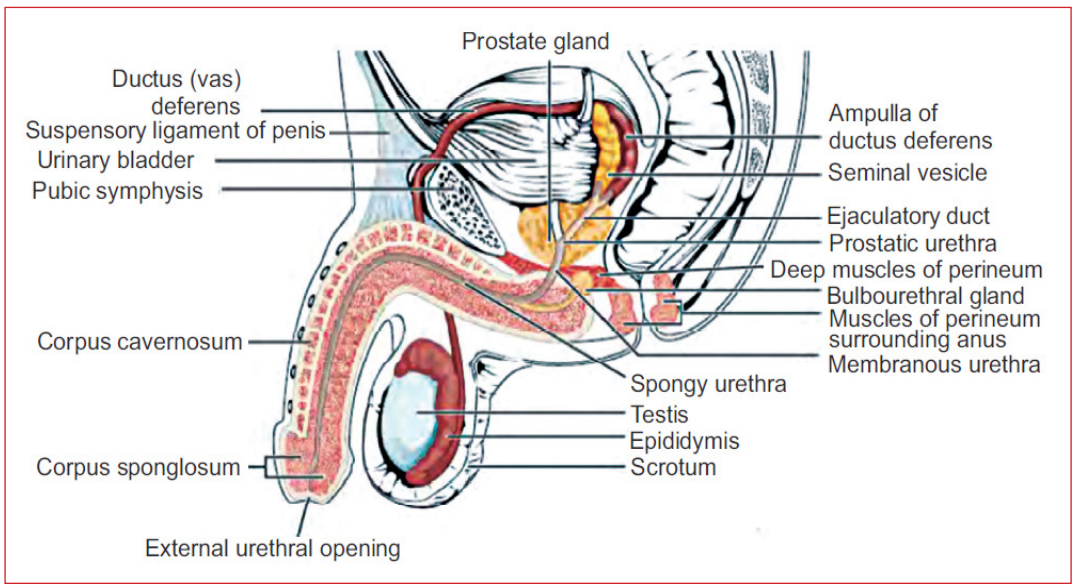


Figure 12.1: Overview of components of male reproductive system

Each testis contains more than 90 meters of tiny, tightly-packed tubes called seminiferous tubules. They are the functional units of the testes, where sperm are produced and testosterone is secreted.

In between the seminiferous tubules in the testes are interstitial cells, also called Cells of Leydig. These cells secrete testosterone. A high concentration of testosterone is necessary for sperm production. Testosterone is also needed throughout a man's life to maintain his secondary sex characteristics. The seminiferous tubules join together to form the epididymis. The epididymis is a coiled tube about 6 meters long lying atop the testes inside the scrotum. Its functions are to help sperm mature and to store mature sperm until they leave the body.

In addition to these organs, the male reproductive system consists of a series of ducts and glands.

Ducts include the vas deferens and ejaculatory ducts. They transport sperm from the epididymis to the urethra in the penis.

Glands include the seminal vesicles, prostate gland, and bulbourethral glands (also called Cowper's glands). They secrete substances that become part of semen.

- Two seminal vesicles contribute about 60% of the volume of semen. The fluid from the seminal vesicles is thick, yellowish, and alkaline. It contains mucus, the sugar fructose (which provides most of the sperm's energy), a coagulating enzyme, ascorbic acid, and local regulators called prostaglandins.
- The prostate gland secretes its products directly into the urethra through several small ducts. This fluid is thin and milky; it contains anticoagulant enzymes and citrate (a sperm nutrient). The prostate gland is the source of some of the most common medical problems of men over age 40. Benign (noncancerous) enlargement of the prostate occurs in more than half of all men in this age-group and in almost all men over 70. In addition, prostate cancer, which most often afflicts men 65 and older, is one of the most common human cancers.
- The bulbourethral glands are a pair of small glands along the urethra below the prostate. Before ejaculation, they secrete clear mucus that neutralizes any acidic urine remaining in the urethra. Bulbourethral fluid also carries some sperm released before ejaculation, which is one reason for the high failure rate of the withdrawal method of birth control (coitus interruptus).

Semen is the fluid that is ejaculated from the urethra. Semen contains secretions from the glands as well as sperm. The secretions control pH and provide the sperm with nutrients for energy.

Table 12.1: Parts of the male reproductive system and their functions

Structure	Function
Testes	Produce sperm cells Produce the hormone testosterone
Epididymis	Produces and stores sperm cells
Vas deferens	Carries sperm from the epididymis to its junction with the urethra.
Seminal vesicle	Secretes fructose into the semen, which provides energy for the sperm.
Prostate gland	Secretes an alkaline buffer into the semen to protect the sperm from the acidic environment of the vagina.
Cowper's gland	Secretes mucus-rich fluids into the semen that may protect the sperm from acids in the urethra.
Urethra	Carries semen during ejaculation Carries urine from the bladder to the exterior of the body.
Penis	Deposits sperm into the vagina during ejaculation Contains the urethra

12.1.2 Female reproductive system

The female reproductive system is a collection of organs and other structures located primarily in the pelvic region. Most of the structures are inside the body. The female reproductive system has several functions:

- Producing eggs, which are female gametes
- Secreting female sex hormones
- Receiving sperm during sexual intercourse
- Supporting the development of a fetus
- Delivering a baby during birth
- Breastfeeding a baby after birth

During puberty, a girl develops into a sexually mature woman, capable of producing eggs and reproducing.

Sexual development in females

The main differences between boys and girls at birth are their reproductive organs. Unlike males, females are not influenced by the male sex hormone testosterone during embryonic and fetal development. This is because they lack a Y-chromosome. As a result, females do not develop male reproductive organs. The human female reproductive system consists of the primary sex organs or the gonads (ovaries), the genital ducts (oviducts or the uterine/fallopian tubes, uterus, cervix and vagina) and the external genitalia, along with a pair of mammary glands.

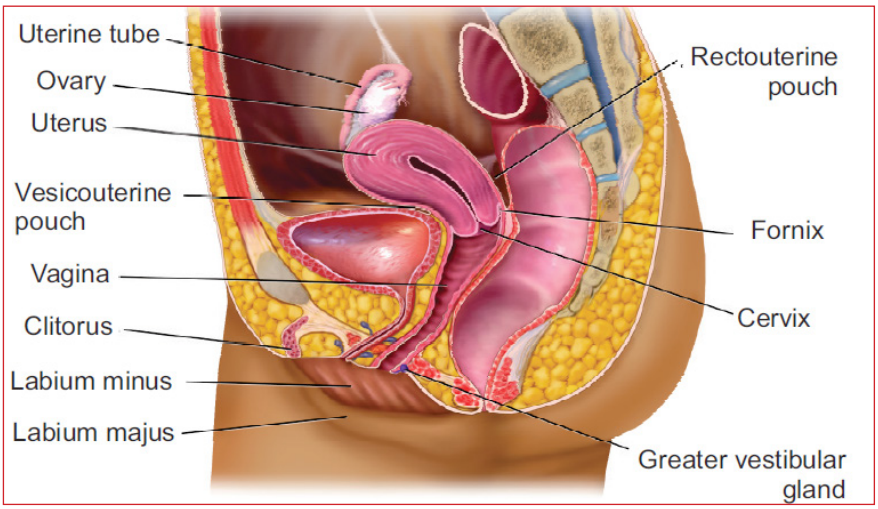
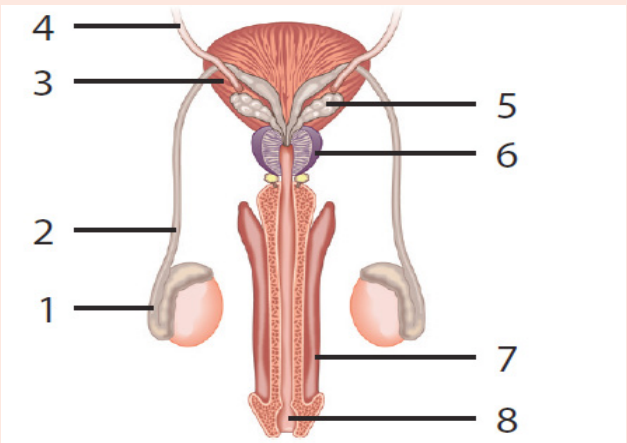


Figure 12.2: Overview of human female reproductive system

Structure	Function
Ovaries	Produce the hormone estrogen and progesterone Production of eggs
Fallopian tubes (oviducts)	Carry the ovum from the ovary to the uterus Usually the site of fertilization
Fimbria	Sweep the ovum into the oviduct following ovulation
Uterus (womb)	Pear-shaped organ in which the embryo and fetus develop. Involved in menstruation
Cervix	Separates the vagina from the uterus Holds the fetus in place during pregnancy Dilates during birth to allow the fetus to leave the uterus
Vagina	· Extends from the cervix to the external environment · Provides a passageway for the sperm and menstruation flow · Functions as the birth canal.

Application activity 12.1

The figure below shows the parts of the male reproductive system.



a. Identify the parts represented by the numbers 1 to 8.

b. What are the functions of the parts 1, 2, 5 and 8?

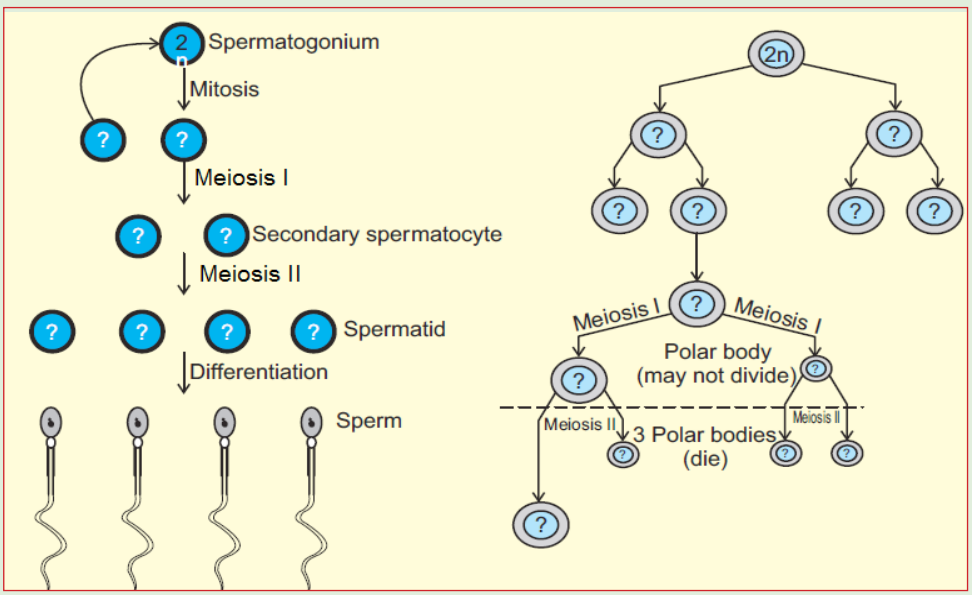
12.2 Gametogenesis

Activity 12.2

To understand the process of gametogenesis and haploid nature of gametes.

Gametes are haploid cells that are formed from diploid germ cells through the process of gametogenesis. The significance of developing haploid gametes lies in the fact that after fertilization, the developing zygote attains the diploid status back. In this way, the developing embryo gets the single copy of all the chromosomes from each parent.

Based on the chart diagrams of spermatogenesis and oogenesis shown below, compute the number of chromosomes at each stage, assuming 2n = 46.



The process of formation of haploid male gametes or spermatozoa from diploid reproductive cells in males is called spermatogenesis. The complete process is broadly divided into two parts:

a. Formation of spermatids and
b. Spermiogenesis or spermatoleosis.

Formation of spermatids

The process of formation of spermatids is further divided into three stages as:

a. **Multiplication phase**: The primordial germ cells or sperm mother cells differentiate from germinal epithelium of testis and increase in size with prominent nuclei. These cells divide repeatedly by mitosis (i.e., equational division) and produce a number of diploid daughter cells, known as spermatogonia. Thus, in this stage, multiplication of germ cells takes place mitotically.

b. **Growth phase**: In this phase, spermatogonia increase in size by accumulating food reserves and are now called primary spermatocytes.

c. **Maturation phase**: The primary spermatocytes (which are diploid) undergo first maturation division which is **meiotic division** (or **reductional division)** to produce two haploid secondary spermatocytes. These haploid secondary spermatocytes divide further by mitosis to give rise to four haploid spermatids. This mitotic division is called second maturation division.

The spermatids so produced are non-motile rounded structures that metamorphose into functional and motile spermatozoa through a process known as **spermiogenesis** or **spermatoleosis**. The spermatozoa from testis are incapable of fertilizing an ovum. They undergo several morphological, physiological and biochemical changes as they move through the epididymis to attain this structural and physiological maturity. The epididymis i) provides a favourable environment to spermatozoa in acquiring fertilizing ability and ii) stores them until they are ejaculated or move down to the vas deferens.

The morphological changes include structural remodelling of acrosome and formation of disulfide linkages. The physiological and biochemical changes include increase in net negative charge on spermatozoa, change in pattern of motility, change in content of sialic acid, increase in specific activity and reflection power, resistance to pH and temperature and changes in metabolic patterns.

Spermiogenesis

A series of changes in spermiogenesis that transform a non-motile spermatid into motile, functional spermatozoa are listed below:

- The nucleus shrinks and flattens by losing water. Only DNA is left in the nucleus, making cells very light that aids to its motility.
- The two **centrioles** of a centrosome form proximal and distal centrioles. The proximal centriole lies at the posterior end of nucleus and the distal centriole gives rise to axial filament of the flagellum and acts as a basal granule.

- The **mitochondria** gather around axial filament and gradually unite to form spiral sheath or nebenkern. It acts as power house of the sperm and provides energy.
- The **golgi bodies** form the covering over nucleus called acrosome. During acrosome formation, one or more vacuoles start enlarging with a small, dense body called pro-acrosomal granule which further enlarges to form acrosomal granule. The vacuole loses its liquid content and forms the cap of spermatozoan. The remaining part of golgi apparatus is reduced and discarded from sperm.

During all these steps, head of the developing sperm remains embedded in sertoli cells for nourishment. At the end, fully formed spermatozoan shows distinct head, middle piece and tail region.

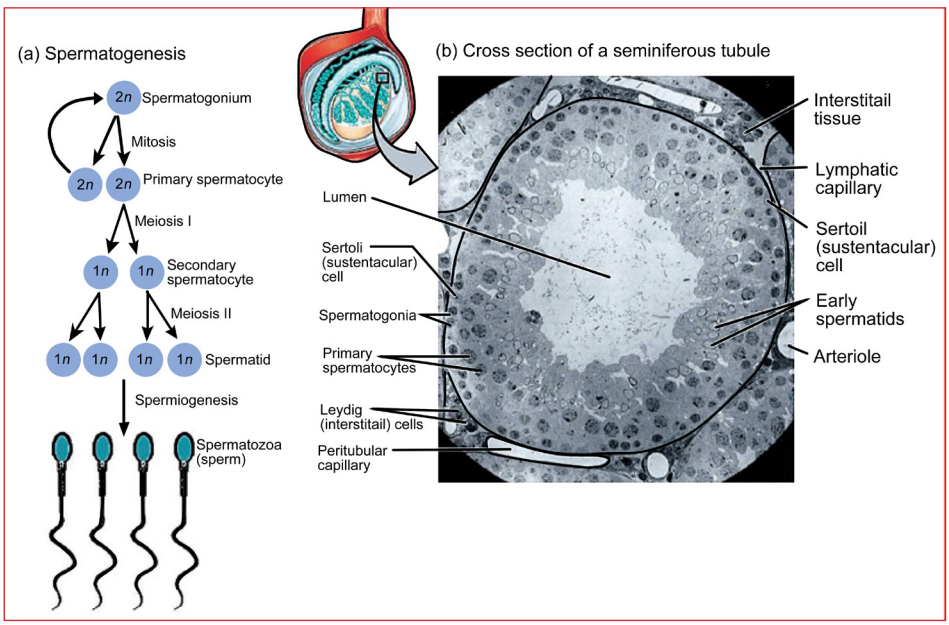


Figure 12.3: (a) Process of spermatogenesis showing chromosome numbers at various stages and the cross-section of a seminiferous tubule showing histological arrangement of various cell types (b) Stages in the formation of spermatozoan from spermatid and acrosome formation from Golgi apparatus during spermiogenesis.

Structure of spermatozoa

The sperms are microscopic and motile cell. Each sperm is composed of four parts—a head, a neck, a middle piece and a tail. A plasma membrane covers the whole body of sperm.

i. **Head** is the enlarged end of the sperm, containing an elongated haploid nucleus. The anterior of the nucleus is covered by a cap-like structure

called **acrosome**. The acrosome contains enzymes sperm lyftins or **hyaluronidases**, which are used to contact and **penetrate the ovum at the time of fertilization**.

ii. **Neck** is very short and is present between the head and middle piece. It contains the proximal centriole towards the nucleus which plays a role in the first cleavage of the zygote and the distal centriole which gives rise to the axial filament of the sperm.

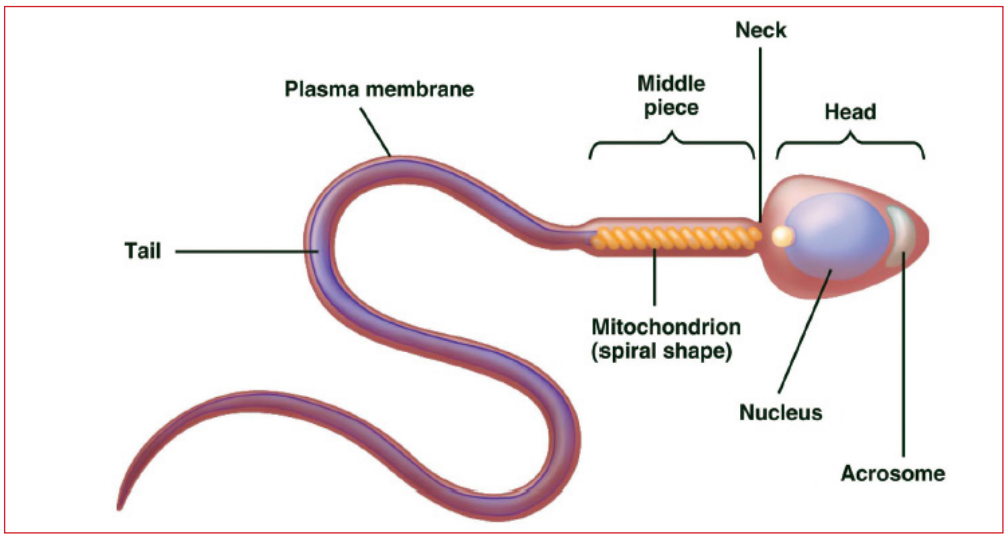


Figure 12.4: Structure of a sperm

iii. **Middle piece** possesses **numerous mitochondria** which **produce energy for the movement of the sperm**. At the end of the middle piece, there is a ring centriole (annulus) with unknown function.

iv. **Tail** is several times longer than the head. It consists of an axial filament surrounded by a thin layer of cytoplasm. The **tail provides motility to the sperm**, which is essential for fertilization.

The male ejaculates about 200 to 300 million sperms during a coitus. For a normal fertility, at least 60 per cent sperms of the ejaculate must have normal shape and size, and at least 40 per cent of the normal sperms must show vigorous motility. Sperms remain alive and retain their ability to fertilize an ovum from 24 to 48 hours after having been released in the female genital tract.

12.2.1 Oogenesis

The process of oogenesis occurs in the ovaries. The three phases of proliferation, growth and maturation occur in discontinuous steps.

a. Proliferative or multiplication phase: During early foetal development, certain cells within the germinal epithelium of the ovary become enlarged.

These cells proliferate by mitosis, producing undifferentiated germ cells called egg mother cells or oogonia (2n). The oogonia divide mitotically to produce groups of oogonia, termed follicles.

b. Growth and differentiation phase: During this long phase, which may last upto years, one cell in a follicle prepares for the formation of ovum. It starts meiotic division but gets arrested at prophase-I stage and is called primary oocyte. The remaining cells of the follicle lose the potential to become primary oocyte and are known as the follicular cells or granulosa cells. These follicular cells serve to protect and nourish the primary oocyte. The complete follicle with a primary oocyte surrounded by a layer of follicular cells is called the primary or the ovarian follicle.

c. Maturation phase: At puberty, only one of the primary oocytes resumes division per menstrual cycle, alternately in each ovary. The tertiary follicle matures into a Graafian follicle, within which the primary oocyte divides to form two very unequal cells - a large secondary oocyte (n) and a very small 1st polar body or polocyte (n). The 1st polar body may further be divided into two polar bodies. However, the secondary oocyte again gets arrested at metaphase stage of meiosis-II and is released from the ovary during ovulation. It waits in the oviduct for the sperm to arrive. If fertilization occurs, sperm entry into the secondary oocyte marks the resumption of meiosis. The 2nd maturation division (meiosis-II) again divides the secondary oocyte into two unequal daughter cells—a large ootid and a very small 2nd polar body. The ootid undergoes maturation into a functional haploid ovum. A thin vitelline membrane develops outside the plasma membrane of the ovum that protects and nourishes the latter.

Structure of ovum

An ovum is a spherical, non-motile cell, in the secondary oocyte stage of oogenesis, where the second maturation division is yet to occur. Human ovum is extremely small in size i.e., 0.15 mm in diameter, polar and microlecithal. The large nucleus is called germinal vesicle or later the female pronucleus. The nucleolus is called the germinal spot and cytoplasm is known as ooplasm.

The peripheral layer of ooplasm, known as cortex, is more viscous and contains cytoskeletal structures like microtubules and microfilaments, pigment granules and cortical granules of mucopolysaccharides. The inner part of cytoplasm, called the endoplasm is with cell-organelles, informosomes, tRNAs, histones, enzymes etc. The ovum is covered over by a thin, transparent vitelline membrane which is further covered over by zona pellucida. There is a narrow space between these two membranes known as perivitelline space. During

discharge of ovum from the Graafian follicle, several layers of follicular cells adhere to the outer surface of zona pellucida and are arranged radially forming corona radiata.

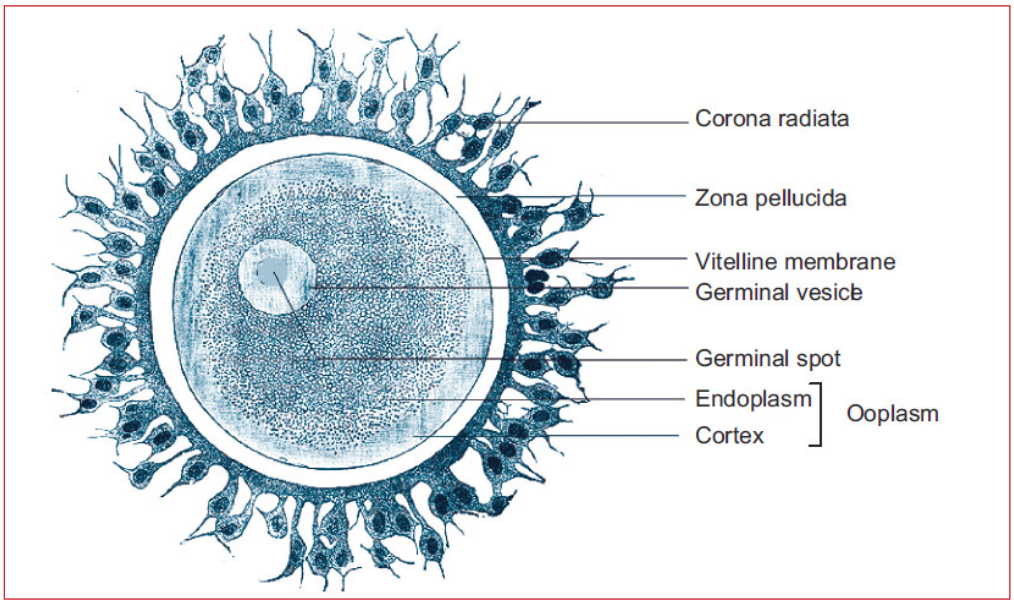


Figure 12.5: Structure of a mature human ovum with corona radiata surrounding it.

	Spermatogenesis	Oogenesis
1.	It occurs in the testis.	It occurs in the ovaries.
2.	The whole process is completed in the testes so that mature spermatozoa are released from the testes.	The process gets completed in the oviduct i.e., oocytes at metaphase-II stage are released from the ovaries.
3.	Equal meiotic divisions occur.	Unequal meiotic divisions occur.
4.	No polar body is formed.	Polar bodies are formed at each meiotic division.
5.	One spermatogonium produces four functional spermatozoa.	One oogonium produces only one functional ovum.
6.	A primary spermatocyte undergoes first meiotic division to produce two secondary spermatocytes.	A primary oocyte undergoes first meiotic division to produce one secondary oocyte and one polar body.

7.	A secondary spermatocyte further divides by meiosis-II to produce two spermatids.	A secondary oocyte undergoes meiosis-II to produce one ootid and one polar body.

Application activity 12.2

On the basis of your observations, draw the structure of a human spermatozoan and an ovum, labelling the following parts along with the functions of each:

Sperm	Egg
Nucleus	Zona pellucida
Middle piece	Vitelline membrane
Acrosome	Corona radiata
Flagellum	Ooplam

12.3 Menstrual cycle in humans

Activity 12.3

Human beings grow and develop from childhood to adulthood, during such period of growth and development, there are changes in some parts of body which may occur physiologically, physically and even psychologically. These changes prepare individual adulthood to reproduce. Different researches indicated these changes to be coordinated by different types of hormones.

1. Describe the hormones involved during such period of changes in body parts?
1. Discuss the significance of these hormones you have mentioned above during such period of changes.
1. Describe the role of hormones involved during menstrual cycle and birth.
1. Which day of the cycle will ovulation take place.

12.3.1 Menstrual cycle

The menstrual cycle refers to the periodical changes in the reproductive behaviour of a female which tend to occur in a sequence of events one after the other in the periodical circle. At the onset of puberty, the cycle begins and repeats after 28 days unless interrupted by pregnancy. The changes are stimulated

by the gonadotrophic hormone such as; follicle stimulating hormone (FSH) and luteinizing hormone (LH). These hormones stimulate ovaries to secrete; oestrogen (steroid) and progesterone hormones. These four hormones are involved in menstrual cycle. Two of them including; FSH and LH are produced by pituitary gland and the other two are released by ovaries respectively. The most obvious sign of the cycle is the monthly discharge of blood a process called menstruation. The first day of menstruation is regarded as the first day of the cycle. Menstrual cycle is divided into three phases or events:

a. Follicular phase

Menstrual cycle usually begins when blood is first discharged from the uterus during the first to fifth day (1-5 days). Following the reduction of progesterone, the hypothalamus releases gonadotropin releasing hormone (GnRH) which stimulates anterior pituitary gland to secrete follicle stimulating hormone (FSH). FSH brings about the following effects;

- Stimulates the development of a primary follicle
- Contributes to the shedding of uterine wall
- Causes production of oestrogen by uterine cells. The oestrogen produced promotes healing, repair and growth of uterine lining, inhibits further secretion of FSH. Oestrogen levels keep on raising until day 13 where they stimulate secretion of luteinizing hormone (LH) by anterior pituitary gland.

b. Ovulatory phase

Around the 14^{th} day, the high levels of oestrogen cause release of luteinizing hormone (LH) the release of LH brings about ovulation (release of mature egg from the ovary). Immediately after and slightly before ovulation, a woman is fertile and can conceive a baby if she has sexual intercourse or if sperm is present in her oviduct.

c. Luteal phase

After ovulation, the remains of ovarian follicle form corpus luteum also known as Yellow body, which secrete large amounts of progesterone hormone and smaller oestrogen.

These two hormones; stimulate further development of mammary glands, inhibit release of FSH and thickening wall of uterus in anticipation of pregnancy. If oocyte (ovum) is not fertilized with in about 36 hours of being shed into oviduct, it dies and corpus luteum gets smaller. Thus levels of progesterone and oestrogen keep on reducing until day 28 days i.e. 14 days after ovulation.

Low levels of progesterone remove the inhibitory effect on FSH, causing its release thus menstruation and the cycle starts again.

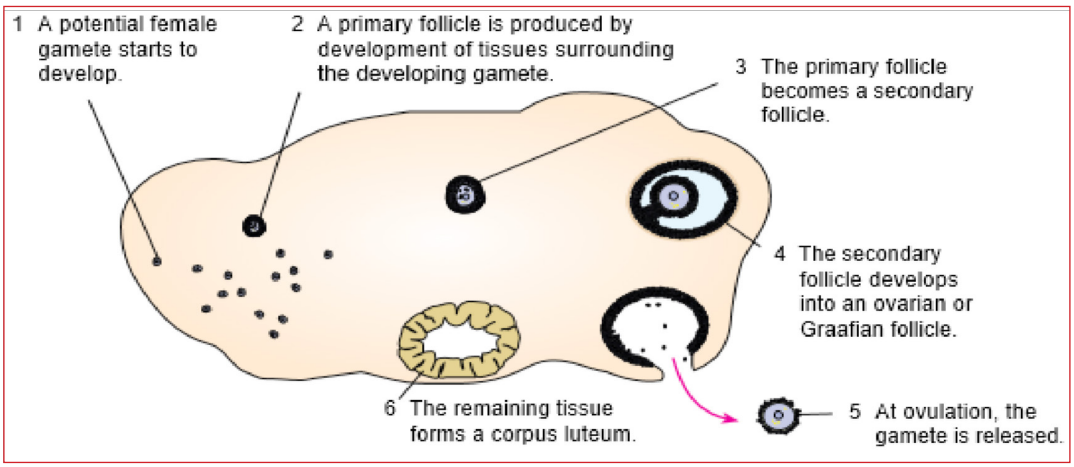


Figure 12.6: Growth of ovarian follicle

Role of hormones

The same hormones that control female puberty and oogenesis also control the menstrual cycle: estrogen, LH, and FSH. Estrogen controls the secretion of the two pituitary hormones by acting on the hypothalamus, which controls the pituitary gland. When the estrogen level rises in the blood, it stimulates the pituitary (via the hypothalamus) to secrete more or less LH and FSH.

In negative feedback, rising levels of hormones feedback to the hypothalamus and pituitary gland to decrease production of the hormones. In positive feedback, rising levels of hormones feedback to increase hormone production. During most of the menstrual cycle, estrogen and progesterone provide negative feedback to the hypothalamus and pituitary gland. This keeps their levels more or less constant. During days 12–14, however, estrogen provides positive feedback to the hypothalamus and pituitary gland. This causes a rapid rise in the production of estrogen by the ovary and leads to ovulation. Another hormone involved in the menstrual cycle is progesterone. The word "progesterone" literally means "pro-gestational hormone."

Progesterone is a hormone that promotes gestation, or the carrying of a fetus. The function of progesterone in the menstrual cycle is to maintain the endometrium of the uterus. Change in the levels of these four hormones (estrogen, LH, FSH, and progesterone) occur during the menstrual cycle. After menstruation occurs, estrogen secreted by the ovaries increases. This causes the endometrium of the uterus to thicken. FSH from the pituitary stimulates follicles in the ovary to mature. The maturing follicles produce estrogen, and

the level of estrogen in the blood rises. When estrogen reaches a high level in the blood, it stimulates the pituitary gland to release a surge of LH. The spike in LH stimulates the one remaining mature follicle to burst open and release its oocyte.

During the first half of the cycle, negative feedback keeps levels of FSH, LH, estrogen, and progesterone relatively stable. During ovulation, positive feedback causes a burst of FSH, LH, and estrogen. During the second half of the cycle, progesterone rises as the corpus luteum in the ovary matures and produces this hormone. Negative feedback helps keep levels of the other three hormones fairly constant. After the oocyte is released, LH stimulates the mature follicle to develop into a corpus luteum. The corpus luteum then starts secreting progesterone, which maintains the endometrium of the uterus. What happens next depends on whether the egg has been fertilized.

- If the egg has been fertilized, it will soon start producing a hormone that helps maintain the corpus luteum. As a result, the corpus luteum will continue producing progesterone and maintain the endometrium.
- If the egg has not been fertilized, the corpus luteum will disintegrate and stop producing progesterone. Without progesterone, the endometrium will break down, detach from the uterus, and pass out of the body during menstruation.

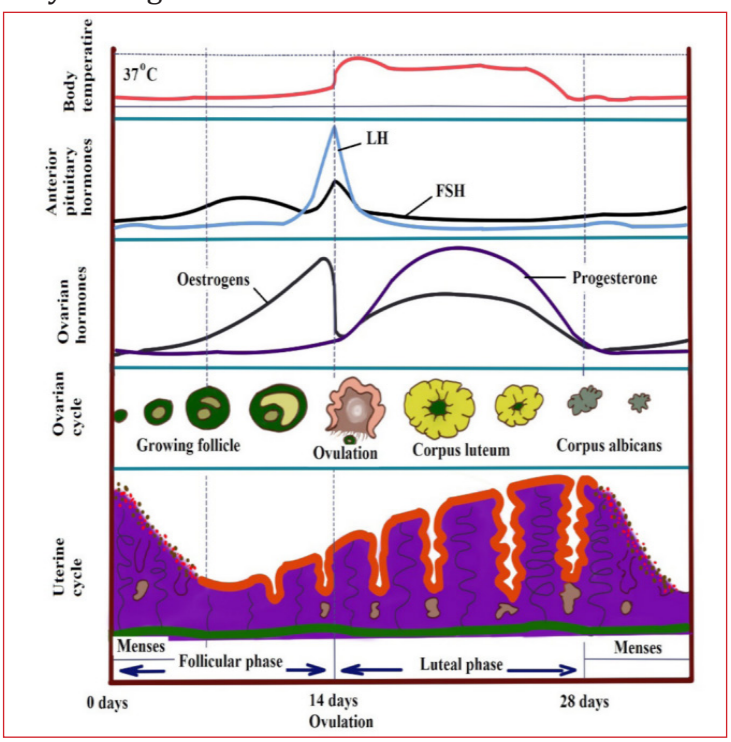


Figure 12.7: Hormones involved in menstrual cycles

The uterine can also be divided into three phases (events):

Menstrual phase: when endometrium tissue is discharged and vaginal bleeding occurs at the end of ovulatory cycle if pregnancy has not occurred. It is called menstruation.it describes the shedding of endometrium when implantation does not occur. When pregnancy does not occur the level of progesterone falls and these results shedding of endometrium. Menstrual bleeding lasts between 3 and 5 days. The first day of the period is the first day of the cycle.

Proliferative phase: It stimulates the thickening of endometrium of the uterus. This thickness of endometrium is stimulated by oestrogen from follicles before ovulation. This results the development of ovary. It acts like follicular phase.

Secretory phase: it occurs after ovulation for describes further thickening of endometrium (endometrium tissue become more complex) in preparation for implantation. This is stimulated by progesterone which is secreted by corpus luteum and this occurs when corpus luteum is functioning. It acts like lacteal phase.

Estrous cycle

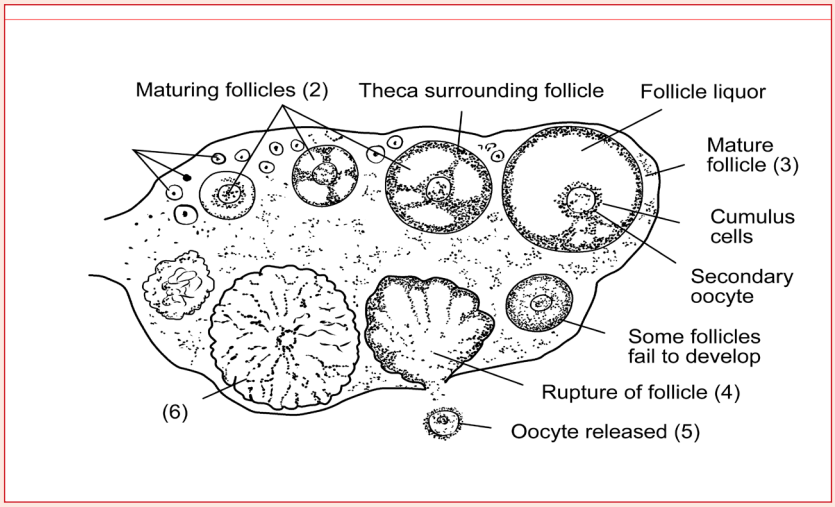
The estrous cycle (also oestrous cycle; derived from Latin oestrus meaning sexual desire) comprises the recurring physiologic changes that are induced by reproductive hormones in most mammalian eutherian females. Estrous cycles start after sexual maturity in females and are interrupted by anestrous phases or pregnancies. Typically, estrous cycles continue until death. Some animals may display bloody vaginal discharge, often mistaken for menstruation, also called a "period".

Differences from the menstrual cycle

Mammals share the same reproductive system, including the regulatory hypothalamic system that releases gonadotropin releasing hormone in pulses, the pituitary that secretes follicle stimulating hormone and luteinizing hormone, and the ovary itself that releases sex hormones including estrogens and progesterone. However, species vary significantly in the detailed functioning. *One difference is that animals that have estrous cycles reabsorb the endometrium if conception does not occur during that cycle. Animals that have menstrual cycles (primates) shed the endometrium through menstruation instead. Another difference is sexual activity. In species with estrous cycles, females are generally only sexually active during the estrus phase of their cycle. This is also referred to as being "in heat". In contrast, females of species with menstrual cycles can be sexually active at any time in their cycle, even when they are not about to ovulate.*

Application activity 12.3

1. The diagram below represents a section through a mammalian ovary.



i. Name the structure labelled (6)
ii. What is the origin of this structure?
iii. What is the function of this structure if an ovum has been fertilized?
iv. State what will happen to this structure next if pregnancy has not occurred.
v. State which hormone is needed to cause the changes seen in the diagram and indicated by the sequence (1) (2) (3)

12.4 Copulation, fertilization and fetal development

Activity 12.4

Make a research in the books in the library about the process of fertilization and the human embryonic development. Take short notes. If possible download a movie on Youtube.com that shows the human embryonic development.

12.4.1 Copulation

It is the act of mating where sperms from male are transferred into the female tract. Male mammals have an intromittent organ called penis which becomes erect at a moment of mating for insertion into female's vagina. The erection of penis is brought by hydraulic action (penis becomes gorged with blood). This occurs as a result of sexual arousal which brings about by ejaculation (release

of sperm). The semen's are secreted from accessory glands into vas deferens and bladder sphincter closes preventing urine from entering urethra. Sperms are expelled from epididymis into vas deferens and out of the body by a series of muscle contraction of penis. In a female, sexual arousal results in the swelling of clitoris and stimulates the secretion of mucus which lubricates vagina during sexual intercourse.

12.4.2 Fertilization

Fertilization is the fusion of male and female nuclei to form zygote. Copulation results in the ejection of spermatozoa into vagina. The spermatozoa swim in the watery mucus of vagina and uterus up into the oviduct where the fertilization takes place in the upper part of the oviduct. From the vagina or uterus spermatozoa propel using energy from mitochondria. If ovulation has already taken place, the egg and sperm meet in the upper part of oviduct and once they come into contact, acrosome raptures and release lytic enzyme which dissolve corona radiata of the egg and soften zona pellucida and vitelline membrane. The following processes take place:

a. Capacitation

This is a stage where by sperm undergoes essential changes while passing through female genital track and this takes about 7 hours. These changes include the removal of a layer of glycoprotein from outer surface of sperm, by enzyme in uterus. Cholesterol also is removed to weaken the membrane.

b. Acrosome reaction

This involves the releasing of enzyme found in acrosome such as hyaluronidases and protease. These enzymes digest corona radiata (narrow path in the follicle cells) and the zona pellucida (a protective glycoprotein surrounding the plasma membrane of the egg).

c. Fusion

In this stage the head of sperm will fuse with the microvilli surrounding the secondary oocyte and penetrate its cytoplasm.

d. Cortical reaction

This stage involves the releasing of enzymes by lysosomes in cortical granules (outer region of the secondary oocytes); the enzymes cause the zona pellucida to thicken and harden forming a fertilization membrane. This cortical reaction prevents the entry of other sperm inside ovum (polyspermy).

e. Zygote formation

The secondary oocyte is stimulated to complete meiosis II, during this time of stimulation the nucleus of sperm and secondary oocyte are called pro-nuclei and then the two nuclei fuse to form the zygote (2n).

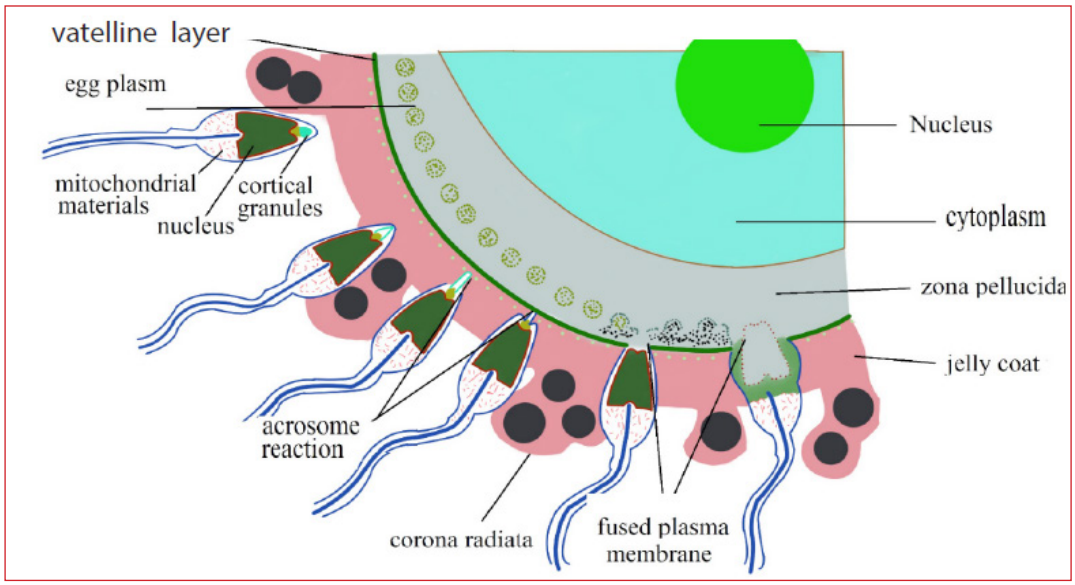


Fig 12.8: Process of fertilization

12.4.3 Embryonic development

The zygote spends the next few days travelling down the oviduct (Fallopian tube) by peristaltic contraction and by beatings of the cilia in wall of the oviduct toward the uterus. As it travels, it divides by mitosis several times to form a ball of cells called a morula. The cell divisions, which are called cleavage, increase the number of cells but not their overall size. More cell divisions occur, and soon a fluid-filled cavity forms inside the ball of cells. At this stage, the ball of cells is called a blastocyst.

The blastocyst reaches the uterus and becomes embedded in the endometrium at roughly the 5th – 10th day. Once in the uterus the blastocyst burrows into the uterine wall a process called implantation. After implantation, the blastocyst becomes embryo. It grows through multiplication and differentiation of its cells forming tissues and organs. The heart and blood vessels are the first organs formed and embryo now called foetus.

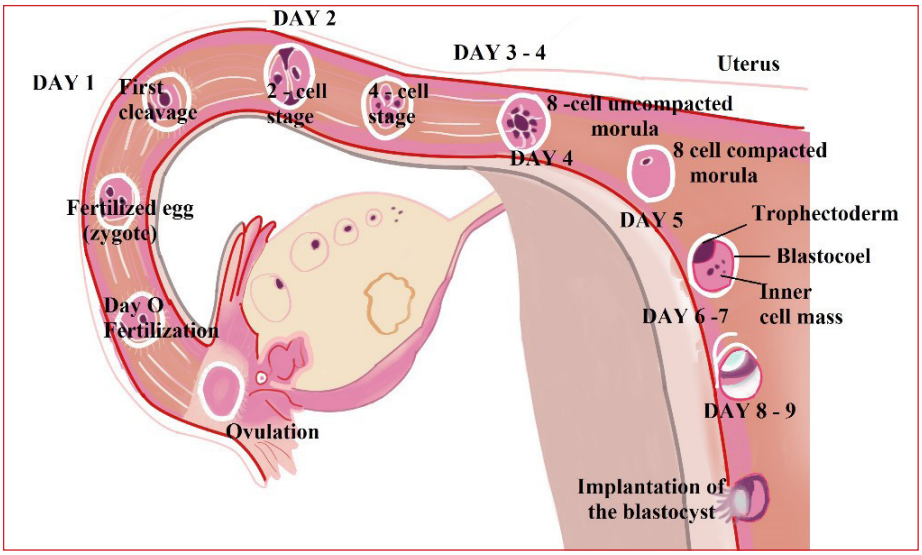


Figure 12.9: Embryo development during the first nine days

a. Stages of embryo development

There are three major stages of embryo development;

i. Cleavage

The cleavage consists of the division of zygote without increase in mass into a ball of consisting of many daughter cells.

ii. Gastrulation

It is the development of different layers of cells in the embryo. It generally occurs during the second week after fertilization. During gastrulation, cells of the embryo migrate to form three distinct cell layers: the ectoderm, mesoderm, and endoderm. Each layer will eventually develop into certain types of tissues and cells in the body of vertebrates.

- **Ectoderm**: it forms tissues that cover the outer body; develops into cells such as nerves skin, hair, and nails.
- **Mesoderm**: it forms tissues that provide movement and support; develops into cells such as muscles, bones, teeth, and blood.
- **Endoderm**: it forms tissues involved in digestion and breathing; develop into organs such as lungs, liver, pancreas, and gall bladder.

iii.Organogenesis and Differentiation

Differentiation of cells leads to the development of specific organs and tissues within the three cell layers. This is called organogenesis. All the major organs begin to form during the remaining weeks of embryonic development.

b. Extra-embryonic membranes

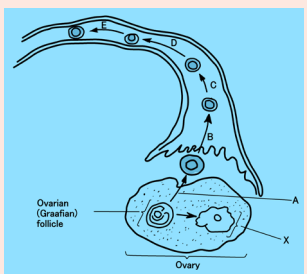
These membranes are part of placenta. The outer cells of the blastocyst, the trophoblast grow and develop into an outer layer or membrane called the chorion. This plays a major role in nourishing and removing waste products from the developing embryo.

The amnion is a thin membrane covering the embryo like an umbrella and has a protective function. Between the embryo and the amnion is the amniotic fluid. The amniotic fluid supports the embryo and protects it from mechanical shocks. The yolk sac has no significant function in humans but is important in reptiles and birds, where it absorbs food from the separate yolk and transfers food to the gut of the developing embryo. Note:

The first trimester of the development or the embryo is critical. There is high risk of spontaneous abortion or miscarriage due to alcohol, infection, radiations (X-rays), nutritional deficiencies, genetic mistakes or abnormalities in the developing embryo. From the 8th week until birth (around 38 weeks), the developing organism is called a foetus. The foetus is not as sensitive to damage from environmental exposures as the embryo, and toxic exposures often cause physiological abnormalities or minor congenital malformation. All major structures are already formed in the foetus, but they continue to grow and develop.

Application activity 12.4

The diagram below shows some of the events which take place in the ovary and oviduct (Fallopian tube) around the time of fertilization.



a. Name the following:

i. The process labelled A.

ii. The type of nuclear division taking place at D and E.

iii. The structure labelled X.

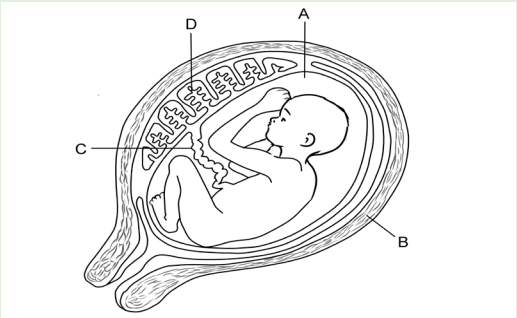
iv. One hormone produced by structure X.

b. On the diagram, use the letter F to label the region where fertilization took place.

12.5 Role of placenta in the development of an embryo

Activity 12.5

1. The drawing below shows a developing human fetus inside the uterus.



a. Name the parts marked A to D.
b. Name four substances which pass from the mother to the embryo.
c. Name one substance which passes from the embryo to the mother.
d. What are the functions of the parts labelled A to D?
e. What is the importance of the placenta?

The placenta is a temporary organ in which nutrients and wastes are exchanged between the mother and the embryo or foetus.

The foetal part of the placenta consists of the allantoides and chorion. The chorion forms many large projections called chorionic villi which contain a dense network of foetal capillaries which in turn are connected to two umbilical arteries and umbilical vein in the umbilical cord. The umbilical arteries carry blood from the foetus to the placenta, while the umbilical vein carries blood in the opposite direction. Although maternal blood in the endometrium is in close proximity with the foetal blood in the umbilical capillaries, they do not mix because they separated by membranes of the villi and capillary.

12.5.1 Functions of the placenta:

- Allows diffusion of nutrients such as water, glucose, amino acids, simple proteins and mineral salts from maternal blood.
- It is a site of gaseous exchange: haemoglobin of the foetus has high affinity to oxygen compared to adult haemoglobin.
- It offers passive natural immunity on the foetus. Certain maternal antibodies can cross the placental barrier.

- It protects foetal circulation from the high pressure in the maternal circulation
- Prevents mixing of maternal and foetal blood which would cause agglutination (clotting) if the two blood types are incompatible.
- It produces and secretes hormones such as the HCG (human chorionic gonadotrophin), progesterone, oestrogen, and relaxin.

Note that

- The action of HCG is similar to that of LH. HCG stimulates the corpus luteum to secrete progesterone and oestrogen throughout the first trimester. HCG is produced in such large quantities that some of it is excreted in the urine of a pregnant woman (positive test of pregnancy). Secretion of HCG declines around tenth week and the corpus luteum reduces.
- The placenta does not give complete protection to the foetus. Certain pathogens, toxins, and drugs can enter the foetal circulation and cause damage. Examples are; HIV, rubella toxins, alcohol, nicotine and heroin.

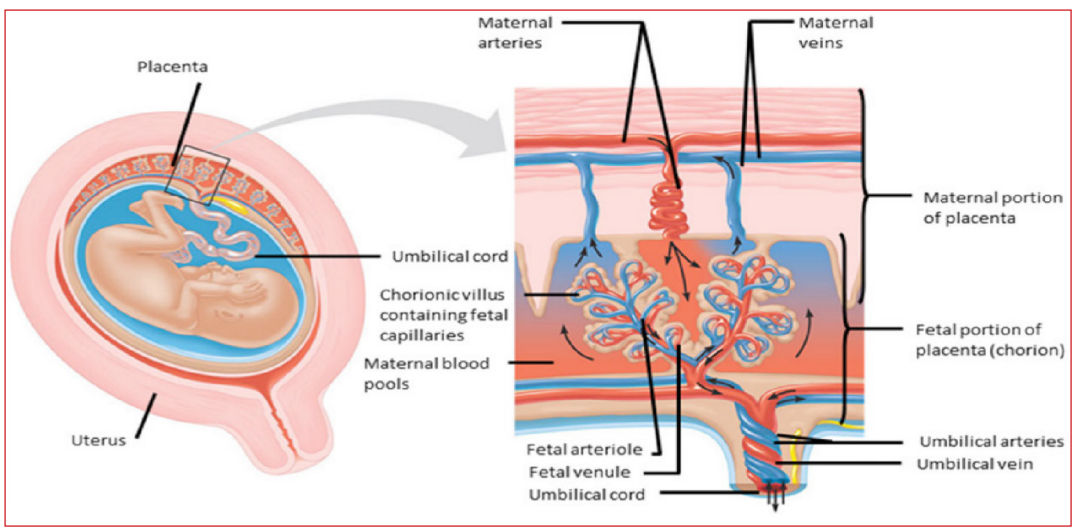


Figure 12.10: Structure of the placenta

12.5.2 Working of the placenta

Blood from the mother enters the maternal blood vessels of the placenta under pressure, forcing the blood into the empty spaces. When the mother's blood contacts the foetal blood vessels, gases are exchanged.

Oxygen from the mother's blood is exchanged with carbon dioxide from the foetus's blood. A release of pressure brings the mother's blood back from the placenta and into her veins.

The substances that are moved from the mother to the foetus include:

- Water
- Glucose by passive diffusion
- Hormones
- Amino acids by active transport
- Lipids by membrane lipid diffusion
- Oxygen is released by the maternal haemoglobin. The haemoglobin of the foetus has a higher affinity for the oxygen.
- Alcohol, many drugs, nicotine (if taken by mother during pregnancy) – Vitamins, minerals.

The substances that are moved from the foetus to the mother include:

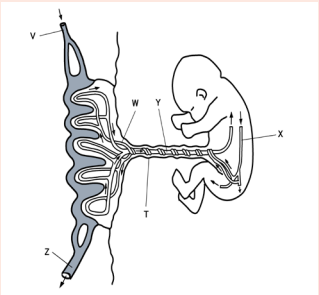
- Carbon dioxide is taken up by the maternal plasma and transported to the lungs of the mother for excretion.
- Urea passes into the maternal blood and passes to her kidneys for excretion.

The exchange between the mother and the foetus is possible because of specific structures in the placenta:

- The plasma surface membranes of the cells in the walls of the chorionic villi have microvilli, which increase their surface area for the exchange of substances by diffusion, facilitated transport and pinocytosis.
- Numerous mitochondria are found in these cells. They provide the energy for the active transport and pinocytosis.
- The cell surface membranes contain carrier molecules (protein) used in the uptake of materials into the villi by active transport.
- Numerous small vesicles are found inside the cells of the villi as a result of materials being taken up from the blood by pinocytosis.

Application activity 12.5

1. The diagram shows the structure of the placenta and parts of the fetal and maternal circulatory systems.



a. Complete the table by listing the blood vessels that carry oxygenated blood. Use the letters in the diagram to identify the blood vessels.

Circulatory system	Blood vessels that carry oxygenated blood
Maternal	
Fetal	

b. Name structure T and describe what happens to it after birth.

c. The placenta is adapted for the exchange of substances between the maternal blood and the fetal blood. Describe the exchanges that occur across the placenta to keep the fetus alive and well.

12.6 Physiological changes in females during pregnancy, gestation period, birth and Parental care

Activity 12.6

Use the image on the introductory activity 12 to describe the physiological changes that can be observed to the pregnant woman on the photo and make short notes.

Pregnancy refers to the development that take place between fertilization of the ovum to birth of the foetus. When fertilized egg becomes implanted in uterine wall, pregnancy results. And a number of important events take place during this period.

The period from fertilization to birth is called gestation period. In human it is about nine months.

12.6.1 Changes during pregnancy

A pregnant woman's body undergoes various; physiological, physical and behavioural changes.

a. Some physiological changes during pregnancy:

- Respiration rate rises for increased maternal oxygen consumption which is needed for demand of placenta, uterus and foetus.
- More blood vessels grow and pressure of expanding uterus on large veins causes blood to slow in its return to the heart.
- Rise up and out of pelvic cavity this action displaces the stomach and intestine.
- Blood volume increase greatly.
- Placenta produces large amount of progesterone and oestrogen by 10 to 12 week of pregnancy to control uterine activity.
- Increased requirement of calcium due to increase of parathyroid gland.
- Experiences warm (hot flashes) caused by basal metabolic rate and increased hormonal level.
- Stretching of abdomen wall and ligaments that support uterus.
- Kidney work extra hard to excrete waste products of both mother and foetus.

b. Some physical changes during pregnancy

- Breast may become large and more tender because of increased level of oestrogen hormone progesterone thus breast gets even bigger to prepare for breast feeding.
- Nipples may stick out more.
- By the end of third trimester, a yellow, watery, pre-milk may leak from nipples.
- Changes in hair and nail growth and texture due to hormone changes.
- Leg cramp caused by fatigue from carrying pregnant weight.
- Feet and ankles may swell because of extra fluid in the body during pregnancy.

c. Some behavioural changes during pregnancy

- Physical discomfort such as urinary frequency can be frustrating.
- Fear and anxiety lessen especially foetal movement are felt.
- Self-introspection
- Nesting behaviour begins. Some woman exhibit mood swings and emotional liability.

12.6.2 Delivery process

By the end of pregnancy, near the time of birth, the amniotic sac raptures (breaks) and amniotic fluid drains through birth canal and labour usually begins which involves the contractions of muscular walls of the uterus.

Initiation of birth: Uterine contractions starts when the foetal pituitary gland secretes adrenocorticotrophic hormone (ACTH) which stimulates foetal adrenal gland to secrete corticosteroids. These hormones pass into blood sinuses in placenta to cause maternal cells to secrete prostaglandins (local hormone) and cause uterine wall to contract. This contraction pushes the foetal head against the cervix to stimulating stretcher receptor to send information to mother's brain and causes release of oxytocin hormone. The prostaglandin and oxytocin hormone together result intense contraction of uterine walls called labour which stimulates more release of oxytocin hormone and as positive feedback mechanism.

The delivery process can be summarized into three main stages

- **Dilation stage**: During this stage, water sac filled with amniotic fluid forms and precedes the head, widening soft tissue of birth canal, cervix, and vagina for canal of constant diameter. The amnion raptures and amniotic fluid drains through vagina.
- **The expulsion stage**: During this stage, cervix is fully dilated while abdominal muscle bear down in supporting rhythmic contraction of uterus shorten the uterine wall and baby is pushed into and through the birth canal. The head and shoulder align themselves first.
- **Placenta stage**: This stage begins with complete expulsion of baby and ends with expulsion of foetal membrane. The cord is clamped and cut when delivery of baby is complete. This leads carbon dioxide enrichment into baby's blood which activates respiratory centre and baby begins to breath with the first cry at the same time foetal circulation changes to baby's own systemic and pulmonary circulation.

12.6.3 Parental care

The degree of maturity in mammalian new-borns varies from one species to another. New-born in pigs can move around and eat solid food while new-born in humans, dogs and rat are quite helpless and require a lot of parental care to survive.

All mammals feed their young ones by milk which contain all the nutrients required by new born for the first few days. Parents also protect new born from

predators and from unfavourable weather. Some species make nest just before delivering the new born. Some parents also become aggressive when they have young one. As the young one grow older the parent start gathering food for them. Once the new born get old enough to gather food for themselves can leave on their own. In humans' parental care extends for very long time up over 18 years. In humans breastfeeding is associated with many benefits:

- It makes earlier a closer contact between the mother and her infant
- Breastfed babies do not get too fat
- The infant has a better control over its own milk intake, this prevents over eating in late life
- Fats and irons from breast milk are better absorbed than those in cow's milk and milk is easily digested.
- Breast feeding provides important antibodies that help to prevent respiratory infections and meningitis,
- Breastfeeding helps the mother's reproduction organ return to a normal state more rapidly
- Breast feeding promotes the secretion of LH (and prolactin) and this makes a delay in follicle development and ovulation,
- The act of sucking on the breasts, promotes the development of the jaw, facial muscles and teeth (sucking from a bottle requires less effort).
- Pulmonary circulation. After delivery, uterus contract so that placenta separates from
- Uterine wall expelled out as the sign of birth end.

APPLICATION ACTIVITY 12.6

1. Copy and complete the table to show, for each hormone, the precise site of its secretion, and its effects on the ovary or on the endometrium of the uterus.

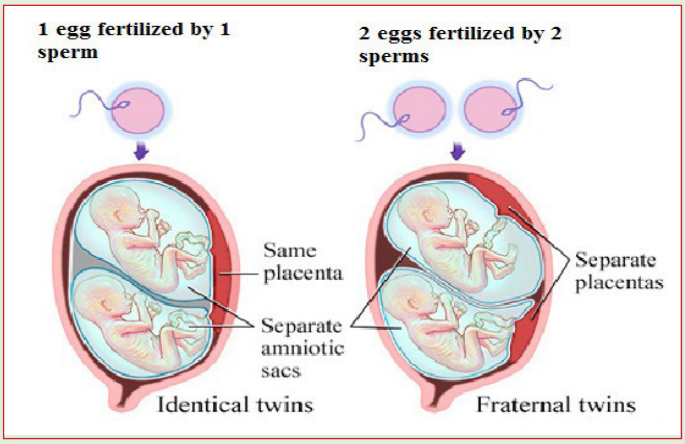
Hormone	Site of secretion	Effect(s) of hormone	
		Ovary	Endometrium
FSH			None
LH			None
Estrogens		None	
Progesterone		None	

2. Identify three events that occur as a fetus grows and develops.
3. Why is an embryo generally more susceptible than a fetus to damage by toxins in the

12.7 Twins and multiple births

Activity 12.7

Use the image below to answer the questions that follow:



a. What is the difference between the formation of the two types of twins?

b. Which type of twins are very much alike in appearance? Why?

c. Which type of twins that can develop into individuals with different sexes?

Twins are individuals born to the same mother at the same time. Twins include;

- **Fraternal twins or non-identical twins or dizygotic twins**: These are twins which develop from two separate egg cells fertilised by two different sperms. Fraternal twins are genetically different since they develop from different gametes.
- **Identical twins or monozygotic twins**: these are twins which develop from the same fertilised egg. Identical twins are genetically similar since they develop from the same sperm and the same egg.
- **Siamese twins: are conjoined twins** i.e. they have not completely separated during the embryo development. As consequence, they share same organs. Conjoined twins develop without separating completely and are born attached to one another. Such twins may be separated surgically.

Fraternal twins or dizygotic twins are the result of two separate ova fertilized by separate sperm. This may occur when two ovarian follicles reach maturity and rupture at the same time. Fraternal twins may be of the same sex or different sexes. Even if of the same sex, however, they are as genetically different as any siblings might be.

Identical twins or monozygotic twins are the result of the splitting of the very early embryo before the cells start to become specialized (usually within 8 days after fertilization).

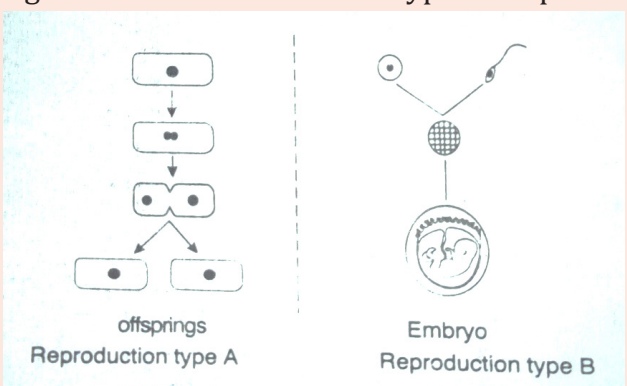
For example, if a 16-cell stage becomes separated into two groups of 8 cells each, each group will usually continue to develop in the usual way. Another possible cause is the development of two inner cell masses within the blastocyst. This, too, is before significant specialization has taken place and each inner cell mass may develop into a complete individual. Twins of this type may be called monozygotic, meaning that they have come from one fertilized egg. ***Identical twins are always of the same sex, are very much alike in appearance, and in other respects are genetically identical.***

Siamese twins (also known as conjoined twins) are monozygotic twins whose bodies are joined together during pregnancy. This occurs when the zygote starts to split after fertilization and fails to separate completely.

Multiple births arise when several eggs are released at the ovulation and are fertilised or when a zygote splits into several zygotes. It is commonly occurring in mammals such as; pigs, dogs and cats.

APPLICATION ACTIVITY 12.7

1. The diagram below illustrates two types of reproduction



a. Name reproduction types A and B.
b. State 2 advantages of type A.
c. How does the reproduction type A differ from identical twins?

12.8 Infertility and in-vitro fertilization

ACTIVITY 12.8

You may have understood different couples with infertility problems being able to conceive by using artificial methods that involves fusing the sperm and the egg on the outside of the female body.

What do you know about those techniques?

Infertility

Infertility is the failure to achieve pregnancy when no contraceptive method is used.

In females, infertility may be due to:

- Failure to ovulate due to the lack of some hormones
- Damage of the Fallopian tubes / oviducts, for example the tubes may be completely blocked by nature or after an infection,
- Damage on the uterus; for example, the endometrium can be destroyed
- Damage on the cervix, for example the cervix may be narrow or too wide or may stop producing cervical mucus needed for the sperm to reach uterus
- Antibodies against sperms, for example, the cervix, the uterus or the oviduct of a woman can produce antibodies against her husband's sperms.

Some causes of infertility/barrenness in males include

- Absence of sperms in the semen (Azoospermia).
- Low sperm count e.g. when ones ejaculate less than 1cm3 of semen.
- Abnormal sperm e.g. sperms with 2 tails, or without tail, or without acrosomes,
- Auto-immunity e.g. antibodies attack one's sperms
- Premature ejaculation: the man has orgasm before copulation
- Impotence i.e. inability to achieve or maintain an erection of the penis.

a. Some social consequences include

- Isolation including exclusion from ceremonies and social gathering.
- Rejection being an outcast and physical abuse perpetrated by community members.
- Stigmatization or recognizable marginalization.
- Status loss that is no respect and social fail.
- Ridicule including insults and verbal abuse.

b. Some economic consequences include

- Cost of infertility by either modern biomedical or traditional treatments.
- A feeling of rejection.
- Having few relations, receiving few gifts and less land.
- Marital instability including fear of husband taking second wife.
- Divorcing childless woman
- Violence perpetrated by partner.

Note: While infertility may result into conflicts between couples and families, producing many children also brings about some economic challenges. Many children affect families' financial wellbeing and some parents admit that children are expensive. Consequences of many children per one family include:

- High rate of maternal depression.
- Low rate of immunization and parental care.
- Baby taxing both physical and emotional especially off work after birth.
- I come tend to go up when new members of the family arrive. Men see the boost in their earnings after birth of child.
- There is economic wellbeing decline in time around birth.

c. Increasing fertility

Increasing fertility can be done in various techniques such as:

- Fertility drugs: a synthetic chemical which stimulates ovulation by either proving gonadotrophins such as FSH which stimulates growth of follicles. Or proving chemical which inhibits natural production of oestrogen.
- Artificial insemination: sperm from donor is inserted artificially through cervix of mother to be.
- Using in-vitro fertilization

12.8.1 In-vitro-fertilization

In-vitro fertilization is the process of fertilization where an egg is fertilized by sperm outside the body. It involves the fertilization of egg cell outside the body which are then artificially implanted in the uterus to produce test tube baby. The process involves monitoring and stimulating of woman's ovulatory process removing ovum (egg) from woman's ovaries and letting sperm to fertilize them in liquid laboratory. The fertilized egg (zygote) undergoes embryo cultured for 2 to 6 days and then transferred to the same or another uterus for successful pregnancy. The embryo is implanted in woman's uterus.

Advantages of in vitro-fertilization techniques include

- **Simplicity**: living organisms are extremely complex functional system with protein molecules, RNA molecules and genes. Therefore, the work of Vitro simplifies system under study to focus on small number of components.
- Species specificity in human cells in-vitro method can be studied without extrapolation from experimental animal's cellular response.
- **Automation and convenience**: In-vitro method can be automated, high yielding throughout screening methods for testing molecule in pharmacology.
- **In vitro-fertilisation** can be used to achieve successful pregnancy but the process usually produces more embryos which some scientists wish for research design to improve our knowledge about disease.

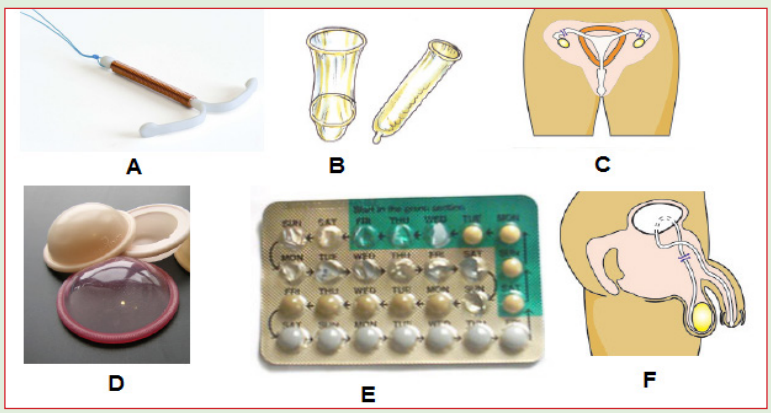
Application activity 12.8

Outline the techniques of in-vitro-fertilization.

12.9 Family planning and contraceptive methods

Activity 12.9

Use the photo below shows various contraceptive methods. Identify each of them.



Which two contraceptive methods among others on the photo are more effective?

Contraception is the prevention of conception that is preventing the fusion of the male gamete with the female gamete. Both natural and artificial methods exist.

Artificial methods

- Oral Contraceptive pills: a chemical method of contraception. One version uses a combination of progesterone and oestrogen that inhibits ovulation. Others are single hormones that require very careful management when taken.
- Intrauterine device (IUD) the coil is placed inside the uterus an exact understanding how this works is unclear. A possible explanation is that it 'irritates' the endometrium such that rejects implantation of embryos. The device is made from plastic or copper and inserted by a doctor. Nevertheless, this device is very effective.
- Condom is another mechanical method of contraception that prevents the sperm from reaching the egg. Composed of a thin barrier of latex this is placed over the erect penis and captures semen on ejaculation. This is also a good barrier to prevent the transmission of sexual diseases.
- Cap (diaphragm) is another barrier method again made from latex. The cap is placed over the cervix to prevent the entry of sperm in semen. This technique requires that the cap is put in position in advance of sexual intercourse and that it is used in combination with a spermicidal cream. When used correctly this is an effective contraceptive however this is not a barrier against the transmission of sexual diseases.
- Sterilisation is a surgical and near permanent solution for contraception such as: Vasectomy. In men this involves cutting the vas deferens and prevents sperm entering the semen. In this state, man still ejaculates normally and releases semen however this does not contain sperm. Tubal ligation involves the cutting of fallopian tube so that eggs cannot reach the uterus. In women the surgery cuts or ties the oviducts thus preventing sperm from reaching the egg in fertilisation.

Natural methods

- Natural birth control methods include specific actions that people can do naturally to help prevent an unintended pregnancy.
- Abstinence: the individual makes the choice to delay sexual intercourse until the decision to conceive a child is made.
- Withdrawal is a behavioural action where a man pulls his penis out of the vagina before he ejaculates. The withdrawal method also relies on complete self-control. You must have an exact sense of timing to withdraw your penis in time.
- Fertility awareness methods: This require a woman to monitor her body to determine when she is most fertile. You then avoid having unprotected sex around the time of ovulation. This natural birth control method

involves paying attention to different body changes (such as basal body temperature or cervical mucus) and recording them to predict when you will ovulate. To be successful, you need to be willing to record and chart your fertility signs. Then, you (and your partner) must agree to not have sex (or to use backup birth control) for 7 days before and 2 days after you ovulate. Fertility awareness methods include the Billings Method and temperature method

- Continuous (Lactational Amenorrhea Method) can postpone ovulation for up to 6 months after giving birth. This natural birth control method works because the hormone required to stimulate milk production prevents the release of the hormone that triggers ovulation.

Advantages and disadvantages of birth control

Some advantages of birth control/contraceptives

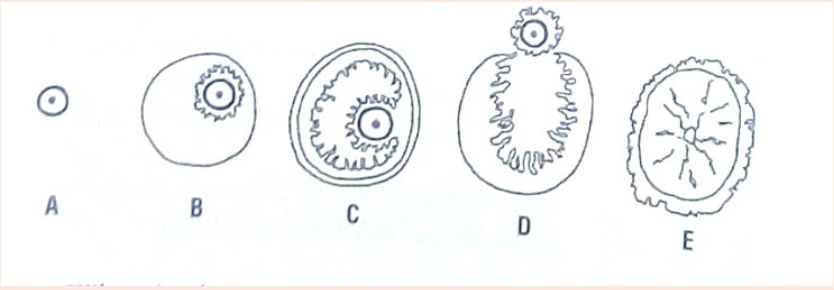
- Gives great protection against unplanned pregnancy if one follows instructions.
- Condoms to some extent protect against pregnancy and STDS.
- Combinations of pills reduce/prevent cysts in breasts and ovaries.
- Improved family wellbeing.
- Improved maternal and infant health.

Some disadvantages of birth control/contraceptives

- Necessity of taking medication continually.
- High cost of medication.
- Hormonal contraceptive does not protect against STDS.
- Eggs may fail to mature in the ovary for a woman who uses hormonal contraceptives.
- Woman must remember to take them regularly.
- Woman must begin using hormonal contraceptive in advance before they become effective.
- Some women experience several; headaches, breast tenderness, chest pain, discharge from vagina, leg cramps and swelling or pain.

Application activity 12.9

1. Which contraceptive methods can protect against sexually transmitted diseases / infections?
2. The diagram shows the sequence of events in the development of a mature ovarian (Graafian) follicle and corpus luteum



a. What is the main hormone produced by the ovary when stage B is present?
b. Which two of stages A to E would you expect to find in the ovary of a woman during the early stages of pregnancy?
c. Give the reason for your answer on b.
d. Some oral contraceptives contain only estrogens. Which of the stages A to E would you expect to find in the ovary of a woman who had been taking such an oral contraceptive for a prolonged period of time?
e. Give reasons for your answer on d.

Skills lab 12

1. Determining the fertile period

Count the number of days of your menstrual cycles and count the number of days for 10 consecutive cycles. Choose the cycle with the highest number of days and the cycle with the lowest number of days. Substract 18 from the lowest cycle and 11 from the highest cycle.

Example: Mary has 27 days as her shortest cycle and 36 as her longest cycle. She has had her menstruation on 09/08/2019. What will be her fertile period?

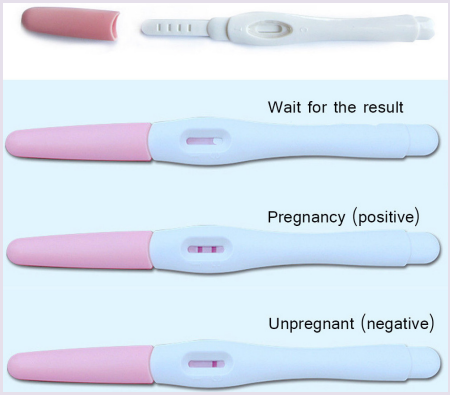
First fertile period: 27 – 18 = 9 (August 9 + 9 =August 17)

Last fertile period: 36 – 11 = 25 (August 9 + 25 =September 3)

The fertile period of Mary will be from 17 August to 3 September 2019

2. Pregnancy test

The pregnancy test works by checking your urine for a hormone called human chorionic gonadotropin (HCG). Your body only makes this hormone if you are pregnant. HCG is released when a fertilized egg attaches to the lining of your uterus when pregnancy begins. If your pregnancy test is positive, it means that you are pregnant. If the pregnancy test is negative, it means that you are not pregnant. Pregnancy tests are most accurate when you take them after you have missed your period.



(Source: https://zionmedicalsolutions.com/product/one-step-pregnancy-test-cassette-25-tests/): Pregnancy test

End unit assessment 12

1. Which of the following do sperm NOT travel through?

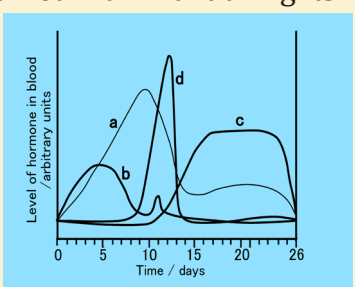
a. Ureter, b. Urethra, c. Vas deferens, d. Epididymis

2. The placenta in humans is derived from the:

a. Embryo only, b. Uterus only, c. Endometrium and embryo

d. None of the above

3. The graph below shows the level of reproductive hormones in the blood of an un-named mammal during its reproductive cycle.



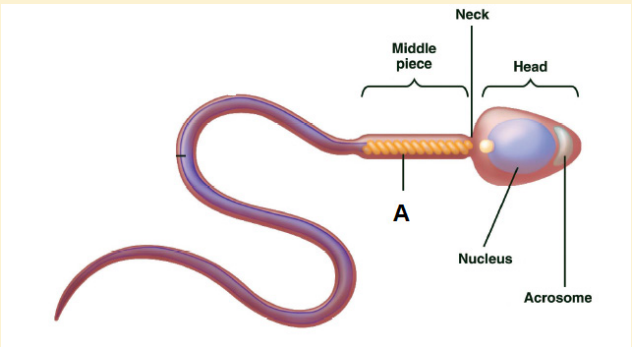
a. Name the hormones labelled (a) to (d)

b. Give the likely day of the cycle on which ovulation takes place and give reasons for your answer.

4. Answer the following questions:

a. Define the term fertilization

b. The diagram below shows the structure of a human sperm.



i. Explain the part played by the organelle labelled A in the process leading to fertilization.

ii. The acrosome contains an enzyme that breaks down proteins. ii) The acrosome contains an enzyme that breaks down proteins. Describe the function of this enzyme in the process leading to fertilization.

5. In humans, widening of the female hips is one example of physical changes that distinguish the sexes but are not essential for reproduction. To what term does the definition in italics refer?

a. What term is used for the time in a young person's life when such changes take place?

b. Name the hormone that maintains such changes throughout the life of a male.

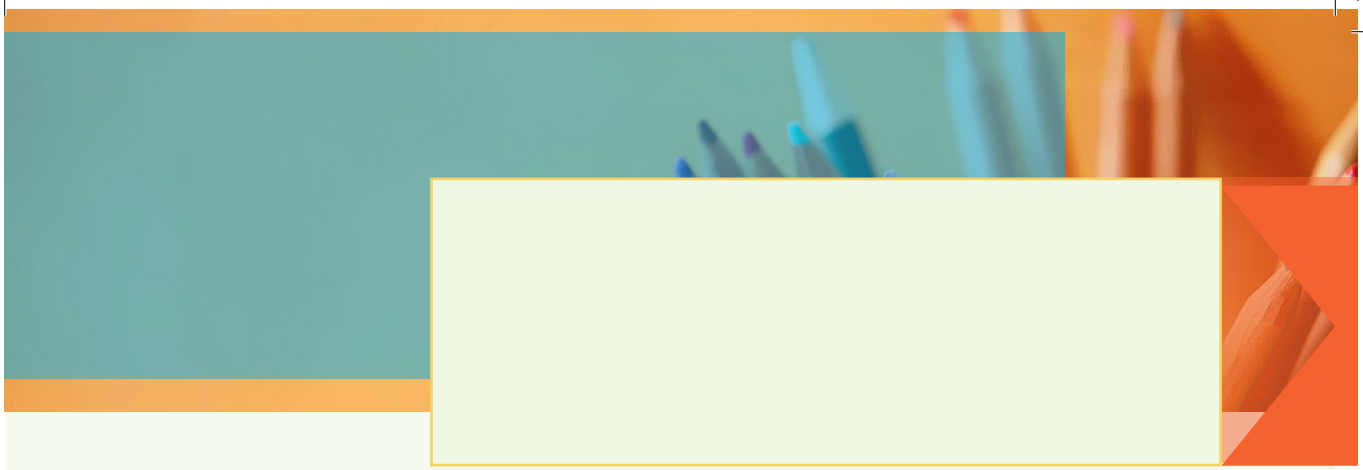
c. Describe the role of estrogen and progesterone in the control of the events of the menstrual cycle.

d. Answer the following questions in relation to the development of a human zygote.

i. By which type of cell division does the zygote divide?

ii. The placenta forms from tissues of the mother and the fetus. Give two roles of the placenta.

iii. Give one change experienced by the mother that indicates to her that the birth process is starting.



UNIT 13

INHERITANCE AND MUTATIONS

Key unit competence: Explain the role of genes in inheritance, how genetic disorders occur and describe the types, causes and effects of mutation in organisms.

Introductory activity 13

Read the passage below and answer the questions that follow

We all are aware of the fact that we look similar to our parents (grand-parents) and siblings in our appearance such as eye color, hair texture, skin color etc. We are also aware of the fact that certain diseases run in the family such as albinism, hemophilia etc. which indicates that certain characters or traits are passed on from parents to their offspring.

a. Why do you resemble your parents or siblings?
b. Which structure do you think controls the transmission of information from parents to their offspring?

For thousands of years, humans have understood that characteristics such as eye colour or flower color are passed from one generation to the next. The passing of characteristics from parent to offspring is called heredity. Humans have long been interested in understanding heredity. Many hereditary mechanisms were developed by scholars but were not properly tested or quantified. The scientific study of genetics did not begin until the late 19th century. In experiments with garden peas, Austrian monk Gregor Mendel described the patterns of inheritance.

13.1 Concept of inheritance and Mendel's laws

Activity 13.1

Analyze the photo below and answer the questions that follow:

The young cat look similar to her mother.

a. What characteristics does the young cat receive from its mother?
b. How are information transmitted from the mother cat to its offspring?
c. The diploid number of chromosome for the cat is 38 (2n = 38). How many chromosomes does the young cat receive from its mother? Why?

An organism produced by sexual reproduction tends to have two parents and inherits certain traits from father and certain traits from mother. It leads to variation in organism. So heredity and variation is characteristics of sexually reproducing organism. The study of heredity and variations in biology is referred to as Genetics.

13.1.1 Definition of genetic terms

- **Gene**: Gene is the entity/unit which has the information for particular trait. For example: in garden pea, gene for stem height has information for height whether it would be long or small.
- **Locus**: The position of gene on chromosome constitutes its loci/locus.
- **Allele**: The alternate forms of genes are known as Alleles. A pair of alleles for each trait is present in the zygote of an organism. For example: in garden pea, true breeding tall parent plants have two similar alleles (TT).

- **Dominant allele**: In individual, out of two alleles for the particular trait, only one allele is expressed. The expressed allele is known as dominant. For example, allele (T) for tallness is expressed in F1 individuals (Tt), dominant allele. Dominant allele is generally referred by capital alphabet.
- **Recessive allele**: In individual, out of two alleles for the particular trait one allele is under expressed. The under-expressed allele is known as recessive. For example, allele (t) for shortness is not expressed in F1 individuals (Tt), recessive allele. Recessive allele is generally referred by small alphabet.
- **Co-dominant**: It's a phenomenon when both alleles present in an individual, are equally expressed. For example, in humans, Blood cells express both the alleles M and N (alternate form of gene encoding Red blood cell membrane protein) when present together.
- **Linkage**: The genes are said to be linked when present on the same chromosome and inherited together as unit.
- F1: F symbolized filial, which means "progeny" in Latin. F1 is the filial generation first, produced by cross between parent individuals.
- F2: F2 is the filial generation second, produced by cross between F1 individuals.
- **Phenotype**: The morphological appearance for particular trait constitutes its phenotype. For example: In the cross between tall and dwarf parent plants, F1 plants are tall. Tallness is their phenotype. In F2 plants, tall and dwarf plants are obtained in ration of 3: 1, it is phenotypic ratio.
- **Genotype**: The combination of allele for a particular trait in an individual constitutes its genotype. For example: In the cross between tall and dwarf parent plants, F1 plants are Tt. "Tt" constitutes their genotype for the trait stem height. Similarly, F2 plants are tall and dwarf. But genotype of all tall F2 plants is not same, one third are pure (TT) while two third are hybrid (Tt). So genotypically F2 ratio is 1: 2: 1.
- **Homozygous**: When in an individual, two alleles for a particular trait are alike, then individual is considered homozygous for the particular trait. For example, parent plants tall and dwarf plants are homozygous for stem height.
- **Heterozygous**: When in an individual, two alleles for a particular trait are different then individual is considered heterozygous for the particular trait. For example, F1 plants are genotypically "Tt". They are heterozygous for stem height.

- **Monohybrid cross**: 'It is a cross between two individuals of a species which is made to study the inheritance of a single pair of factors or genes of a trait.' A ratio among the offspring of F2 generation of a monohybrid cross is called a 'monohybrid ratio.' It is usually 3 : 1 (phenotypic ratio) or 1 : 2 : 1 (genotypic ratio), in which 1/4 individuals carry the recessive trait, 1/4 pure dominant and 1/2 have impure dominant trait.

13.1.2 Mendel's laws of inheritance

Mendel's experiments

In 1856, Gregor Mendel conducted experiments in garden pea (Pisum sativum) in the limited space of a monastery garden. Garden pea plant has both male (pollen-producing part) and female parts (pollen-receiving part). Since both the male and female parts are on the same plant, it has tendency to undergo self-fertilization. Because of self-fertilization, the tall plants always give rise to tall plants and dwarf plants always produce dwarf plants. Such true breeding varieties are known as pure lines. Furthermore, he was lucky to get pure lines in garden pea.

He then carefully conducted hybridization experiments between two parent plants expressing contrasting form of single trait. He also made sure that self-fertilization didn't happen by removing male parts from one parent (say tall plants) before female part got matured. In his initial experiments, he carefully transferred pollen from male parent (say dwarf plant) to tall parent's female part and analyzed transmission of one particular trait (stem height) in all progenies of the first generation (also known as F1 generation where F symbolizes the Latin word "filial" meaning progeny and 1 represents first). Furthermore, he followed the transmission of same trait (stem height) in second (F2) and third generation (F3) progenies as well which were naturally produced by self-fertilizing power among first generation plants and second-generation plants. He maintained the quantitative records of all his experiments.

Since Mendel focused on one trait at a particular time, a cross between parents which differs in contrasting form of single trait is known as Monohybrid cross or inheritance.

Fig 13.1: Gregor Mendel: Father of genetics (Source: http://www.biography.com/people/gregor-mendel-39282)

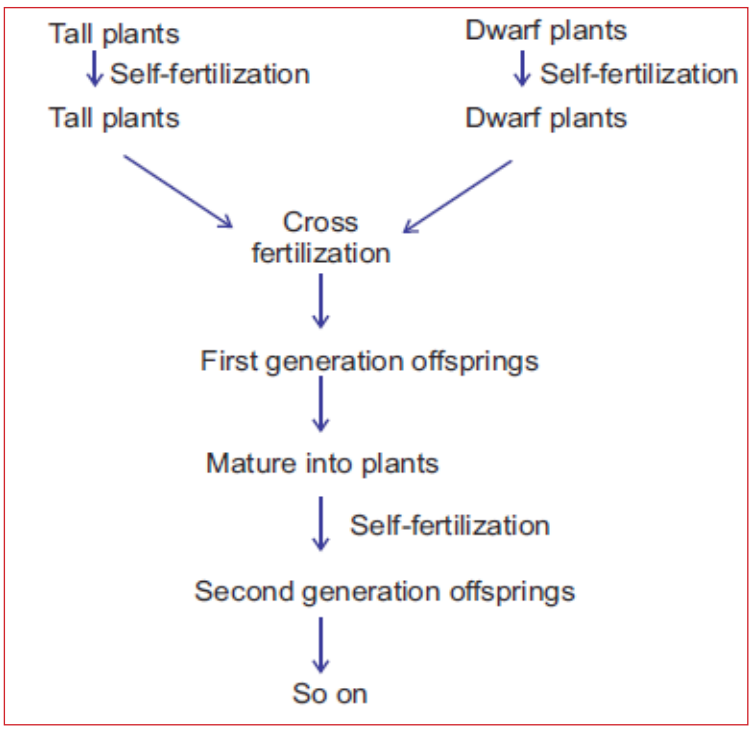


Figure 13.2: Hypothetical experimental plan by Mendel to follow the inheritance of particular trait or monohybrid inheritance (for example – stem height).

13.1.2 Monohybrid inheritance

Mendel first worked with plants that differed in a single characteristic, such as flower color.

Hybridization is a cross between two individuals that have different traits. A hybridization in which only one characteristic is examined is called a monohybrid cross. The offspring of such a cross are called monohybrids. Mendel noted that hybridizing true-breeding (P-generation) plants gave rise to an F1 generation that showed only one trait of a characteristic. For example, a true-breeding purple-flowering plant crossed with a true-breeding white-flowering plant always gave rise to purple-flowered hybrid plants. There were no white-flowered hybrids!

Mendel wanted to know what happened to the white-flowered plants' "heritable factors." If indeed the white flower "heritable factor" had disappeared, all future offspring of the hybrids would be purple-flowered. To test this idea, Mendel let the F1 generation plants self-pollinate and then planted the resulting seeds.

Mendel's results

The F2 generation plants that grew included white-flowered plants! Mendel noted the ratio of white flowered plants to purple-flowered plants was about 3:1. That is, for every three purple-flowered plants, there was one white flowered plant.

Mendel carried out identical studies over three generations, (P, F1, and F2), for the other six characteristics and found in each case that one trait "disappeared" in the F1 generation, only to reappear in the F2 generation. Mendel studied a large number of plants so he was confident that the ratios of different traits in the F2 generation were representative.

Mendel's observation

Mendel carried out experiments to follow the pattern of inheritance of particular trait in several generations. On crossing tall plants (which provided the female part) verse dwarf plants (which provided pollen), he observed that (Figure 13.3).

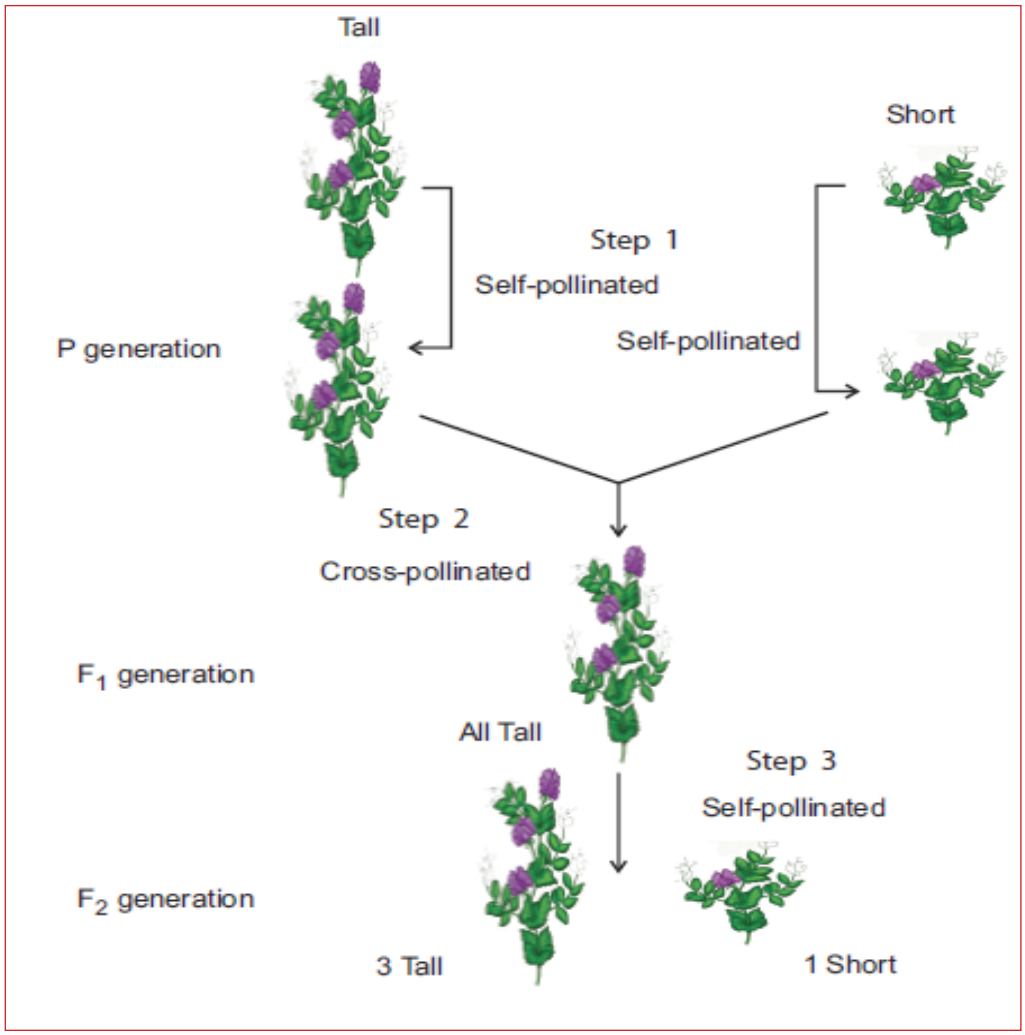


Figure 13.3: Experimental observation from a cross between tall and dwarf plants

- First generation progenies were always tall.
- Second generation progenies (also known as F2 generation) include tall plants as well as dwarf plants almost in ratio of 3 (tall plants): 1 (dwarf plants).

Mendel then performed the reciprocal cross (A similar cross where tall plants provided male parts whereas dwarf plants represented female plants). Mendel observed similar results.

On performing similar cross-fertilizing experiments with parent plants showing other contrasting set of traits such as seed colour, seed shape, seed coat colour, pod colour, pod shape and flower position/arrangement (figure 13.3), he observed similar observation and concluded that:

- First generation progenies were always showing one form of trait expressed in one of the parent plants.
- Second-generation progenies include the plants showing both contrasting forms of traits, almost in ratio of 3:1.

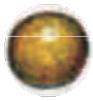
Seed Shape	Seed Colour	Seed Coat Colour	Pod Shape	Pod Colour	Flower Position	Stem Length
 Round	 Yellow	 Coloured	 Full	 Green	 Side	 Long
 Wrinkled	 Green	 White	 Pinched	 Yellow	 End	 Short

Figure 13.4: Seven pairs of contrasting traits in garden pea, the inheritance pattern was followed.

On self-fertilization of F2 plants for various contrasting traits (for example: for stem height), Mendel observed the following points:

- Dwarf F2 plants always yielded dwarf plants only.
- All F2 tall plants were not genetically same. The one-third tall plants produced tall plants only but two-third tall plants yielded both tall plants and dwarf plants in the ratio of 3: 1. It means phenotypic ratio is 3: 1 but genetically the ratio is 1:2:1.

The results of Mendel´s experiment were published in the monograph – "Experiments in Plant Hybridization" in 1866.

13.1.3 Principles of inheritance (Mendel's postulates)

Based on consistency of his results in transmission of seven contrasting traits, he derived postulates which later became principles of inheritance.

- There are two factors (Unit factor in pairs) for each trait. In pure lines of plants, both the factors for particular trait (stem height) are alike. For example, if Factor "T" donates height, there are two factors for each trait. The tall plants have TT and dwarf plants have tt.

- At the time of gamete formation, the factors for particular trait randomly segregate with equal likelihood. Each gamete contain single factor, therefore the gamete is always pure for the trait. Later on, it becomes popular as "Mendel's principle of segregation". For example: all the gametes from tall plants have single factor "T" and dwarf plants have "t" (Figure 13.5).
- After fertilization, when gametes from parents randomly fuse, factors for a particular trait also unite together. For example, in a cross between tall and dwarf plants, gamete from tall plant with factor "T" fuses with gamete from dwarf plant with factor "t" to form "Tt" organism.

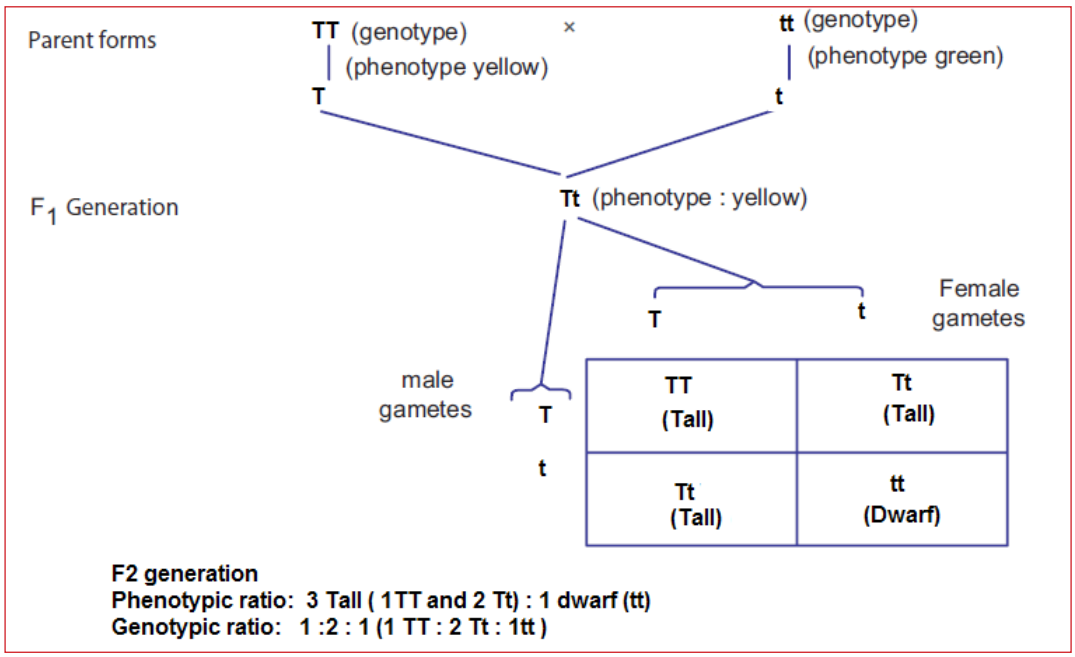


Figure 13.5: Mendel's monohybrid experiment on garden pea (Pisum sativum)

Test Cross: It is cross between hybrid forms (dominant phenotype) with other parent with recessive form of particular trait (homozygous recessive). It is generally used to identify the genotype of hybrid form. The progenies are observed. If all progeny demonstrates only dominant form of trait thereby indicating that unknown genotype must be homozygous for the particular trait. Or If F1 progeny shows both dominant and recessive form of trait in the ratio of 1: 1 indicating that unknown genotype must be heterozygous for the particular trait.

There can be two possible genotypes of an unknown dominant phenotype as illustrated below.

Possibility 1: If the unknown is homozygous yellow (YY), then crossing with green recessive (yy) gives all yellow offspring (i.e., all Yy) as shown below.

Possibility 2: If the unknown is heterozygous yellow (Yy), then crossing with green recessive results in 50% yellow (Yy) and 50% green (yy) progeny as shown below.

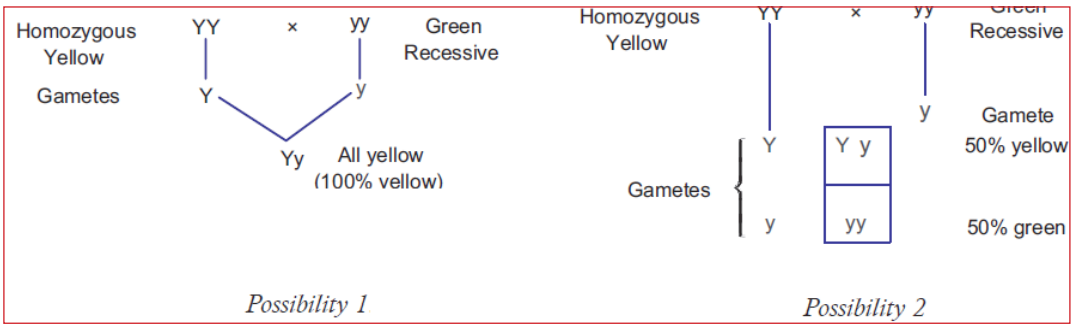


Figure 13.6: Test cross in monohybrid crosses

Mendel's laws

- **First law of Mendel: the law of segregation**: there are two factors controlling a given characteristic and these factors separate during gamete formation.
- **Second law of Mendel: the law of independent assortment**: factors controlling different characteristics are inherited independently of each other.

Application activity 13.1

1. Complete the table below about the number of chromosomes (4 marks)

Organisms	Body cell (2n)	Gamete (n)
Gorilla	48	24
Fruit fly	8	4
Cotton	52	26

a. How many chromosomes does a gorilla receive from its father?
b. What is the number of sex chromosomes in an egg cell of a fruit fly?
c. What is the number of autosomes in a leaf cell of a cotton plant?
d. What is the number of autosomes in a sperm cell of a rat?

2. A plant with terminal flowers stems is crossed with a plant with axial flowers. All F1 plants produced had axial flowers. /6 marks

a. Which allele is dominant?

b. With a punnet square, show the genotypic and phenotypic ratio of the F1 and F2 generation.

c. If there are 360 plants with axial flowers in the F2 generation, what is the number of plants with terminal flowers?

13.2 Co-dominance, multiple alleles and lethal alleles

Activity 13.2

Analyze the photo below and answer the questions that follow:

The cow observed on the photo has a roan coat colour. The roan coat of this shorthorn cattle is made up of red and white hairs. Both the red and white hair alleles are codominant. Therefore cattle with a roan coat are heterozygous for coat color. It is an offspring of a cross between a red bull cattle and a white bull cattle. What is the difference between this mode of transmission with complete dominance?

Codominance occurs when both traits appear in a heterozygous offspring. Neither allele is completely dominant nor completely recessive. For example, roan shorthorn cattle have codominant genes for hair color. The coat has both red and white hairs. The letter R indicates red hair color and W white hair color.

In cases of codominance, the genotype of the organism can be determined from its phenotype.

The heifer below is RW heterozygous for coat color.

Fig 13.7: Roan coat in cow

The roan coat of this shorthorn heifer is made up of red and white hairs. Both the red and white hair alleles are codominant. Therefore cattle with a roan coat are heterozygous for coat color (RW).

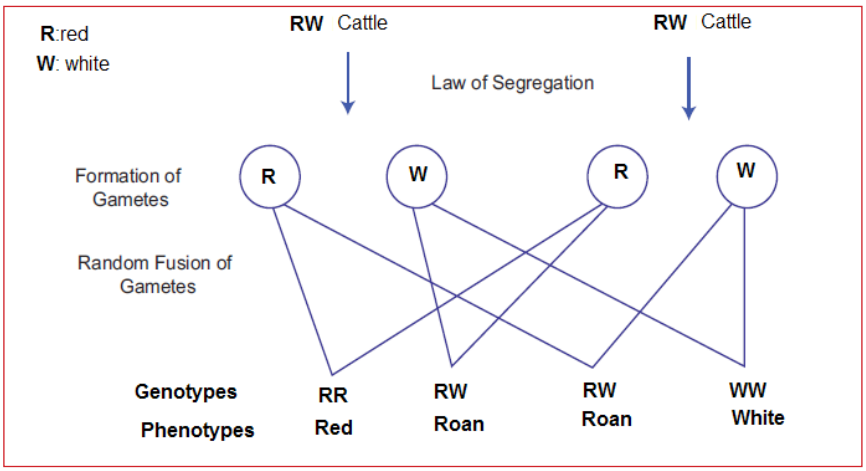


Figure 13.8: Cross between heterozygous RW cattle demonstrating co-dominance and characteristic phenotypic ratio 1 red: 2 roan: 1 white.

Incomplete dominance

Incomplete dominance occurs when the phenotype of the offspring is somewhere in between the phenotypes of both parents; a completely dominant allele does not occur.

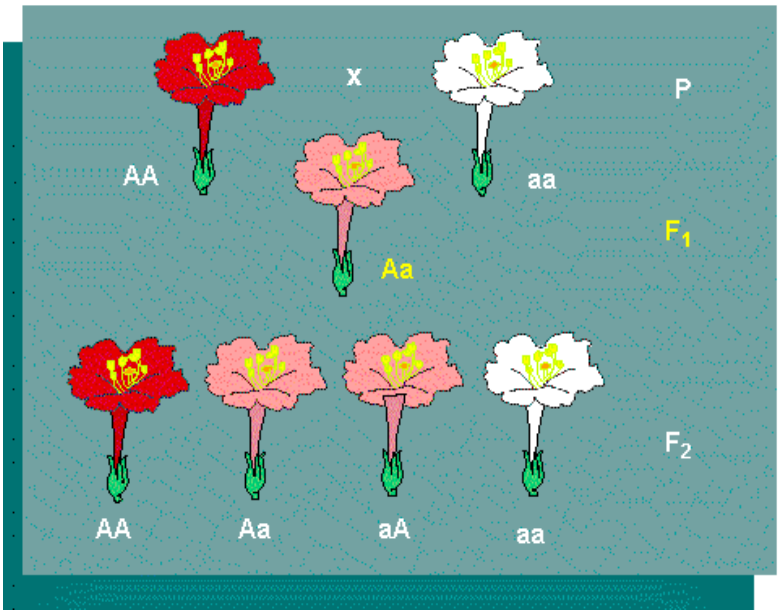


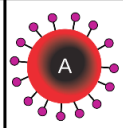
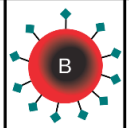
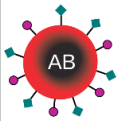
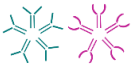
Fig 13.8: Incomplete dominance

Multiple alleles

When three or more alleles determine a trait, the trait is said to have multiple alleles. The human ABO blood group is controlled by a single gene with three alleles: I^A, I^B, and the recessive i allele. The gene encodes an enzyme that affects carbohydrates that are found on the surface of the red blood cell. A and B refer to two carbohydrates found on the surface of red blood cells. There is not an O carbohydrate. Type O red blood cells do not have either type A or B carbohydrates on their surface.

The alleles I^A and I^B are dominant over i. A person who is homozygous recessive ii has type O blood. Homozygous dominant I^AI^A or heterozygous dominant I^Ai have type A blood, and homozygous dominant I^BI^B or heterozygous dominant IBi have type B blood. I^AI^B people have type AB blood, because the A and B alleles are codominant. Type A and type B parents can have a type AB child. Type A and a type B parent can also have a child with Type O blood, if they are both heterozygous (I^Bi, I^Ai). The table below shows how the different combinations of the blood group alleles can produce the four blood groups, A, AB, B, and O.

Table 13.9: Blood groups

	Group A	Group B	Group AB	Group O
Red blood cell type				
Antibodies in Plasma	 Anti-B	 Anti-A	None	 Anti-A and Anti-B
Antigens in Red Blood Cell	 A antigen	 B antigen	 A and B antigens	None
Genotypes	I^AI^A, I^Ai	I^BI^B, I^Bi	I^AI^B	ii

Lethal alleles

Sometimes genes have serious effect on development, physiology of the organism in such a way that organism is unable to survive. Such genes are known as lethal genes. The particular allele responsible for death of the organism is known as lethal alleles. Lethal allele can be dominant or recessive.

For example: The dominant allele A in chicken has serious effect on development of the organism and results in following phenotype:

- Aberrant form "creepers" in Heterozygous individual (Aa)
- Completely "lethal" in homozygous dominant (AA).

When two heterozygous creeper individuals are mated, progeny are obtained in phenotypic ratio of 2 (Creeper): 1 (Normal) instead of 3: 1 monohybrid Mendelian ratio.

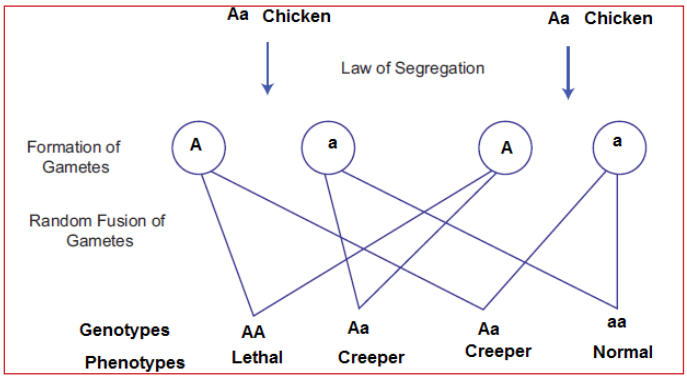


Figure 13.10: Cross between two creepers chickens demonstrating lethality and characteristic ratio 2 Creeper: 1 normal

Application activity 13.2

1. When red-flowered petunia plants are crossed with white-flowered plants, all the resulting F1 plants have pink flowers.

a. Explain how this is possible using genetic diagrams.

b. The F1 plants are crossed to produce an F2. Draw a genetic cross to show the genotypes and phenotypes of the F2 plants.

2. A man with blood group B marries a woman with blood group AB. Indicate the type of blood group that their children will not have. Show your working.

13.3 Dihybrid inheritance

Activity 13.3

Make a research in different books and use the internet about the dihybrid inheritance.

Mendel then thought how the segregation of factors for a particular trait at the time of gamete formation (Principle of segregation) could be effected with the segregation of factors for the other traits. With this question in his mind, he carried out similar sets of cross hybridization experiments between parents differing in contrasting set of two traits, (for example, round or wrinkled seed shape and yellow or green seed colour). Such a cross between parents which differs in contrasting form of two traits is known as Dihybrid cross or inheritance. The F1 progeny generated is known as Dihybrid.

The cross was made between the double dominant plants (round seed shape with yellow seed colour) with double recessive parent (wrinkled seed shape with green seed colour) and the following points were observed:

- All round yellow seeds were observed in F1 generation indicating dominant factor for a gene was expressed in the same manner as in monohybrid cross.
- On self-fertilization of F1 plants, F2 seeds were obtained and segregated in the ratio of 9 : 3 : 3 : 1 based on their phenotype.

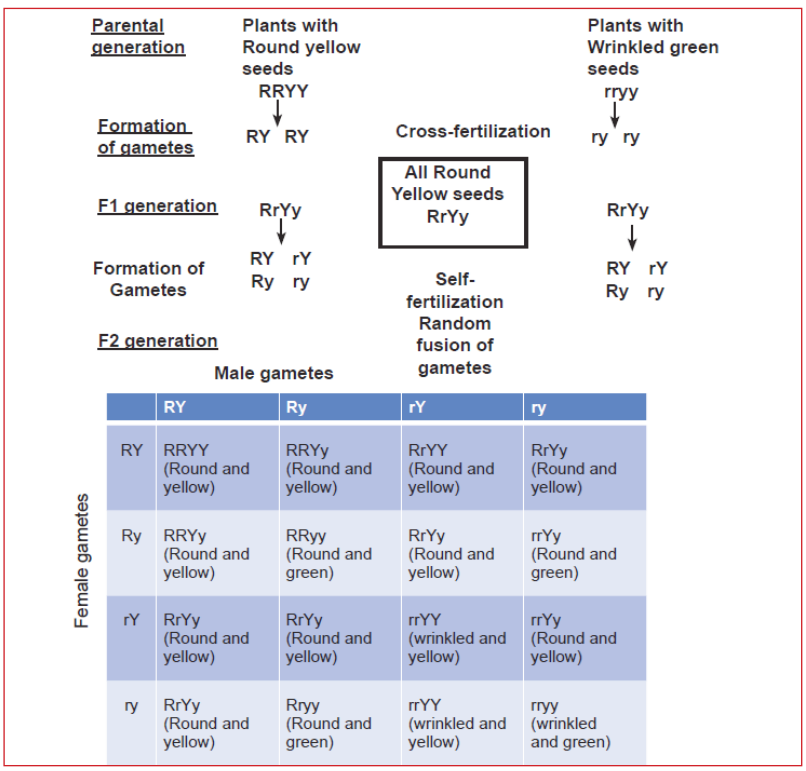
In addition to parental phenotype combination, two new phenotype combinations/ recombinants (wrinkled and yellow and round and green seeds) were observed. Mendel hypothesized that the factors for different traits separate and assort independently in the gametes (factor for seed shape can assort with any seed colour factor and vice versa) then F1 plants should produce four types of gametes.

So male and female F1 plant gametes can fuse randomly and combine in 16 possible ways which can be simply represented by a simple square popularly known as Punnett's square.

Mendel observed similar results when he analyzed results of dihybrid cross for the other pair of traits as well.

- The dihybrid results did not contradict monohybrid results, the round seeds and wrinkled seeds as well as yellow and green seeds were in ratio of 3: 1. He hypothesized dihybrid cross event as two independent monohybrid cross events.

(Punnett's square or checker-board: square-shaped presentation used to predict result of a particular cross or breeding experiment in which gametes from each parent are placed on the top and left side of the square. This diagram is used to predict the ratio of genotypes and phenotypes of the individual when gametes from parents randomly fuse. It is named after Reginald C. Punnett, who devised the approach.)



	RY	Ry	rY	ry
RY	RRYY (Round and yellow)	RRYy (Round and yellow)	RrYY (Round and yellow)	RrYy (Round and yellow)
Ry	RRYy (Round and yellow)	RRyy (Round and green)	RrYy (Round and yellow)	rrYy (Round and green)
rY	RrYy (Round and yellow)	RrYy (Round and yellow)	rrYY (wrinkled and yellow)	rrYy (Round and yellow)
ry	RrYy (Round and yellow)	Rryy (Round and green)	rrYY (wrinkled and yellow)	rryy (wrinkled and green)

Figure 13.11: Dihybrid cross between plants with dominant round yellow seeds with plants with recessive traits wrinkled and green seeds through two generations.

The phenotypic ratio is: 9 Yellow - Round: 3 Yellow – wrinkled: 3 green - Round: 1 green: wrinkled.

Table 13.1: Ratio of phenotypes in dihybrid crosses: 9 Yellow / Round: 3 green / round: 3 Yellow / Wrinkled: 1 short/Red

Gametes	YR	Yr	yR	Yr
YR	YYRRWW Yellow / Round	YYRr Yellow / Round	YyRR Yellow/ Round	YyRr Yellow/ Round
Yr	YYRr Yellow / Round	YYrr Yellow / wrinkled	YyRr Yellow / Round	Ttww Yellow/ wrinkled
yR	YyRR Yellow / Round	YyRr Yellow / Round	yyRR Green / Round	yyRr Green / Round
Yr	YyRr Yellow / Round	Yyrr Yellow / wrinkled	yyRr Green / Round	yyrr Green / Wrinkled

Note: The genotypes can be seen in specific locations as seen below in this table where every genotype has a specific colour

Table 13.2: Ratio of genotypes: 1 YYRR: 2 YYRr: 1YYrr: 2 YyRR: 4 YyRr: 2 Yyrr: 1 yyRR: 2 yyRr: 1 yyrr

Gametes	YR	Yr	yR	Yr
YR	YYRRWW Yellow / Round	YYRr Yellow / Round	YyRR Yellow / Round	YyRr Yellow / Round
Yr	YYRr Yellow / Round	YYrr Yellow / wrinkled	YyRr Yellow / Round	Ttww Yellow / wrinkled
yR	YyRR Yellow / Round	YyRr Yellow / Round	yyRR Green / Round	yyRr Green / Round
Yr	YyRr Yellow / Round	Yyrr Yellow / wrinkled	yyRr Green / Round	yyrr Green / Wrinkled

Law of independent assortment

From the result of dihybrid cross experiments, Mendel gave the following postulates:

- The dominant allele of a particular gene is expressed in the presence of alleles of other genes for different traits.

- On self-fertilization F1 plants, F2 plants were observed in the phenotypic ratio 9:3:3:1 (Dihybrid ratio). He concluded that factors for different traits assort segregate and assort independently in the gamete. This is popularly known as Law of Independent Assortment.

Significance of test crosses in dihybrid inheritance

Test cross can be used to differentiate genotype of dihybrid organisms (whether it is homozygous and heterozygous for the traits) if phenotypically same for a traits.

For example: plants with similar phenotype rounded seed shape and yellow seed color can have different genotype RRYY or RrYy. So the genotype of such plants can be identified by test cross. So the plant with unknown genotype is crossed with plant with recessive form of both the traits. There are two possibilities.

1. If progeny plants are observed in phenotypic dihybrid test ratio 1 (round and yellow):1 (round and green):1 (wrinkled and yellow):1 (wrinkled and green), then the parent plant must have heterozygous genotype for both the traits.

Expected ratio for dihybrid test cross

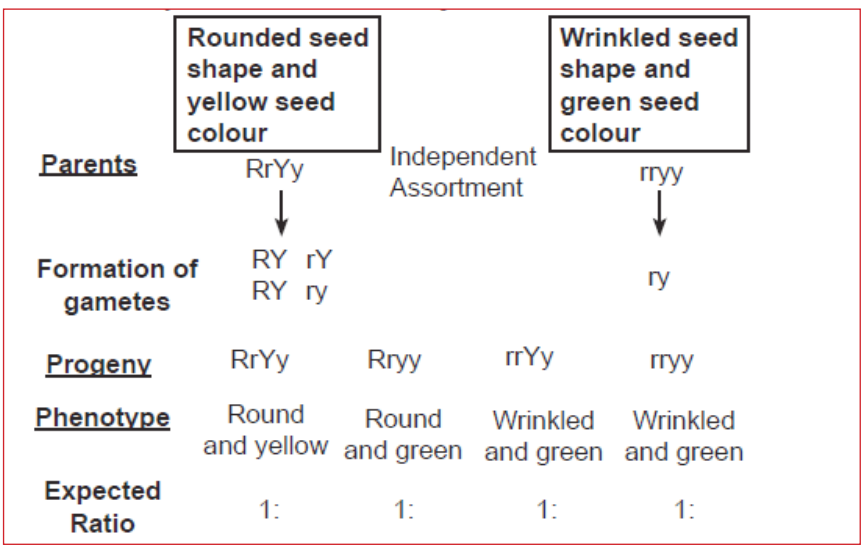


Figure 13.12: Dihybrid test cross ratio when plant has dominant heterozygous genotype for two traits

2. If after the cross all the plants are formed with dominant phenotype i.e., round seed shape and yellow seed colour, it indicates that given parent plant must have homozygous genotype for both the traits.

Application activity 13.3

1. A homozygous purple-flowered short-stemmed plant was crossed with a homozygous red-flowered long-stemmed plant and the F1 phenotypes had purple flowers and short stems. When the F1 generation was test crossed with a double homozygous recessive plant, the following progeny were produced.

- 52 purple flower, short stem
- 47 purple flower, long stem
- 49 red flower, short stem
- 45 red flower, long stem

Explain these results fully.

2. In tomatoes, the allele for red fruit, R, is dominant to that for yellow fruit, r. The allele for tall plant, T, is dominant to that for short plant, t. The two genes concerned are on different chromosomes.

a. A tomato plant is homozygous for allele R. Giving a reason for your answer in each case, how many copies of this allele would be found in:
   i. A male gamete produced by this plant.
   ii. A leaf cell from this plant.

b. A cross was made between two tomato plants.
   i. The possible genotypes of the gametes of the plant chosen as the male parent were RT, Rt, rT and rt. What was the genotype of this plant?
   ii. The possible genotypes of the gametes of the plant chosen as the female parent were rt and rT. What was the genotype of this plant?
   iii. What proportion of the offspring of this cross would you expect to have red fruit? Use a genetic diagram to explain your answer.

13.4 Linkage and crossing over

Activity 13.4

Genes may be located on the same chromosome or on different chromosomes. Make a research on the transmission of genes located on the same chromosome and genes located on different chromosomes.

According to chromosomes theory of Inheritance, it is the chromosomes which segregate and assort independently in the gametes. So the question arises as

to then what happens to genes located on same chromosome? Do they always remain together or linked (exception to law of independent assortment)? Or, do they segregate and assort independently, if yes what could be the mechanism?

Linkage

There are cases when genes (present on the same chromosome) for different traits do not show independent assortment, inherit together and behave as if genes are linked; the phenomenon is known as linkage. For example: two genes for trait flower colour and pollen grain texture in sweet pea (Lathyrus odoratus) where blue flower colour (B) allele is dominant over red flower colour (b) and long pollen (L) is dominant over round pollen (l). A test cross was carried out between heterozygous plant with double homozygous recessive plant (bbII), the observed phenotype had higher frequency of parental phenotype (87.4%) and lower frequency of recombinants phenotype (12.6%) in contrast to expected dihybrid test ratio. It indicated that genes do not assort independently and appear as if they are linked.

However, occasionally they may separate therefore resulting in lower frequency of recombinants.

Such genes are identified as linked when present on the same chromosome and do not assort independently and tends to form parental phenotype but occasionally they may separate resulting in low recombinants frequency. This phenomenon is known as linkage.

Phenotype	Observed frequency	Expected frequency if assorted independently
Blue and long (parental)	43.7%	25%
Blue and round	6.3%	25%
Red and long	6.3%	25%
Red and round (parental)	43.7%	25%

Linkage with crossing-over

Now the question arises what could be the possible mechanism for the separation of the genes located on the same chromosomes. The answer is crossing-over or recombination. Crossing-over is the physical exchange of chromosome parts between non-sister chromatids of the homologous chromosomes during meiosis division. The chiasma formation (observed by Janssens in 1909) clearly provides the site at which non-sister chromatids of paired homologous

chromosomes cross over. The cross-over event between two gene loci in non-sister chromatids is responsible for formation of recombinant chromatids and their separation.

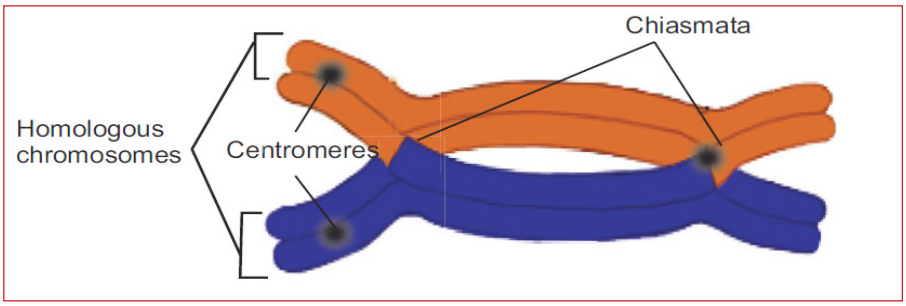


Figure 13.13: Micrograph demonstrating chiasmata formation in homologous chromosomes.

Here two paired homologous chromosomes (each with two sister chromatids) with centromeres and gene loci are shown.

Two alleles of a gene A (A and a) and two alleles of gene B (B and b) occupy same position in homologous chromosomes. The crossing over between two non-sister chromatids involves breakage of non-sister chromatids and reunion of broken parts. The chromatids which participate in crossing over generate recombinants chromatids. In the recombinants, the alleles on the same chromatid get separated and combine with alleles of non-sister chromatid.

Significance of Recombination/crossing-over

- The major significance is generation of variations. Due to crossing over, genes even on the same chromosome can be assorted differently. It leads to variations in the progeny. The variations are very useful in nature as it provides raw material on which natural selection can act.
- The frequency of crossing over becomes higher with increase in physical distance between gene loci. So recombinant frequency between two genes can be used to determine distance between genes, hence it helps to create chromosome map.

The recombination frequency or crossover frequency or crossover value (COV) is calculated using the formula:

$$\text{Recombination frequency} = \frac{\text{Number of individuals showing recombination X 100}}{\text{Number of offspring}}$$

Application activity 13.4

1. Pure-breeding Drosophila with straight wings and grey bodies were crossed with pure-breeding curled-wing, ebony bodied flies. All of the offspring were straight-winged and grey-bodied. Female offspring were then test-crossed with curled-wing, ebony-bodied males, giving the following results.

Straight-wing, grey body	113
Straight-wing, ebony body	30
Curled-wing, grey body	29
Curled-wing, ebony body	115

a. State the ratio of phenotypes expected in a dihybrid test cross such as this.

b. Explain the difference between the expected result and the results given.

c. Calculate the crossover value.

13.5 Sex determination and sex linkage

Activity 13.5

In 1910 by Morgan while working with white-eye (mutant) Drosophila. He carried several breeding analysis with white-eyed male drosophila and red-eye female drosophila. The F1 flies (male and female) are all red-eyed. On mating F1 male and female, he found F2 flies with red-eye and white eye in the ratio of 3 :1 in accordance with Mendelian monohybrid ratio thereby concluding that white-eye colour is recessive character. In Mendel's cross, expression of recessive trait in F2 is not associated with sex of the individual. Can you explain why?

Mostly, the organisms that produce their progeny using sexual reproduction have two sexes, male and female. Occasionally, there are hermaphrodites which have characteristics of both sexes. Sex determination is the biological system which initially determines sex of the organism while development.

13.5.1 System for sex determination

Based on whether genes play an important role in sex determination, there are two types of systems:

a. Genetic sex determination in which chromosomes (especially sex chromosomes) play an important role in determining sex of the individual.

   For example: mammals

b. Non-genetic sex determination in which other environmental factors such as diet, temperature etc., play an important role in sex determination. For example: Certain reptiles

13.5.2 Sex determination in humans

In humans and other placental mammals, male and female differ in their chromosome complement. Generally, there are two types of chromosomes, autosomes and sex chromosomes. Generally in one sex (mostly female), both the sex-chromosomes are alike/homomorphic (XX) and in other sex (male), there are two different/heteromorphic sex chromosomes (XY).

As the females are homomorphic (44 autosomes and XX, they produce single type of ovum, containing 22 autosomes and one X chromosome while males are heteromorphic (44 autosomes and XY) and therefore, they produce two types of sperm, one containing 22 autosomes and an X chromosome while other with 22 autosomes and a Y chromosome.

It is the Y chromosome which determines the sex of an individual. Y chromosome has Testis determining factor (TDF) gene which produces testis determining factor which causes primordial gonadal tissue in developing foetus to differentiate into testis. In the absence of TDF, tissue differentiates into ovaries. So, the

- Individuals with Y chromosome are genetically male.
- Individuals without Y chromosome are genetically female.

Thus, the sex in human is determined at the moment of conception or fertilization of male (sperms) and female gamete (ovum). If ovum gets fertilized by sperm containing an X-chromosome, then resulting zygote will have two XX chromosomes and will develop into female.

But if ovum gets fertilized by sperm containing a Y-chromosome, then resulting zygote will have two XY chromosomes and will develop into male. So biologically, father is responsible for sex of the child.

13.5.3 Sex linkage

Have you ever wondered that some variations are associated with particular sex of the individual? For example, the diseases like colourblindness, Haemophila etc., are more common in male as compared to female. Is mutation sex associated?

There are certain genetic traits, the expression of which depends upon sex of the individual or inheritance of sex chromosomes. The transmission of such traits (or alleles responsible for traits) is tied up or linked with the sex chromosomes; inheritance pattern of such genes is known as sex-linked inheritance. The phenomenon is called as sex linkage.

Sex linkage was first demonstrated in 1910 by Morgan while working with white-eye (mutant) Drosophila. He carried several breeding analysis with white-eyed male drosophila and red-eye female drosophila. The F1 flies (male and female) are all red-eyed. On mating F1 male and female, he found F2 flies with red-eye and white eye in the ratio of 3: 1 in accordance with Mendelian monohybrid ratio thereby concluding that white-eye colour is recessive character. In Mendel's cross, expression of recessive trait in F2 is not associated with sex of the individual.

13.5.4 Types of sex linkage

There are two types of sex-linked inheritance:

1. **Genes located on X chromosomes demonstrate X-linked inheritance.**

It is of two types' X-linked recessive inheritance and X-linked dominant inheritance.

- X-linked recessive inheritance, gene causing a mutant phenotype (variant phenotype) is recessive. It is more common in male. As male has single X chromosome only, they are pure for X-linked genes (hemizygous). While for female to express X-linked recessive trait, both the X chromosome should carry recessive allele. Here, criss-cross inheritance pattern is seen when recessive trait from male are transmitted through their daughter to their grandson.
- **For example**: Hemophilia A in human, here individuals lack a clotting factor; thus, a minor cut may cause excessive bleeding. It follows X-linked recessive inheritance.
- **X-linked dominant inheritance**: Here, the gene causing for a mutant phenotype (variant phenotype) is dominant. It is less common than X-linked recessive trait. Only a few X-linked dominant traits have been identified.

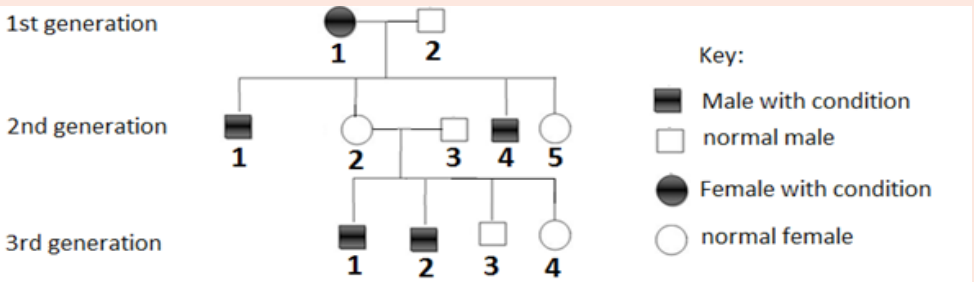
For example: X-linked hypophosphatemia is X-linked dominant trait that can cause bone deformity in human.

2. Genes located on Y-chromosomes demonstrate Y-linked inheritance

Here, genes are transmitted according to inheritance of Y chromosomes. All males receive Y chromosome from their father, so here Y-linked genes (hence their information) are directly passed from father to son. This type of inheritance is also known as Holandric ("wholly male") inheritance.

Application activity 13.5

1. The diagram below shows the pedigree of a family with red-green color blindness, a sex linked condition.



a. Define the term sex linkage.

b. Deduce, with a reason, whether the allele producing the condition is dominant or recessive.

c. Determine all the possible genotypes of the individual (2nd generation-1) using appropriate symbols.

d. Determine all the possible genotypes of the individual (3rd generation-4) using appropriate symbols.

13.6 Mutations and genetic disorders

Activity 13.6

Read the sentence below and answer to the questions that follow:

The big fat cat ate the rat.

a. Suppose the sentence is message hold on chromosome and code for the development of body parts, what will happen on the body when the word ATE is deleted?

b. What would happen if T in the word CAT is replaced by R?

c. What would happen if word CAT is doubled?

d. Which one of the following can have a great effect on the meaning of the sentence: removing one letter or adding one letter to the sentence? Compare the effect to that of the development of body parts.

In humans, how can we study inheritance pattern of different genetic disorders? So here, we have to study the history of families of person suffering from particular genetic disease by making a tree or chart.

Also, we can predict the chance of transmission of disease to future generation. Genetic disorders are the diseases which are caused by abnormalities in genetic information of the organisms. Genetic diseases are quite rare in population and their frequency varies from 1 1000 to 100,000.

13.6.1 Types of genetic disease

Single gene disorder: caused by abnormalities in single gene so that its product becomes either non-functional or abnormal. For example: haemophilia.

There are two types:

1. **Autosomal-linked disorde**r: in this case, the affected gene is located on the autosomes and it can be dominant and recessive. In autosomal dominant, the affected gene allele is dominant in its expression. Only one allele is sufficient to cause the disease in affected person. Affected person will have 50% chance to pass it to offspring if he or she marries a normal person and it inherits in every generation in affected person's family. For example: Huntington's disease is a neurodegenerative genetic disease that affects muscle coordination.

   In autosomal recessive, affected gene allele is recessive. Both copies of allele must be recessive for a person to be affected by the disease.

An affected person usually has unaffected parents who each carry a single copy of the mutated gene. For example: Albinism disease which is characterized by the complete or partial absence of the pigment in the skin, hairs and eyes.

2. **Sex-chromosome linked disorder**: here the affected gene is located on the sex chromosome. Inheritance of this genetic disorder depends upon sex of the affected person

Pedigree Analysis: Studies of Inheritance of Genetic Diseases in Humans

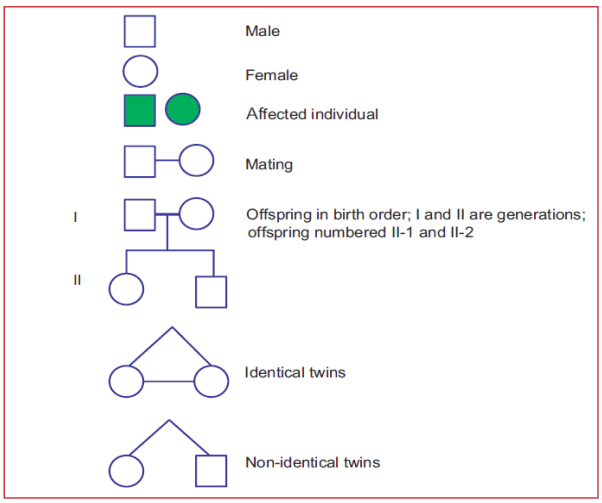


Figure 13.14: Symbols used in human pedigree analysis

The inheritance pattern of different genetic diseases can be studied by pedigree analysis. It involves collection of information about the family's history for a particular genetic trait. Then the expression of trait is represented into a family tree (also known as Pedigree tree).

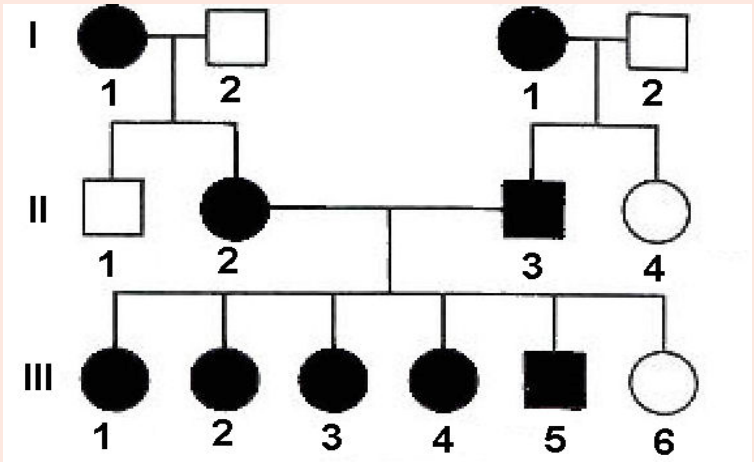
In a pedigree, squares symbolize males, and circles represent females. A horizontal line joining a male and female indicates the couple. Vertical lines indicate offspring which are listed left to right, in order of birth. Shading of the circle or square indicates an individual who has the trait being traced.

Mutations

Mutations are changes in the genetic material of a cell (or a virus). If a point mutation occurs in a gamete, or in a cell that gives rise to gametes, it may be transmitted to offspring and to a succession of future generations. If the mutation has an adverse effect on the phenotype of a human or other animal, the mutant condition is referred to as a genetic disorder, or hereditary disease.

Application activity 13.6

1. In humans, Huntington's disease is caused by a dominant, mutant gene. Draw a genetic diagram to show the possible genotypes and phenotypes of the offspring produced by a man with one allele for the disease and a woman who does not suffer from the disease.
2. The diagram shows a family tree for a condition known as polydactyly.



a. State whether polydactyly is controlled by a dominant or a recessive allele.

b. Explain which evidence from the family tree confirms your answer to (a).

c. Explain what the chances are for a third child of parents 2 and 3 having polydactyly. You may use a genetic diagram to help your explanation.

13.7 Types of mutations

Activity 13.7

The mutations can occur in a gene or on a chromosome. Mutations can also occur in somatic cells and in germinal cells. What is the meaning of gene, chromosome, somatic cell and germinal cell.

Mutations can broadly be categorized into two types: gene mutations and chromosomal mutations.

13.7.1 Gene mutations (point mutations)

Mutations within a gene can be divided into three general categories: base-pair substitutions and base-pair insertions and deletions.

a. Substitution

A base-pair substitution is the replacement of one nucleotide and its partner in the complementary DNA strand with another pair of nucleotides. One purine replaced by another purine or pyrimidine replaced by another pyrimidine is called **transition**. However, pyrimidine replacing purine or purine replacing pyrimidine is called **transversion**. Some substitutions are called **silent mutations** because, due to the redundancy of the genetic code, they have no effect on the encoded protein. In other words, a change in a base pair may transform one codon into another that is translated into the same amino acid. For example, if CCG mutated to CCA, the mRNA codon that used to be GGC would be GGU, and a glycine would still be inserted at the proper location in the protein.

Substitution mutations are usually **missense mutation**; That is the altered codon still codes for an amino acid and thus makes a sense, although not necessarily the right sense. But if a point mutation changes a codon for an amino acid into a stop codon, translation will be terminated prematurely, and the resulting polypeptide will be shorter than the polypeptide encoded by the normal gene. Alterations that change an amino acid codon to a stop codon are called nonsense mutations, and nearly all **nonsense mutations** lead to nonfunctional proteins.

Table 17.4: Point mutations

	No mutation	Silent mutation	Nonsense mutation	Missense mutation
DNA level	TTC	TTT	ATC	TCC
mRNA level	AAG	AAA	UAG	AGG
Protein level	Lys	Lys	STOP	Arg

b. Insertions and deletions

Insertions and deletions are additions or losses of one or more nucleotide pairs in a gene. These mutations have a disastrous effect on the resulting protein more often than substitutions do. Because mRNA is read as a series of nucleotide triplets during translation, the insertion or deletion of nucleotides may alter the reading frame (triplet grouping) of the genetic message.

Such a mutation called a f**rameshift mutation** will occur whenever the number of nucleotides inserted or deleted is not a multiple of 3. All the nucleotides that are downstream of the deletion or insertion will be improperly grouped into codons, and the result will be the extensive missense ending sooner or later in nonsense premature termination.

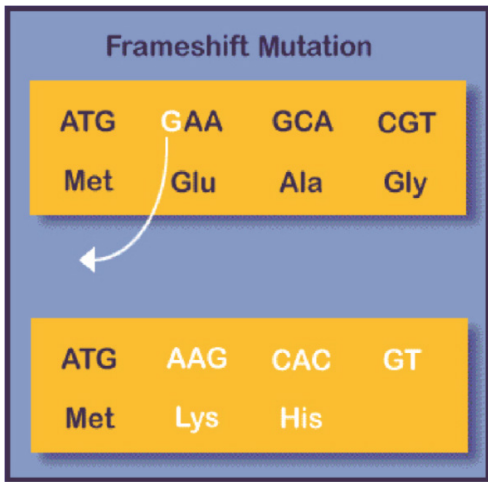


Figure 13.15: Frame-shift mutation

13.7.2. Large-scale mutations in chromosomal structure (chromosomal mutations)

Physical and chemical disturbances, as well as errors during meiosis, can damage chromosomes in major ways or alter their number in a cell. Here, we survey these chromosomal alterations and see how this information applies to some important disorders in humans.

a. Alterations of chromosome number: aneuploidy and polyploidy

Ideally, the meiotic spindle distributes chromosomes to daughter cells without error. But there is an occasional mishap, called a **nondisjunction**, in which the members of a pair of homologous chromosomes do not move apart properly during meiosis I, or in which sister chromatids fail to separate during meiosis II. In these cases, one gamete receives two of the same type of chromosomes and another gamete receives no copy. The other chromosomes are distributed normally. If either of the aberrant gametes unites with a normal one at fertilization, the offspring will have an abnormal chromosome number, known as **aneuploidy**. If the chromosome is present in triplicate in the fertilized egg (so the cell has a total of 2n+1 chromosomes), the aneuploid cell is said to be **trisomic** for that chromosome. If a chromosome is missing (so the cell has 2n-1 chromosomes), the aneuploid cell is **monosomic** for that chromosome. Mitosis will subsequently transmit the anomally to all embryonic cells.

If the organism survives, it usually has a set of symptoms caused by the abnormal dose of genes located on the extra or the missing chromosome.

Some disorders caused by the nondisjunction of chromosomes

- **Trisomy 21: Down syndrome**

One of the most common chromosome abnormalities is Down syndrome, due to nondisjunction of chromosome 21 resulting in an extra complete chromosome 21, or part of chromosome 21. Down syndrome is the only autosomal trisomy where an affected individual may survive to adulthood. Individuals with **Down syndrome often have some degree of mental retardation, some impairment of physical growth, and a specific facial appearance. With proper assistance, individuals with Down syndrome can become successful, contributing members of society. The incidence of Down syndrome increases with maternal age.**

- **Abnormal numbers of sex chromosomes**

Sex-chromosome abnormalities may be caused by nondisjunction of one or more sex chromosomes. Many conditions are known in which there are an abnormal number of sex chromosomes.

An X chromosome may be missing (XO), or there may be an extra one (XXX or XXY). There may also be an extra Y chromosome (XYY). Any combination of X and Y chromosomes, as long as there is a Y chromosome, will produce a male (up to XXXXY). **These individuals can lead relatively normal lives, but they cannot have children. They may also have some degree of mental retardation. These syndromes include Klinefelter's syndrome, Turner syndrome and trisomy X.**

- **Klinefelter's syndrome** is caused by the presence of one or more extra copies of the X chromosome in a male's cells. Extra genetic material from the X chromosome interferes with male sexual development, preventing the testicles from functioning normally and reducing the levels of testosterone.
- **Triple X syndrome (trisomy X)** results from an extra copy of the X chromosome in each of a female's cells. Females with trisomy X have a lower IQ than their siblings.
- **Turner syndrome** results when each of a female's cells has one normal X chromosome and the other sex chromosome is missing or altered. The missing genetic material affects development and causes the characteristic features of the condition, including short stature and infertility.

Some organisms have more than two complete chromosome sets. The general term for this chromosomal alteration is polyploidy, with the specific terms triploidy (3n) and tetraploidy (4n) indicating three or four chromosomal sets respectively.

b. Alterations of chromosome structure

Breakage of a chromosome can lead to four types of changes:

- **A deletion** removes a chromosomal segment.
- **A duplicatio**n repeats a segment.
- **An inversion** reverses a segment within a chromosome
- **A translocation** moves a segment from one chromosome to another nonhomologous one. The most common type of translocation is reciprocal, in which nonhomologous chromosomes exchange fragments. Nonreciprocal translocations, in which a chromosome transfers a fragment without receiving a fragment in return, also occur.

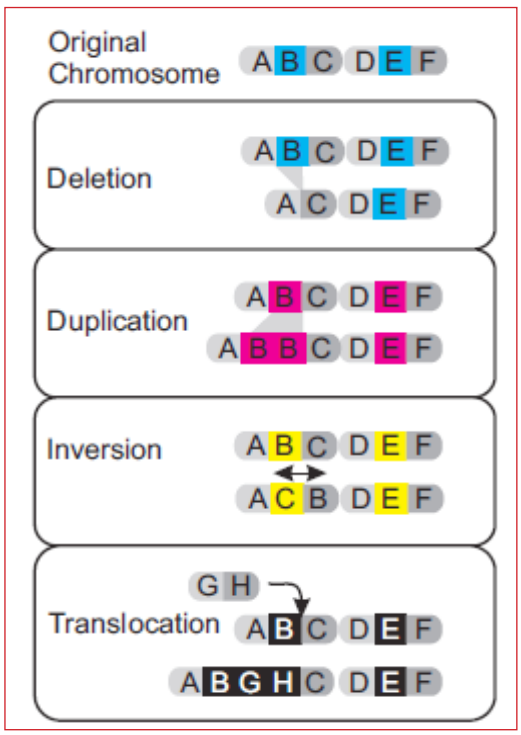


Fig 13.16: Chromosomal mutations

Somatic mutations occur in the body of an organism. Such mutations are passed on only to cells that come from the original mutant cell. They are never passed on to offspring. **Germ mutations** occur in the reproductive cells of an organism. Such mutations can be passed on to offspring.

While mutations can occur spontaneously, some can be caused by exposure to physical or chemical agents in the environment called **mutagens**. Common environmental mutagens include ultraviolet rays from the sun and various chemicals, such as asbestos, cigarette smoke, and nitrous acid. High-energy radiation, such as medical X rays, can cause DNA strands to break, leading to the deletion of potentially important genetic information.

Application activity 13.7

1. Suggest why:

a. A mutation in which one nucleotide of a triplet code is altered often makes no difference to the protein molecule coded by the DNA.

b. The addition or deletion of three nucleotides in the DNA sequence of a gene often has less effect on the encoded protein than the addition or deletion of a single nucleotide.

13.8 Causes, effects and significance of mutations

Activity 13.8

Nowadays there are different cases of antibiotic resistance, insecticide resistance and herbicide resistance. Antibiotics are not killing the bacteria that they used to kill. Insecticides are not killing the insects that they used to kill. Can you identify a reason for this case of resistance? Is this resistance good or bad?

13.8.1 Causes of mutations

Have you ever wondered for the causes of variation? Sometimes we say its spontaneous or sometimes we say don't stand in sunlight for so long, or Nuclear weapons or World War II has prolonged mutagenic effect on the victims or don't take particular medicine, it might be mutagenic. So what could be the causes of mutation? Discuss with your friends.

i. Random mutations can occur spontaneously due to chance as:

a. DNA replication errors

- Normally each base exists in its more stable keto form and is responsible for the normal Watson-Crick base pairing of T with A and C with G. However, under certain physiological conditions, rare imino and enol forms (tautomers) of the bases are present, leading to altered base pairing affinities.

- If by chance, there is looping out of DNA from the template strand, it may be missed by DNA polymerase, resulting in deletion mutation. Similarly, if additional untemplated base is synthesised by DNA polymerase, addition mutation results.

b. Spontaneous chemical changes include depurination and deamination

- When bond breaks between the base and the deoxyribose sugar, purine is removed from the DNA, resulting in an apurinic site. Thousands of purines are lost in each mammalian cell cycle. If these apurinic sites are not repaired, DNA polymerase will not be able to add a complementary base and will dissociate from the DNA. Induced mutation happens due to mutagens (agents that induce mutations). It can be physical mutagens or chemical mutagens.

13.8.2 Effects of mutations on phenotypes

Spontaneous or induced mutagens cause changes in genotype which influences the phenotype. The phenotype can be physiological, morphological, biochemical, anatomical etc. So let's think of effect of mutation on phenotype.

A gene represents the smallest unit that can code for protein. Gene is made up of DNA consisting of four nucleotides present in a particular sequence, which, when read in triplet codons, code for a particular amino acid sequence of a protein. Proteins play a number of important roles in the body, such as enzymes, hormones, structural etc. Whenever nucleotide sequence in DNA changes, it can lead to alteration in amino acid sequence affecting the function of the protein. For example: Albinism is caused by an autosomal recessive mutation. Tyrosine is converted to DOPA by the enzyme tyrosinase and DOPA is converted to melanin, the pigment which gives color to the skin. Melanin absorbs light in the ultraviolet (UV) range and protects the skin against UV radiation from the sun. If a mutation occurs in the gene responsible for production of tyrosinase, tyrosine cannot be converted to DOPA and melanin cannot be produced. Therefore, people with such a mutation have white skin, white hair and red eyes and are very sensitive to light.

13.8.3 Significance of mutations

Mutations can be harmful, beneficial, or have no effect. If a mutation does not change the amino acid sequence in a protein, the mutation will have no effect. In fact, the overwhelming majority of mutations have no significant effect, since DNA repair mechanisms are able to mend most of the changes before they become permanent. Furthermore, many organisms have mechanisms for eliminating otherwise permanently mutated somatic cells.

- **Harmful mutations**

Mutations can cause result in errors in protein sequence, creating partially or completely non-functional proteins. These can obviously result in harm to the cell and organism. As discussed in the previous lesson, to function correctly and maintain homeostasis, each cell depends on thousands of proteins to all work together to perform the functions of the cell. When a mutation alters a protein that plays a critical role in the cell, the tissue, organ, or organ system may not function properly, resulting in a medical condition. A condition caused by mutations in one or more genes is called a genetic disorder, which will be discussed in the next chapter.

However, only a small percentage of mutations cause genetic disorders; most have no impact on health. If a mutation does not change the protein sequence or structure, resulting in the same function, it will have no effect on the cell. Often, these mutations are repaired by the DNA repair system of the cell. Each cell has a number of pathways through which enzymes recognize and repair mistakes in DNA. **Because DNA can be damaged or mutated in many ways, the process of DNA repair is an important way in which the cell protects itself to maintain proper function.**

A mutation present in a germ cell can be passed to the next generation. If the zygote contains the mutation, every cell in the resulting organism will have that mutation. If the mutation results in a disease phenotype, the mutation causes what is called a **hereditary disease**. On the other hand, a mutation that is present in a somatic cell of an organism will be present in all descendants of that cell. If the mutation is present in a gene that is not used in that cell type, the mutation may have no effect. On the other hand, the mutation may lead to a serious medical condition such as **cancer.**

- **Beneficial mutations**

A very small percentage of all mutations actually have a positive effect. These mutations lead to new versions of proteins that help an organism and its future generations better adapt to changes in their environment. The genetic diversity that results from mutations is essential for evolution to occur. Without genetic diversity, each individual of a species would be the same, and no one particular individual would have an advantage over another. Adaptation and evolution would not be possible. **Beneficial mutations lead to the survival of the individual best fit to the current environment, which results in evolution**.

Application activity 13.8

1. In most people, the first amino acids in their β-globin polypeptide chains are:

1	2	3	4	5	6	
Val	His	Leu	Thr	Pro	Glu	rest of chain

Use the genetic code in mRNA (cfr unit of protein synthesis) to answer the questions that follow:

The DNA triplet for the sixth amino acid (Glu) in most people is CTT. In some people this DNA triplet is CAT.

a. What type of mutation is the change from CTT to CAT?
b. Use the genetic code above to identify the amino acid in the β-globin polypeptide chains of people with this mutation.
c. State the consequences for a person of having two copies of the mutated gene.

End unit assessment 13

I. Choose whether the given statements are True (T) or False (F)

1. Mutations can broadly be categorized as somatic and germ-line, depending on whether mutation occurs in a somatic cell or gamete.
2. When breaks occur in chromosomes, their structures do not change.
3. Induced mutation happens due to mutagens (agents that induce mutations).
4. Removal of amino group from a base is called deamination.
5. Albinism is caused by an autosomal recessive mutation.
6. Haemophilia A and Haemophilia B are a result of mutations in different genes.
7. There is no interaction between genotype and environment that determines the phenotype shown by any individual.
8. Sickle cell anaemia is due to a dominant sex-linked allele.
9. Mutagens are DNA sequences which get changed due to radiations and chemicals.
10. Mutation has important role in bacterial resistance to antibiotics.

II. Multiple choice questions

1. A point mutation that changes a codon specifying an amino acid into a stop codon is called

a. missense mutation b. nonsense mutation

c. Frame shift mutation d. silent mutation

2. Sickle cell anaemia results because of

a. deletion mutation b. insertion mutation

b. Substitution mutation d. chromosomal mutation

3. Which of the following is not ionising radiation

a. X rays c. UV rays

b. cosmic rays d. alpha rays

4. Which of the following chemicals can affect non-replicating DNA?

a. nitrous acid b. Acridine dyes

c. Bromouracil d. None of the above

5. Phenotype of individual depends upon

III. Long answer type questions

1. Mutations can broadly be categorized as somatic and germ-line, depending on whether mutation occurs in a somatic cell or gamete.
2. When breaks occur in chromosomes, their structures do not change.
3. Induced mutation happens due to mutagens (agents that induce
4. Describe the types of mutation and causes of mutations.
5. Explain the significance of mutations.
6. Explain that gene mutation occurs by substitution, deletion, inversion and insertion of base pairs in DNA. Outline how such mutations may affect the phenotype.
7. Answer the following question on genetics

a. Define the words below

i. Allele

ii. Locus

iii. Autosome

iv. Homologous chromosome

b. State and explain the laws of Mendel.

c. Some coat colours in cats are sex linked. Black coat colour is codominant to ginger. A cat that has one allele for black and one for ginger is tortoiseshell. The gene for this coat colour is carried on the X chromosome. Describe the genotype and phenotype of the offspring of a cross between a pure breeding black female cat and a ginger male cat.

8. In an experiment, a homozygous tomato plant with a purple hairy stem was crossed with a homozygous tomato with a green, hairless stem. Both purple and hairy are dominant. The F1 plants were allowed to self pollinate to produce an F2. The F2 seeds were planted and the resulting phenotypes are shown below:

Purple, hairy stem	150
Purple, hairless stem	48
Green, hairy stem	15
Green, hairless stem	15

a. What is the ratio of phenotypes in the F2?

b. What was the expected ratio of phenotypes? Why?

c. Why do you think there is a difference between the observed and expected results?

d. What could be the results if the two genes were linked?

REFERENCES

1. Barbara, A., Jean, B, Niamh, G., Douglas W. (2009). Biology, CK-12 Foundation, California, USA.
2. Benjamin Cummings. 8th Ed. San Francisco, US. Pp. 142-148.
3. Campbell, N.A., Reece, J.B., Urry, A.L., Cain, L.M, Wasserman, A.S., Minorksy, V.P and Jackson, B.R. (2008). Biology. 8th edition. Pearson international, San Francisco, USA.
4. Fullick, A. (2006). GCSE Biology. AQA Science Exclusively endorsed and approved by AQA. Nelson Thornes Ltd. Cheltenham
5. Fullick, A., Mwinshekhe, H., Maddu, M., and Nyabua, S. (2011). A level Biology. Malaysia Ashton Editorial and Juice Creative, Ashton, Malasia.
6. Kent, M. (2000). Advanced biology. Anew mainstream text for the new specifications. Oxford university press, New York, USA.
7. ROSS and WILSON, (2006), Anatomy and physiology, 10th edition, SPAIN
8. M.B.V. Roberts M.A. Ph.D., (1986), Biology, a functional approach, 4th edition, Cambridge University, ENGLAND.
9. TAYLOR D. J., (1999), Biological Sciences, 3rd edition, Cambridge University Press, UK.
10. PURVES and ORIANS, 1987, Life: the science of Biology, 2nd edition, Sinauer Associates inc. Publishers. Massachusetts, USA.
11. Jones, M., Fosbery, R., Gregory, J., and Taylor, D. (2014). Cambridge International AS and A Level Biology coursebook fourth Edution. United Kingdom: Cambridge University Press.
12. Kent, M. (2000). Advanced Biology: A new Mainsream text for the new specifications. Oxford University Press. New York, USA.
13. Keaneth S. and SALADIN, 2004, Anatomy and physiology, 3rd edition, Mc Graw Hill, New York, USA.
14. Mackean.D.G, and Hayward, D. (2014). cambridge IGSCE biology 3rd edition. London:
15. Hadder education
16. Mader, S. S., Baldwin, A., Roush, R., & Stephanie Songer, M. T. (2010). Biology 10th Edition. McGraw-Hill companies, Boston, UK.
17. Miller L. (2006). Biology: Florida students' and teachers'edution. Prentice Hall Biology, Boston. UK.
18. Morgan, S. (2000). Practice in Biology: Progressive questions for AS and A level. Cambridge
19. Neil A. Campbell, Reece J.B., Urry L.A., Cain M.L., Wasserman S.A., Minorsky

P.V., and Jackson R.B. (2008). Biology. Pearson Benjamin Cummings. 8th Ed. San Francisco, US.

20. Mader, S. (2004). Biology. 8th Edition. Mc Graw Hill. New York, USA.
21. Pete, K., Frank, S. (2008). OCR Biology, Heinemann, London, UK.
22. Taylor, D. (2008). Biological science. Cambridge: Cambridge university press.
23. Clegg C.J. et al . (2006). Advanced Biology Principles and Applications. Hodder Headline Group.London
24. Oyugi C.et al .(2007) ,Secondary Biology A Pracical Approach, Kenya literature bureau, Nairobi
25. https://www.sciencedirect.com/topics/veterinary-science-and-veterinary-medicine/saltatory-conduction
26. https://www.news-medical.net/life-sciences/What-are-Telomeres.aspx
27. https://www.compoundchem.com/2015/03/24/dna/
28. https://biologydictionary.net/positive-and-negative-feedback-homeostasis/
29. http://craves.everybodyshops.com/is-it-safe-to-tear-off-the-mold-and-eat-the-rest-of-the-bread/
30. https://www.healio.com/endocrinology/news/print/endocrine-today/%7B15afd2a1-2084-4ca6-a4e6-7185f5c4cfb0%7D/penicillin-an-accidental-discovery-changed-the-course-of-medicine
31. https://www.britannica.com/topic/food-preservation
32. https://www.britannica.com/topic/water-purification