BIOLOGY

for Rwandan Schools

Student's Book

Senior 5

TABLE CONTENTS

PREFACE

This book, viz., '**Comprehensive** Biology for Rwanda Schools Student's Book for Senior 5' has been developed in accordance with the recommendations of Rwanda Education Board (REB). It has been prepared to cater to the learners' requirement of a book on this subject. Books not only distribute knowledge on the subjects but also prepare the learners to be well-integrated in the society and exploit employment opportunities. This book also serves the same purpose.

The topics covered in this book help the learners to have a better understanding of the impact and influence biology has on a modern scientific world. These include interdependence between organisms within their environment; transport across the cell membrane; chromosomes and nucleic acids; DNA replication; cell and nuclear division; protein synthesis; autotrophic nutrition; transport system in plants; gas exchange in animals; smoking and related diseases; general principles of homeostasis; regulation of glucose; regulation of temperature; behaviour and responses in mammals; immune system, vaccination and antibiotics; human reproductive system and gametogenesis; genetics; and mutations.

The book is rich with illustrations which will help the learners to obtain practical learning. It enhances curiosity and interest in the subject and helps to understand the impact of biology on the society. The language is carefully and skilfully constructed to make reading interesting and comprehension easy for the learners.

Any suggestions for the improvement of this book will be gratefully appreciated and acknowledged.

—Authors

Unit 1

Interdependence between Organisms within their Environment

Key Unit Competence

To be able to explain complex relationships between organisms within their environment.

LEARNING OBJECTIVES

At the end of this unit, learners should be able to:

- explain the various interactions of organisms in nature.
- appreciate the relationships existing among the organisms within their environment.
- state the significance of organisms' interactions in nature.
- explain the terms interspecific and intraspecific competition.
- compare interspecific and intraspecific competition.
- describe the adaptations of predators to catch and kill prey and adaptations of prey to avoid predators.
- interpret graphs for predator-prey relationships.
- classify examples of species interactions, e.g., competition, predation, parasitism, commensalism, and mutualism.
- recognise the role of saprophytes in mineral recycling.

1.1 INTERRELATIONSHIP AMONG THE ORGANISMS AND THEIR EFFECTS

ACTIVITY 1

Study the various Biological interactions among organisms. State why biological interactions are important and how they help the ecosystem. Classify them according to their effects on the environment and other organisms. You can use the table of interactions given in the following text. Illustrate your study as charts or make notes in your exercise book.

No organism exists in an absolute isolation. Every organism interacts with other organisms within a community. Thus, different organisms interacting with one another within a community forms a concept called **biological interactions** or **interrelationship among organisms**. These interactions among the organisms can be beneficial or harmful or even neutral. They have the potential to influence and mould the structure, growth, and maintenance of populations within a community. Moreover, in some cases, these interactions may result into long-term ecological and evolutionary changes among the individuals participating in these interactions.

These interactions may involve individuals of the same species or different species. When the interactions involve individuals of the same species, it is called **intraspecific interaction**. On the other hand, when the interactions involve individuals of different species, it is called **interspecific interaction**.

Biological interactions can be generally classified into different categories based on whether the effects of interactions are beneficial, harmful or neutral for each of any two species. Thus based on these criteria, biological or population interactions may be divided into **basic interactions and relationships**. All the interactions are indicated by signs such as +, + or –,–, or +,–, even 0, 0. The **sign (+)** indicates that a particular species is benefitting from the interactions. The **sign (–)** indicates that a particular species in the interactions is being harmed, While **sign (0)** indicates neutral position where it is neither benefited nor harmed in the interactions. The important species interactions are:

Table 1: Interrelationship among the organisms

Types of Interaction	Effect on Species 1	Effect Species 2	General Nature of Interaction
Competition, ***direct interference type***	–	–	Direct inhibition of each species by the other
Competiton, ***resource use type***	–	–	Indirect inhibition when common resource is in short supply
Commensalism	+	0	Population 1, the commensal, benefits, while 2, the host, is not affected.
Parasitism	+	–	Population 1, the parasite, generally smaller than 2, the prey, and also harms the prey
Predation (including **herbivory**)	+	–	Population 1, the predator, generally larger than 2, the prey, and kills the prey
Mutualism	+	+	Interaction favourable to both and obligatory

1.2 INTER AND INTRASPECIFIC RELATIONSHIPS AMONG THE ORGANISMS AND THEIR SIGNIFICANCES

ACTIVITY 2

You are now familiar with the words intra and interspecific. Can you cite some examples of interactions from your surroundings distinguishing these terms? Discuss and note down how many examples you can point out. Also discuss the severity of types of competition.

1.2.1 Competition (–,–)

Competition refers to the interaction of two organisms striving for the same resource. Generally, competition is of two types: intraspecific and interspecific competition. In both types of competitions, the two or more species competing for the same resource inhibit one another directly or indirectly. That is why they are denoted as (–,–) signs.

(a) Intraspecific Competition

Intraspecific competition is a competition where individuals of the ***same species*** compete for the same limited resources in an ecosystem. The resources could be food, water, space, light, mates or any other resource which is required for survival.

Significance of Intraspecific Competition

Intraspecific competition acts as an *important regulator of population size*, meaning successful individuals will survive while unsuccessful individuals will die. It can also be called population density dependent regulator. Moreover, since intraspecific competition results individuals with different reproductive success, it can be a selective factor in evolution.

(b) Interspecific Competition

Interspecific competition is a type of competition in which individuals of different **species compete** for the same limited resources in an ecosystem. The resources could be food, space, light, water, etc. In this kind of interaction, populations of the two or more species are affected adversely.

Significance of Interspecific Competition

Structuring ecological communities

Gause's exclusion principle states that the species with identical ecological requirements cannot coexist over a long period of time. The less-fit species in the competition will be replaced by the better-fit species. Thus, in such situations, where interspecific competition is intense, the competition acts as one of the most important factors in structuring ecological communities and also as an agent of natural selection.

Character displacement

Competition can cause species to evolve differences in traits. The characteristics that enable an organism to reduce competition will function to improve fitness; therefore, influencing the evolution of characteristics related to the acquisition of resources.

Example: Two Darwin finches of the Galapagos Islands. The **medium ground** finches Geospizafortis and the **small ground** finches G. fuliginosa. When both the species live on separate isolated islands, they possess similar but overlapping beak size. However, when they live on the same island, the beak size of the medium ground finch is much larger than that of the medium ground finches that live on isolated island. Similarly, the beak size of ground finch is smaller than that of the ground finches that live on isolated island.

Under the pressure of competition for food on the same island, selection favours medium ground finches to have a large beak size to eat larger seeds; and selection favours small ground finches to have small beak size to eat smaller seeds. Therefore, when the shift involves changes in features of the species' morphology, behaviour, or physiology, it is referred to as **character displacement**.

Studies of character displacement are important because they provide evidence that competition plays a very important role in determining ecological and evolutionary patterns in nature. This is also known as the evolution of specialization.

Difference between Intraspecific and Interspecific Competition

	Intraspecific Competition		Interspecific Competition
1.	It is a competition among the individuals of the same species.	1.	The competition is among the members of different species.
2.	The competition is for all the requirements.	2.	The competition is for one or a few requirements.

3.	The competing individuals have similar type of adaptation.	3.	The competing individuals have different types of adaptations.
4.	It is more severe due to similar needs and adaptations.	4.	It is less severe as the similar needs are a few and the adaptations are different.
5.	Example includes finding mating partners.	5.	Examples include competition for food.

1.2.2 Parasitism (+,–)

Parasitism describes a relationship between two organisms where one benefits and the other is harmed. A **parasite** is an organism that benefits from the relationship, while a **host** is the one which is harmed in the relationship. Parasites can be a number of things, including plants, animals, and even viruses and bacteria.

Types of Parasitism

Parasites are classified by how they interact with their host. Overall, parasites are much smaller than their hosts and reproduce at a faster rate.

Figure 1.1: Ectoparasitism (A flea on a dog's skin)

(a) Ectoparasites

The term "*ecto*" in Greek means outside. Therefore, parasites that live on their host are termed **ectoparasites**. Examples of ectoparasites are fleas, ticks, and mites (Figure 1.1). These parasites live on larger animals, like cats, dogs and deer.

(b) Endoparasites

Similarly, the term "*endo*" in Greek means inside. Parasites that live inside their host are termed **endoparasites**. These include the things like parasitic worms, bacteria, and viruses. Tapeworms are endoparasites. They live in human intestines where they feed on the partially-digested food in their host's intestines. It is a fully protected environment and they grow and thrive in these conditions.

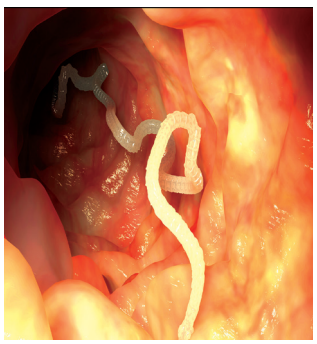


Figure 1.2: Endoparasitism

The tapeworms have no digestive system of their own, but absorb nutrients through their skin from partially digested food as they pass through the host (Figure 1.2).

Tapeworms are parasitic worms and are most often referred to as just parasites. They literally survive through their host's nutrients. Parasites need hosts to survive.

Significance of Parasitism

1. **Parasitism alters the behaviour and morphology of their hosts.** This alteration increases the chance of being preyed by the predators thereby assisting the parasites to move from one host to another to complete their life cycle.
2. **Parasitism promotes coexistence in biodiversity.** Usually in an ecosystem, a competitively dominant species out-competes a competitively inferior species and doesn't allow coexistence with this species. However, parasites reduce the competitive ability of the dominant species in a biodiversity and, thereby, allow a competitively inferior species to exist together with a dominant species.
3. **Parasitism affects the keystone species and modifies the structure of the ecosystem.** In an ecological community, the effect of parasitism is the strongest when the hosts are keystone or dominant species with crucial functions in an ecosystem.
4. **Parasitism leaves parasite with no responsibility. A social parasite** is a parasite that takes advantage of the interaction of other organisms. The best example of a social parasitism is **brood parasitism**. This is an interaction where the parasite, typically a bird, deposits its eggs in the nest of another species (Figure 1.3). The host (another species) then 'babysits' the egg in place of the parasite (bird), allowing the parasite to deposit eggs in other nests instead of spending time hatching their own young.

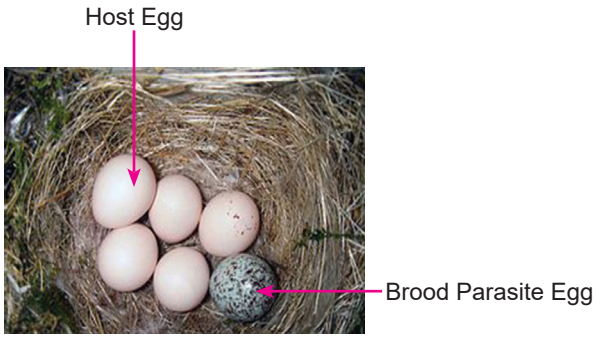


Figure 1.3: A bird nest with brood parasite eggs

This therefore leaves the parasite with no responsibility of rearing their young. And it gives them more time to focus on other things such as producing more offspring. Most species of **cuckoo bird** are brood parasites, and there is even one species of fish **(spotted catfish)** which parasitizes the 'nest' of another fish species!

SELF EVALUATION

(i) ..... is the competition where individuals of the same species compete.

(ii) ..... states that two species requiring same ecological requirements cannot occupy the same ecological niche.

(iii) ..... is a parasite that takes advantage of the interaction of other organism.

(iv) Parasites that live ..... are called ectoparasites.

1.2.3 Predation (+,–)

ACTIVITY 3

Look out for predator and prey relationships in wildlife channels. You can also watch movies exhibiting these relations on the following link: *https://www.youtube.com/watch?v=8MvKCHl5zzo*. Observe and discuss the following questions while you watch:

- Why is predation important?
- Giving examples of food chain, name predators and prey.
- Why does different predators have different preys?

Predation is an interaction between the two species, i.e., predator and prey, in which one species (predator) uses another species as food (prey). In other words, one organism kills and consumes another. Predation influences the distribution, abundance and diversity of species in ecological communities.

Types of Predation

Generally, predation can be divided into:

(a) Carnivory

Carnivory takes place when a predator consumes meat, rather than plants, and consequently kills its prey. Organisms that prefer meat to plants are accordingly called **carnivores**. The example of the lion hunting the buffaloes is called **carnivory** (Figure 1.4). In this type of predation, a predator kills its prey more or less immediately. Other examples are a shark eating a tuna or a Venus fly trap consuming a fly.

Figure 1.4: Lion attacking buffaloes

(b) Herbivory

Herbivory is the act of animals eating plants. Or when an animal uses a plant as food, it is called herbivory. Example, when a deer eats grass, the plant is the prey and the animal the predator (Figure 1.5). Additionally, organisms do not have necessarily to be larger than their prey to be successful predators. Venomous snakes are able to take advantage of a variety of large prey items because an injection of venom can be quite fatal.

Figure 1.5: Herbivory: Deer eating grass

Predation can also occur as **parasitism**, in which the prey is a host that supports a parasite, such as a virus. In this case, the prey may be harmed but not killed outright like the antelope. Unlike carnivory, a parasite feeds for an extended period on a living host. For example—a tapeworm living in the body of a deer or a mistletoe "feeding" on a mesquite tree.

Not all predators are animals. Carnivorous plants, such as the **Venus fly trap** and the **pitcher plant**, consume insects. Pitcher plants catch their prey in a pool of water containing digestive enzymes, whereas the Venus fly trap captures an insect between the two lobes of a leaf and seals the insect inside with digestive enzymes. These plants absorb nutrients from the insects as they become available during digestion.

Predation and Adaptation

Adaptation in Predator Species

Based on their experience, predators also undergo certain adaptations to be an efficient hunter or killer. These adapted traits are passed down from generation to generation. **Predators** exhibit traits such as sharp teeth (Figure 1.6), claws, and venom that enhance their ability to catch food. They also possess extremely acute sensory organs that help them to find potential prey. Depending upon the requirement that arises, predators also adapt themselves to become much more efficient. Examples of some adapted animals are:

(a) The ability of raptors to spot potential prey from over a kilometre away.
(b) The acute sense of smell of moles.
(c) The ability of owls to locate mice by sound.
(d) The ability of pit vipers to sense body heat while tracking prey.
(e) The ability of bats and dolphins to echolocate.

Predators catch their prey either by pursuing potential prey or by ambushing them. Organisms that give chase are capable of short bursts of speed like Cheetah (Figure 1.7). Those that lie in wait tend to be camouflaged to avoid detection.

Figure 1.6: Adapted sharp teeth (canine) of lion

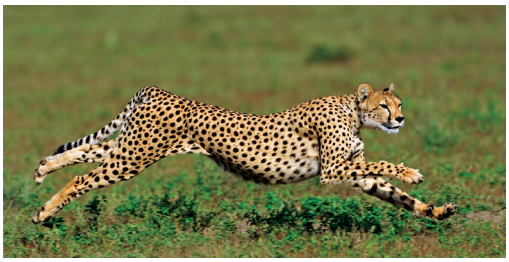


Figure 1.7: Cheetah adapted to run fast to capture prey

Adaptation in Prey Species

In the same way, as much as predator adapts itself to capture prey, preys also adapt as much as possible to escape from the predators. Many, such as leaf insects, moths, a variety of frogs and small lizards, and herbivorous mammals, are cryptically coloured to make them more difficult to see.

Figure 1.8: Red-spotted newt

Figure 1.9: Monarch butterfly

Behaviourally, they freeze after detecting the presence of a predator. This lack of movement helps them better blend in with their background and inhibits the ability of the predator to find them. But when the predators venture too close, prey will take flight, running or flying to escape. When a chase ensues, prey will typically survive if they stay out of reach until the predator gets tired.

Some species take extra time by distracting the predator. Examples include moths that flash brightly coloured hind-wings, lizards that drop their tails, and insect larvae that discharge slime. Such actions surprise the predator and give the prey a few extra moments to escape.

Mimicry

Some prey exhibit bright colouration signalling as poisonous individuals. Such aposematic colouration helps prevent predation by signalling to potential predators that the vividly-coloured individual is toxic. Toxins may be manufactured within the body, as with the **red-spotted newt** (Figure 1.8), or they may be acquired passively via consumption of toxic plants, as with the **monarch butterfly** (Figure 1.9).

Not all the species that exhibit vivid colouration are truly toxic. Some have evolved patterns and colours that mimic those of toxic species. Examples of such **Batesian mimicry** include the extraordinarily polymorphic *Papiliodardanus* swallow tail butterfly in southern Africa and Madagascar. Females of this species occur in a wide variety of physical appearances, nearly all of which mimic distasteful species of the *Danaeus* and *Amauris* genera with which they co-occur (Figure 1.10).

Figure 1.10: Batesian mimicry—Non-toxic Papiliodardanus swallow tail butterfly females occur in a variety of forms, each of which mimics the physical appearance of toxic species. Palatable butterflies (middle column) mimic the warning colouration of poisonous butterfly species on the left and right butterflies

Adaptation in Herbivory

Herbivory is the consumption of plant material by animals, and herbivores are animals adapted to eat plants. As in predator-prey interactions, this interaction drives adaptations in both the herbivore and the plant species it eats.

Adaptation in Plants

Though plants cannot move like animals, they also develop certain mechanism to escape from herbivores. For example, plants have evolved defences, including thorns (Figure 1.11) and chemicals, to keep themselves away from being eaten by herbivores. Scientists have identified thousands of plant chemical defense compounds, including familiar compounds such as nicotine and cocaine.

Figure 1.11: Cactus

Adaptation in Herbivores

To counteract the adaption of plants and maximize the nutrient intake, **herbivores** also have adapted themselves that allow them to determine which plants contain fewer defensive compounds and more high-quality nutrients.

Some insects, such as butterflies, have chemical sensors on their feet that allow them to taste the plant before they consume any part of it. Mammalian herbivores often use their keen sense of smell to detect bitter compounds, and they preferentially eat younger leaves that contain fewer chemicals.

Predator-Prey Relationships (Cycle)

Predator-prey relationships are characterized by oscillation of both predator and prey populations over a period of time. By **oscillation**, we mean there is a regular pattern of increase and decrease

of populations of both predator and prey (Figure 1.12). Generally, the predator is a carnivore, while the prey is a herbivore. However, this general truth may vary depending upon the kind of predator-prey interactions. For example, parasites become predator when they feed on their host (prey); herbivores become predator when they feed on plants (prey).

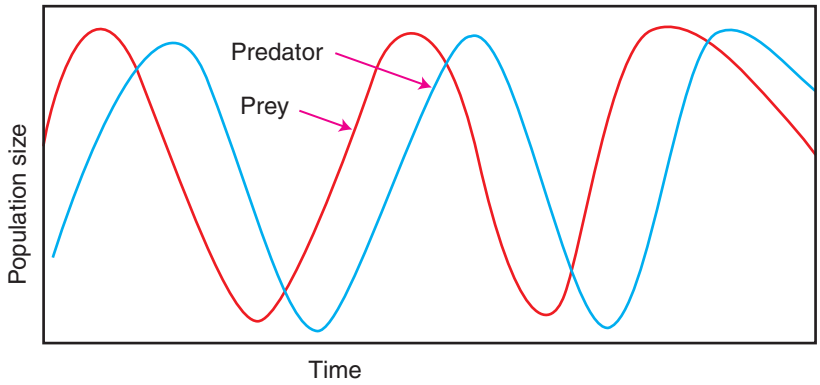


Figure 1.12: Predator-prey relationship (Oscillations)

The main reason of oscillation is that as the predator population increases, it progressively consumes larger number of prey until the prey population starts to decline. Then the declining prey population no longer supports the large increasing predator population. As the prey population declines, the predator now faces a food shortage, and many of them starve or fail to reproduce. As a result, the predator population declines sharply to a point where the reproduction of prey more than balances its losses through predation. Eventually, the population of prey increases, which is followed by an increase in the population of predators. In this manner, there is a regular pattern of increase and decrease in the population of both prey and predator over a time period (Figure 1.12).

Significance of Predation

Predation Prevents a Single Species from Becoming Dominant

A keystone predator is a species that reduces the density of the strongest competitors in a community. These keystone predators may feed on the dominating prey species and prevent it from becoming dominant. Thus, they are tied up to the balance of organisms in a particular ecosystem. Addition or removal of these keystone predators can have drastic cascading effects on the equilibrium of many other populations in the ecosystem. For example, in grassland, herbivores (grazers) may prevent as single dominant species from taking over.

Predation can Either Increase or Decrease Species Richness

In an ecological community where predator and prey exist together, predator has the ability to either increase or decrease the number of prey species. The predator to change the number of prey depends on the favourability of the environment and also on whether prey is a competitively dominant species or competitively inferior species in a community. When keystone predator feeds on dominant prey, it generally promotes species richness by releasing the inferior prey species to coexist with the dominant species.

Experiment: In an experiment, Paine and others introduced keystone predator *Pisaster*, a sea star, in a community (Figure 1.13). This sea star feeds on mussel. In due course of time, they found out that this predator helped in maintaining species diversity by preventing competitive exclusion of weaker competitors. Moreover, predation by Pisaster was a key factor in maintaining populations of at least seven other species. In fact, it was Paine and others who have generated the concept of keystone predators.

Figure 1.13: Pisaster feeding on mussel

Predation as Source of Natural Selection

Predation is an important factor of moulding evolution of traits for both predators and prey species. Natural selection favours the fittest individuals in a community. Thus, the process of natural selection favours predators that are more efficient in capturing prey than the less efficient predators. In the same way, the process of natural selection favours prey species that are more efficient in escaping or deterring predators than the less efficient prey species.

On the one hand, predators impose strong selective force on their prey to evolve into the most efficient prey against the predators. On the other hand, prey species also counter-impose strong

selective pressures on their predators to evolve into the most efficient predator against the prey. Since these selection forces are working side-by-side on both predator and prey, these two parties evolve together. Thus, coevolution is evident. The process of evolution taking place side-by-side on two closely associated species is called **coevolution**.

For example: Natural selection process selects faster foxes that can hunt rabbits efficiently. Simultaneously, natural selection process also selects faster rabbits that can run fast to escape efficiently from the foxes. The process of selecting the most efficient predator and prey can go on and on.

ACTIVITY 4

Aim: Discuss and interpret the graphical illustrations for relationships between predators and prey.

Materials Required:

1. Graph papers and pencils
2. Computers (Microsoft Excel/Word)
3. Predator-prey data (Snowshoe hare and lynx)

Predator-Prey Data:

		Snowshoe Hare	Canada Lynx
S. No.	Year	Pelts (thousands)	Pelts (thousands)
1	1845	20	32
2	1847	20	50
3	1849	52	12
4	1851	83	10
5	1853	64	13
6	1855	68	36
7	1857	83	15
8	1859	12	12
9	1861	36	6
10	1863	150	6
11	1865	110	65
12	1867	60	70
13	1869	7	40
14	1871	10	9
15	1873	70	20

		Snowshoe Hare	Canada Lynx
S.No.	Year	Pelts (thousands)	Pelts (thousands)
16	1875	100	34
17	1877	92	45
18	1879	70	40
19	1881	10	15
20	1883	11	15
21	1885	137	60
22	1887	137	80
23	1889	18	26
24	1891	22	18
25	1893	52	37
26	1895	83	50
27	1897	18	35
28	1899	10	12
29	1901	9	12
30	1903	65	25

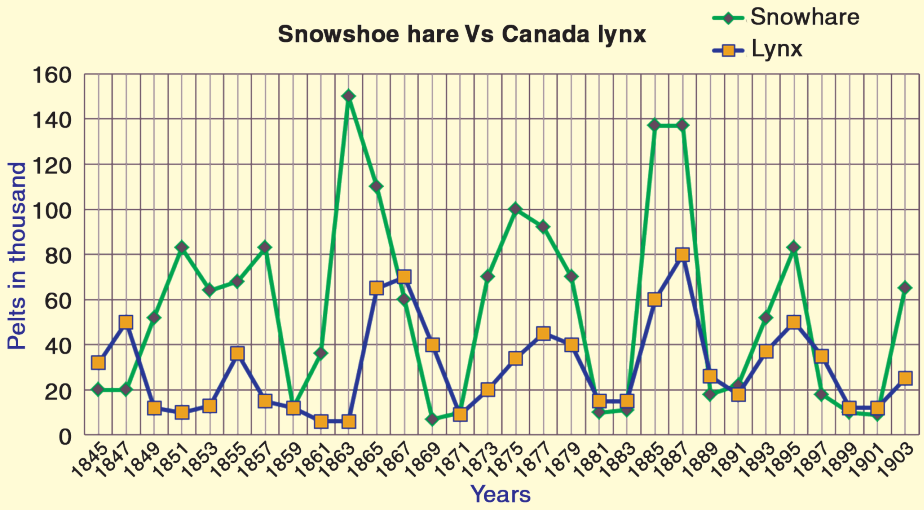


Figure A1: Predator-prey relationship graph (prey = Snowshoe hare; predator = lynx)

Procedure:

1. Plot the above predator-prey data on your graph paper.
2. Or you can use Microsoft excel programme on computer to automatically plot the data.
3. The graph will look something like the graph given in figure A1 above.
4. Once you have plotted, discuss and interpret your graph whether it follows the predator-prey pattern (oscillation).

Observation:

Discuss the following questions for better understanding:

- In the year 1863, the snowhare population was high. What can you say about lynx population?
- In 1845, the predator lynx population was more than the prey but gradually it reversed. What inference can you draw from the change?

SELF EVALUATION

Complete the sentence with the correct assertion

(i)Thorn is an adaptation of plant against ..... .

(ii) Process of evolution taking place side-by-side on two closely associated species is called a ..... .

(iii) ..... prevents a single species from becoming dominant.

(iv) Some ..... exhibit bright colouration signalling as poisonous individuals.

1.2.4 Mutualism (+, +)

It is an interaction of two or more species where the interacting species mutually benefit from each other. And these interacting species mutually **benefit from each other so much that they become completely dependent on one another**. They cannot survive and thrive without each other. That is the reason why this interaction is termed as **mutualism or obligate symbiosis**. Mutualism seems to replace parasitism as **ecosystems evolve towards maturity**, and it seems to be especially important when some aspect of the environment is limiting (such as water or infertile soil).

Figure 1.14: Bee and flower

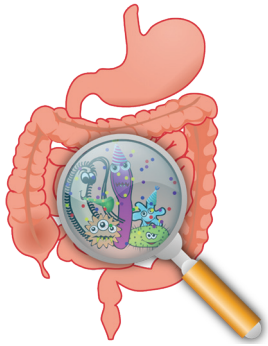


Figure 1.15: Human intestine harbouring *E.coli*

Examples:

Bees and flowers: Bees depend on flowers for food in the form of nectar and pollen. And the flowering plants depend on bees or other pollinators to carry their male reproductive cells specifically to the female parts of other flowers of the same species. In this way, bees depend on flower for food, while flower depends on bees for pollination (Figure 1.14).

Humans and *E.coli*: Inside our own bodies, there are hundreds of different types of bacteria that live just in our large intestine. Most of these are uncharacterized, but we do know a lot about *E.coli*, which is one of the normal bacteria found in all human large intestines (Figure 1.15). Humans provide *E.coli* with food and a place to live. In return, the *E.coli* produce **vitamin K** and make it harder for pathogenic bacteria to establish themselves in our **large intestine**. Whether or not most of the other species of bacteria found in our digestive tract aid in digestion, absorption, or vitamin production isn't completely known, but they all make it harder for invasive pathogens to establish a foothold inside us and cause disease.

Significance of Mutualism

Mutualism is a type of symbiosis, which means living together. The most important impact of mutualism is that the species which cannot survive individually, can survive by partnering

with other individual species. By living together and depending upon each other, they could overcome harsh and unfavourable conditions and thrive in the ecosystem. Mutualism thus helps in moulding or structuring community towards better species interactions.

As seen in the above example, *E.coli* alone might not be able to survive efficiently in the other environment like they do in the stomach of human beings. In the same way, we humans might not get the same benefits that we get from *E.coli* if instead, we harbour other pathogenic organisms. Thus, in a situation where an individual species cannot survive by itself, mutualism gives a better chance of survival and reproduction.

1.2.5 Commensalism (+, 0)

It is an interaction of two or more species in which one species is benefited while the other species is neutral or is not benefited. The species which is benefitted is designated with "+" sign, while the species which is neutral is designated as "0". In commensalism, the species which is unaffected is the **host**. The species that benefit from the association is called **commensal**. Commensal may obtain nutrients, shelter, support or locomotion from the host species. Normally, commensal relation is often between a larger host and a smaller commensal. Moreover, during the interaction, the host remains unchanged, whereas the commensal species may show great morphological adaptation.

Examples:

Oysters sometimes have a small, **delicate crab** (Figure 1.16) in the mantle cavity. These crabs are usually commensal, although sometimes they overdo their guest status by partaking of the host's tissues.

Another example is, the **cattle egret follows cattle** (Figure 1.17), **water buffalo**, and other large herbivores as they graze. The herbivores flush insects from the vegetation as they move, and the egrets catch and eat the insects when they leave the safety of the vegetation. In this relationship, the egrets benefit greatly, but there is no apparent effect on the herbivore.

Figure 1.16: Crab inside oyster

Figure 1.17: Cattle egrets and cattle

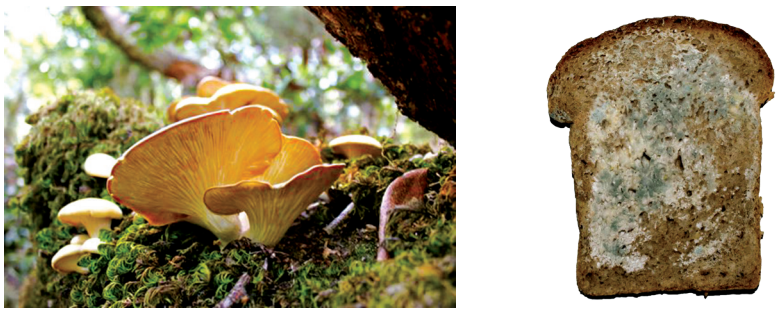
Significance and Criticism of the Concept

The associations between two populations of species that result in positive effects are exceedingly widespread and are important in determining the function and structure of populations and communities.

Some biologists argue that the commensal in commensalism must be likely mutualistic or parasitic in a small scale which is undetected. And it is unlikely that the host is also completely not harmed or neutral. Example: Epiphytes intercepting substantial amounts of nutrients from the host plant must be affecting the host in some other way which might be unnoticed.

1.2.6 Saprophytism

In Greek, sapro-("putrid matter") + phyte ("plant, growth"). The condition of certain living organisms feeding and living on dead organic matter is simply called saprophytism. It is generally exhibited by saprophytes. Saprophytes are living organisms which feed on dead organic matter such as dead plant or animal tissue. In this regard, they are detrivores. They break down organic matters in simpler forms that can be taken up and recycled by plants. Thus, they play a very important role in soil biology. Examples include most fungi (Figure 1.18 (a and b), bacteria, and some orchids.



(a) (b)

Figure 1.18: (a) Mushroom (molds) (b) Bread mold, *R. nigricans*

The term "saprophyte" is a misnomer. By definition, "Phyte" means a plant, and bacteria and fungi are not categorized as plants. Most of the saprophytes lack chlorophyll, and therefore, cannot perform photosynthesis. Thus, they depend on the food energy they absorb from the decaying organic matters. This means that they are heterotrophs and are considered consumers in the food chain.

They are characterized by their use of a particular kind of digestion mechanism, called extra-cellular digestion. In this process, they secrete digestive substances into the surrounding environment through which they break down organic matter into simpler substances. The nutrient-rich broken organic substances are then directly absorbed through the membrane of the organism's cells and are metabolized.

One of the most common saprophytic fungi belongs to Rhizopus family. These fungi have an extensive network of hyphae, similar to tiny roots, which grow through the organic matter. They grow in a network called a mycelium. Mycelium helps the fungus to penetrate into the organic matter where the hyphae secrete digestive enzymes and absorb the resulting nutrients.

The most common form of Rhizopus is bread mold, *R. nigricans* (Figure 1.19). These fungi can also be seen in fruits, especially stone fruit, and vegetables, faeces and the soil. The fungus grows very rapidly, maturing within four days, though some fungi might take longer period. The fungus needs a warm, moist environment to thrive. People can prevent or save from Rhizopus infection by keeping food under refrigeration or in the freezer so that the spores never get a chance to grow.

Significance of Saprophytism

Many micro saprotrophs and other decomposers, involving insects, snails and beetles help in recycling valuable nutrients from dead organic matter which is released back into the soil to be reabsorbed by plants. For example— in a rainforest ecosystem, to promote healthy rainforest, nutrients such as iron, calcium, potassium and phosphorous are essentially required. The decomposers derive these essential nutrients from decaying organic matters and then release into the soil where the plants reabsorb it again.

SELF EVALUATION

Complete the sentence with the correct assertion

(i)Mutualism ..... both organisms.

(ii) (+, 0) sign exhibits .....

(iii) ..... helps in nutrient recycling.

(iv) Cattle egret follows water buffalo and exhibits .....

1.3 SUMMARY

- The basic species interactions are competition (direct interference type), competition (resource use type), commensalism, parasitism, predation, mutualism and saprophytism.
- **Competition**
- Competition is an interaction of two organisms striving for the same resource. It is of two types: Interspecific competition is a competition of individuals of the same species competing for a limited resource, while intraspecific competition is a competition of different species competing for a limited resource.

- Competition helps in structuring ecological communities and also plays an important role in character displacement.
- **Parasitism**
- Parasitism is a relationship between two organisms where one benefits and the other is harmed. The two types of parasitism are: Ectoparasite and endoparasite. A social parasite is a parasite that takes advantage of the interaction of other organisms.
- Parasitism alters the behaviour and morphology of their hosts; it promotes coexistence in biodiversity; it affects the keystone species and modifies the structure of ecosystem.
- **Predation**
- Predation is an interaction between species in which one species (predator) uses another species as food (prey). It can be divided into: Carnivory, parasitism, cannibalism, herbivory.
- Predation prevents a single species from becoming dominant; it also either increases or decreases species richness; and it acts as a source of natural selection.
- **Mutualism**
- Mutualism is an interaction of two or more species where the interacting species mutually benefit from each other so much that they become completely dependent on one another. Example: Bees and flower.
- Mutualism helps in moulding or structuring community towards better species interactions.
- **Commensalism**
- Commensalism is an interaction of two or more species in which one species is benefited while the other species is neutral or is not benefited. Example: Cattle egret and cattle.
- It helps in determining the function and structure of populations and communities.
- **Saprophytism**
- Saprophytism is a condition of certain living organisms feeding and living on dead organic matters. Example: Mold (mushroom).
- Many micro saprotrophs and other decomposers, involving insects, snails, beetles, etc., help in recycling valuable nutrients such as iron, calcium, potassium and phosphorous from dead organic matter which is released back into the soil to be reabsorbed by plants.

1.4 GLOSSARY

- **Biological interactions:** It is a process of different organisms interacting with one another within a community.
- **Brood parasitism:** This is an interaction where the parasite, typically a bird, deposits its eggs in the nest of another species. The host (another species) then 'babysits' the egg in place of the parasite (bird), allowing the parasite to deposit eggs in other nests instead of spending time hatching their own young.

- **Carnivore plants:** Not all predators are animals. Carnivorous plants, such as the Venus fly trap and the pitcher plant, consume insects. Pitcher plants catch their prey in a pool of water containing digestive enzymes, whereas the Venus fly trap captures an insect between the two lobes of a leaf and seals the insect inside with digestive enzymes.
- **Commensalism:** It is an interaction of two or more species in which one species is benefited while the other species is neutral or is not benefited.
- **Competition:** It refers to the interaction of two organisms striving for the same resource. Generally, competition is of two types: intraspecific and interspecific competition.
- **Gause's exclusive principle:** It states that two species with identical ecological requirement cannot occupy the same ecological niche.
- **Herbivory:** It is an act of animal eating plants. Or when an animal uses a plant as food, this is called herbivory. Example, when a deer eats grass, the plant is the prey and the animal the predator.
- **Interspecific competition:** It is a type of competition in which individuals of different species compete for the same limited resources in an ecosystem.
- **Interspecific interaction:** The interaction which involves individuals of the different species.
- **Intraspecific competition:** It is a competition where individuals of the same species compete for the same limited resources in an ecosystem.
- **Intraspecific interaction:** The interaction which involves individuals of the same species.
- **Keystone predator:** A keystone predator is a species that reduces the density of the strongest competitors in a community.
- **Mutualism:** It is an interaction of two or more species where the interacting species mutually benefit from each other.
- **Oscillation:** It is a regular pattern of increase and decrease populations of both predator and prey.
- **Parasitism:** It is a relationship between two organisms where one benefits and the other is harmed.
- **Predation:** Predation is an interaction between species in which one species (predator) uses another species as food (prey); one organism kills and consumes another.
- **Saprophytism:** The condition of certain living organisms feeding and living on dead organic matters is called saprophytism. In Greek, sapro-("putrid matter") + -phyte ("plant, growth").

1.5 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. Organisms' interaction does only harm.
2. Commensalism harms both species.
3. Competing for food is an example of interspecific competition.
4. Herbivory is the act of predation.
5. Predation never promotes species richness.
6. There is a regular pattern of increase and decrease population in oscillation.
7. Parasitism doesn't promote coexistence of biodiversity.

II. Multiple Choice Questions

1. Both species are denoted by (+, +) in
   (a) Mutualism (b) Saprophytism
   (c) Commensalism (d) Protocooperation
2. When two species compete for a shared resource, it is called
   (a) Predation (b) Exploitative competition
   (c) Interference competition (d) Apparent competition
3. Adaptations of a predator are
   (a) Sharp teeth of lion
   (b) Acute sense of smell of moles
   (c) Echolocation of bats
   (d) All the above
4. Mineral recycling in a rainforest is done by a
   (a) Saprophyte (b) Commensal
   (c) Predator (d) Ectoparasite
5. Brood parasitism is an interaction where
   (a) A parasite kills the host
   (b) A parasite lives in the host
   (c) A parasite deposits its sperms to the other species' nest
   (d) A parasite deposits its eggs to the other species' nest

6. In sexual cannibalism, normally
   (a) Males eat females
   (b) Males eat the younger males
   (c) Females eat males
   (d) Females eat the younger females
7. A flea on a dog is an example of
   (a) Parasitism
   (b) Commensalism
   (c) Predation
   (d) Coevolution
8. Saprophytes are
   (a) Predators
   (b) Plants
   (c) Parasites
   (d) Detrivores
9. A commensal is
   (a) species that benefits association
   (b) species that benefits from the association
   (c) species that is negatively affected from the association
   (d) species that negatively affects the association
10. The interaction of bees and flowers is an example of
   (a) Protocooperation
   (b) Commensalism
   (c) Mutualism
   (d) None of these

III. Long Answer Type Questions

1. Giving suitable examples, explain the various interactions of organisms in nature.
2. Giving examples, describe in your own words, the adaptations of predator species to catch and kill prey and the adaptions of prey species to avoid predators.
3. What are saprophytes? With one example, describe how saprophytes help in recycling minerals.
4. Briefly compare interspecific and intraspecific competitions with suitable examples.
5. Draw a predator-prey relationship graph and interpret it.
6. Give two examples of the following:
   (a) Predation
   (b) Parasitism
   (c) Commensalism
   (d) Mutualism
7. How does interrelationship among organisms commit for a sustainably developed environment? Cite examples to support your answer.
8. With examples, state in your own words, the significance of organisms' interactions in nature.

Unit 2

Transport Across the Cell Membrane

Key Unit Competence

To be able to explain the physiological processes by which materials move in and out of cells and the significance of these processes in the life of organisms.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- describe and explain the processes and significance of movement in and out of the cell mentioned in the content.
- recall that the increasing size of organisms is constrained by its ability to obtain resources through diffusion across the cell surface and its ability to move substances out of cells.
- explain the movement of water between cells and solutions with different water potentials and explain the effects on plant and animal cells.
- carry out an investigation on simple diffusion using plant tissues and non-living materials.
- apply the knowledge of hypertonic environments in food preservation by salting.
- research adaptations of plants and animals to salty habitats.
- interpret and present data in graphic and table form on the effects of varying concentrations of : e.g., sugar and salt on plant and animal tissues.
- appreciate the importance of movement of substances across cells.
- show concern when exposing living organisms to concentrated media.
- distinguish between endocytosis and exocytosis.

2.1 INTRODUCTION

ACTIVITY 1

All the students stand in close proximity so that your shoulders touch each other. Now, your heads exhibit phosphate groups and bodies fatty acid chains. Entire arrangement is of a lipid bilayer cell membrane.

Toss two balls in the air. One small and one big. What will you observe? Which ball is likely to reach first on ground and why? Can you now state how the transport of substance occurs across the cell membrane?

The internal environment of a cell is maintained differently from that of its external environment by a thin surface membrane called the cell or plasma membrane. The plasma membrane is a lipid 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**".

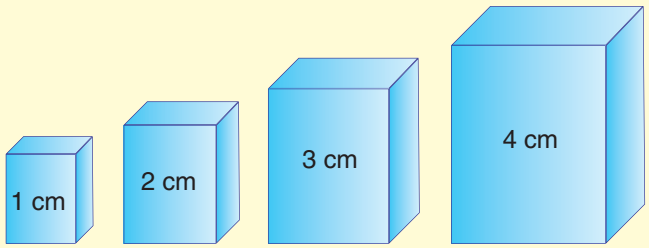
A cell membrane, therefore, determines which substances can enter the cell (comprising those which may be important for the vital activities within the cell) and also regulates the outflow of substances (consisting of excretory waste and water). This feature of the membrane not only maintains difference 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 of the membrane is permeable to non-polar and uncharged molecules such as O_2, CO_2, 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.

ACTIVITY 2

Aim: To calculate surface areas and volumes of the given cubes to illustrate the principle that surface area to volume ratio decreases with increasing size.

Materials Required: Cube sets (4 in nos.) of the side length of 1 cm, 2 cm, 3 cm and 4 cm.

Background: As the size of any object increases without changing in its shape, the surface area to volume ratio decreases. Based on the same principle, as the cell size increases and exceeds a limit, the membrane fails to transport sufficient material across the cell membrane that would be enough for the increased volume of the cell.



Procedure:

1. For each cube, calculate the Surface Area using the formula -
   Surface Area = 6 × (side length)^2
2. For each cube, calculate the Volume using the formula -
   Volume = (side length)^3
3. Calculate Surface Area to Volume ratio for each cube.
4. Record the data and observe the trend with respect to increase in size of the cube.

Discussion:

1. Correlate the observation obtained using cubes with living cells while stating the reason why the cell membrane behaves selective in nature.
2. Discuss your observation.

2.2 GRADIENTS ACROSS THE PLASMA MEMBRANE

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 2.1).

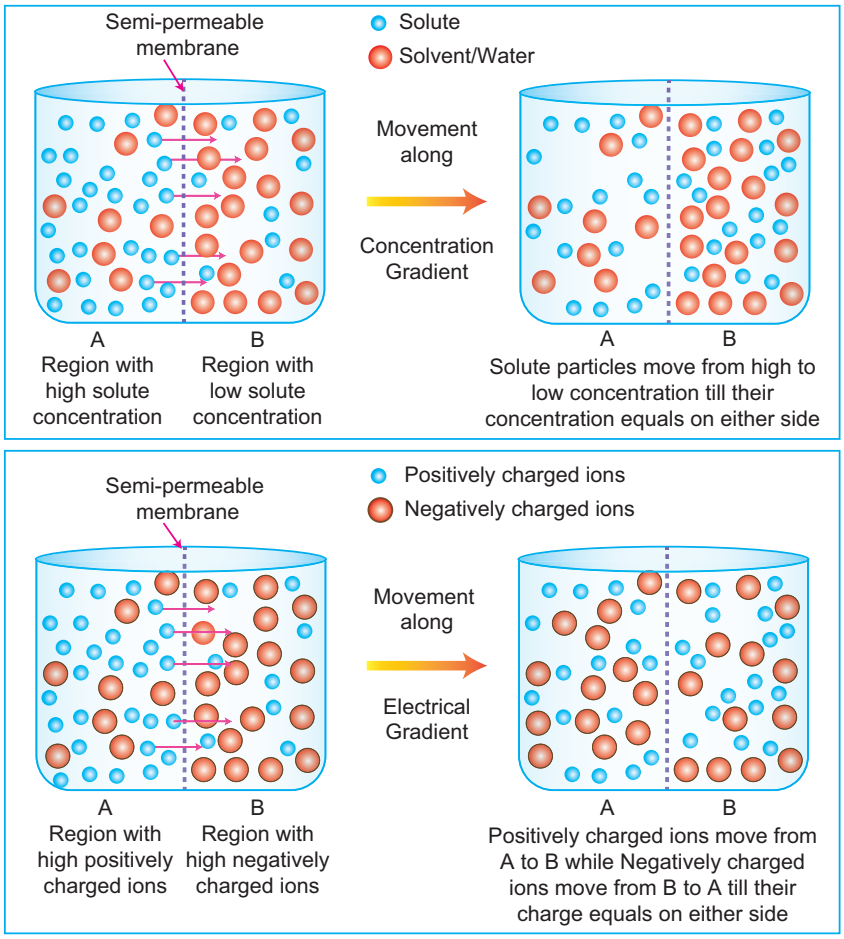


Figure 2.1: Movement of particles or ions with respect to concentration and electrical gradient across a semi-permeable membrane

The occurrence of concentration gradient and membrane potential helps in the movement of substances across plasma membrane. Substances tend to move down the concentration gradient (downhill movement) known as passive movement, i.e., from high to low concentration. Similarly, a negatively charged molecule will tend to move to positively charged region and vice-versa. Therefore, these two parameters greatly affect the ion movements across the membrane (by diffusion as explained in the following section) and together constitute the **electrochemical gradient**.

2.3 MOVEMENT OF SUBSTANCES ACROSS PLASMA MEMBRANE

As mentioned before, plasma membrane is selectively permeable. Figure 2.2 enlists all the processes involved in movement of substances across cells.

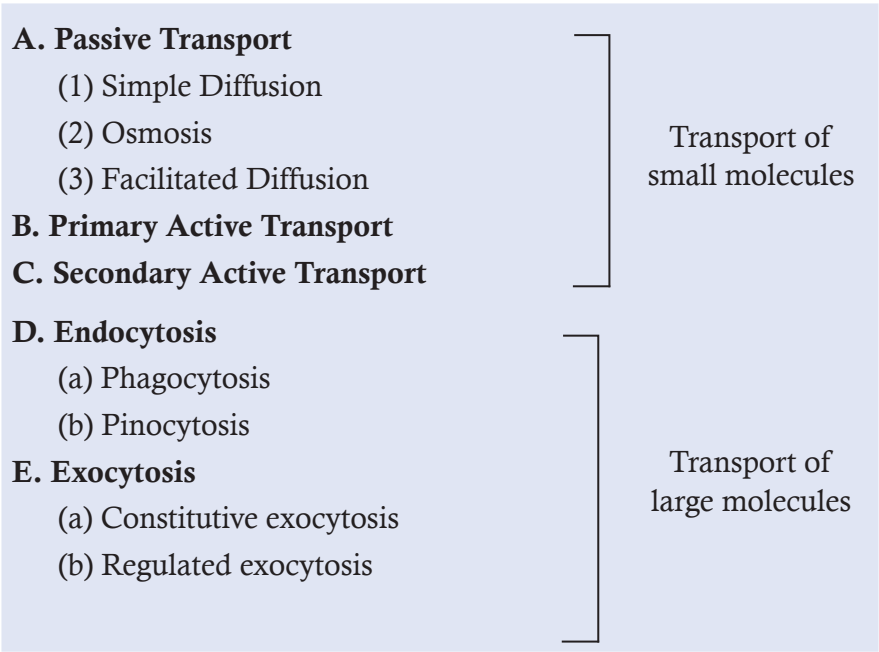


Figure 2.2: Processes involved in the transport of molecules across plasma membrane

Transport mechanisms can be broadly classified into two types:

Passive Transport—It involves the movement of molecules along the electrochemical gradient without the use of ATP (Downhill transport). Occurs by diffusion or osmosis.

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

2.4 PASSIVE TRANSPORT

Below is an account of different means of transport across the plasma membrane:

2.4.1 Simple Diffusion

It 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.

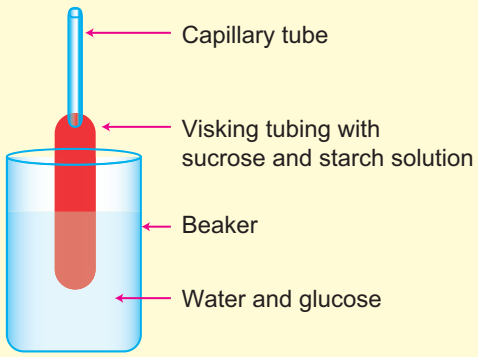
Diffusion is also regarded as the random mixing of particles in which the particles continue to move down their concentration gradient until an equilibrium is reached and the particles are evenly distributed throughout the solution (refer to Figure 2.1).

ACTIVITY 3

Aim: To investigate simple diffusion using plant tissues and visking tubing.

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

Background: Visking tubing is a partially permeable artificial membrane that mimics the cell membrane, i.e., it allows only smaller molecules (e.g., water molecules, glucose etc.) to pass through while restricts the larger ones (e.g., starch). In simple diffusion, the direction of movement is determined by the concentration gradient and the molecules flow from a region of its higher concentration to a region of lower concentration (or along electrical gradient).



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 diffusion 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.

Discussion:

1. Compare the change in water level (in the capillary) with what you have studied in theory.
2. Discuss your observation.
3. What would you expect if instead of water you had taken 20% sucrose solution in the beaker and performed the same experiment?

Factors Affecting the Rate of Diffusion

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

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 hard outer covering on the eye. In absence of diffusion, the eyes would dry out.

Imbibition

It is a special type of diffusion involving the absorption of water molecules by solids such as absorption of water by wood or seeds!

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 of the flowers to attract the pollinating animals, spreads in the air by diffusion.
10. Diffusion plays an important role in imbibition and osmosis.

2.4.2 Osmosis

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. 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 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 to the region of their lower chemical potential 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 2.3):

- 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. The cell is termed turgid. For example, red blood cells when placed in a hypotonic solution, cause hemolysis.

Reverse Osmosis

It is used as a process for water purification. It uses pressure in excess of the osmotic pressure that forces water to pass through the semi-permeable membrane. As a result, all the solutes are retained on one side whereas pure water accumulates on the other side!

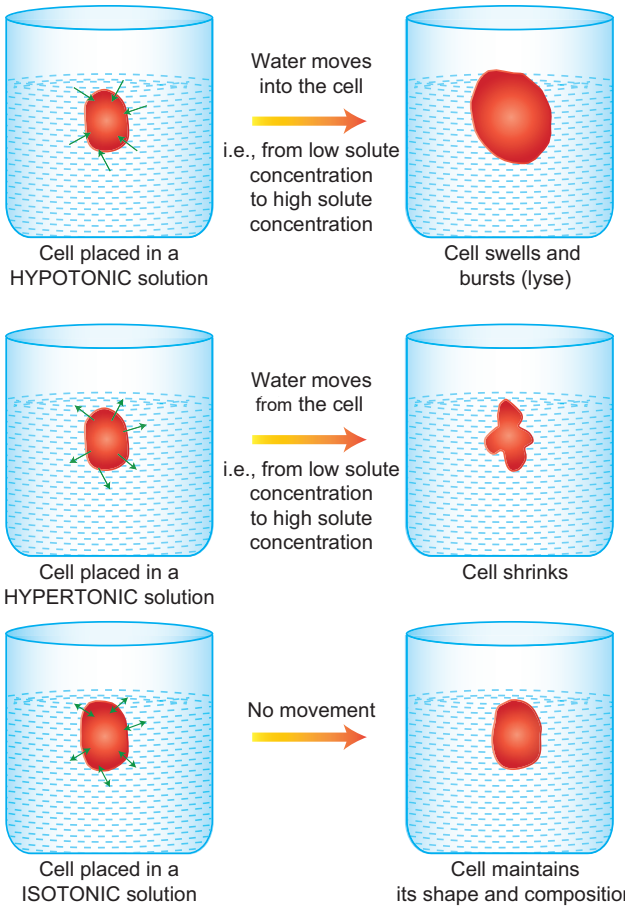
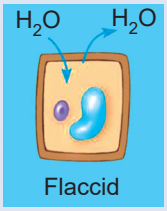


Figure 2.3: Movement of water molecules when a cell is placed in three types of solution—Hypotonic, Hypertonic and Isotonic with respect to the cell

- 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 the 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.
- If the medium is hypotonic with respect to the cell, i.e. the concentration of solutes in the cytosol is higher than that of the solution. In this condition, water diffuses into the cell due to osmotic pressure and the cell becomes turgid, or bloated.
- 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.  Turgid	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.  Flaccid	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.  Plasmolysed

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, and two historically significant such foods are dried and salted cod (usually referred to as salt fish) and salt-cured meat. 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

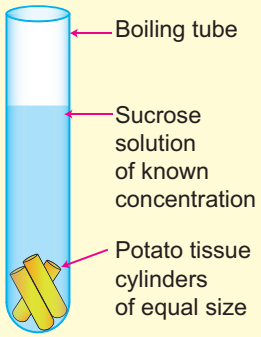
- Cut your vegetables up in pieces before you put them into the salt water to preserve food by salt-curing. As you chop a vegetable and put it into the salt water, it makes its own juice. Nowadays, you might want to use a smaller container. Just make sure the water has plenty of salt added. Let the vegetables stand in the salt water for at least 10 days in order to "pickle." Pickle simply means preserved 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.

ACTIVITY 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 (L_i).
3. Take sucrose solutions of different concentration in boiling tubes and label them.
4. Immediately add 3 potato tissue cylinders in each boiling tube.
5. Seal the tube with an aluminium foil paper to prevent water loss by evaporation.
6. Leave the tube rack aside for 1h.
7. Measure the length of the cylinders in each tube. This is the final length (L_f).
8. Calculate the % change in length for each using the formula -
   % change in length = $[(L_f - L_i)/ L_i] \times 100$.
9. Calculate the average of the three readings obtained for each tube.
10. Plot a graph of mean % change in length versus the sucrose concentration used.
11. Draw the best fit line for all the points obtained.
12. 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).

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

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

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 the 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. Water molecules (or molecules in gaseous state) show random movement as they possess kinetic energy. Therefore, as the concentration of water in a solution increases, the kinetic energy or its water potential increases. Hence, when two solutions are kept in close contact, water molecules with higher kinetic energy tend to move towards the one with lower kinetic energy. 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 signalled 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 salt water 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).

SELF EVALUATION

Complete the sentence with the correct word

(i)In hypotonic solution, a cell ..... .

(ii) In lungs, CO_2 diffuses out of blood by the process of ..... .

(iii) Purification of blood by kidneys takes place by the process of ..... .

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

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

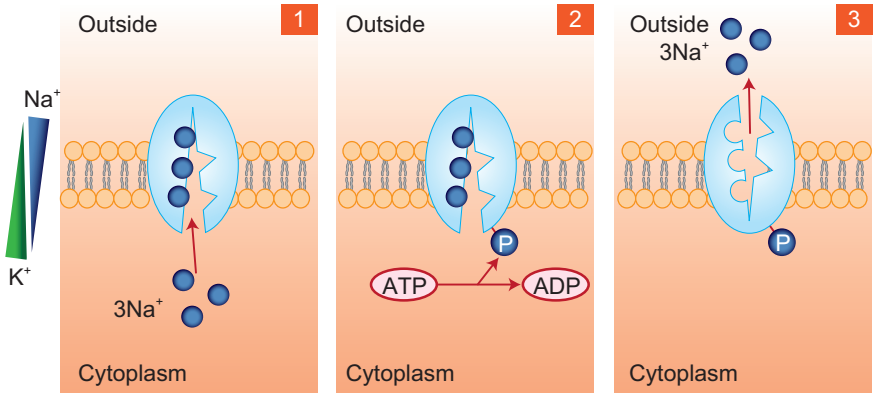
2.5 ACTIVE TRANSPORT

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.

2.5.1 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 (Figure 2.4); 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.



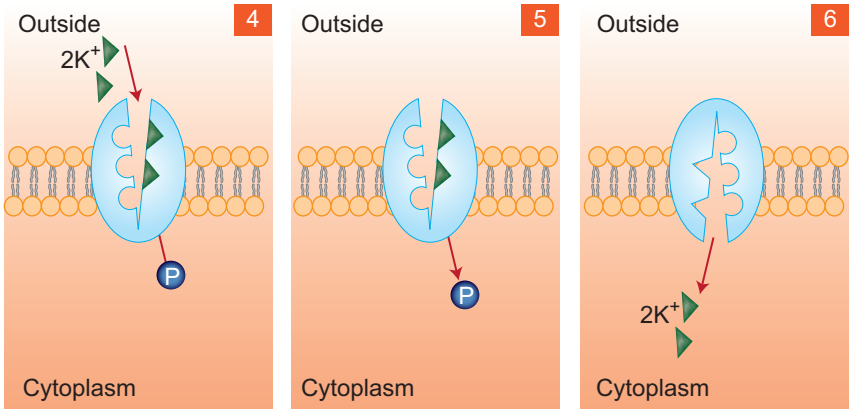


Figure 2.4: Working of $Na^+ - K^+$ pump. The concentration of Na^+ is more outside than inside while that of K^+ ions is more inside. Steps involved — (1) 3 Na^+ ions bind to the pump facing the cytoplasm, (2) Binding of Na^+ promotes ATP hydrolysis and thus phosphorylation of pump, (3) Conformational 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, and (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 favourable 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^+ (Figure 2.5).

(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 (Figure 2.5). 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.

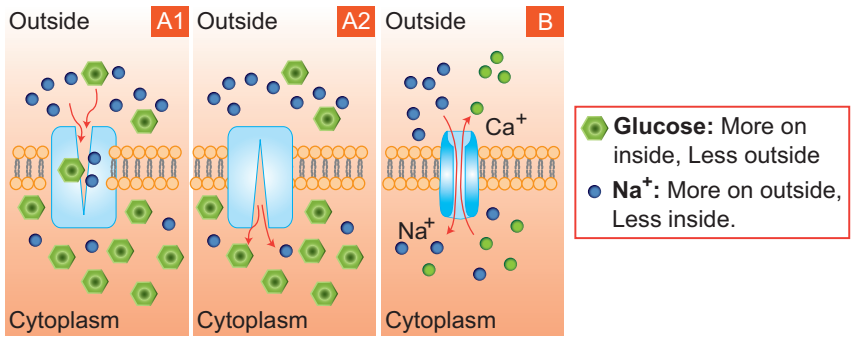


Figure 2.5: A (1 and 2) - Symport of 1 molecule of glucose with 2 molecules of Na^+ ions by secondary active transport. Note that the two molecules are transported in the same direction. B-Antiport of 1 molecule of Na^+ into the cell and 1 molecule of Ca^{2+} out of the cell. Note that the two molecules are transported in opposite direction

2.5.2 Factors Affecting the Process of Active Transport

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.

2.5.3 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.

(iv) 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.

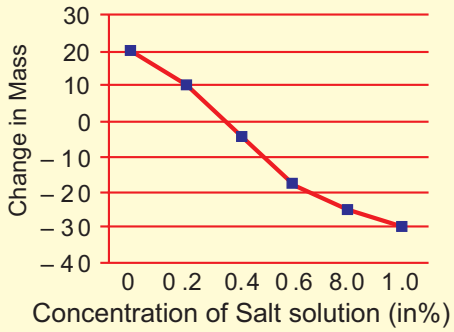
Active transport is also important for the transport of nutrients, including ions, sugars, amino acids into the cells and transport of toxic substances out of the cell (e.g., ABC transporters in bacteria and eukaryotic cells).

ACTIVITY 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 (M_i). Different concentrations of salt solutions (0%, 0.2%, 0.4%, 0.6%, 0.8% and 1% NaCl) was taken in different boiling tubes. 1 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 (M_f). The change in weight was then calculated by subtracting M_i from M_f. When the data was 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: What concentration of salt is isotonic to the potato tissue? Why?

Question 3: Which of the salt concentrations are hypotonic and hypertonic with respect to potato tissue?

Question 4: What is the effect on the size and weight of the tissue when it is placed in a hypotonic, hypertonic and isotonic solution?

Discussion: Discuss your interpretation.

2.6 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.

2.6.1 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 2.6).

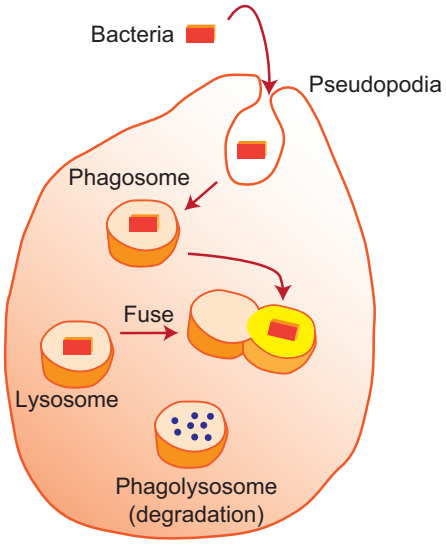


Figure 2.6: Process of phagocytosis showing the ingestion of a bacteria by a cell

2.6.2 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 broken down 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 (Figure 2.7).

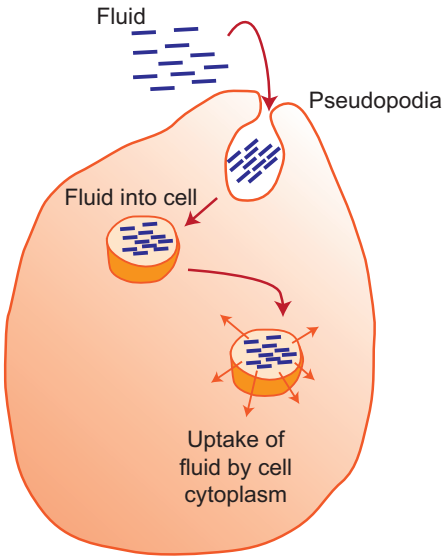


Figure 2.7: Process of pinocytosis showing the uptake of fluid by a cell

2.7 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 2.8)

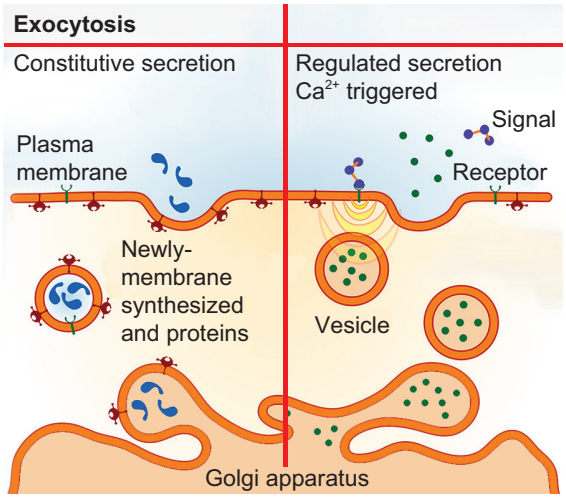


Figure 2.8: Exocytosis

Table 2.1: Comparision 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.

SELF EVALUATION

Complete the sentence with the correct word

(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) Who coined the term endocytosis?

2.8 SUMMARY

- Every cell is surrounded by cell or plasma membrane which regulates the movement or exchange of ions or molecules between the cell and its medium. This property of cell is called **cell permeability**.
- The presence of **concentration** and **membrane potential** (together called **electrochemical gradient**) helps in the movement of substances across the membrane.
- Plasma membrane mediates transport of smaller molecules by **passive** and **active transport** whereas larger molecules are transported by **endocytosis**.
- In **passive transport**, ions/molecules move from higher concentration to lower concentration which includes diffusion and osmosis and there is no utilization of energy.
- **Simple diffusion** is the movement of small hydrophobic molecules from higher concentration to lower concentration by dissolving in phospholipid bilayer till equilibrium is reached.
- **Osmosis** is a movement of water molecules from low solute concentration to high solute concentration side (or from higher solvent concentration to lower solvent concentration).
- **Active transport** is the movement of ions/molecules from lower concentration to higher concentration. It is of two types: **Primary** and **Secondary active transport**. The former involves direct utilization of energy in the form of ATP hydrolysis while the later involves movement of molecules against concentration gradient but coupled with the movement of a second molecule in an energetically favourable direction without direct utilization of ATP. The movement may be **symport, uniport** or **antiport**.
- **Endocytosis** is the ingestion of large particles such as bacteria, macromolecules and fluids into the cell in the form of small vesicles. It is further of two types, viz., **phagocytosis** (cell eating, engulfing of solid particles) and **pinocytosis** (cell drinking, uptake of liquid fluids).

2.9 GLOSSARY

- **Active transport:** Transport of moleculer across cell membrane utilizing energy in the form of ATP.
- **Diffusion:** It is the movement of solutes from higher concentration to lower concentration through semi-permeable membrane.
- **Endocytosis:** Cells engulf molecules which cannot pass through the plasma membrane.
- **Exocytosis:** Cells expel molecules which cannot pass through the plasma membrane by exocytosis.
- **Osmosis:** It is a movement of water molecules from ion solute concentration to higher solute concentration.
- **Osmotic potential:** The potential of water molecules to move from a hypotonic solution to a hypertonic solution across a semi-permeable membrane.
- **Passive transport:** Transport of ions and molecules through cell membrane without utilization of energy.
- **Phagocytosis:** It is a food capturing process of bacteria and protozoans. In eukaryotes, this process is used for remolving aged cells or those which have stopped functioning.
- **Pinocytosis:** It is a non-specific process which involves engulfing of either pre-dissolved or already broken down substances.
- **Plasmolysis:** It is the process in which cells lose water in a hypertonic solution. Plasmolysis can lead to cell's death.
- **Wall pressure:** The pressure exerted by water inside the cell against the cell wall. It is also called Turgor pressure.
- **Water potential:** It is the measure of potential energy in water. It drives the movement of water through plants.

2.10 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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) Passive transport (b) Active transport
   (c) Endocytosis (d) 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. Distinguish between endocytosis and exocytosis giving suitable examples.

Unit 3

Chromosomes and Nucleic Acids

Key Unit Competence

To be able to describe the structure of a chromosome and how DNA is folded into a chromosome.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- describe the composition of chromosomes and the structure of nucleotides.
- use of complementary base pairing to write the sequence for messenger RNA and the first DNA codes for three base codons.
- appreciate the importance of the presence of DNA in chromosomes.
- state how nucleotides pair.
- describe the structure of DNA and RNA.
- explain that the structure of the DNA molecule is described as a ladder twisted into a spiral.
- draw the structure of DNA (6-10 base pair sequence).
- explain the Watson-Crick hypothesis of the nature of DNA.
- research on how Watson and Crick determined the nucleotide base pairing pattern.
- outline the significance of telomeres in permitting continued replication.
- acknowledge the role of telomeres in preventing the loss of genes and its relation to the development of cancer.
- distinguish between RNA and DNA.
- describe the nature of genes.
- describe the structure of a genetic code.

3.1 COMPOSITION OF CHROMOSOME

ACTIVITY 1

Did you know that your genes are tightly packed in a structure called chromosomes? So, find out the composition and importance of chromosomes (Use internet).

Chromosomes are made of long aggregates of genes formed from condensed chromatin. Chromatin is made up of DNA, proteins, RNA and other macromolecules. It is located in the nucleus of a cell.

Deoxyribonucleic acid (DNA) is the storehouse of genetic information in the cell. A complete set of an organism's DNA is called a **genome**. And a **gene** is a segment of DNA that encodes for a particular trait. **Chromosomes** are the structures that hold genes; they are made up of strands of DNA tightly wrapped around histone proteins. Chromosome is basically composed of three components— (A) Nucleotides, (B) Histones proteins and (C) Non-histones proteins.

A. Nucleotides

The monomers that make up Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA) are called **nucleotides**. Nucleotide has three components:

1. Pentose (five-carbon) sugar,
2. Nitrogenous (nitrogen-containing) base, and
3. Phosphate group.

Pentose Sugar

Pentose sugar has five carbon atoms, which are numbered 1' to 5' respectively (Figure 3.1). In DNA, the pentose sugar is deoxyribose: a hydrogen atom (H) is attached at the 2' carbon position. In RNA, the pentose sugar is ribose: hydroxyl group (OH) is attached at the 2' carbon position.

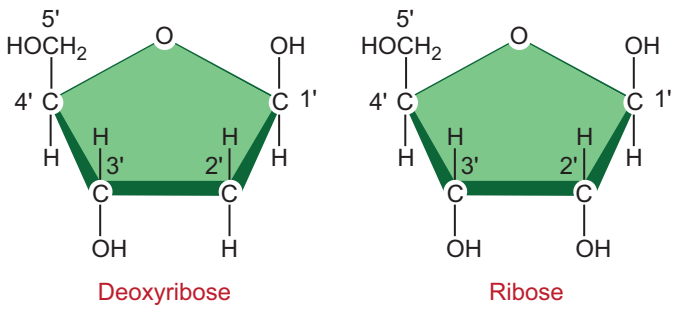


Figure 3.1: Structures of deoxyribose and ribose in DNA and RNA

Nitrogenous Bases

There are two classes of nitrogenous bases—Purines and Pyrimidines. **Purines** are nine-membered, double-ringed structures (Figure 3.2). In these purines, the carbons and nitrogens are numbered 1 to 9. There are two purines—**Adenine (A)** and **Guanine (G)**. Pyrimidines are six-membered, single-ringed structures (Figure 3.2). The carbons and nitrogens in these pyrimidines are numbered 1 to 6. Pyrimidines are of three types—**Thymine (T)**, **Cytosine (C)**, and **Uracil (U)** (Figure 3.2).

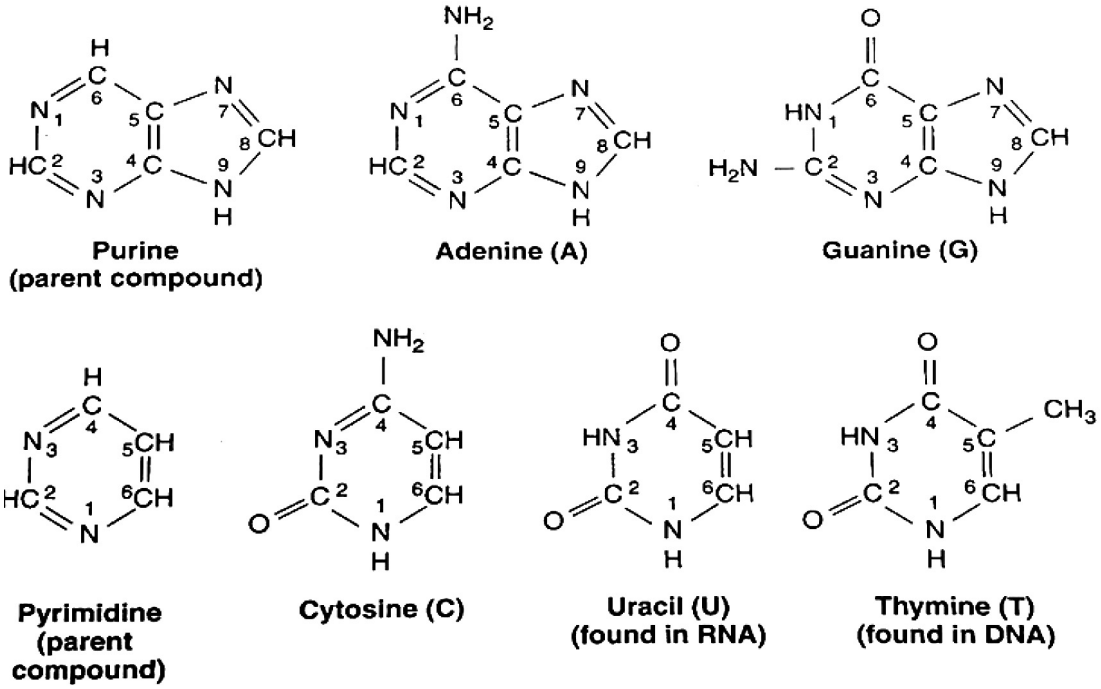


Figure 3.2: Structures of nitrogenous bases in DNA and RNA

Table 3.1: Difference between DNA and RNA base composition

DNA	RNA
Adenine	Adenine
Guanine	Guanine
Cytosine	Cytosine
Thymine	Uracil

Phosphate Group

The phosphate group (PO_4^{2-}) is attached to the 5' carbon of the sugar in both DNA and RNA (Figure 3.3). Due to this phosphate group, DNA is **negatively charged**.

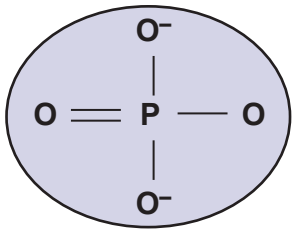


Figure 3.3: Phosphate group

B. Histones Proteins

Histone proteins play an important role in **organizing the physical structure of the chromosome**. They are most abundantly found in chromatin where they are wrapped around by DNA strands. Moreover, they are small basic proteins with a net positive charge that assist their binding to the negatively charged DNA (due to phosphate groups which are negatively charged).

In eukaryotes, there are five main types of histone proteins (Figure 3.4). They are—H1, H2A, H2B, H3, and H4. H1 is loosely attached to the rest of the histone core proteins. That is why H1 can be easily separated from the rest of the histone proteins. And two each of H2A, H2B, H3, and H4 form **core of eight histone proteins**. These core proteins are also called **histone octamers**. A strand of DNA measuring 147 bp segments wraps around this histone octamers for about 1.7 times. Each nucleosome is connected by a strand of DNA called **linker DNA**. For example, Human linker DNA ranges from 38-53 bp long.

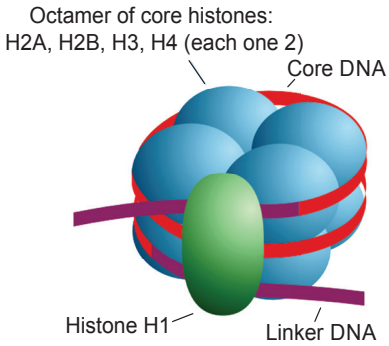


Figure 3.4: Arrangement of histone proteins

C. Non-histones Proteins

Excluding histone proteins, the rest of the proteins associated with DNA come under the category of non-histone proteins. Non-histone proteins in so many ways are different from histone proteins. Some of the differences are:

1. The number of non-histone proteins is ***much lesser*** than histone proteins.
2. Non-histone proteins are acidic proteins, which are ***negatively charged***.
3. They play important role in the process of DNA replication, DNA repair, transcription, gene regulation, and recombination.
4. They vary in number and type from cell type to cell type within an organism at different times in the same cell type, and from organism to organism.

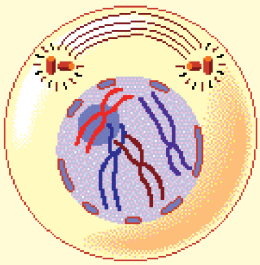
ACTIVITY 2

Aim: Observe the structure of chromosomes at prophase stage of mitotic cell division.

Materials Required:

1. Permanent slide of prophase stage of mitotic cell division.
2. Compound microscope

Background: Prophase is the first phase of mitosis. At this phase, no nucleolus is seen; the chromosomes start condensing. Thread-like structure of chromosomes is seen under compound microscope.

S. No.	Stage of Mitosis	Identifying Features	Expected Diagrams
1.	Prophase	• No nucleolus • Condense chromosomes in the nucleus	 Prophase

Procedure:

1. Take the permanent slide.
2. Place it on the stage of the compound microscope.
3. Observe the prophase stage of mitotic cell division.
4. Draw a well-labelled diagram of the structure of prophase stage chromatin.

Discussion:

1. Is there any difference between the structure of chromatin which you have observed and what you have learned in the theory class?
2. What can you say about the nuclear membrane and spindle fibres in prophase stage observed under a compound microscope?

3.1.1 The Importance of the Presence of DNA in Chromosomes

(a) Protection

The packaging of DNA in chromosomes helps in protecting DNA from being damaged.

(b) Conserve Space

If we take the DNA from all the cells in a human body and line it up, end to end, it would form a strand 6000 million miles long! In order to store this very long important material, DNA molecules are tightly packed around proteins called histones to make structures called **chromosomes**.

The packaging of DNA in chromosomes helps in conserving space in cells. Approximately, about two metres of human DNA can fit into a cell that is only a few micrometres wide.

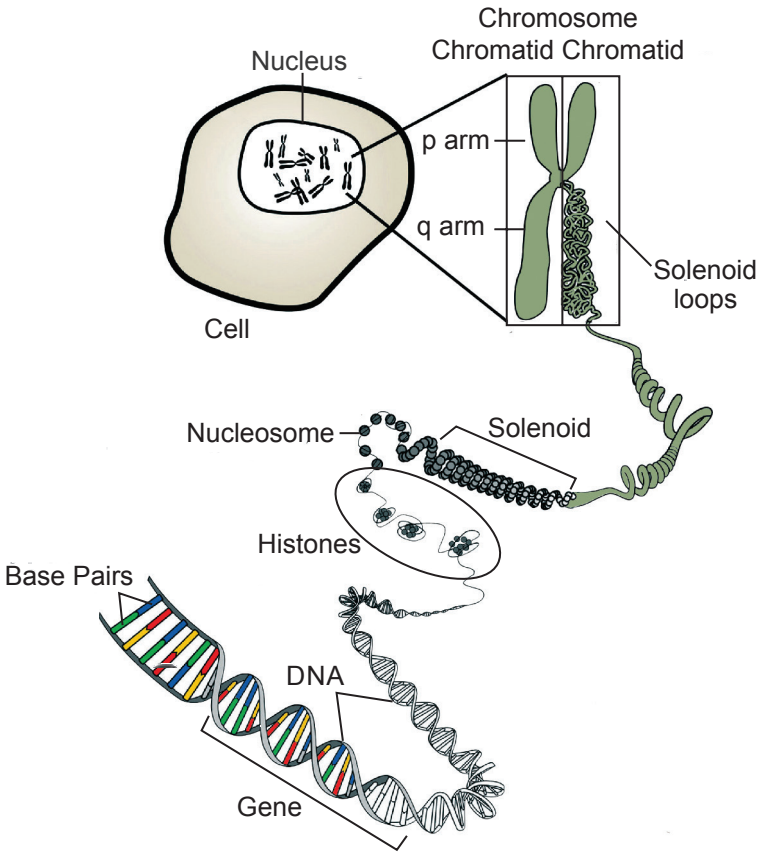


Figure 3.5: To better fit within the cell, long pieces of double-stranded DNA are tightly packed into structures called chromosomes

(c) Control of Gene Expression

Chromatin is a complex of DNA and proteins that forms chromosomes within the nucleus of eukaryotic cells. In its extended form, chromatin looks like beads on a string (Figure 3.5) under the microscope. The beads are called nucleosomes, while the link between them is a strand of DNA.

The packaging of DNA in chromatin form helps in controlling gene expression. Highly compacted chromatin is not accessible to the enzymes involved in DNA transcription, replication, or repair.

Chromatin has two main regions. The less condensed regions of chromatin are the regions where active transcription takes place. This region is called **euchromatin**. On the other hand, the condensed region of chromatin is where transcription is inactive or is being actively inhibited or repressed. This region is called **heterochromatin**.

3.2 STRUCTURE OF NUCLEOTIDES

ACTIVITY 3

1. Discuss the following in the class.
   - Nucleotide sequences make DNA, and DNA makes you. If DNA is a double stranded structure, how do the two strands in DNA join or stick together to form double stranded structure?
2. Make a report on it and present it to the class.

3.2.1 Nucleotide

A basic unit of **nucleotide** is made up of *pentose sugar*, a *nitrogenous base*, and a *phosphate sugar*. However, a combination of only a pentose sugar and nitrogenous base, without phosphate group, is called **nucleoside**.

Nucleotide	Nucleoside
Pentose sugar + Nitrogenous base + Phosphate group	Pentose sugar + Nitrogenous base

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 ($\mathbf{PO_4^{2-}}$) attaches to the 5' **carbon** of pentose sugar. Thus, by attaching phosphate group to a nucleoside yields a **nucleoside phosphate** or **nucleotide**.

In DNA, the complex of **deoxyribose, nitrogenous base and phosphate group** is called DNA nucleotide (a **deoxyribonucleotide**) (Figure 3.7), whereas in RNA, the complex of **ribose, nitrogenous base and phosphate group** is called RNA nucleotide (a **ribonucleotide**) (Figure 3.6).

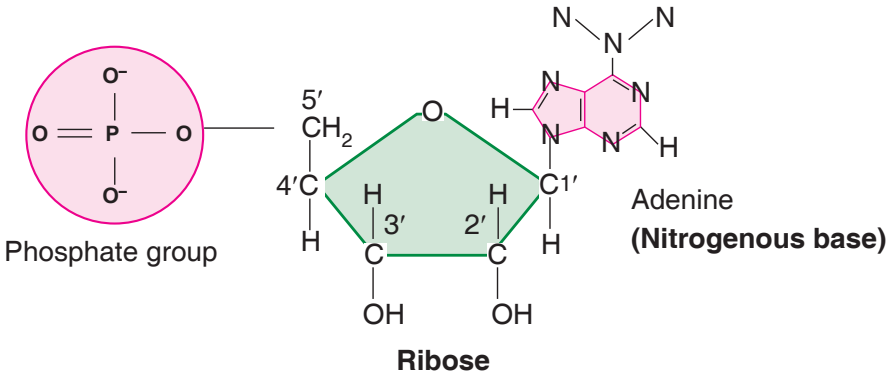


Figure 3.6: RNA nucleotide **(ribonucleotide)**

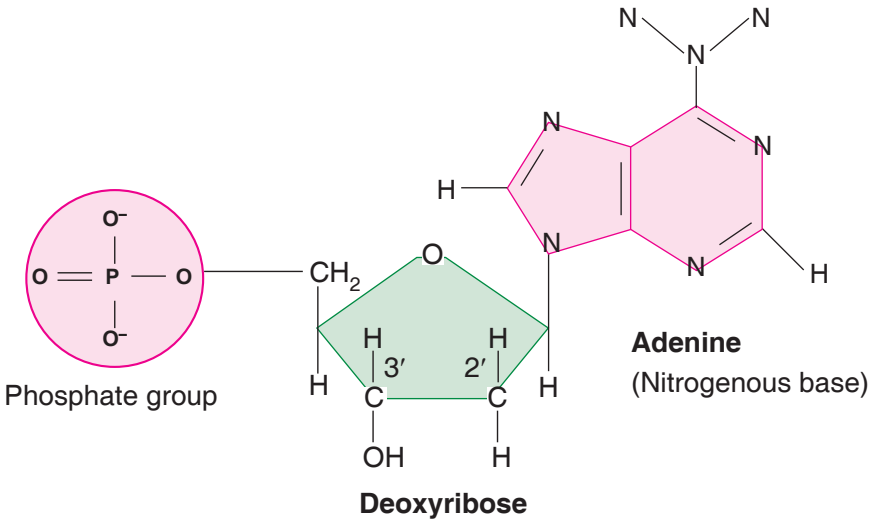


Figure 3.7: DNA nucleotide (**deoxyribonucleotide**)

3.2.2 Phosphodiester Bond

Two nucleotides are covalently joined together by a bond called **phosphodiester bond** (Figure 3.8). In phosphodiester bond, the phosphate group, which is attached on 5' of one nucleotide, forms a bond with the 3' carbon of another nucleotide. In this way, many phosphodiester bonds are formed in between sugar and phosphate groups. The repeated sugar-phosphate-sugar-phosphate backbone is a strong one. Because of this strong backbone, DNA and RNA are stable structures.

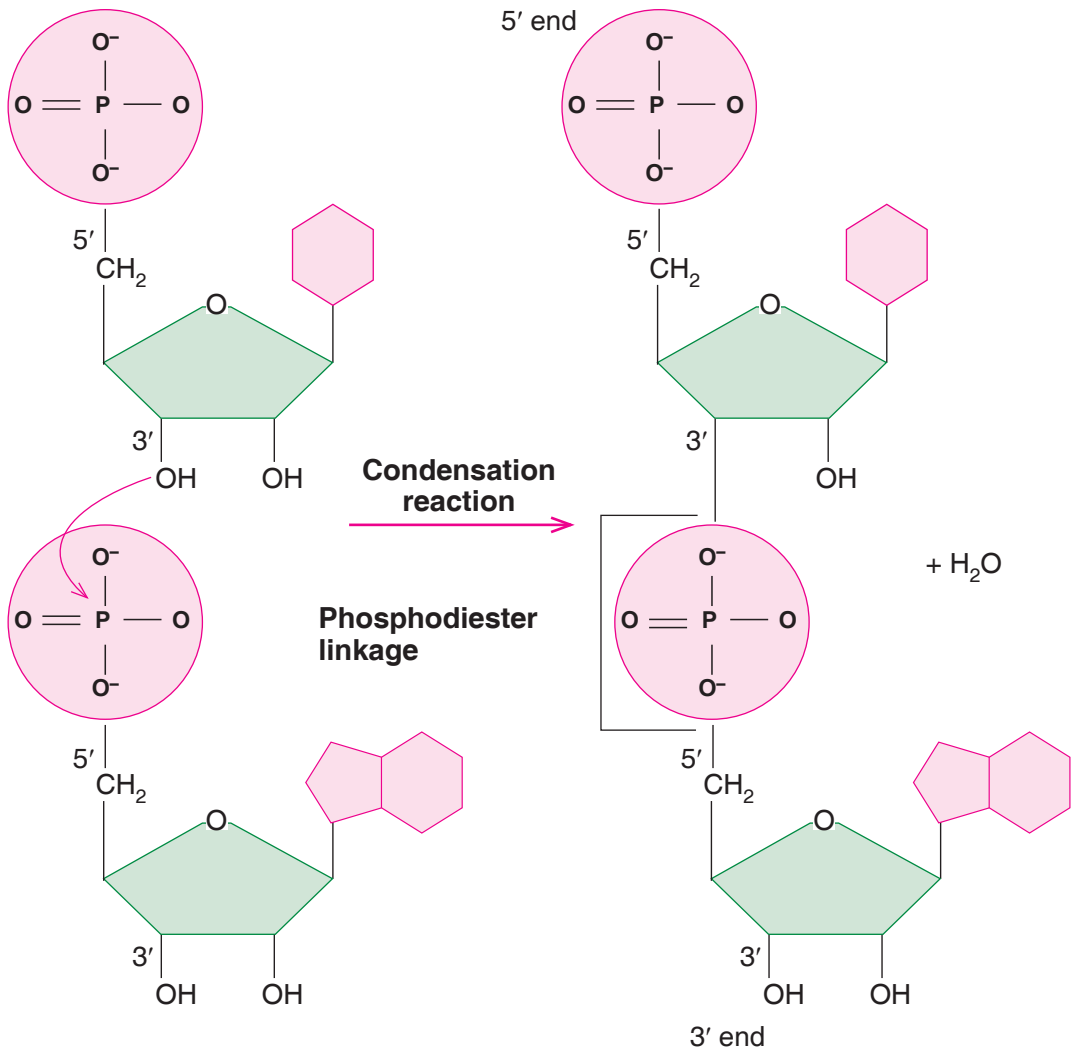


Figure 3.8: A figure showing phosphodiester bond formation (between two ribonucleosides)

3.2.3 Polarity

Polynucleotide chains have polarity. On one end, there is a 5' carbon with a phosphate group ($\mathbf{PO_4^{2-}}$). On the other end, there is a 3' carbon with a **hydroxyl group (OH)** on it (Figure 3.8). The ends of polynucleotide are frequently referred to as the 5' end and the 3' end.

3.2.4 Chargaff's Rules: The Rules of Base Pairing

Erwin Chargaff's rules state that DNA of all organisms should have a 1:1 ratio of pyrimidine and purine bases. Thus, 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 3.2: Difference between purine and pyrimidine

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

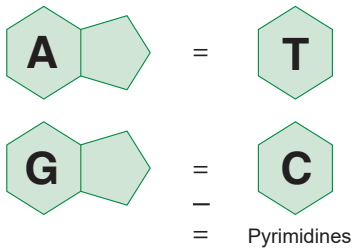


Figure 3.9: Chargaff's rule

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.

SELF EVALUATION

Complete the sentence with the correct word

(i)..... is a segment of DNA that encodes for traits.

(ii) The two Purines are ..... and ..... .

(iii) Uracil is present in ..... .

(iv) Two nucleotides are covalently joined by ..... .

(v) A-T bases and G-C bases are called ..... base pairs.

3.3 STRUCTURE OF NUCLEIC ACIDS—DNA AND RNA

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 3.10), thymine and adenine have two **hydrogen bonds**; while guanine and cytosine have **three hydrogen bonds**. Hydrogen bonds or interactions play a 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.
(c) In both the cases, in the middle of the helix, a complementary base pairing is formed by **hydrogen bonds**.

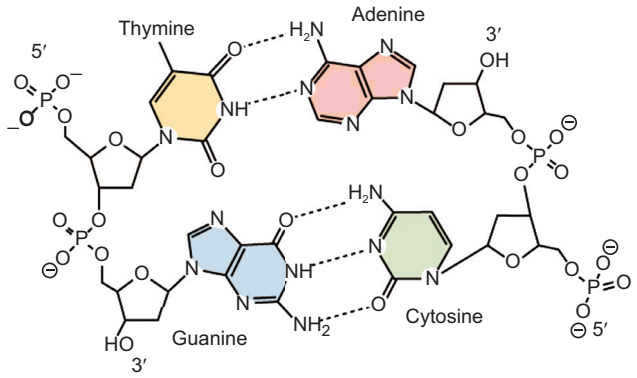


Figure 3.10: Structure of DNA [See the hydrogen bonds between the four bases (T-A, G-C)]

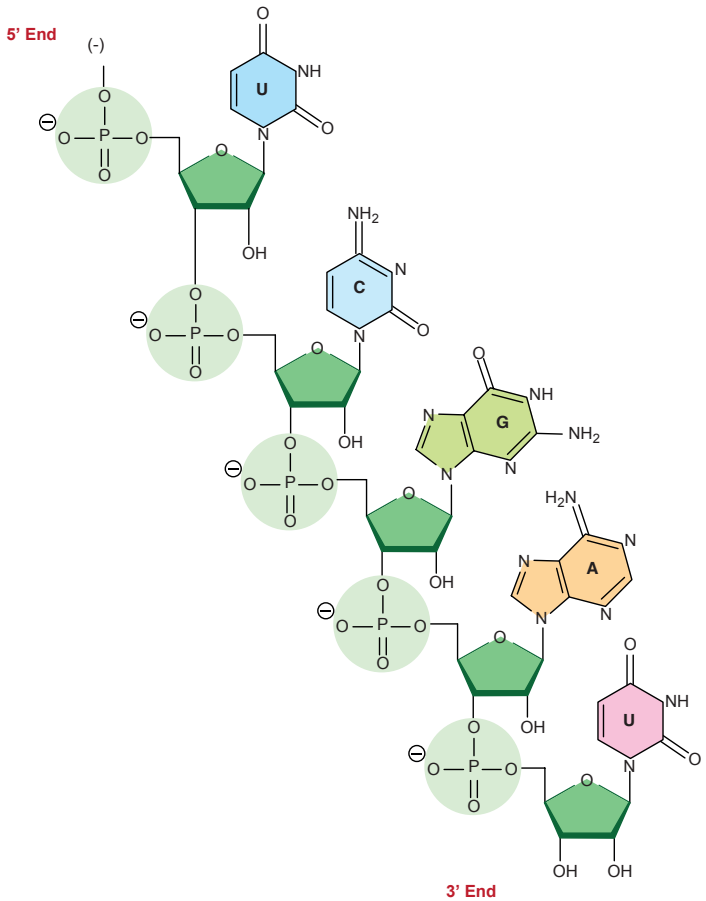


Figure 3.11: Chemical structure of RNA

ACTIVITY 4

Aim: Design the structure of DNA molecule and complimentary base pairing using plastic model shapes or homemade kits.

Materials Required:

1. Plastic models of pentose sugars, phosphate groups, nitrogenous bases (A, G, T, and C).

Or

2. Homemade kits of pentose sugars, phosphate groups, nitrogenous bases (A, G, T, and C).

Procedure:

1. Before you start the activity, study the composition of chromosome (DNA) properly.
2. By using the plastic models, construct the structure of DNA.
3. Or in the same way, by using the plastic models, make the complementary base pairs of nucleotides (A, G, T, and C).
4. Once the construction of the structure of DNA and the complementary base-pairing are ready, give a presentation to the class.

Note: 1. Remember the Chargaff's rule of base pairing concept.

2. Remember the structure of DNA.

3.4 THE WATSON-CRICK HYPOTHESIS OF THE NATURE OF DNA/THE STRUCTURE 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 3.12) of DNA are:

1. Two polynucleotide chains ***wind around each other*** in a right-hand double helix (Figure 3.12).
2. 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).

3. 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 two hydrogen bonds with Thymine (T). Similarly, Guanine (G) will form three hydrogen bonds with Cytosine (C). This specific base paring is called **complementary base pairing** (Figure 3.12).

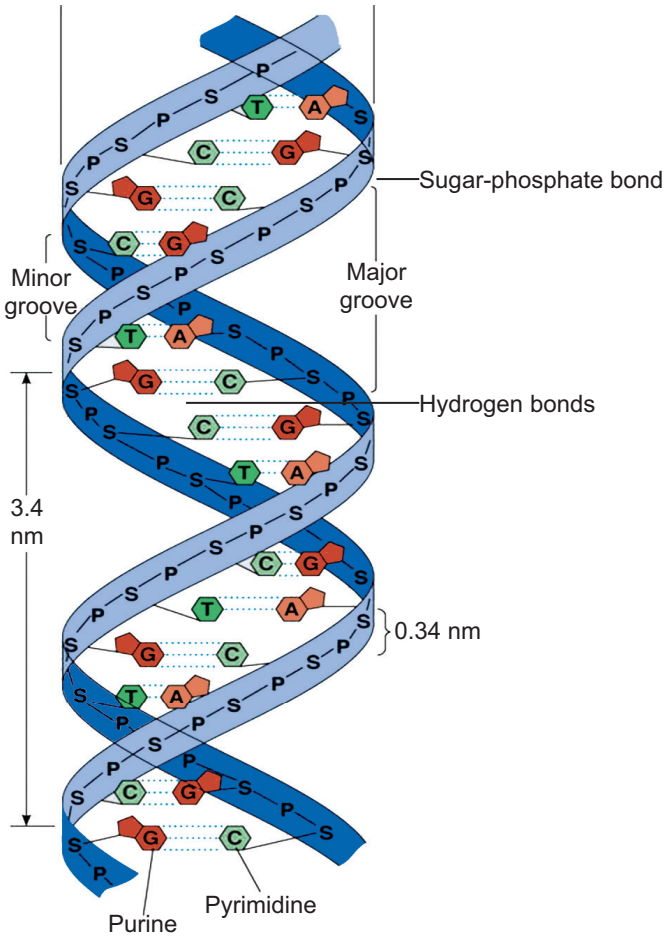


Figure 3.12: Double helical structure of DNA (Schematic)

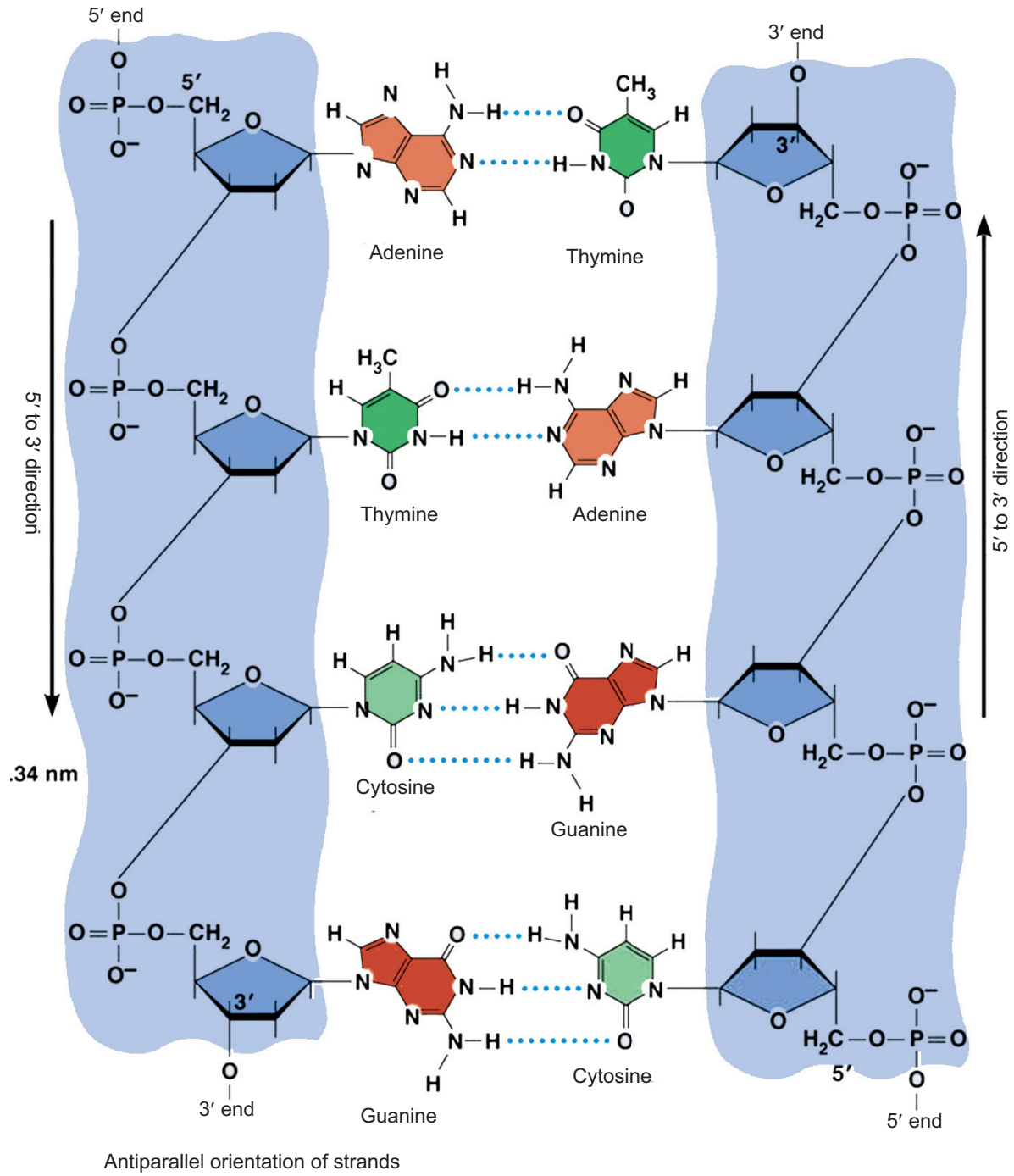


Figure 3.13: Chemical Structure of DNA

4. The distance between adjacent bases is **0.34 nm** in the DNA helix. A complete turn of the helix takes **3.4 nm**. One complete turn, which is 360° turn, accommodates 10 base pairs (bp). And the diameter of the helix is 2 nm (Figure 3.13).
5. There are major and minor grooves in the double helix. The **two sugar-phosphate backbones** of the double helix are not equally spaced from one another along the helical axis, because of the way the bases bind with each other. As a result, there is an unequal size of grooves between the backbones. The wider groove is called *major groove*; rich in chemical information. The narrower groove is called **minor groove**; less rich in chemical information (Figure 3.13).

3.4.1 DNA is also Described as a Twisted Ladder Structure

A typical ladder has two long wooden or metal side strands or pieces between which a series of rungs or bars are set in suitable distances (Figure 3.14). In the structure of DNA, the pentose sugars and phosphate groups make up the "long two side strands or pieces" of a typical ladder. And the A-T and G-C base pairs which are bonded by **hydrogen bonds** make up the "**rungs or bars**"of a typical ladder (Figure 3.15).

But unlike a typical ladder which is straight, the two strands of DNA are twisted into spiral. Scientists call this a double helix. DNA also folds and coils itself into more complex shapes. The coiled shape makes it very small. In fact, it is small enough to easily fit inside any of our cells. If a DNA from a cell is unfolded, it would stretch out to a length of about six feet. The structural twisted nature of DNA has been attributed to enhance its stability and strength. Thus, for these simple similarities with a typical ladder, DNA is also referred to as a twisted ladder structure.

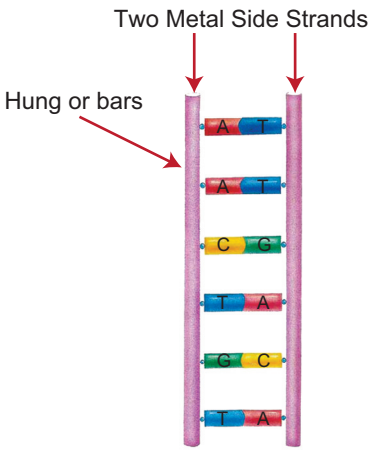


Figure 3.14: A typical ladder

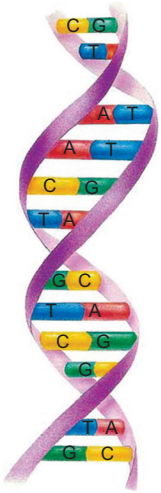


Figure 3.15: A twisted ladder DNA Structure

3.5 SIGNIFICANCE OF TELOMERE IN PERMITTING CONTINUED REPLICATION

3.5.1 What is Telomere?

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 neighbouring chromosomes. In vertebrates, the repetitive sequence of nucleotides in telomeres is TTAGG. In humans, this sequence is repeated about 2500 times.

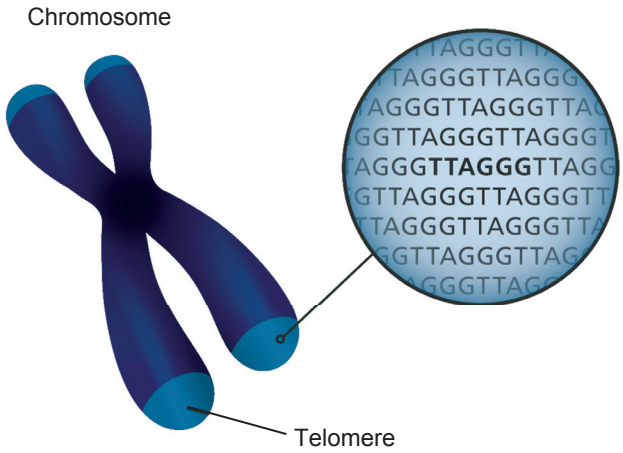


Figure 3.16: A diagram showing the region of telomere

3.5.2 How is the Length of Telomere Maintained?

In the process of DNA replication, the length of chromosome (precisely the length of telomere) is shortened by about 25-200 bases per replication cycle. Elizabeth Blackburn and Carol W. Greider have shown that the enzyme telomerase maintains the length of chromosome by adding telomere repeats (TTAGGG) at 3' end overhang, which serves as template to previous DNA replication (Figure 3.17). The complementary sequence (5' end) to this newly synthesized telomere is then added by the regular replication machinery.

3.5.3 Significance of Telomere in Replication

1. Telomeres help in **organising** the chromosomes in the nucleus of the cell.
2. Telomeres *protect loss of important genes*: During DNA replication, the chromosomes are shortened by about 25-200 bases per replication. If this process of shortening the chromosomes continues, there will be loss of important genes. However, fortunately, the ends of the chromosomes are protected by telomeres; and telomeres are non-coding regions.

Thus, even if there is loss at the tip of chromosomes in every round of replication, the loss of telomeres (non-coding regions) doesn't affect the important genes.

3. Telomeres prevent the end of chromosomes from fusing with its neighbouring chromosomes.

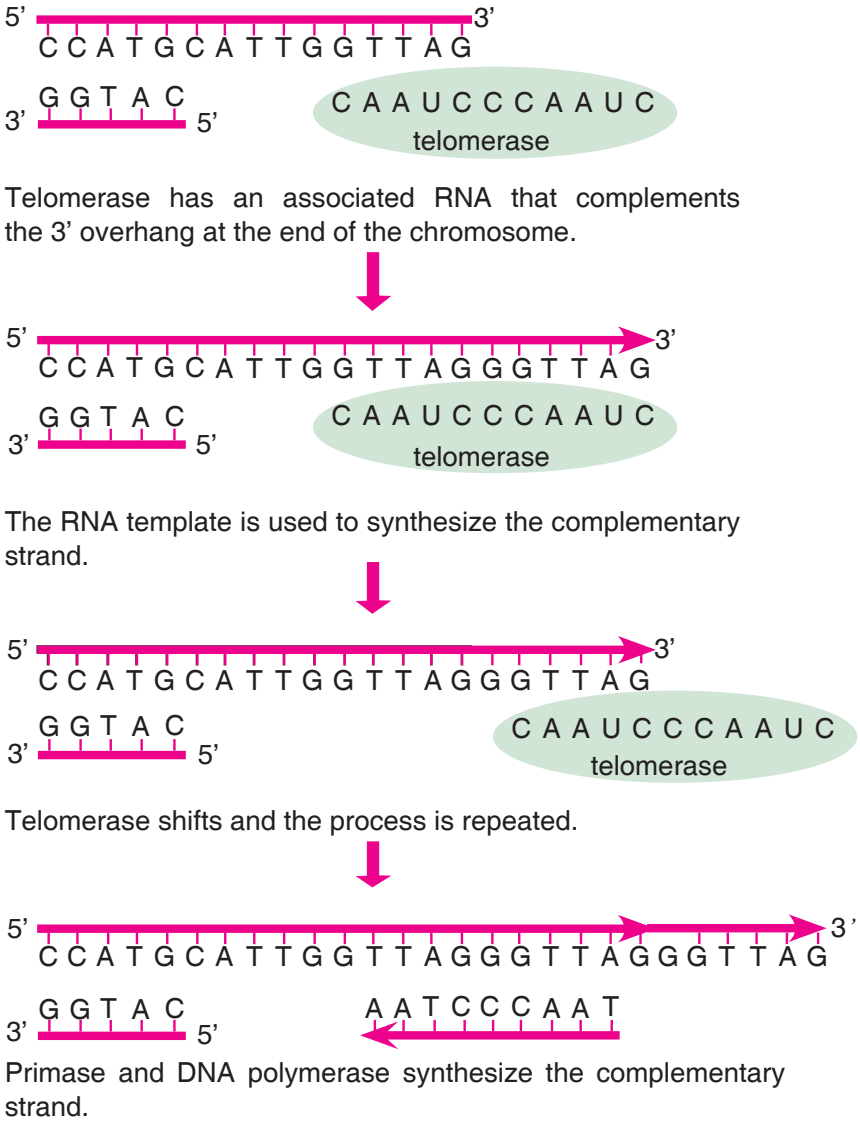


Figure 3.17: Synthesis of telomeric DNA by telomerase

Telomeres and Ageing

Telomeres are thought to be related to ageing. Newborn babies are reported to have telomeres ranging from around 8000 to 13,000 base pairs. These base pairs tend to decline by around

20-40 every year. Thus, by the time someone is 40-year-old, they could have lost up to 1600 base pairs from their chromosomes. However, no significant shortening of telomeres is observed in old people. It has been observed that telomerase is typically active in germ cells and adult stem cells, but is not active in adult somatic cells.

Telomeres and Cancer

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. In the absence of telomerase, the cancer cells would become inactive and would stop dividing resulting into death of the cancer cells. 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.

ACTIVITY 5

Aim: Compare the structures of DNA and RNA by using charts and diagrams.

Materials Required:

1. Chart Papers
2. Pencils or colour pens
3. Glue
4. Scales or rulers

Procedure:

1. Draw the structures of DNA and RNA given on page 55.
2. Write down three to four major differences between DNA and RNA.
3. Discuss on the diagrams you have drawn on the chart papers.
4. Also discuss the differences you have noted down.
5. Make a report on it and present it to the class.

Feedback Time:

1. Ask your biology teacher to comment on your presentation.
2. Most probably, your teacher will ask you to improve in certain areas.
3. Note those points of improvements and incorporate it in the next presentation.

3.5.4 Major Differences between DNA and RNA

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

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

Table 3.3: Differences between DNA and RNA

S.No.	DNA	RNA
1.	Double stranded	Single stranded (normally) with some exception such as *riovirus*
2.	Deoxyribose sugar	Ribose sugar
3.	The base composition is: (a) Adenine (b) Thymine (c) Guanine (d) Cytosine	The base composition is: (a) Adenine (b) Thymine (c) Guanine (d) 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 complementary 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.

SELF EVALUATION

Complete the sentence with the correct word

(i) Watson and Crick proposed the model of ..... .

(ii) Enzyme ..... maintains the length of telomere.

(iii) ..... can be used to cure cancer.

(iv) ..... bonds are seen in both DNA and RNA.

(v) ..... directs synthesis of proteins in the body.

3.6 NATURE OF GENES

ACTIVITY 6

Just like a person has his/her own character and personality, genes also have their unique characters or nature. By nature we mean the inherent character or basic constitution of a gene. So, find out the nature of genes from the internet. Make a report on the same and present to the class.

1. A complete set of an organism's DNA is called **genome**. A **gene** is a segment of DNA that encodes for a *particular trait*. *For example*—black hair, brown hair etc.
2. **Chromosomes** are the structures that hold genes; they are made up of strands of DNA tightly wrapped around histone proteins.
3. Genes are located on the chromosomes.
4. In the chromosome, a gene is found in a pair or alternative forms called alleles. An allele is one of two or more versions of the same gene or gene locus. Two alleles for each gene, one from each parent, are passed on to offspring. Homozygous pair refers to two of the same alleles (Figure 3.18); and heterozygous pair refers to two different alleles.
5. Each gene allele occupies a specific position in each chromosome called locus (plural- loci).
6. Alleles are either **dominant** or **recessive**. Dominant allele will be expressed wherever it is present, even if it is paired with recessive allele. But recessive allele is expressed only when it is paired with another recessive allele.

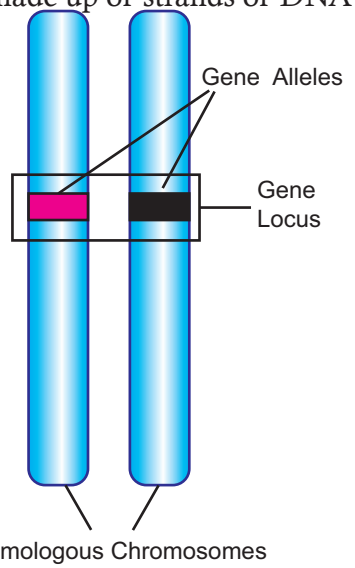


Figure 3.18: A diagram specifying the position of gene, locus

7. When two or more alleles are present in a gene, the condition is called **multiple alleles**. Example: Human blood types. The ABO Blood Type in human beings is determined by three alleles. I^A, I^B, i. Both I^A and I^B are codominant alleles. They are dominant to the allele, "i." Allele "i" is recessive (Table 3.4).

Table 3.4: Human blood type

Genotype	Blood Type
I^AI^A	A
I^Ai	A
I^BI^B	B
I^Bi	B
I^AI^B	AB
Ii	O

8. The gene may change its phenotypical (trait) expression due to sudden change in its genetic composition. The changed gene is known as **mutant gene**. The phenomenon of change in genetic composition is known as **mutation**.

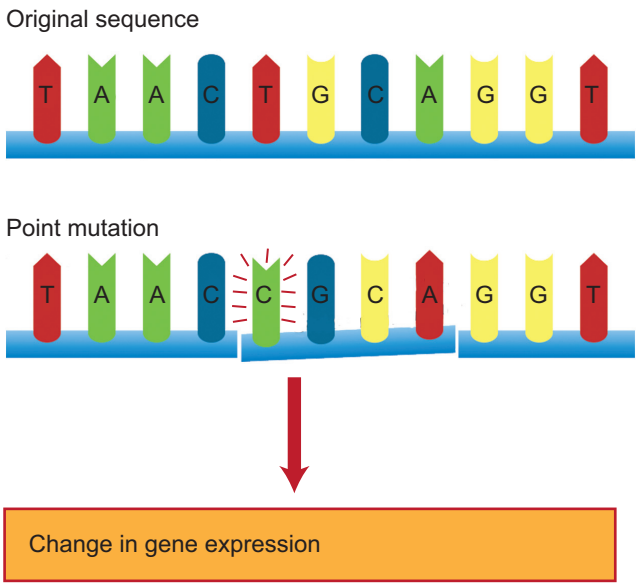


Figure 3.19: Mutation in a DNA sequence. [T base is replaced by C base]

9. Genes duplicate themselves very accurately by DNA replication. **DNA replication** is the process of producing two identical DNA replicas from one original DNA molecule during cell cycle. It occurs in all living organisms and is the basis for biological inheritance.

10. **Central Dogma:**

The central dogma of molecular biology is an explanation of the flow of genetic information, from **DNA** to **RNA**, to make a **functional protein** within a biological system.

Figure 3.20: Central Dogma-information flow in a biological system

11. **Split Genes:**

In most eukaryotes, the genes are not continuous. Rather, the exons, the coding regions, in the m-RNA are interrupted by several distinct units of non-coding regions called **intron**. Since, the exons are split by introns, such genes are called **split genes or mosaic genes or discontinuous genes**. The intron regions are removed in the latter stage of transcription by a process called **splicing**. However, introns are absent in prokaryotes.

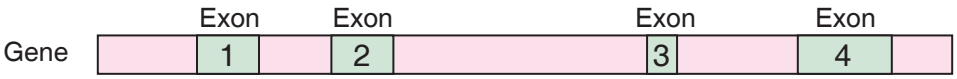


Figure 3.21: A diagram showing m-RNA regions of exons and introns

12. **Genetic Code:**

In the process of translation, ribosome reads the sequence of the m-RNA in a group of three nucleotides called **codons** or **nucleotide triplets**. Thus, the genetic code is the set of rules by which information encoded in the form of codons or nucleotide triplets in the m-RNA is translated into proteins by living cells using ribosome machinery. Each codon specifies a particular amino acid with some exceptions.

13. **One Gene/One-Polypeptide Hypothesis:**

George Beadle and Edward Tatum came up with the idea that each gene encodes the structure of one enzyme. This idea was called the **one-gene/one-enzyme** hypothesis. However, presently it is known that many enzymes have multiple polypeptide subunits, and each subunit is encoded by a separate gene. This relationship is now referred to as the **one gene/one-polypeptide hypothesis**.

3.7 GENETIC CODE

ACTIVITY 7

1. Discuss the following in the class.

   The genetic code (codons) in m-RNA code for amino acids; and there are 64 possible codons (sense and nonsense codons). But there are only 20 standard amino acids. How is it possible that there are excess codons present to code for only 20 amino acids?

2. Make a report on it and present it to the class.

Genetic Code

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. In other words, the genetic code is a set of rules that specify how the nucleotides sequence (ATGC) of an m-RNA is translated into the amino acid sequence of a polypeptide chain.

The Structure of Genetic Code

The structure of genetic code is related to a series of exciting discoveries.

It was **George Gamow** (1954), a physicist, who argued that since there are only 4 bases and if they have to code for 20 amino acids, the code should constitute a combination of bases. In order to code for all the 20 amino acids, he suggested that the code should be made up of three nucleotides (**triplet code**). The permutation and combination of three nucleotides 4^3 ($4 \times 4 \times 4$) would generate 64 codons. Proving that codon was triplet (i.e., three nucleotides) was quite a challenging task. But the chemical method developed by **Har Govind Khurana** for synthesizing RNA molecules with defined combinations of bases (homopolymers and copolymers), and **Marshall Nirenberg's** cell free system for protein synthesis finally helped the genetic code to be deciphered. In the 1968, both of them, Marshall Nirenberg and Hare Gobind Khurana along with Robert Hollye were awarded Nobel Prize in Physiology and Medicine. Finally, a checker board for genetic code (Figure 3.22) was prepared which is as follows.

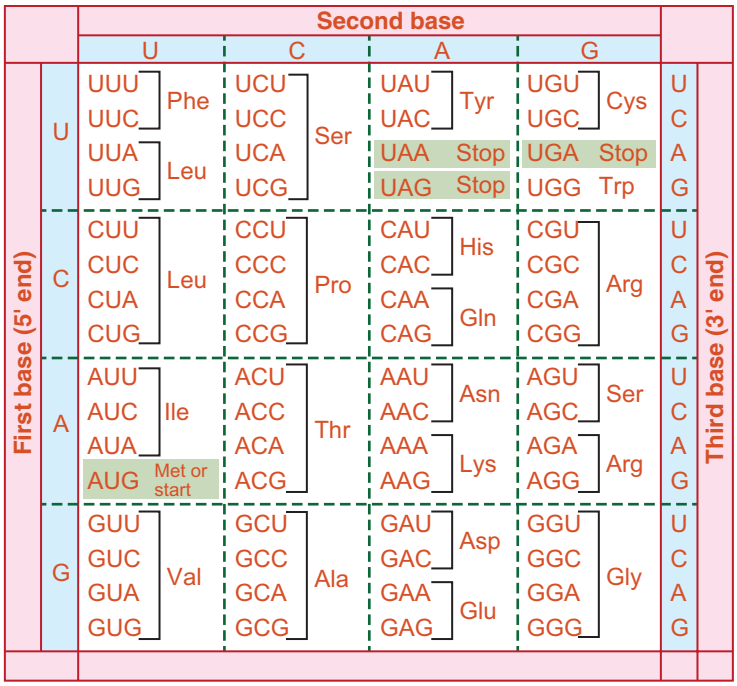


Figure 3.22: Genetic Code: The first, second and third bases as read from 5' to 3' direction constitute the triplet code in RNA. The codon AUG specifies methionine and is usually the starting point for protein synthesis. The word 'stop' indicates codons serving as signals to terminate protein synthesis. For each amino acid more than one codon have been identified. It would be clear from the Figure that while the first and second bases remain the same for a particular amino acid, the third base can be different

SELF EVALUATION

Complete with the correct word

(i)The phenomenon of change in genetic constitution is called .....

(ii) Two of the same alleles result in ..... pair.

(iii) Alleles can be ..... or ..... .

(iv) The sense codon AUG, is a ..... codon.

3.8 SUMMARY

- Chromosome is composed of three main components: Nucleotides, histones proteins, and non-histones proteins.
- Nucleotide is subdivided into pentose sugar, nitrogenous bases, and phosphate groups.

- The presence of DNA in chromosomes is important for three main reasons—Protection from damage, conserve space, and control of gene expression.
- Nucleotide is made up of pentose sugar, nitrogenous bases, and phosphate groups; whereas, nucleoside is made up of pentose sugar and nitrogenous bases.
- Phosphodiester bond connects the phosphate group, which is attached on 5' of one nucleotide, with the 3' carbon of another nucleotide. This bond is a strong bond. That is why DNA is a stable structure.
- Polynucleotide chains have polarity. On one end, there is a 5' carbon with a *phosphate group*. On the other end, there is a 3' carbon with a *hydroxyl group* on it.
- Chargaff's rules state that DNA of all organisms should have a 1:1 ratio of purine (A, G) and pyrimidine (T, C) bases. The specific base pairing of A-T bases and G-C bases is called complementary base pairs.
- In 1953, Watson and Crick proposed the double helix structure of DNA.
- The two strands of DNA are anti-parallel; the bases on both strands are bonded by hydrogen bonds in line with Chargaff's rules. DNA has major and minor grooves.
- DNA is also described as twisted ladder structure.
- RNA has a hydroxyl group at 2' carbon of pentose sugar. It has a uracil base instead of thymine.
- Unlike DNA, RNA is not the genetic material of many organisms except for few viruses.
- DNA is double stranded while RNA is normally single stranded; DNA transfer genetic material while RNA is involved directing the synthesis of proteins.
- A telomere is a region of repetitive nucleotide sequences at each of the tip of chromosomes.
- Telomere protects important genes from being deleted, and thus allows a continued replication.
- Telomere regions are synthesized by a telomerase enzyme.
- Telomeric regions are important in ageing and cancer treatment.
- A gene codes for a specific trait.
- A particular gene can be present in two versions called alleles. When more than two versions of gene are present, it is called multiple alleles.
- Alleles can either be dominant or recessive.
- Genes duplicate themselves through the process of DNA replication.
- Genes are copied from DNA to RNA through a process called transcription.
- Message in the m-RNA is translated into proteins through a process called translation.
- Many enzymes have multiple polypeptide subunits, and each subunit is encoded by a separate gene. This relationship is called one gene/one-polypeptide hypothesis.
- It 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.

- Out of 64 codons, 61 codons are sense codons and 3 codons are non-sense codons.
- A codon is made up of three nucleotides or triplets.
- Genetic code is almost universal; it shows degeneracy.

3.9 GLOSSARY

- **Alleles:** An allele is one of two or more versions of the same gene or gene locus.
- **Central dogma:** The flow of genetic information, from DNA to RNA, to make a functional protein within a biological system.
- **Chargaff's rule:** It is a rule that states that DNA of all organisms should have a 1:1 ratio of pyrimidine and purine bases. Thus, 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).
- **Chromosomes:** They are the structures that hold genes; they are made up of strands of DNA tightly wrapped around histone proteins.
- **Gene:** A gene is a segment of DNA that encodes for a particular trait.
- **Genetic code:** It is the set of rules by which information encoded in the form of codons or nucleotide triplets in the m-RNA is translated into proteins by living cells using ribosome machinery.
- **Histone proteins:** They are proteins that play an important role in organizing the physical structure of the chromosome.
- **Multiple alleles:** The condition where two or more alleles are present in a gene. The ABO Blood Type in human.
- **Nucleoside:** A combination of only a pentose sugar and nitrogenous base, without phosphate group, is called nucleoside.
- **Nucleotides:** The monomers that make up deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are called nucleotides. Nucleotide has three components:—Pentose (five-carbon) sugar, Nitrogenous (nitrogen-containing) base, and Phosphate group.
- **Phosphodiester bond:** It is a chemical bond where the phosphate group, which is attached on 5' of one nucleotide, forms a bond with the 3' carbon of another nucleotide. Many phosphodiester bonds are formed in between sugar and phosphate groups.
- **Split genes:** The exons, the coding regions, in the m-RNA are interrupted by several distinct units of non-coding regions called intron. Since the exons are split by introns, such genes are called split genes or mosaic genes or discontinuous genes.
- **Telomerase enzyme:** It is an enzyme which maintains the length of chromosome by adding telomere repeats (TTAGGG) at 3' end overhang, which serves as template on previous DNA replication.
- **Telomere:** A telomere is a region of repetitive nucleotide sequences at each of a chromosome.

3.10 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. In DNA, the pentose sugar is ribose.
2. RNA has a hydrogen atom at 2' carbon position.
3. Pyrimidine is a single-ringed structure.
4. DNA contains adenine, thymine, guanine, and cytosine.
5. Out of these five histone proteins, H1 is loosely attached to the rest of the histone core proteins.
6. Non-histone proteins are acidic proteins.
7. Purine bases use its 9 position nitrogen to attach with 1' carbon in pentose sugar.
8. DNA is left-handed double helix.
9. UAG, UGA and UAA nucleotides are stop codons.
10. In genetic code, degeneracy means degeneration of DNA.

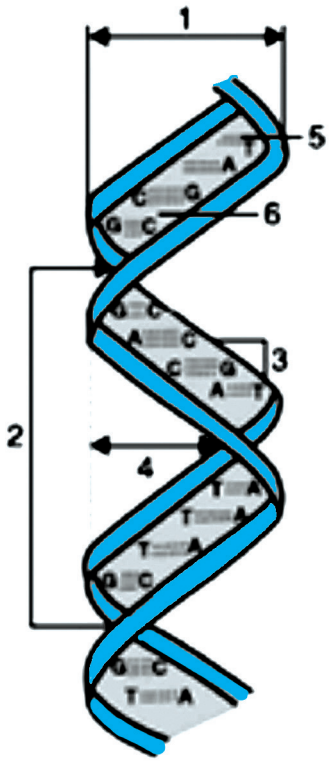
II. Multiple Choice Questions

1. Codon is a group of
   (a) 2 nucleotides (b) 3 nucleotides
   (c) 4 nucleotides (d) 5 nucleotides
2. Newborn babies have telomeres ranging from around
   (a) 8,000 to 13,000 base pairs (b) 8,000 to 16,000 base pairs
   (c) 8,000 to 12,000 base pairs (d) None of these
3. Split genes are
   (a) Genes with splitting chromosomes
   (b) Genes separated from one another
   (c) Genes where exons are interrupted with introns
   (d) Genes where introns are interrupted with exons
4. Mutant gene is
   (a) A gene with different mother genes
   (b) A gene where nucleotide sequence has changed due to mutation
   (c) A gene where different genes exist together
   (d) A gene of different shape and size
5. Splicing is process of
   (a) Removing exons (b) Removing introns
   (c) Removing coding genes (d) Removing DNA

6. Recessive allele will express only when
   (a) It occurs with dominant alleles (b) It occurs with other recessive allele
   (c) It is absent (d) It is present with proteins
7. 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
8. Nitrogenous bases of the two strands of DNA are linked with
   (a) Hydrogen bonds (b) Covalent bonds
   (c) Ionic bonds (d) Phosphodiester bonds
9. DNA does not have
   (a) Adenine (b) Cytosine
   (c) Guanine (d) Uracil
10. Gene codes for
   (a) Polypeptides (b) Blood
   (c) Specific trait (d) Specific genome

III. Long Answer Type Questions

1. In your own words, describe the composition of chromosomes.
2. List at least three differences between the structures of DNA and RNA.
3. Why is DNA important in chromosomes?
4. What is telomere? Give the significance of telomere in replication and its importance in cancer treatment.
5. Describe structure of a Genetic code.
6. In your own words, explain why the structure of DNA is described as a ladder twisted into a spiral.
7. Draw the structure of DNA having at least 6 base pair sequence.
8. How did Watson and Crick determine the nucleotide base pairing pattern? Explain in your own words.
9. In your own words, describe the nature of genes.
10. (i) Identify the structure shown in figure.
   (ii) Write the measurement (distance) of the parts marked (1), (2), (3), (4) and (5).
   (iii) How many H-bonds are there at the place marked (6)?
   (iv) How many different forms of the shown structure have been reported to occur in the living organisms? Give their names.
   (v) Which of them has/have left handed spiral and which of them right handed spiral?
   (vi) Mention any 2 other special features of the form having left handed spiral.



11. Explain the role of nucleic acids in detecting HIV-AIDS. Describe NAT and also tell why NAT is not suitable for detecting ultra-law HIV-I DNA and RNA within host cellular compartments.

Unit 4

DNA Replication

Key Unit Competence

To be able to explain the process of DNA replication and its significance to living organisms.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- determine how the structure of DNA enables it to reproduce itself accurately.
- appreciate the importance of proper DNA replication.
- state semiconservative replication as a process by which DNA unzips and each new molecule of DNA (daughter DNA) contains one intact strand from the original DNA (parent DNA) and one newly synthesised strand.
- apply knowledge of complementary base pairing in DNA to interpret Meselson and Stahl's experiment to test different hypothetical models for DNA replication using *E.coli* grown in a heavy nitrogen (^{15}N) medium.
- acknowledge improper DNA replication would result into genetic changes in the nucleus that would have both positive and negative effects on organisms. For example, changes in the metabolism of cells, variation that can result into evolution and mutations that may lead to death.
- state the role of enzymes involved in replication of DNA.
- list the ingredients used to make DNA in a test tube.
- describe how semi-conservative replication of DNA takes place.
- state that conservative and dispersive replications are other hypothesis for DNA replication.
- explain the importance of DNA replication in organisms.

DNA replication is the process by which DNA makes a copy of itself during cell division. It produces two identical replicas from one original DNA molecule. This biological process occurs in all living organisms and is the basis for biological inheritance.

4.1 MODELS OF DNA REPLICATION

ACTIVITY 1

Look in books and on the internet how DNA replicates. Research on semi-conservative model of DNA replication. Also, try to find other models of DNA replication and present your findings to class.

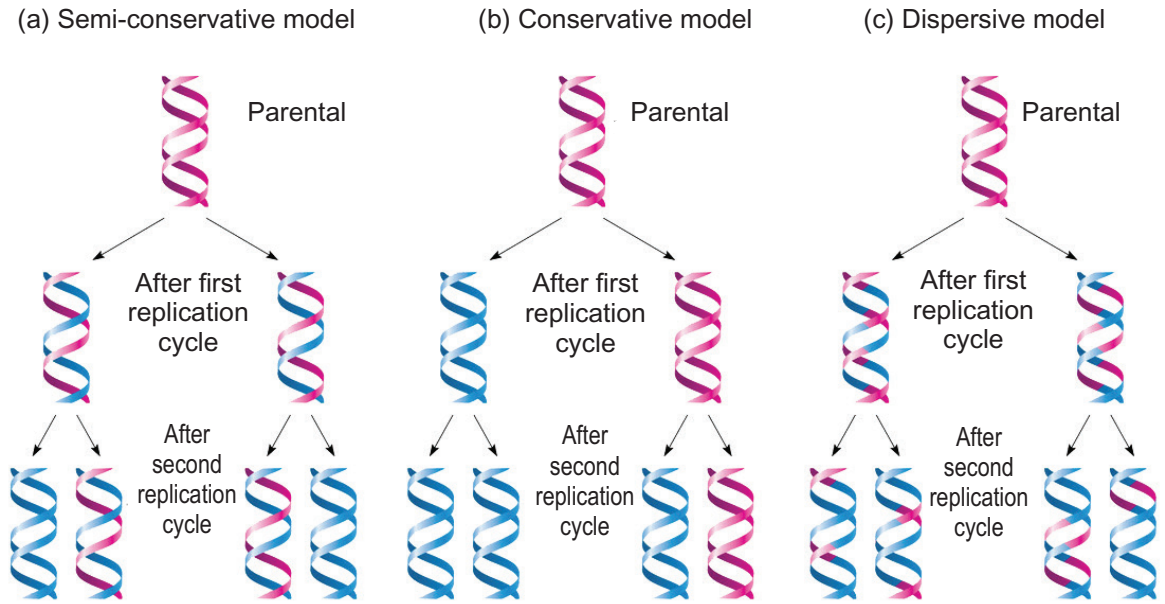


Figure 4.1: Three different models of DNA replication

4.1.1 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 (Figure 4.1).

4.1.2 Other Two Models of DNA Replication

Apart from semiconservative replication model, two other models for DNA replication were also proposed at that time. The two other DNA replication models are:

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 (Figure 4.1).

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 (Figure 4.1).

4.2 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.

4.3 EXPERIMENTAL EVIDENCE OF SEMI-CONSERVATIVE DNA REPLICATION

ACTIVITY 2

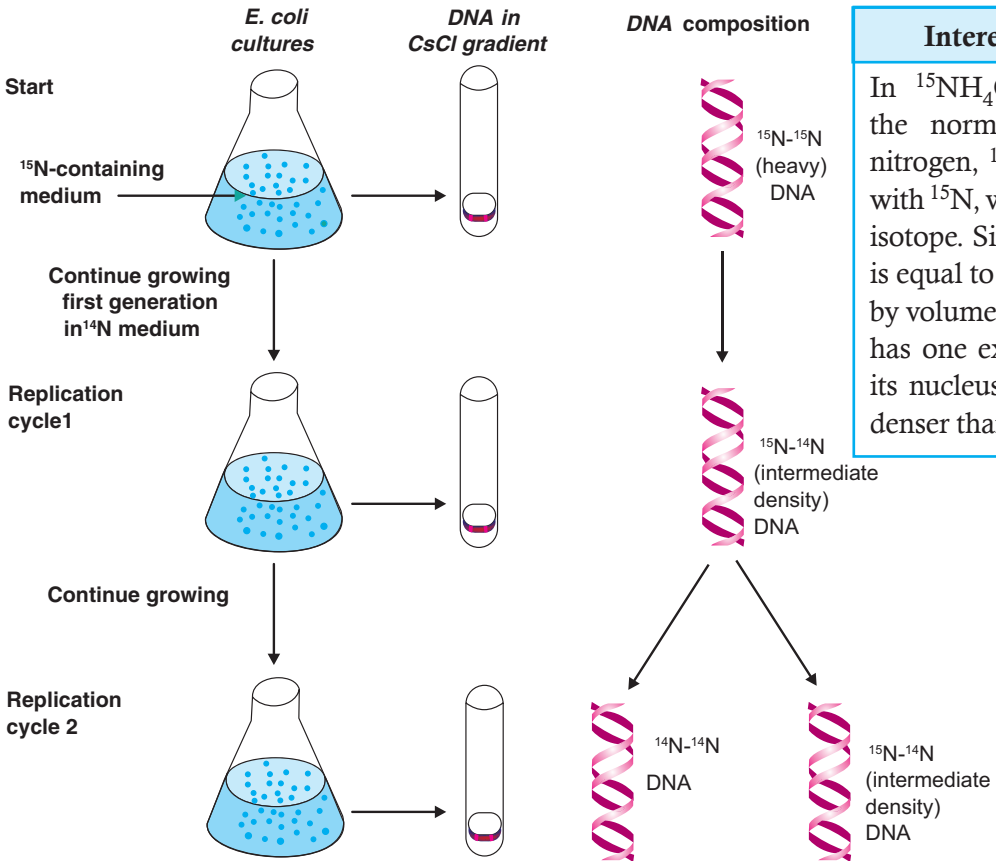
If semi-conservative model is the correct model of DNA replication, research and present your case by supporting it with experimental evidence. Also tell how semi-conservative model disproved other models of replication.

In 1958, Matthew Meselson and Franklin Stahl performed the experiment to test and prove that DNA replication is **semi-conservative.** In their experiment, they 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 4.2).

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 analysed 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 analysed the extracted DNA by simply mixing it with a solution of cesium chloride and then centrifuged at high speed.



Interesting Fact

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.

Figure 4.2: The Meselson-Stahl Experiment

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 4.2).

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 (Figure 4.2) 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.

SELF EVALUATION

(i) ..... is the process by which DNA makes a copy of itself.

(ii) ..... and ..... proposed the semi-conservative model of DNA replication.

(iii) ..... and ..... are two other models of DNA replication.

4.4 ENZYMES AND PROTEINS INVOLVED IN DNA REPLICATION

ACTIVITY 3

Different parts of a car function together to smoothly and efficiently run a car. DNA replication is also like a running car. It requires different components or parts to smoothly and efficiently carry out DNA replication. Now, find out and discuss the enzymes and proteins involved in DNA replication. Make a table suggesting their roles and importance.

4.4.1 DNA Polymerase

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. And the term DNA polymerase by definition encompasses enzymes that catalyses the synthesis of DNA.

There are five DNA polymerases.

1. DNA polymerase I
2. DNA polymerase II
3. DNA polymerase III
4. DNA polymerase IV
5. 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. The elongation is done in 5′ → 3′ direction, DNA polymerase I, II, III, IV and V are involved in DNA repair. On the other hand, DNA polymerase I, II, IV, V are involved in DNA repair.

4.4.2 DNA Helicase

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

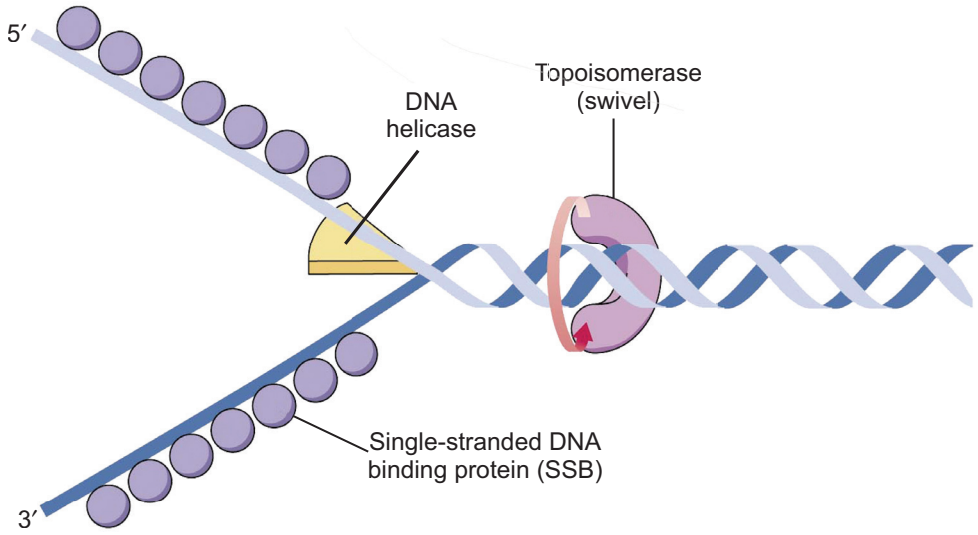


Figure 4.3: A diagram showing DNA helicase, SSB, and Topoisomerase unwinding double stranded DNA

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.

4.4.3 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 stabilise them, so that the separating two strands of DNA do not reform double stranded DNA by complementary base pairing (Figure 4.3).

4.4.4 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 4.4). This nick is the point where the sugar-phosphate backbone between adjacent nucleotides is unconnected. So, what DNA ligase does is to join the two fragments resulting into a longer and continuous DNA strand.

Chemically, DNA ligase catalyses 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).

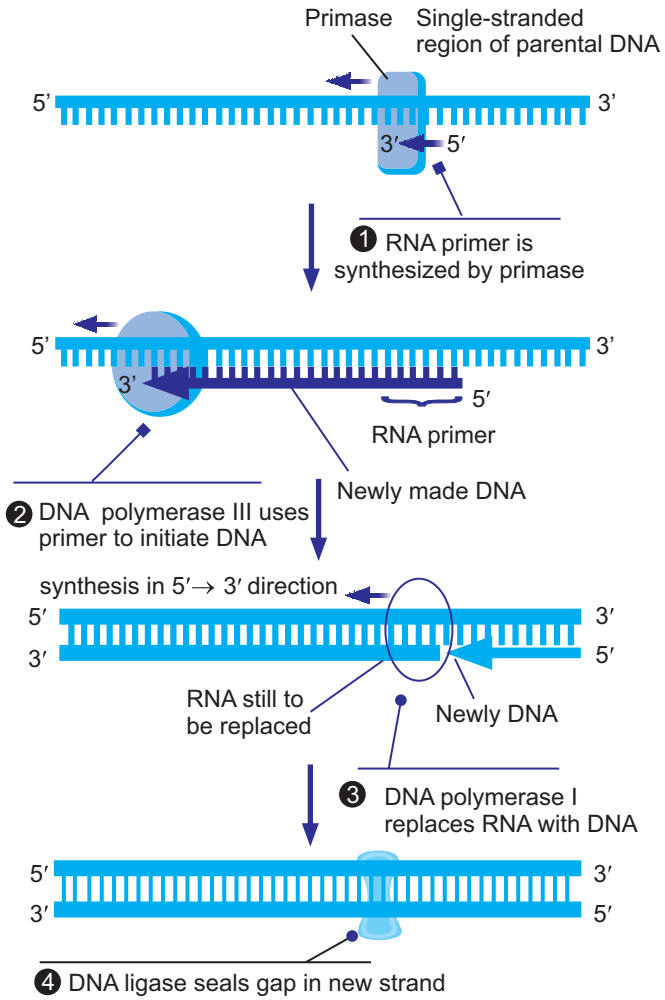


Figure 4.4: A flow diagram showing DNA ligase sealing the gap in a new DNA strand

4.5 MECHANISM OF DNA REPLICATION

ACTIVITY 4

Use models, charts, video clips and illustrations to understand the process of DNA replication. Once you are done, answer the following questions.

- Why is DNA replication important?
- Where does DNA replication take place in the body?
- How does the mechanism of DNA replication occur?

List of the Ingredients used to Make DNA in A Test Tube

Having studied in the vitro DNA synthesis reaction in detail, the scientists have found out that in order to synthesize DNA, the following components are required for making DNA in a test tube.

1. **A DNA template:** The template (original) DNA that is to be copied. A template is a molecule which is used to make a complementary DNA molecule in the DNA synthesis. Normally, the two parental DNA strands act as DNA templates.
2. **dNTPs (deoxynucleotides):** A mixture of four deoxyribonucleoside 5'-triphosphate (dNTPs) precursors namely: dATP, dGTP, dTTP, and dCTP. These dNTPs are the precursors for the nucleotide formation in DNA. Without these dNTPs, new DNA cannot be synthesized.
3. **DNA polymerase I (DNA Pol I):** An enzyme to carry out DNA synthesis.
4. **A primer:** A primer is a short DNA sequence that will bind with the single parent DNA strand and start the DNA synthesis reaction. Without primer, the coming nucleotides cannot directly base-pair with parent DNA template.
5. **Magnesium ions (Mg^{2+}):** It is required for DNA polymerase activity to run optimally.
6. **Buffer:** Provides a suitable chemical environment for optimum activity and stability of the DNA polymerase.

4.5.1 Mechanism of DNA Replication in Prokaryotes

Prokaryotic cells are quite simple in structure. They have no nucleus, no organelles and a small amount of DNA in the form of a single, circular chromosome. Example is *Escherichia coli* (*E.coli*). The mechanism of DNA Replication can be discussed clearly in the following points.

1. DNA replication starts when DNA helicase **unwinds or unzips** the DNA at the **origin of replication** in both the directions.
2. The locally denatured segment of DNA is called the **replication bubble**. The two separated parent DNA strands are called **template strands**.
3. A Y-shaped structure which is formed when DNA unwinds or unzips to expose the two parent single template strands for DNA replication is called as **a replication fork** (Figure 4.5). In most of the cases, replication forks are formed in both sides and, thus, move simultaneously in two opposite directions. In other words, the movement of replication fork is **bidirectional** (Figure 4.5).
4. In the next step, DNA helicase recruits DNA **primase** enzyme. Primase enzyme **synthesizes a short RNA primer** (about 5-10 nucleotides) on the two template strands through which new nucleotides are added by DNA polymerase III.

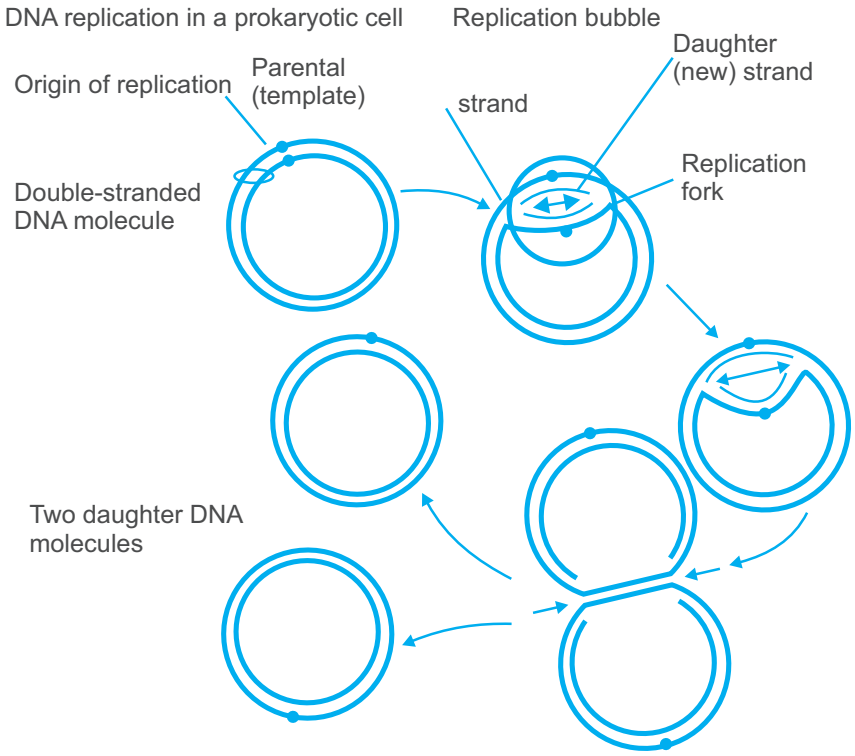


Figure 4.5: A diagram showing replication bubbles

5. The denaturing or separating two strands of DNA have the tendency to reform (reanneal) double stranded DNA. A protein called **single-strand DNA-binding (SSB) proteins**

bind to each single-strand DNA and stabilise them, so that the separating two strands of DNA do not reform double stranded DNA.

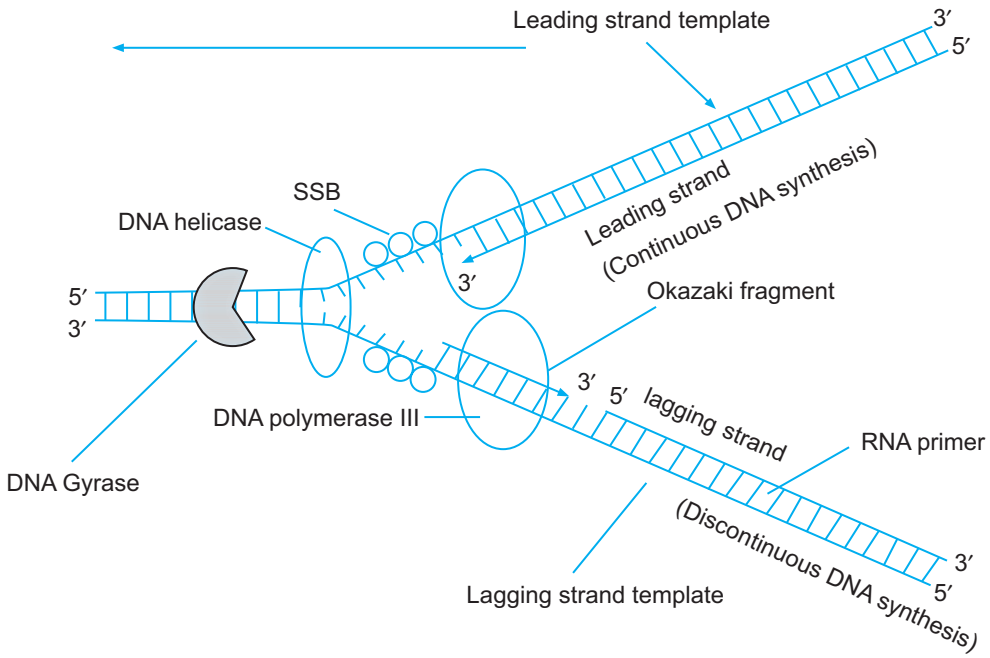


Figure 4.6: DNA replication fork

6. As the two single-strands of DNA are held in Y-shaped position and are stabilized by SSB proteins, the DNA polymerase III now comes and **starts adding nucleotides** by forming **phosphodiester bonds** at the 3′-OH of the primer.
7. The DNA polymerase III can add nucleotides only in **5′-3′ directions**. However, the two strands of DNA run in opposite directions forming a polarity. Thus, to maintain the 5′-3′ polarity of DNA synthesis on both of the two single templates, DNA is simultaneously made in opposite directions of the two template strands (Figure 4.6).
   (a) The new DNA strand that is synthesized in the same movement of the replication fork is called the **leading strand**. This strand requires a **single primer** for the complete DNA replication.
   (b) On the contrary, the other new DNA strand that is synthesized in the opposite direction of the movement of the replication fork is called the **lagging strand**. This

strand requires **primers again and again**. Therefore, the newly synthesized DNA strand is **discontinuous in nature**. And the newly synthesized fragments of DNA on lagging-strand are called **Okazaki fragments**.

8. The unwinding of the DNA to form a replication fork creates a tension which is relaxed by **DNA gyrase or topoisomerase**.
9. At the end of the DNA replication, the RNA primers on the previous Okazaki fragments are removed by **DNA polymerase I**.
10. After the DNA polymerase I left, a **single-stranded nick** is left at the site of the removal of primer. DNA ligase seals the nick. This completes the process of DNA replication.

4.5.2 Mechanism of DNA Replication in Eukaryotes

Eukaryotic cells have nucleus, multiple organelles and more DNA arranged in multiple, linear chromosomes. Examples–Yeast (*Saccharomyces cerevisiae*), Humans. DNA replication in eukaryotes (having linear chromosomes) is initiated at **multiple sites** of origin of replication (Figure 4.7). In yeast cells, replicators are approximately 100 bp sequence called **autonomously replicating sequences (ARS)**.

The **origin of replication** or **replicator** is located at the centre of each replicon. Replicator is a DNA sequence that directs the initiation of replication. The initiation of DNA synthesis at the replicator takes place by a mechanism involving several groups of initiator proteins.

- Firstly, **origin recognition complex (ORC)**, a multi-subunit protein complex, binds to a replication origin.
- Secondly, **mini-chromosome maintenance (MCM)** proteins bind to the replication origin. MCM proteins include several DNA helicases that unwind the double helix.
- Thirdly, **helicase loaders**, a third set of proteins, mediate binding of MCM proteins to origin of origin recognition complex (ORC).

Pre-replication Complex

The complete group of DNA-bound protein is now called as a **pre-replication** complex. And at this stage, the DNA is said to be "**licensed**" for replication.

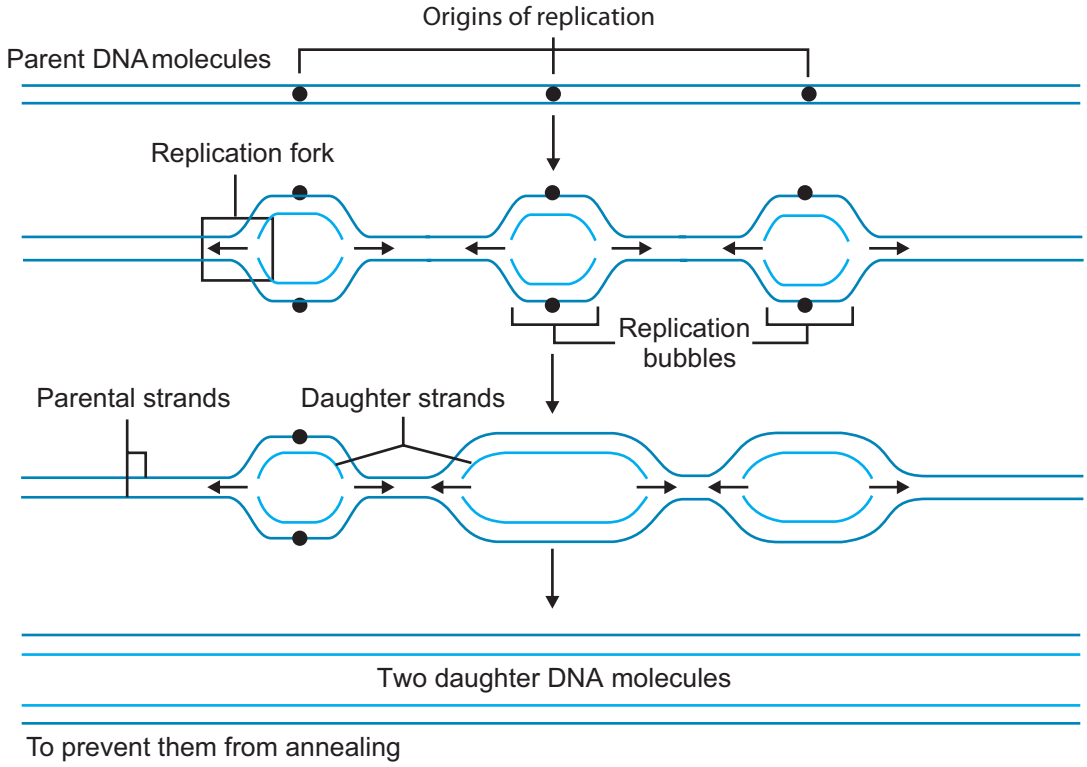


Figure 4.7: DNA replication in eukaryotes

Replication Bubble (Multiple)

Initiation of DNA synthesis at the origin of replication is followed by formation of **replication bubble**. This bubble is formed by two replication forks that begin to synthesize DNA in opposite directions away from the origin (Figure 4.7). And these bubbles grow in size as replication proceeds in both 5' and 3' end directions. Wherever the growing replication bubble of one replicon meets the replication bubble of an adjacent replicon, the DNA synthesized by the two replicons is joined together. Eventually, the DNA synthesized at numerous replication sites is linked together to form two double stranded daughter molecules.

Significance of Multiple Replicons

In humans, the haploid genome has 24 chromosomes. These chromosomes consist of about **3 billion base pairs** long. And eukaryotic chromosome is **25 times** longer than the prokaryotic chromosome. Moreover, the movement of replication fork is much **slower** in eukaryotes than in prokaryotes. In this kind of condition, if eukaryotic chromosome has only one origin of replication or replicator per chromosome, replication of each chromosome would take many

days. So, the question is how does the eukaryotic chromosome replicate faster despite having a huge amount of chromosomes?

The answer lies in two main characters of the eukaryotic chromosomes. And they are:

(a) DNA replication is initiated at many origins of replication throughout the genome.

(b) DNA replication is bidirectional in nature. In other words, the replication forks move in two directions at a time.

4.5.3 The Rate of Replication in Prokaryotes and Eukaryotes

Prokaryotes

The genome *E.coli* consists one replicon with a size of 4.6 Mb (million base pairs, the entire genome size). The rate of each replication fork movement is about **1000 base pair (bp) per second**. With this rate, *E.coli* takes about 42 minutes to replicate its entire chromosome.

Eukaryotes

The eukaryotic genome consists of multiple replicons. For example, in humans, there are about 10,000-100,000 replicons for an average of 30-300 kb (1000 base pairs). And the rate of replication fork movement is about 100 bp per second. Thus, it takes about 8 hours to replicate the entire genome.

SELF EVALUATION

Complete the sentence with correct word:

(i)The full form of ORC is ..... .

(ii) The tension ahead of the replication fork is relaxed by ..... .

(iii) The newly synthesized strand is ..... in nature.

(iv) It takes about ..... hours to replicate the entire genome in Eukaryotes.

(v) DNA replication in Eukaryotes is ..... in nature.

4.6 MECHANISMS THAT ENSURE ACCURACY OF DNA REPLICATION

(A) Complimentary Base Pairing

The nitrogen bases of DNA follow the Chargaff's rule of base pairing. In simple words, this rule says that Adenine (A) base pairs with Thymine (T); Guanine (G) base pairs with Cytosine (C). This base pairing is very strict and accurate. Thus, the complementary base pairing directs the DNA to replicate very accurately and prevents any mistake to occur.

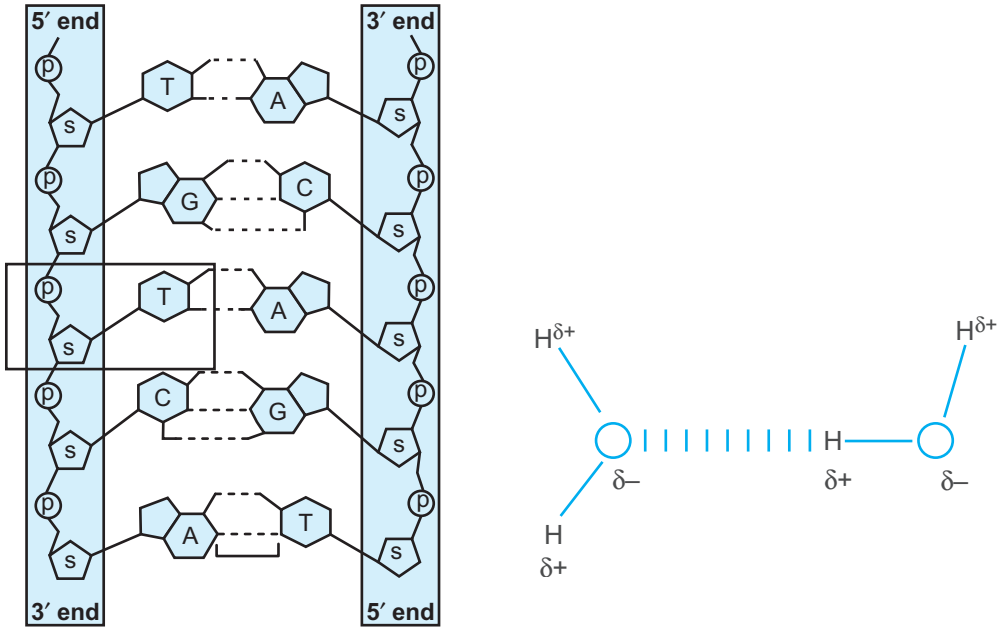


Figure 4.8: (a) Complementary base pairing of DNA (b) A hydrogen bond

Base pairing between purines and pyrimidines is possible because of hydrogen bonds. We can simply define **hydrogen bond** as the **attractive force** between the hydrogen attached to an electronegative atom of one molecule and an electronegative atom of a different molecule (Figure 4.8 b). In the structure of DNA, both the strong electronegative atoms, oxygen (O) and Nitrogen (N), are partially negatively charged (δ–), while the hydrogen (H) has the partial positive charge (δ+). Hydrogen bonds or interactions play very important role in binding the two bases of the opposite strands in the DNA.

(B) Semi-conservative Nature of DNA

In DNA replication, two of the original strands of DNA act as templates for new DNA to be synthesized. So, when the new strands of DNA are synthesized, they are just the complimentary bases of the two original template strands of DNA. In this way, original sequence of DNA is semi-conserved with the two original strands of DNA. Thus, the semi-conservative nature of DNA makes the DNA replication highly accurate.

(C) Proofreading

DNA Pol I and DNA Pol II polymerase enzymes have **3′-to-5′ exonuclease activity**, which means that they can remove incorrectly inserted nucleotides from the 3′ end to 5′ end of the

DNA chain. Thus, they play important role in **proofreading mechanism**. The insertion of incorrect nucleotides by both DNA Poly I and DNA Poly III occurs at a frequency of one base in a million (10^{-6}).

When incorrect nucleotides are inserted in the newly synthesized DNA, the 3′-5′ exonucleases move backward and remove the incorrect nucleotide from the newly synthesized DNA. Then they resume the forward movement and insert the correct nucleotides in place of the incorrect nucleotides. With this proofreading mechanism, the chances of error occurrence in DNA replication is reduced to one base in a billion (10^{-9}) instead of one base in a million (10^{-6}).

(D) Mismatch Repair

After DNA Replication if there are any mismatched base pairs on the newly synthesized strand, it can be corrected by methyl-directed mismatch repair. In contrast to proofreading mechanism where only one base is repaired by DNA polymerase, the mismatch repair mechanism can replace about thousand bases to make one repair. The **Mut family** of enzymes plays an important role in mismatched repair.

Main Differences Between Prokaryotic and Eukaryotic DNA Replication

Table 4.1: Differences between prokaryotic and eukaryotic DNA replication

S. No.	DNA Replication in Prokaryotes	DNA Replication in Eukaryotes
1.	Single origin of replication per DNA molecule	Multiple origin of replications per DNA molecule
2.	Occurs inside cytoplasm of the cell	Occurs inside nucleus of the cell
3.	It occurs only at one point	It occurs at multiple points
4.	It has one replication bubble	It has multiple replication bubbles
5.	It has one replicon	It has multiple replicons
6.	Initiation is carried out by DNA helicases	Initiation is carried out by multiple proteins like origin recognition complex (ORC), minichromosome maintenance (MCM) proteins, helicase loaders
7.	No licensing is required	Licensing for replication is required
8.	DNA polymerase I and III are involved	DNA polymerase α, ε, and δ are involved
9.	The rate of DNA replication is about 1000 bp per second	The rate of DNA replication is about 100 bp per second
10.	Okazaki fragments ranges from 1000-2000 bp long	Okazaki fragments ranges from 100-200 bp long

4.7 EFFECTS OF IMPROPER DNA REPLICATION

A. Mutation: A Key to Variability and Evolution

DNA alterations are occasionally beneficial because DNA base-sequence changes, or mutations, provide the genetic variability that is the raw material of evolution. In other words, mutation provides variation that can result into beneficial evolution.

Example: Resistance of Bacteria to Drug. The *Esherichia coli* (bacterium) lives in colon of human beings. Initially if they are exposed to chloramphenicol, an antibiotic drug, they die. When Cavilli and Maccacro (1952) exposed the bacteria to high concentration on chloramphenicol, they found out that the bacteria have mutated and were 250 times resistant to antibiotics. In this case, mutation has provided variability in the bacterial population to evolve into a new species which has high survivability against the antibiotic drugs. Thus, mutation is beneficial for the bacterial population.

B. Lethal Mutation: Mutation that May Lead to Death

One of the best examples is **Tay-Sachs disease (TSD)**. TSD is a fatal autosomal recessive genetic disorder. It is caused by a mutation in the Hexosaminidase A (alpha polypeptide) [**HEXA gene**]. A genetic mutation is a permanent alteration in the DNA sequence that makes up a gene; this mutation is lethal. It mostly occurs in children and leads to progressive destruction of the nervous system. When a child with Tay-Sachs reaches the age of three or four years, the nervous system is severely affected. Eventually, death occurs by the age of five years.

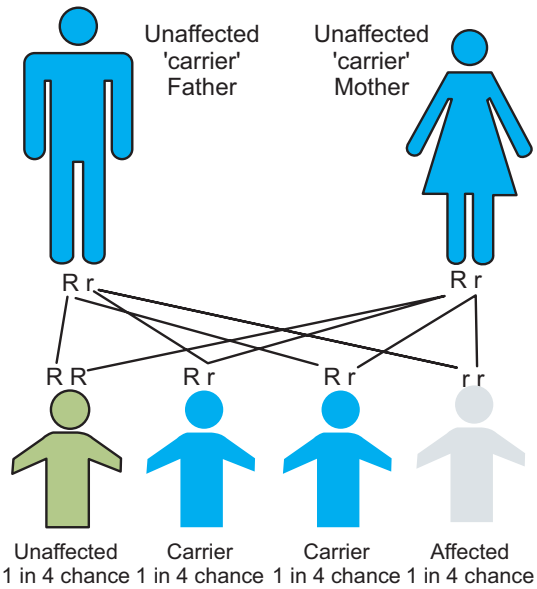


Figure 4.9: A diagram showing the chances of inheriting Tay-Sachs when both the parents are carriers

Mutation in Hex-A Gene Causes Tay-Sachs: Tay-Sachs disease results from defects in a gene on chromosome **15** due to mutation. The gene located on chromosome 15 codes for the production of the enzyme Hex-A. In normal people, either or both Hex-A genes are active. Thus, the synthesis of this enzyme prevents the abnormal build-up of the GM2 ganlioside lipid.

ACTIVITY 5

Discuss the rate of replication in prokaryotes and eukaryotes. State the main difference between prokaryotes and eukaryotes. Also revise DNA replication processes in both prokaryotes and eukaryotes.
Make a report on it and present it to the class.

SELF EVALUATION

Complete the sentence with correct word:

(i)..... is an example of lethal mutation.

(ii) ..... plays an important role in proofreading mechanisms.

(iii) Alkaptonuria is also known as ..... disease.

(iv) ..... provides variation that can result into beneficial evolution.

(v) Base pairing in DNA occurs due to ..... bonding.

4.8 SUMMARY

- DNA replication is the process of producing two identical DNA replicas from one original DNA molecule.
- DNA replication plays an important role in reproduction, DNA repair and growth of organisms.
- DNA replicates semi-conservatively, where the two original strands act as template while the other two strands are newly synthesized.
- The other two models of replication are conservative and dispersive DNA replications.
- Meselson and Franklin Stahl performed the experiment to test and prove that DNA replication is semi-conservative.
- Enzymes and Proteins Required for DNA Replication are:
  - — DNA polymerase I and III are functionally required for replication. But DNA polymerase I, II, IV, V are involved in DNA repair.
  - — DNA helicase has the role of unzipping or unwinding the double strand structure of DNA.
  - — DNA gyrase serves as a main swivel that prevents supercoiling of the DNA ahead of the replication fork.

— SSB proteins relax the tendency of the two separated DNA strands to reform double stranded DNA.

— DNA ligase seals the nick at the end.

- The list of the ingredients to make DNA in a test tube involves : a DNA template, dNTPs, DNA polymerase I, primers, magnesium ion, and buffer solutions.
- In Prokaryotes, DNA replication starts with DNA helicase unwinding or unzipping the double stranded DNA. Replication forks are formed, then, primers bind on the two separated strands of DNA. DNA polymerase III starts synthesizing new DNA strands on both the strands at 5′-3′ directions.
- The synthesis of DNA is discontinuous and thus produces numerous small Okazaki fragments.
- DNA polymerases I and III have 3′-5′ exonuclease activity. Thus, they remove the primers and replace the gap with complementary nucleotides.
- In Eukaryotes, replication takes place at multiple sites of origin of replications. In yeast cells, replicators are approximately 100 bp sequences called autonomously replicating sequences (ARS).
- Many replicons are formed.
- DNA replication is initiated by multiple proteins.
- Many replication bubbles are formed.
- The main polymerase enzymes involved are: DNA polymerase α, $\beta\delta$, ε; they have different roles.
- The eukaryotic cells have chromosomes 25 times longer than the prokaryotes. Prokaryotes have only one replicon. Eukaryotes have multiple replicons, which help in replicating faster than if there were only one replicon.
- The rate of replication in prokaryotes is about 1000 bp per second, whereas the rate of replication in eukaryotes is about 100 bp per second.
- There are basically four mechanisms that ensure accuracy of DNA replications: Complimentary base pairing, semiconservative nature of DNA, proofreading, and mismatched DNA repair.
- Normally uncorrected mistakes in DNA replication are repaired by DNA repair mechanism. But in very rare cases mistakes are not corrected, leading to mutation.
- On the positive side, mutation can bring species variation and evolution. On the negative side, mutation can bring defects in metabolic pathway and may also cause death.

4.9 GLOSSARY

- **3′-to-5′ exonuclease activity:** DNA Pol I and DNA Pol II polymerase enzymes have this activity, which means that they can remove incorrectly inserted nucleotides from the 3′ end to 5′ end of the DNA chain.
- **Alkaptonuria:** It is a rare inherited genetic disorder in which the body cannot process the amino acids phenylalanine and tyrosine.
- **Chargaff's rule:** This rule says that adenine (A) base pairs with thymine (T); Guanine (G) base pairs with cytosine (C).
- **DNA fyrase:** It is an enzyme which serves as a swivel that prevents supercoiling of the DNA ahead of the replication fork.
- **DNA helicase:** It is an enzyme which unwinds the double stranded DNA.
- **DNA ligase:** It is an enzyme which joins the two DNA fragments into a continuous DNA strand.
- **DNA polymerase:** It is an enzyme that catalyzes the synthesis of DNA.
- **dNTPs:** It is a mixture of four deoxyribonucleoside 5′-triphosphate precursors namely: dATP, dGTP, dTTP, and dCTP.
- **Eukaryotes:** Eukaryotic cells have nucleus, multiple organelles and more DNA arranged in multiple, linear chromosomes. Examples: Yeast, Humans.
- **Mutation:** It is a process by which nucleotide sequence (or base pairs) of DNA is altered.
- **Primase:** It is an enzyme which synthesizes primer.
- **Primer:** A primer is a strand of short nucleic acid sequences (generally about 10 base pairs) that serves as a starting point for DNA synthesis.
- **Prokaryotes:** They have no nucleus, no organelles and a small amount of DNA in the form of a single, circular chromosome. Example is Escherichia coli (*E.coli*).
- **Replication fork:** It is a Y-shaped structure which is formed when DNA unwinds to expose the two parent single template strands for DNA replication.
- **Semi-conservative model:** During DNA replication, each strand of DNA acts as a template for the synthesis of a new complementary strand of DNA. And this complementary strand of DNA could then be bound to the parental strand of DNA.
- **Single-strand DNA-binding proteins (SSB):** These are stabilizing proteins that bind on the separating two stands of DNA so that they do not reform into double stranded DNA structure.
- **Tay-sachs disease (TSD):** TSD is a fatal autosomal recessive genetic disorder. It is caused by a mutation in the Hexosaminidase A (alpha polypeptide) [HEXA gene].

4.10 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. In conservative DNA replication model, two identical daughter DNA strands are formed.
2. Meselson and Stahl experiment proved dispersive DNA replication model after two replication cycles.
3. Without dNTPs, new DNA cannot be synthesized.
4. In Chargaff's rule of base pairing. Adenine base pairs with Cytosine.
5. DNA polymerase I has 3′-5′ exonuclease activity.
6. Tay-Sachs disease (TSD) is a fatal autosomal dominant genetic disorder.
7. Topoisomerase II acts as a swivel to prevent supercoiling of DNA.
8. Mutation can be both beneficial and lethal.
9. Synthesis of DNA in lagging strand is discontinuous.
10. Primer is required again and again in the leading strand of DNA.

II. Multiple Choice Questions

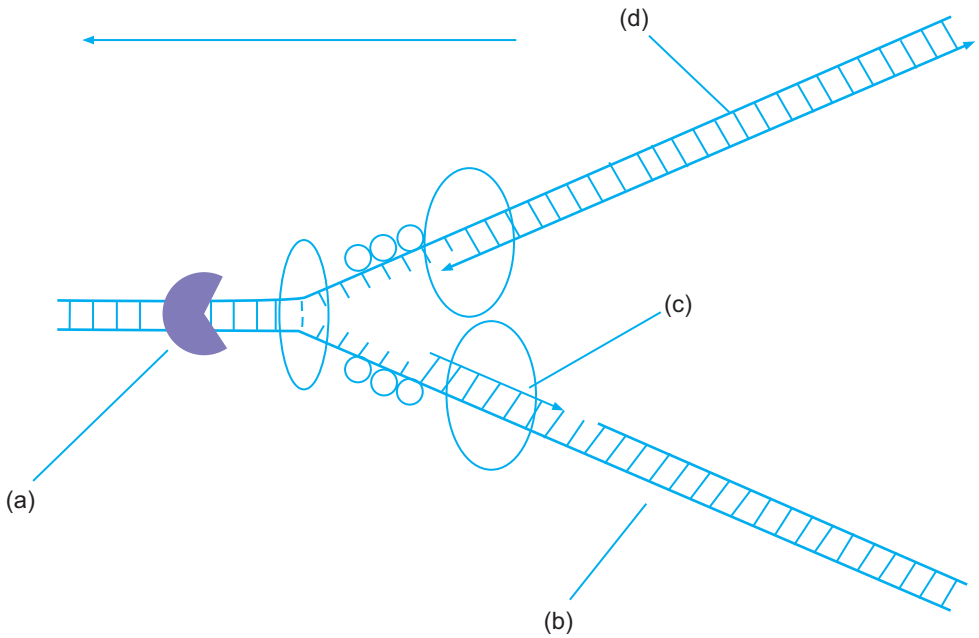
1. DNA replication plays an important role in
   (a) reproduction (b) growth of organisms
   (c) DNA repair (d) All of the above
2. Meselson and Stahl are known for
   (a) Complementary base pairing
   (b) Genetic Code
   (c) Semi-conservative DNA replication
   (d) Conservative DNA replication
3. DNA helicase has a role to
   (a) Seal the nick at the end of DNA replication.
   (b) Relax the tendency of DNA to reform double helix structure.
   (c) Unwinds or unzips double stranded DNA.
   (d) Cut DNA randomly.
4. Which of the following is not an ingredient to make DNA in a test tube?
   (a) dNTPs (b) Primers
   (c) Magnesium ion (d) Calcium ion

5. The mechanisms that ensure accuracy of DNA replications are
   (a) complementary base pairing (b) Proofreading
   (c) Mismatched DNA repair (d) All of the above
6. This happens when mistakes are not corrected by DNA repair mechanism.
   (a) Mutation (b) Replication
   (c) Repair (d) Growth
7. Syntherized fragments of DNA on lagging strand are
   (a) Origin complex (b) Mini chromosome
   (c) Okazaki fragments (d) Autonomously replicating sequence
8. Mut family protein is important in
   (a) Semi-conservative DNA replication
   (b) Mismatched repair
   (c) Hydrogen bonding
   (d) Organizing DNA structure
9. DNA polymerase δ appears to perform
   (a) Synthesis of DNA on the lagging strand
   (b) Synthesis of DNA on the leading strand
   (c) Prevention of supercoiling in DNA
   (d) Unwinding of DNA
10. The main initiator proteins of DNA replication in eukaryotes consist of three proteins except
   (a) Origin recognition complex
   (b) Helicase loaders
   (c) Single-stranded binding proteins
   (d) Minichromosome maintenance proteins

III. Long Answer Type Questions

1. State how complementary base pairing in DNA devises the Meselson and Stahl's semiconservative model of replication.
2. Explain different types of DNA replication models.
3. Describe the roles of enzymes involved in DNA replication.
4. Explain the mechanism to show how the structure of DNA enables it to reproduce itself accurately.

5. Describe the importance of DNA replication in organisms.
6. (i) Identify the structure shown in figure.
   (ii) Write the label (a) to (d).
   (iii) Describe the process wherein DNA unzips and each new molecule of DNA forms daughter DNA.



7. List out the ingredients used to make DNA in a test tube.
8. Mutation are the ultimate fuel for evolution. Describe mutations as a key genetic factor in both positive and negative terminology of biology.
   Also tell how some people get more sick from bacteria and viruses than others. What role does our genes play to get that difference?
9. DNA replicates and form a part of HIV-cure-related research. Investigate on the various aspects of DNA replication detecting HIV DNA.

Unit 5

Cell and Nuclear Division

Key Unit Competence

To be able to describe the stages of the cell cycle and explain the significance of cell and nuclear division in organisms.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- describe the main stages of the cell cycle, including: interphase (growth and DNA replication), mitosis and cytokinesis.
- explain what is meant by homologous pairs of chromosomes.
- explain the meaning of the terms haploid and diploid.
- describe the process of mitosis and meiosis.
- outline the significance of mitosis in cell replacement and tissue repair by stem cells.
- state that uncontrolled cell division can result in the formation of a tumour.
- define meiosis as reduction division in which the chromosome number is halved from diploid to haploid.
- explain the need for reduction prior to fertilisation in sexual reproduction.
- outline the role of meiosis in gametogenesis in humans and in the formation of pollen grain and embryo sacs in flowering plants.
- explain how crossing over and random assortment of homologous chromosomes during meiosis and random fusion of gametes at fertilization leads to genetic variation, including the expression of rare recessive alleles.
- interpret data related to time for different cell cycles to identify tissues from which the cells came.
- apply knowledge of mitosis to predict which set of cells came from and which part of the plant and where other cells have come from.
- make a table showing the phases of the cell cycle mentioning one important event that occurs at each phase.
- compare mitosis and meiosis.
- appreciate the importance of effective cell division.
- show concern to individuals with physical disabilities like Down's syndrome.

ACTIVITY 1

We know that human beings have 46 chromosomes in total. If it is so, will the number of chromosomes increase when gametes from father and mother fuse together during fertilization to form a zygote. Discuss and come out with valid points to support your arguments.

Cell cycle is one of the most important biological events in organisms. Every actively dividing cell undergoes cell cycle. The most prominent events in cell cycle consist of nuclear division (karyokinesis) and cytoplasm division (cytokinesis). During cell cycle, chromosomes undergo many changes such as replication, uncoiling, condensation, pairing, cross over, and separation.

A karyotype is a visual representation of the chromosomes within a single cell where the number of chromosomes, their arrangement, size and structure can be analysed (Figure 5.1).

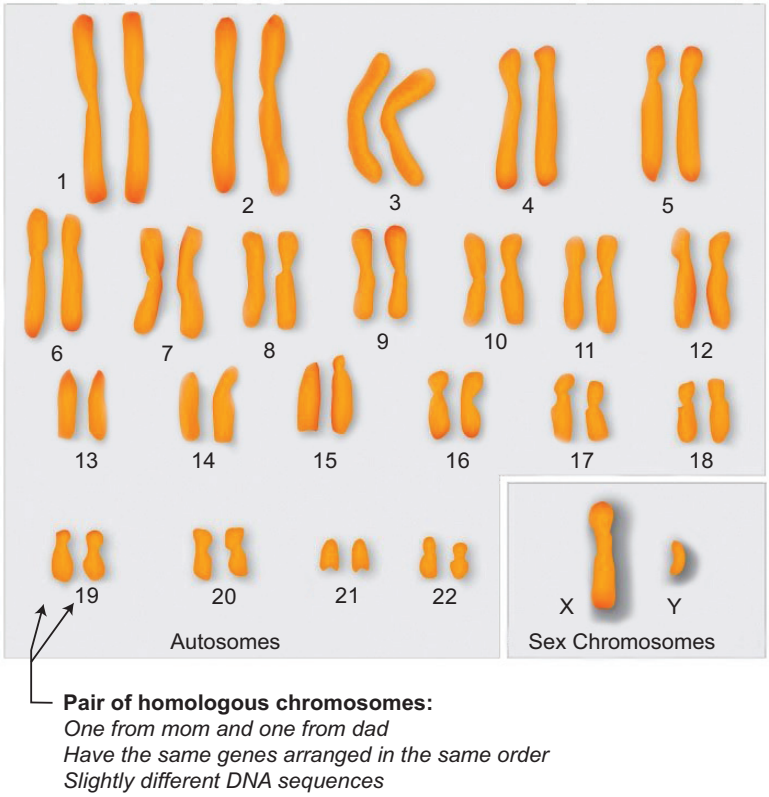


Figure 5.1: Human Karyotype

The chromosome pairs, one from each parent, which is similar in length, gene position, and centromere location, is called as a homologous chromosome. In humans, for example, the 23 chromosome pairs are **homologous chromosomes**. On the contrary, the chromosomes that contain different genes and do not pair during meiosis are called as **non-homologous chromosomes**. For example: In the human karyotype, chromosome 1 and chromosome 2 are non-homologous.

Chromosomes are of two types: (a) autosomes (b) sex chromosomes. Out of 23 pairs of chromosomes, one pair of chromosomes is **sex chromosome**. And chromosomes other than sex chromosome are called **autosomes**. The cells that are involved in reproduction are called **gametes** (Sperm and eggs). The cells that are not involved in gamete formation are called **somatic cells** (Muscle cells, liver cells).

The cells which contain two complete sets (2n) of chromosomes are called **diploid cells**. These cells are formed by the fusion of two haploid gametes, one comes from the female parent and the other comes from the male parent. For example, all the somatic cells are diploid cells. In contrast, cells that contain only one complete set (1n) of chromosome are called as **haploid cells**. Example is gamete cells in humans. Two separate haploid gametes, one from male parent (sperm, 1n) and another from female parent (ovum, 1n), come together and fuse to form **a zygote**, which is a diploid (2n).

5.2 MITOSIS AND ROLE OF MITOSIS IN LIVING ORGANISMS

Cell cycle is a cyclical event of cell growth, mitosis, and cell division. All somatic cells of an organism's body divide by mitosis. The cell cycle basically consists of two phases: Mitotic Phase and Interphase.

1. **Mitotic (M) Phase:** It includes mitosis and cytokinesis. Mitosis is the division of nucleus while cytokinesis is the division of cytoplasm. As result of mitotic phase, one cell divides into completely two identical daughter cells.
2. **Interphase:** A typical cell spends most of its time in interphase. It accounts for about 90% of the whole cell cycle. Interphase involves growth and DNA replication processes. It is further divided into (Figure 5.2):
   (a) **G0:** It is a resting phase and it can be temporary or permanent.
   (b) **G1-Phase:** It is also called the **first growth phase** or **post mitotic gap phase**. During this phase, the cell grows in size and there is an active synthesis of RNA and proteins. In this phase, the cell carries out its physiological functions and prepares

the machinery needed for the cell to proceed to the next stage. A large number of nucleotides, amino acids for histone synthesis and energy rich compounds are formed. Cell organelles also increase in number. However, it shows no change in its DNA content.

(c) **S-Phase:** It is also called **synthetic phase**. In this phase, DNA molecule of each chromosome replicates by the synthesis of a new DNA on the template of the existing DNA. Thus, the DNA content doubles and duplicate set of genes are formed. Along with DNAs, chromatin fibres also replicate. As chromatin fibres are elongated chromosomes, each chromosome comes to have two chromatin threads or sister chromatids which remain attached at a common point called centromere. The cell thus retains the original diploid (2n) chromosome number but now has a duplicate set of genes. S-phase is also called invisible phase of mitosis, since in this phase chromosome prepares themselves for equitable distribution later on. The **centriole** also divides into two centriole pairs in the cells containing the same.

(d) **G2-phase:** It is also called the **second growth phase** or **premitotic gap phase**. The synthesis of RNA and protein continues in this phase and the cell prepares itself to go into the mitotic phase. The phase produces macromolecules for multiplication of cell organelles, spindle formation and cell growth. During G2-phase, a cell contains double DNA content, i.e., 1C to 2C for haploid cells and 2C to 4C for diploid cells.

Data Related to Time for Different Cell Cycles

The time consumed by each stage in the cell cycle varies from organism to organism. In human beings, one round of cell cycle takes 24 hours. The relative time division is (Figure 5.2):

(a) G1 phase takes about 5-6 hours.

(b) S phase takes about 10-12 hours.

(c) G2 phase takes about 4-6 hours.

(d) M phase takes about less than one hour.

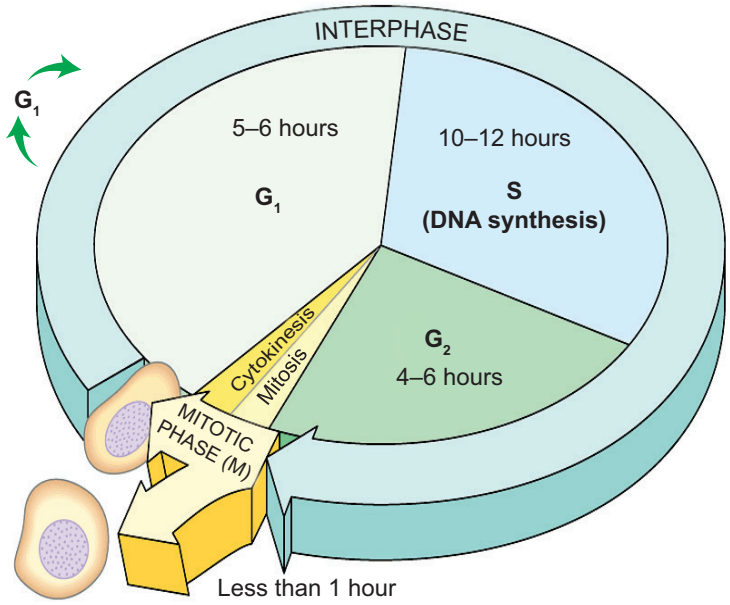


Figure 5.2: The cell cycle

G1 phase is of the most variable length in the cell cycle. Normally, S phase is the longest phase. Cells such as muscle and nerve cells remain in the resting state permanently. On the contrary, cells such as liver cells can resume G1 phase in response to growth factor released during injury.

5.2.1 The Process of Mitosis

Mitosis is one of the phases of cell cycle, which normally last only about less than an hour. It is a process where a single cell divides into two identical daughter cells. And it is normally followed by cytokinesis but not always. The process of mitosis is basically divided into 5 phases:

1. Prophase 2. Prometaphase 3. Metaphase 4. Anaphase 5. Telophase

1. Prophase

- The chromosome fibres become more tightly coiled.
- The chromatids condense into discrete chromosome.
- Each chromosome can be seen to consist of two sister chromatids.
- Nucleolus shrinks and eventually disappears in most species.
- Two pairs of centrioles are seen. The mitotic spindle assembles outside the nucleus.
- The radial arrays of shorter microtubules are called as asters.
- In most animal cells, the centrioles are the focal points for spindle assembly. Higher plants do not have centrioles, though they do have a mitotic spindle.

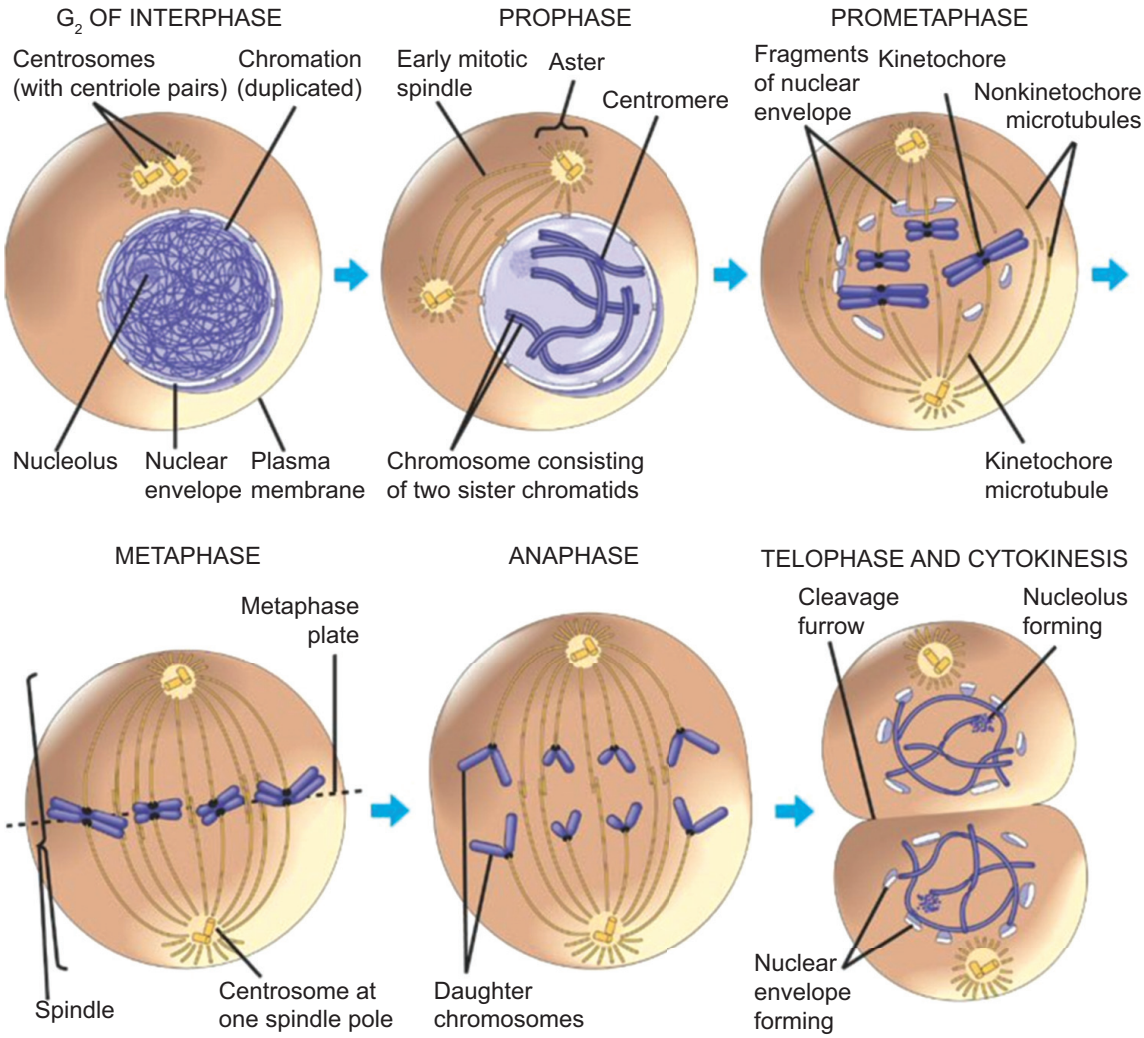


Figure 5.3: Phases of Mitosis (including G2 of interphase)

2. Prometaphase

- The nuclear envelope breaks down at the end of prophase.
- The developing spindle now enters or invades the former nuclear area.
- The chromosomes have even become more condense.
- Kinetochores, a specialized multiprotein complex, bind to each centromere.
- Kinetochore microtubules extend from both the poles and bind to kinetochores of chromatids.
- Non-kinetochore microtubules originate from the two opposite poles and enter into the nuclear area where they overlap in the middle of the spindle.

3. Metaphase

- The centrosomes are now at opposite poles of the cell.
- The kinetochore microtubules from the two poles orient the chromosomes in such a way that their centromeres become aligned at the **metaphase plate**, an imaginary plane that is equidistant between the two poles of the spindle apparatus.

4. Anaphase

- Once the centromeres are attached to the two sister chromatids. They start separating and move towards the opposite poles. Consequently, the joined centromeres of sister chromatids separate and give rise to two daughter chromosomes.
- The separation continues until the two poles of the cell have equivalent and complete chromosomes.

5. Telophase

- The two sets of daughter chromosomes are assembled into two groups at opposite ends of the cell.
- The chromosomes begin to uncoil and assume the elongated state characteristic of interphase.
- A nuclear envelope starts forming around each group of chromosomes.
- The spindle microtubules disappear; and the nucleolus or nucleoli reform.
- At this point, nuclear division is complete and the cell now has two identical nuclei.

Cytokinesis

ACTIVITY 2

Aim: To observe permanent slides of plant root tip and animal cheek cells and outline the differences between the plant cells and animal cells.

Materials Required:

1. Permanent (prepared) slides of animal cheek cells and plant root tips for mitosis.
2. Compound microscope.

Procedure:

1. Take the permanent slides.
2. Try to observe the stages of mitosis and meiosis from the given slides.
3. Draw a well-labelled diagram of the structures you have observed.

4. Outline the differences between how plant cells and animal cells divide.
5. Record your observations in your notebook.

Discussion:

1. Firstly, discuss your result.
2. Secondly, if there is any doubt, ask your biology teachers.

Cytokinesis is a division of cytoplasm. It compartmentalizes the two new nuclei into separate daughter cells, completing mitosis and cell division (Figure 5.3). **In animal cells**, cytokinesis is characterized by a constriction in the middle of the cell. The constriction continues until two daughter cells are produced. **In plant cells**, a new cell membrane and cell wall are assembled between the two new nuclei to form a cell plate. Cell wall material coats each side of the plate, and the result—two progeny cells.

Table 5.1: A table showing phases of cell cycle with one important event at each phase

S. No.	Phase	Main Event
1.	**MITOTIC PHASE (M)**	
	Prophase	• Condensation of chromosomes in the nucleus
	Prometaphase	• Spindle fibres gets attached to the chromosomes and start aligning chromosomes at metaphase plate
	Metaphase	• Chromosomes align at the metaphase plate
	Anaphase	• Chromosomes are separated in two clusters at the two poles
	Telophase and Cytokinesis	• The two clusters of chromosomes have reached the poles and formed two daughter cells • In cytokinesis, separation of cytoplasm has taken place
2.	**INTERPHASE**	
	G0	• It is a resting phase.
	G1	• The cell prepares itself for DNA replication.
	S	• DNA replication takes place.
	G2	• The cell resumes growth before the cell enters the next phase i.e. mitotic phase.

ACTIVITY 3

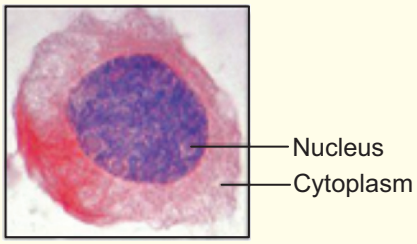
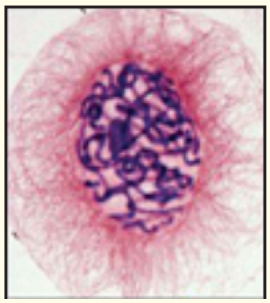
Aim: To Investigate how long onion root tip cells spend in each phase of the cell cycle and present the findings in table form showing the stages of mitosis.

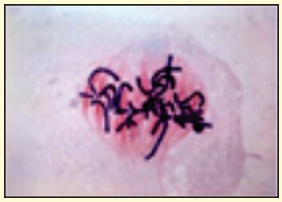
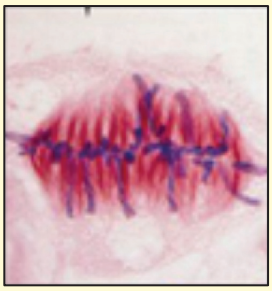
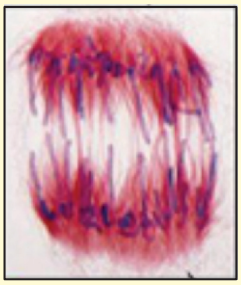
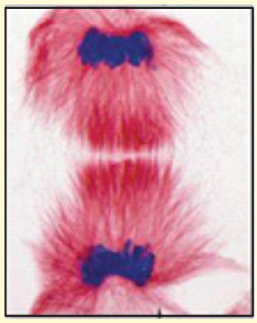
Materials Required:

1. Permanent slides of Onion root tips
2. Compound Microscopes

Procedure:

1. Fix the permanent slides of Onion root tips on the compound microscope.
2. Adjust the lens (10x, 40x etc.) to have a clear view of mitotically dividing onion root cells.
3. Identify the mitotic stage of each cell by following the criteria given in the table below:

S. No.	Stage of Mitosis	Identifying features	Expected Diagrams
1.	Interphase	• Dark nucleus • Presence of nucleolus • No condensation and chromosomes	 Interphase
2.	Prophase	• No nucleolus • Condensed chromosomes in the nucleus	 Prophase

3.	Prometaphase	• Spindle fibres attached on the chromosomes and start aligning chromosomes at metaphase plate	 Prometaphase
4.	Metaphase	• Chromosomes aligned at the metaphase plate	 Metaphase
5.	Anaphase	• Chromosomes are separated in two clusters towards the two poles	 Anaphase
6.	Telophase and cytokinesis	• The two clusters of chromosomes have reached the poles and formed two daughter cells • In cytokinesis, separation of cytoplasm has taken place	 Telophase and Cytokinesis

4. Identify and note down the number of cells at their specific stages. Note it down in your exercise book by copying the following table.

S. No.	Stage mitosis	Number of cells
1.	Interphase	
2.	Prophase	
3.	Prometaphase	
4.	Metaphase	
5.	Anaphase	
6.	Telophase	
	Total cells counted	

5. Onion takes a total time period of 12 hours (720 minutes) to complete mitosis. Now with this information, find out the time period spent by each cell at each stage (i.e. interphase, prophase etc.) by using the given formula:

$$\text{Time for a phase} = \frac{\text{Number of cells in a stage}}{\text{Total number of cells counted}} \times 720 \text{ minutes}$$

For example: Say, 500 cells were counted at interphase stage. And the total number of cells counted was 1000. Then by applying the formula you can calculate how much time was spent by cells at interphase in 12 hours mitosis cycle.

Time for interphase = 500/1000 × 720 minutes = 360 minutes

6. Calculate the time period spent by cells at different stages of mitosis. Note it down by copying the following table in your exercise book. Then analyse the maximum and minimum time spend by cells in all the stages of mitosis.

Observation Table			
S. No.	**Stage of mitosis**	**Number of cells**	**Time Period**
1.	Interphase		
2.	Prophase		
3.	Prometaphase		
4.	Metaphase		
5.	Anaphase		
6.	Telophase		

Notes:

1. Normally, interphase takes the longest time period in the cell cycle.
2. Compare your observations with your class mates.

5.2.2 Significance of Mitosis in Living Organisms

In the early development of an organism, the embryonic cells rapidly proliferate and differentiate into specialized cells of adult tissues and organs. As cells differentiate from time to time, their rate of proliferation usually decreases. As a result, most cells in adult animals are arrested at the Go stage. Some cells at this phase may resume the cell cycle and proliferate when they receive certain signals.

Some of the differentiated cells enter the Go resting phase and wait for the signal to resume the cell cycle to repair injured tissue. There are numerous examples such as skin fibroblast, endothelial cells, smooth muscle cells, and liver cells. Skin fibroblasts upon receiving growth factor, they start secreting collagen and help in repairing cuts or wounds.

Most of the fully differentiated cells no longer possess the capability of cell division. Therefore, they can be replaced by stem cells. **Stem cells** are undifferentiated biological cells that can differentiate into specialized cells and can divide (through mitosis) to produce more stem cells. The prominent role of stem cells can be seen in—blood cells (hematopoietic system), epithelial cells of the skin, and epithelial cells lining the digestive tract (Figure 5.4). All of these cells have short life spans, and they must be replaced continually by continual cell proliferation in adult animals.

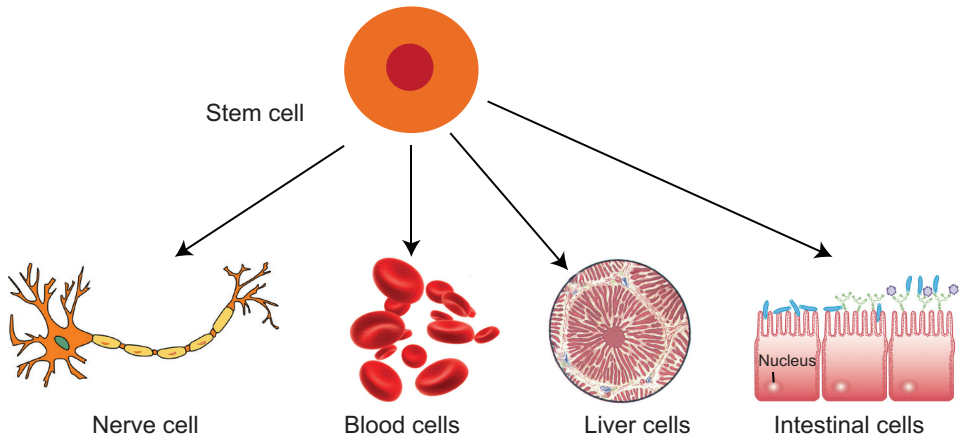


Figure 5.4: Stem cells

The life span of blood cells ranges from less than one day to a few months. All of these cells are derived from the same population of hematopoietic stem cells. In fact, there are more than 100 billion blood cells that are lost every day in humans. If there are no stem cells to replace the loss of these cells, human beings will not be able to survive. Hence, these cells are continually being replaced by cells produced from hematopoietic stem cells in the bone marrow.

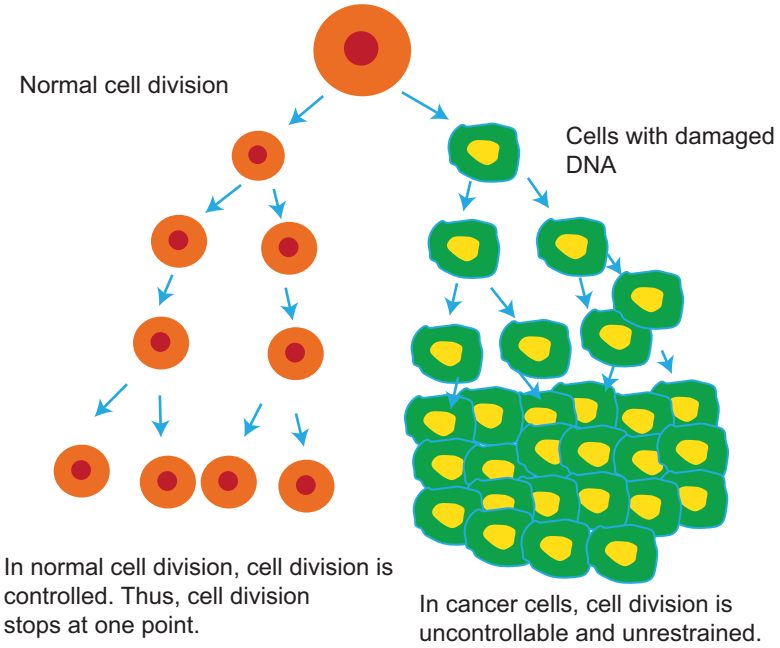


Figure 5.5: A diagram showing normal cell division and uncontrolled cell division (cancer cells)

The **unrestrained, uncontrolled growth of cells in human beings results into a disease called cancer** (Figure 5.5). Cancer essentially is a disease of cell division. In other words, cancer occurs due to failure in controlling cell division.

Tumours

Cancer cells can be dangerous when it starts behaving abnormally in the body. The main problem arises when a single cell in a tissue undergoes a process called transformation. It is a process where a normal cell is converted into a cancer cell. Normally, the body's immune system will recognize the transformed cell as a foreign invading cell and, thus, destroys it. However, if the transformed cell evades or escapes the destruction, it may proliferate and form a **tumour**—a mass of abnormal cells. Tumours can be discussed in three subheadings:

(a) **Benign tumour:** This is a lump of the abnormal cells that remains at the original site. Most benign tumours do not cause serious problems and can be completely removed by surgery.

(b) **Malignant tumour:** These are abnormal cells that have become invasive enough to impair with the functions of one or more organs. An individual with a malignant tumour is said to have cancer.

(c) **Metastasis:** A few tumour cells may separate from the original tumour, enter blood vessels and lymph vessels, and travel to other parts of the body. In the other parts of the body, they may proliferate and form a new tumour. This spread of cancer cells to locations distant from their original site is called **metastasis**.

SELF EVALUATION

Complete with appropriate terms:

(i) In ..... phase of the interphase DNA, replication occurs.

(ii) Karyokinesis is the division of ..... .

(iii) ..... is the resting phase of the cell cycle.

(iv) It approximately takes ..... hours for one round of cell cycle in human beings.

(v) Cancer is the ..... growth of cells.

5.3 MEIOSIS AND ITS ROLE IN LIVING ORGANISMS

ACTIVITY 4

Through micrographs try to observe different stages of Meisois. State the arrangement of chromosomes at every stage. Discuss your observations.

5.3.1 The Process of Meiosis

Meiosis is a reduction division where the number of chromosomes are reduced to half from diploid parent cell to haploid daughter cells. It is divided into two stages: Meiosis I and Meiosis II. The process of Meiosis alternates with an interphase, which is subdivided into G1, S, and G2 phases (Figure 5.2). Meiosis I is further subdivided into prophase I, metaphase I, anaphase I, and telophase I. In the same way, Meiosis II is also subdivided into prophase II, metaphase II, anaphase II, and telophase II.

Meiosis I

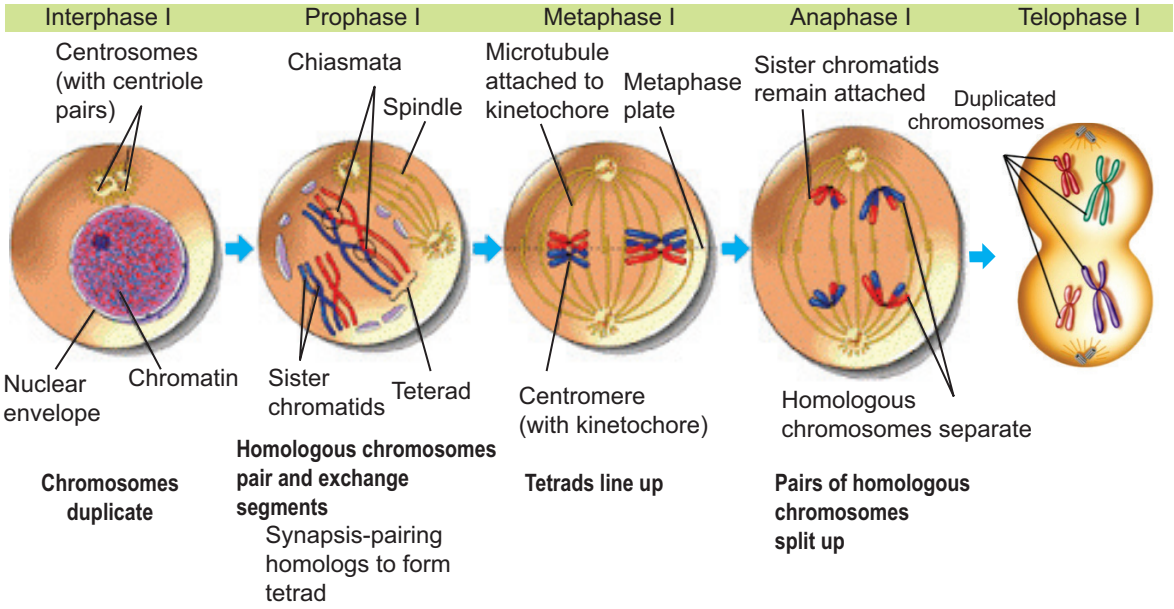


Figure 5.6: The process of Meiosis I

Prophase I

The DNA in prophase I coils tighter, and individual chromosomes first become visible under the light microscope as a matrix of fine threads. Since the DNA has already replicated during the S phase of interphase prior to meiosis I, each of the chromosomes actually consists of two sister chromatids joined together at their centromeres.

Pairing or synapsis

In prophase I, homologous chromosomes become closely associated in **synapsis**. Synapsis includes the formation of an elaborate structure called the **synaptonemal complex**, consisting of homologous chromosomes paired closely along a **lattice or zipper-like structure** of proteins between them (Figure 5.7). The components of synaptonemal complex include a meiosis-specific form of **cohesin**, that helps the two homologous chromosomes to be closely associated along their length.

Crossing over or recombination

Crossing over in meiosis I allows the homologous chromosomes to exchange their chromosomal material. During this, the crossing over between sister chromatids is suppressed. Reciprocal

crossing over occurs only between non-sister chromatids and is controlled in such a way that each chromosome arm usually has one or a few crossovers per meiosis. In human beings, the crossovers are typically two to three in number.

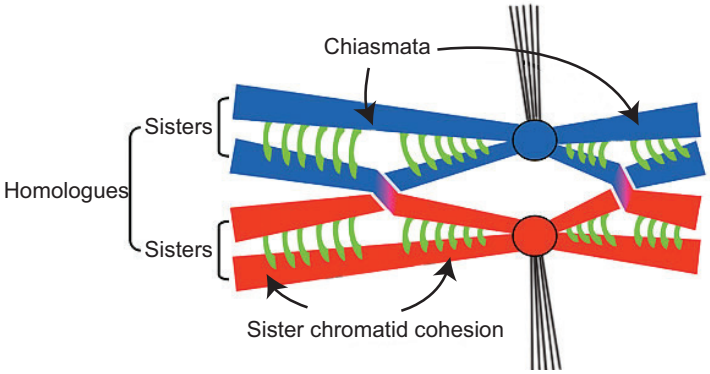


Figure 5.7: Crossing over

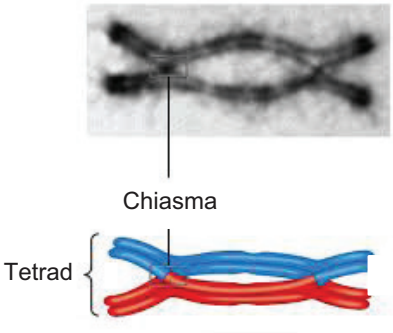


Figure 5.8: Tetrad or bivalent

Once the crossing over process is complete, the synaptonemal complex breaks down, and the homologous chromosomes become less tightly associated. But the homologous chromosomes remain attached at one particular point called **chiasmata** (**chiasma-singular**) (Figures 5.7 and 5.8). At this point, there are four chromatids of the two homologous chromosomes. Two homologous chromosomes consist of two sister chromatids each. This structure of four chromatids of the two homologous chromosomes attached at chiasmata is called as **tetrad or bivalent** (Figure 5.8).

Some of the other events that occur along with synapsis are:

1. The nuclear envelope breaks down.
2. Two pairs of centrosomes migrate to opposite poles.
3. Spindle fibres formation occurs.

Metaphase I

During metaphase I, the chiasmata have moved down on the paired homologous chromosomes towards the ends. At this point, chiasmata are now called as **terminal chiasmata**. The terminal chiasmata hold the homologous chromosomes together so that the homologous chromosomes are now aligned at the equator of the cell. The kinetochores microtubules from the opposite poles become attached to the kinetochore of homologous chromosomes.

The attachment of kinetochore microtubules at the monopolar centromere of each homologue creates a tension on the homologous chromosomes, which are joined by sister chromatid cohesin at chiasmata.

Anaphase I

During anaphase, sister chromatid cohesion is released and the homologous chromosomes are **pulled apart to the opposite poles**, but not the sister chromatids. Now when the spindle fibres have fully contracted, each pole has a complete haploid set of chromosomes consisting of one member of each homologous pair.

Telophase I

In telophase I, the chromosomes are **segregated into two clusters** at the two opposite poles. Then the nuclear membrane reforms around each daughter nucleus. At the two poles, each chromosome has sister chromatids attached to its centromere. And the interesting thing is that the sister chromatids are *no longer identical* because of the crossing over that had taken place in prophase I.

Cytokinesis

Cytokinesis is the process of dividing the cytoplasm and its content into two equal cells (Figure 5.7). Right after telophase I, cytokinesis may or may not occur. Meiosis I is followed by meiosis II, which occurs after an interval of variable length.

Meiosis II

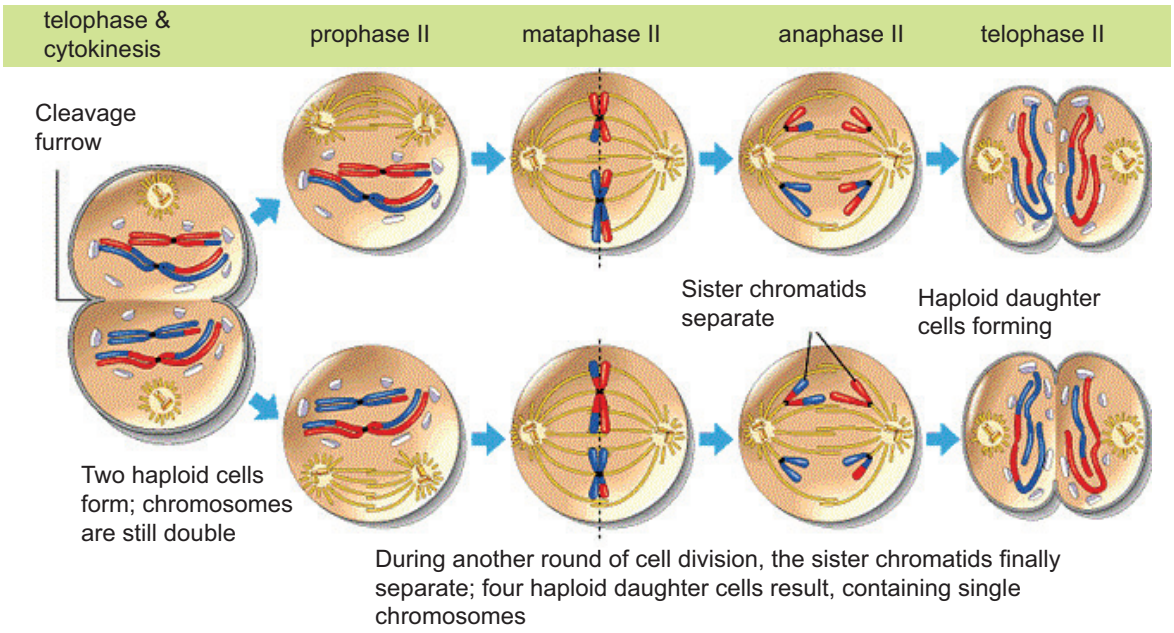


Figure 5.9: Stages of Meiosis II

Meiosis II is like mitotic division, which results into division of two equal cells without DNA replication. Normally, the gap between meiosis I and meiosis II is interrupted by interphase. But the interphase is very brief and it does not contain the S phase. Like mitosis cell division, meiosis II is also subdivided into subphases. They are: (a) Prophase II (b) Metaphase II (c) Anaphase II (d) Telophase II (Figure 5.9).

Prophase II

Prophase II is brief. In prophase II, nuclear envelope breaks down and formation of new spindle fibres takes place.

Metaphase II

In metaphase II, the kinetochore microtubules extend themselves from the two poles and bind to kinetochores of each sister chromatid. These kinetochore microtubules start pulling the sister chromatids toward the two opposite poles. As a result, the sister chromatids are aligned at the metaphase plate.

Anaphase II

In anaphase II, as the spindle fibers contract, the cohesion complex joining the centromeres of sister chromatids is destroyed or cleaved. As a result, the centromeres are split and the sister chromatids are pulled towards the two opposite poles.

Telophase II

In telophase, the nuclear envelope re-forms around the four set of haploid daughter chromosomes. Then cytokinesis follows resulting into complete four set of haploid daughter cells. These haploid daughter cells may follow different fate depending upon the organisms. In animals, these haploid daughter cells develop directly into gametes i.e. sperms and eggs. In plants, fungi, and many protists, they may divide mitotically to produce greater number of gametes.

5.3.2 Meiosis is a Reductional Division

Meiosis reduces the number of chromosomes sets from parental diploid chromosomes (2n) to four haploid (1n) daughter cells. That is why meiosis is called **a reduction division**. In other words, meiosis starts with diploid cell but ends with four haploid cells.

Simple explanation of Meiosis taking place in human beings is given below:

Parent cell = 46 chromosomes (Diploid)

Meiosis I = 2 cells (each chromosome with sister chromatids) = 46 × 2 = 92 chromosomes.

Meiosis II = 4 haploid cells with unreplicated chromosomes = 92/4 = 23 chromosomes (Haploid)

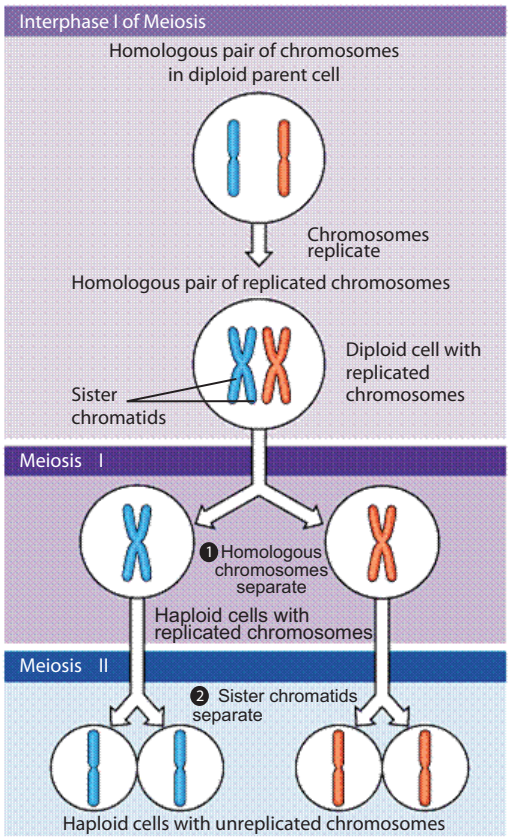


Figure 5.10: Meiosis overview

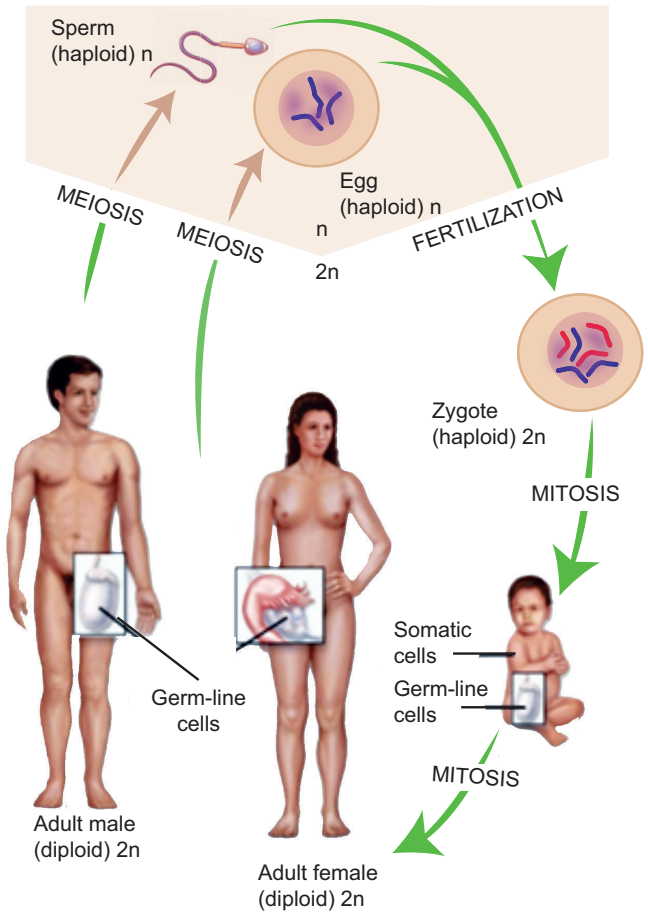


Figure 5.11: Sexual reproduction cycle in human beings.

5.3.3 Significance of Meiosis

Cells Undergo Reduction Division Prior to Sexual Reproduction

Generally, a cycle of reproduction consists of meiosis and fertilization. Before sexual reproduction occurs, gametes undergo meiosis and produce haploid cells. Thus during sexual reproduction, one haploid (1n) gamete comes from the paternal side and another haploid (1n) gamete comes

from the maternal side; then, they both fuse to form a zygote, which is diploid (2n). The fusion of gametes to form zygote or new cell is called as **fertilization** or **syngamy** (Figure 5.10).

If meiosis does not occur before sexual reproduction, the chromosome number would double up with each fertilization. And after few generations, the number of chromosomes in each cell would become impossibly large. For example in humans, in just 10 generations, the 46 chromosomes would increase to about 47104 (46×2^{10}).

Role and Significance of Meiosis in Producing Gametes

Gametogenesis is a biological process by which diploid cells undergo cell division and differentiation to form mature haploid gametes. It occurs through meiosis. In humans, the male gamete (sperm) is produced by a process called **spermatogenesis** and the female gamete (egg) is produced by a process called **oogenesis** through meiotic division.

Here gamete function takes place soon after meiosis but in plants it happens after gametophyte formation sexual reproduction of plants starts with spore formation. Sporophyte is a diploids generation of flowering plant where haploid spores are produced by meiosis which in turns undergoes mitosis to form multi-celled haploid gametophytes. These haploid gametophyte differentiate to produce gametes—sperm and egg cells. Similarly, embryo sac is formed by reduction division. Each of the cells of embryo sac is haploid. Two of the nuclei fuse to produce diploid nucleus.

The Role of Meiosis in Reproduction of Plants

Generally, plants reproducing sexually have life cycle consisting of two phases (Figure 5.11):

(a) **A multicellular gametophyte or haploid stage:** It is a haploid stage with n chromosomes. It alternates with a multicellular sporophyte stage.

(b) **A multicellular sporophyte or diploid stage:** It is a diploid stage with 2n chromosomes, made up of n pairs. A mature sporophyte produces spores by meiosis, a process which reduces the number of chromosomes from 2n to 1n.

Alternation of generations (also known as mutagenesis) refers to the occurrence in the plant life cycle of both a multicellular diploid organism (sporophyte) and a multicellular haploid organism (gametophyte), each giving rise to the other. This is in contrast to animals, in which the only multicellular phase is the diploid organism (such as the human man or woman), whereas the haploid phase is a single egg or sperm cell.

In bryophytes (mosses and liverworts), the dominant generation is haploid, so that the gametophyte comprises the main plant. On the contrary, in tracheophytes (vascular plants), the diploid generation is dominant and the sporophyte comprises the main plant.

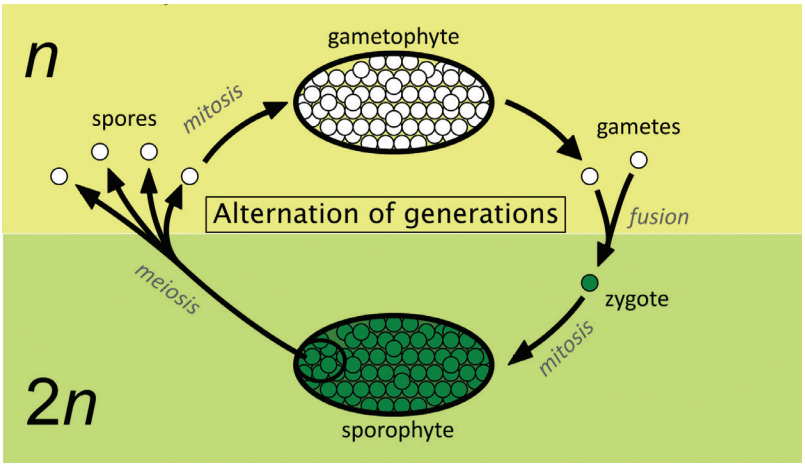


Figure 5.12: A diagram showing a diploid sporophyte (2n) and a haploid gametophyte (1n)

Independent Assortment of Chromosomes

Specifically at metaphase I, each homologous pair of chromosomes positioned independently of the other pairs. As a result, each homologous pair sorts out its maternal and paternal homologue into daughter cells independently of every other pair. This act of separating homologous pairs independently is called **independent assortment**. The random orientation of homologous pairs of chromosomes due to independent assortment in meiosis I (metaphase) increases genetic variation in organisms.

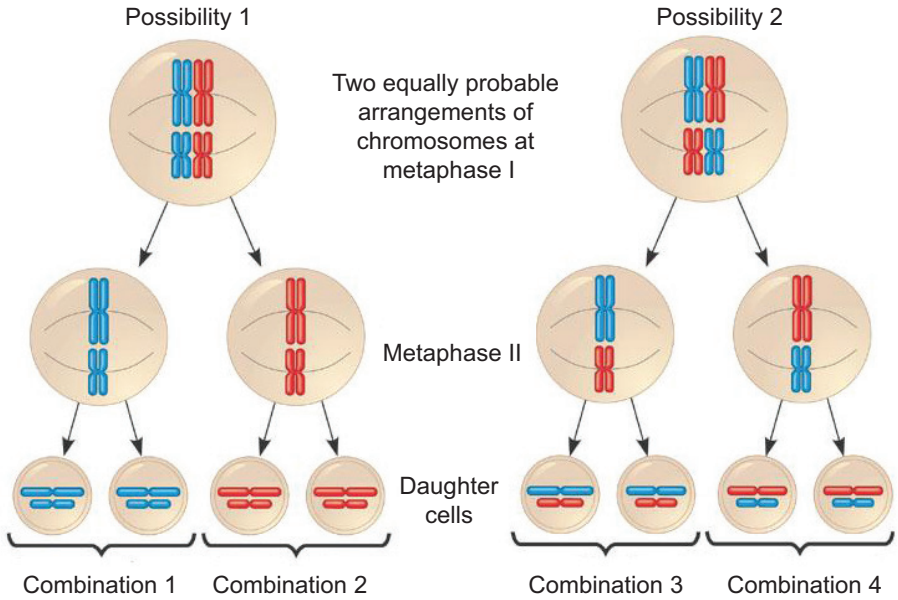


Figure 5.13: Two possibilities due to independent assortment in meiosis

Crossing Over and Random Fertilization

During crossing over, DNA segments of the two parents-paternal and maternal are combined into a single chromosome producing **recombinant chromosomes**, which are non-identical with their sister chromatids. In humans, an average of one to three crossing over events occurs per chromosome pair, depending on the position of their centromeres and on the size of the chromosome. Thus, crossing over is an important event of meiosis that brings genetic variation in sexual life cycles.

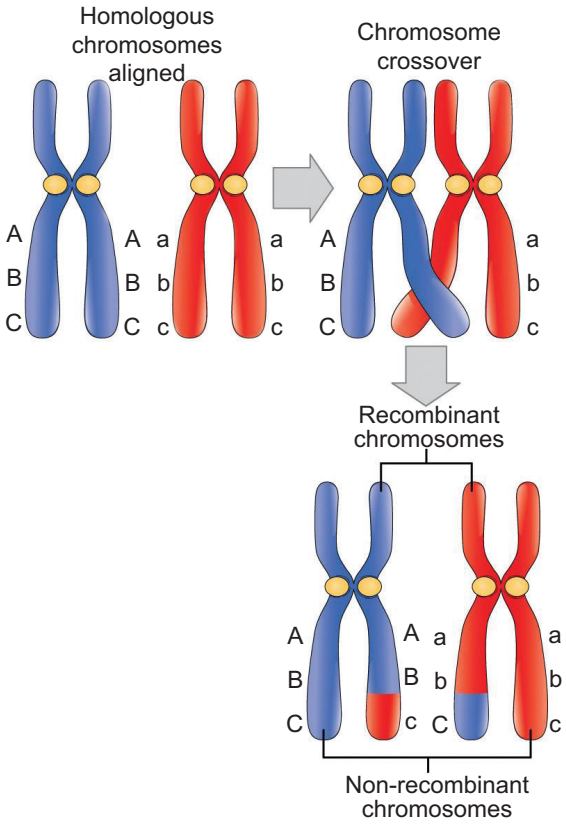


Figure 5.14: Crossing over

Besides independent assortment and crossing over, the **random fertilization** during sexual reproduction also increases genetic variation in organisms. During random fertilization, the male gamete and female gamete fuse to form zygote. The most interesting thing is that this zygote has the possibility of about 70 trillion diploid combinations. The number 70 trillion comes from possible combinations of male and female gametes which are $2^{23} \times 2^{23} = 70$ trillions. The possibility of this enormous number of combinations makes each and everyone of us unique physically and genetically.

Non-disjunction of Chromosomes

Proper separation of chromosomes during meiosis is essential for the normal growth in humans. Any set of chromosomes that do not separate properly during meiosis results in improper separation of chromosomes or non-disjunction, which is a serious issue in human genetics. **Non-disjunction** is a condition in which the homologues or sister chromatids **fail to separate** properly during meiosis. It can lead to the gain or loss of chromosome, a condition called as **aneuploidy**. Example: **Down syndrome** is an autosomal trisomy. It is also called as trisomy 21, where non-disjunction results in an embryo with three copies of chromosome 21 instead of the usual two copies of chromosome 21 (Figure 5.15). It was first discovered by John Langdon Down. The chance of occurrence is one infant in every 800 live births.

The most common symptoms are: They are short. They may also have protruding, furrowed tongues, which causes the mouth to remain partially open. They are mentally retarded. They have a prominent epicanthic fold in the corner of each eye; and typical flat face and round head. Usually, there is a wide gap between the first and the second digits on their feet.

The origin of trisomics condition is through non-disjunction of chromosome 21 during meiosis. Failure of paired homologues to separate during either anaphase I or II may lead to gametes with 23 + 1 chromosome composition instead of the normal 23 gamete chromosome composition. Therefore, instead of 46 normal chromosomes, Down syndrome patient will have 47 chromosomes with three copies of chromosome 21 instead of the normal 2 copies.

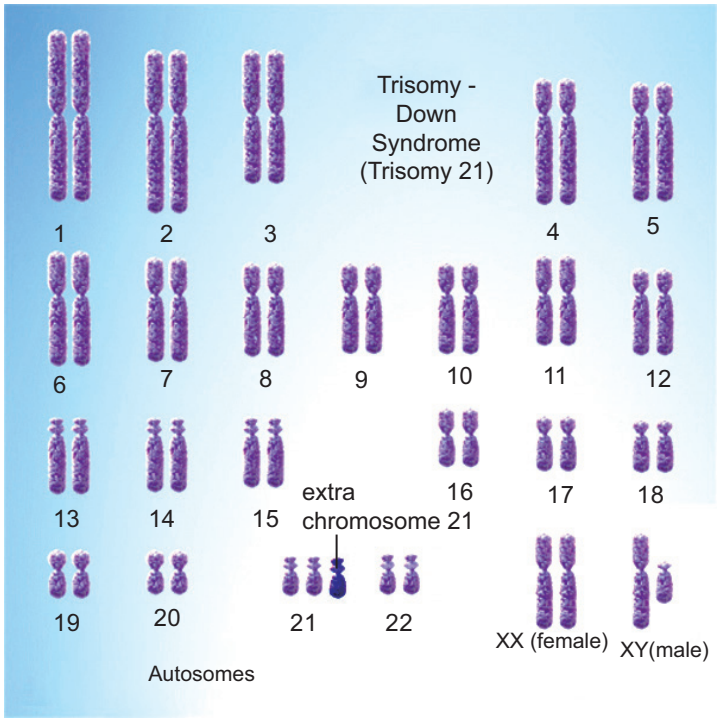


Figure 5.15: Human karyotype showing three copies of chromosome 21 instead of the normal two copies

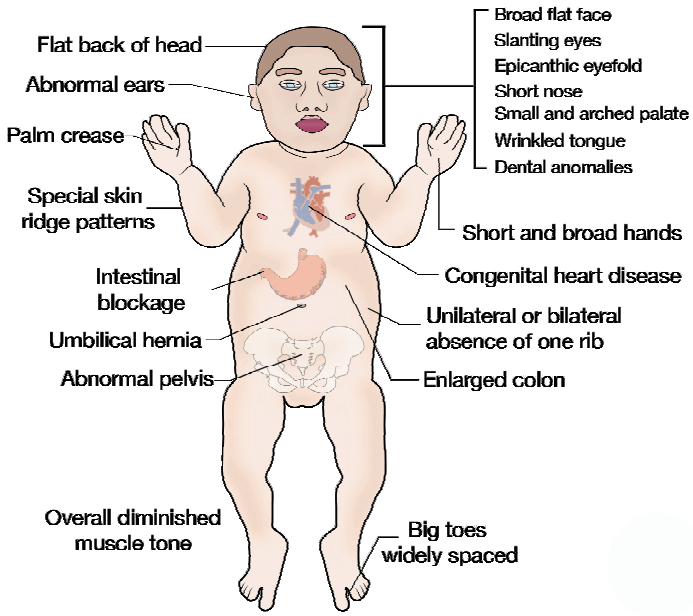


Figure 5.16: Symptoms of Down's syndrome

SELF EVALUATION

Complete with appropriate terms:

(i)Independent assortment of chromosomes takes place at ..... stage of Meiosis I.

(ii) Chiasmata formation occurs at ..... .

(iii) Meiosis is also known as ..... .

(iv) Crossing over and random fertilization brings ..... in life cycles.

(v) Trisomy of chromosome number two leads to ..... syndrome.

5.4 COMPARISON OF MITOSIS AND MEIOSIS

ACTIVITY 5

Cells divided both by mitosis and meiosis contain nucleus which is a genetic material. Can cells divided by mitosis act as carriers of genes to the next generation? Compare mitosis and meiosis in a tabular form. Research, debate and present your findings.

Table 5.2: Comparison between mitosis and meiosis

S. No.	Property	Mitosis	Meiosis
1.	**Occurrence**	Somatic cells	Germ cells/sex cells
2.	**Number of daughter cells**	Two diploid cells (2n)	Four haploid cells (1n)
3.	**Genetic composition**	• The two daughter cells are genetically identical to the parent cell. • It is equational division	• The four daughter cells are genetically different from parent cell and form each other. • It is reduction division
4.	**Number of divisions**	Prophase, prometaphase, metaphase, anaphase, and telophase	**Meiosis I:** Prophase I, Metaphase I, Anaphase I, Telophase I **Meiosis II:** Prophase II, Metaphase II, Anaphase II, Telophase II
5.	**DNA Replication**	Occurs during S phase of interphase prior to mitosis	Occurs during S phase of interphase prior to meiosis I
6.	**Functions in the animal body**	• It enables multicellular adult to arise from zygote • It helps in production of cells in growth and repair • Asexual reproduction in some animals	• It produces gametes (sperms and eggs) • It reduces the number of chromosome by half from diploid (2n) to haploid (1n) • It introduces genetic variation among the gametes
7.	**Synapsis**	It does not occur	Synapsis through synaptonemal complex
8.	**Crossing over**	It does not occur	Crossing over occurs between two non-sister chromatids during meiosis I
9.	**Chiasmata**	No chiasmata formation	Chiasmata, sites of crossing over, formation occurs
10.	**Homologs on the metaphase plate**	Individual chromosomes aligned at metaphase plate	Homologous pairs of chromosomes are aligned at metaphase plate during metaphase I

11.	**Sister chromatids**	Sister chromatids separate at anaphase	During meiosis I, the replicated chromosomes of each homologous pair move toward opposite poles at anaphase I; however, sister chromatids separate only at anaphase II
12.	**Cytokinesis**	Cytokinesis occurs after mitosis	Cytokinesis doesn't occur after meiosis I but occurs after meiosis II
13.	**Centromeres**	Division of centromeres take place at anaphase	Division or cleavage of centromeres takes place only at anaphase II
14.	**Chromosomes at metaphase plate**	Chromosome pairs are aligned at metaphase plate	Duplicated chromosome pairs are aligned at metaphase plate

ACTIVITY 6

Carry out a research project to find out why cultured skin is grown in a medium of proteins similar to blood. Then write a journal entry to summarise the research.

5.5 SUMMARY

- Karyotype is a visual representation of the chromosomes within a single cell.
- Diploid cells contain two complete sets (2n) of chromosomes. Example, skin cells. Haploid cells contain only one complete set (1n) of chromosome. Example, gametes (sperm and egg). Homologous chromosomes are pairs of chromosomes that are similar in length, gene position, and centromere location. Non-homologous chromosomes are chromosomes that contain different genes.
- A typical cell cycle consists of mitotic and interphase phases. Interphase is subdivided into G0, G1, S, G2 phases. S phase is the longest phase.
- Mitosis is subdivided into prophase, prometaphase, metaphase, anaphase, and telophase.
- DNA replication takes place at S phase of interphase prior to mitosis.
- Cytokinesis is a division of cytoplasm and usually follows the process of mitosis.

- Some differentiated cells are arrested at G0 phase; and they resume cell cycle when they receive signal to divide and repair injured tissues. Example, skin fibroblasts.
- Some cells have stem cells that are undifferentiated biological cells which can differentiate into specialized cells and continually replace the dying cells. Example, hematopoietic (blood-forming) system.
- Unrestrained, uncontrolled growth of cells in cell cycle results into a disease called cancer.
- Meiosis is divided into meiosis I and meiosis II. Meiosis I is a reduction division and is subdivided into prophase I, metaphase I, anaphase I, and telophase I. DNA replication takes place at interphase I prior to meiosis I. Synaptonemal complex is formed during prophase I. Crossing over takes place in meiosis I.
- Meiosis II is just like mitosis. There is no DNA replication. It is divided into prophase II, metaphase II, anaphase II, and telophase II.
- Meiosis is a reduction division. It reduces diploid chromosomes to four haploid daughter cells. Reduction division usually happens before sexual reproduce where haploid gametes (sperm and eggs) are formed for fertilization.
- The process of sperm formation is called spermatogenesis; while the process of egg formation is called oogenesis.
- Meiosis also reduces diploid plant into haploid gametes which eventually fuse to form zygote.
- During meiosis, paternal and maternal homologues assort independently into four daughter cells. This process adds genetic variation.
- Crossing over and random fertilization increase genetic variation in sexual life cycles.
- Improper separation of chromosomes during meiosis results into non-disjunction of chromosomes that are responsible for disease such as Down syndrome.

5.6 GLOSSARY

- **Cancer:** It's an unrestrained, uncontrolled growth of cells in human beings. It is essentially a disease of uncontrolled mitotic cell division.
- **Chiasmata (chiasma-singular):** During crossing over of genes, the point where homologous chromosomes remain attached at one particular point is called chiasmata.
- **Crossing over:** The exchange of genetic material between homologous chromosomes that occur during meiosis and contribute to genetic variability.
- **Cytokinesis:** It is a division of cytoplasm.
- **Diploid cells:** Cells which contain two complete sets (2n) of chromosomes (23 + 23 in number) are called diploid cells. Example: somatic cells (Muscle cells).

- **Down syndrome:** It is an autosomal trisomy. It is also called as trisomy 21, where non-disjunction results in an embryo with three copies of chromosome 21 instead of the usual two copies of chromosome 21.
- **Gametogenesis:** It is a biological process by which diploid cells undergo cell division and differentiation to form mature haploid gametes.
- **Haploid cells:** Cells that contain only one complete set (1n) of chromosome (23 in number) are called as haploid cells. Example: sperm and ovum.
- **Independent assortment:** In meiosis I, specifically at metaphase I, each homologous pair of chromosomes positioned independently of the other pairs at metaphase I.
- **Karyotype:** It is a visual representation of the chromosomes within a single cell where the number of chromosomes, their arrangement, size and structure can be analysed.
- **Meiosis:** It's a reduction division where the number of chromosomes is reduced to half from diploid parent cell to haploid daughter cells.
- **Mitosis:** It is a process where a single cell divides into two identical daughter cells. In other words, it's a division of nucleus.
- **Reduction division:** It is a process of meiotic cell division where the number of chromosome sets from parental diploid (2n) cells is reduced to haploid (1n) daughter cells.
- S**tem cells:** They are undifferentiated biological cells that can differentiate into specialized cells (when stimulated by the right factor) and can divide to produce more stem cells. Example: Hematopoietic system.
- **Syngamy or fertilization:** The fusion of gametes (one from mother and one from father) to form a zygote is called as syngamy.
- **Tetrad or bivalent:** The structure of four chromatids of the two homologous chromosomes attached at chiasmata during the process of meiosis is called as tetrad.

5.7 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. Cell cycle is a cyclical event of cell growth, mitosis, and cell division.
2. A typical cell spends most of its time in interphase.
3. Mitosis is a process where a single cell divides into three identical daughter cells.
4. Cytokinesis is a division of cytoplasm.
5. The process of mitosis is basically divided into 5 phases.
6. Meiosis is divided into three stages: Meiosis I, Meiosis II and Meiosis III.

7. The unrestrained, uncontrolled growth of cells in human beings results into a disease called cancer.
8. Cancer occurs due to failure in controlling cell division.
9. Proper separation of chromosomes during meiosis is not essential for the normal growth in humans.
10. The life span of blood cells ranges from less than one day to a few months.

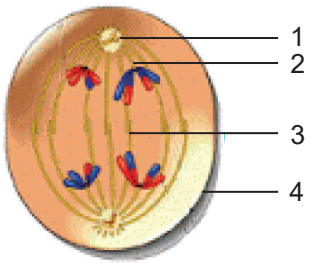
II. Multiple Choice Questions

1. Meiosis starts with diploid cell but ends with ..... haploid cells.
   (a) one (b) two
   (c) three (d) four
2. ..... is a biological process by which diploid cells undergo cell division and differentiation to form mature haploid gametes.
   (a) Gametogenesis (b) Spermatogenesis
   (c) Oogenesis (d) None of these
3. Generally, plants reproducing sexually have life cycle consisting of ..... phases.
   (a) two (b) three
   (c) four (d) five
4. In telophase, the nuclear envelope re-forms around the ..... set of haploid daughter chromosomes.
   (a) one (b) two
   (c) three (d) four
5. The prominent role of stem cells can be seen in—
   (a) blood cells (hematopoietic system)
   (b) epithelial cells of the skin
   (c) epithelial cells lining the digestive tract
   (d) All of these
6. ..... is a condition in which the homologues or sister chromatids fail to separate properly during meiosis.
   (a) Disjunction (b) Non-disjunction
   (c) Down syndrome (d) None of these
7. Which of the events is **not** correct in prometaphase
   (a) Nuclear envelope breaks down
   (b) Spindle fibres invade nuclear area
   (c) Kinetochore binds to centromere
   (d) Chromatids condense into discrete chromosome

8. Which of the event is **correct** in anaphase
   (a) Sister chromatids separate and give rise to daughter chromosomes.
   (b) Chromosomes are aligned at the metaphase plate.
   (c) Cytokinesis starts occurring.
   (d) Chromosomes begin to uncoil.
9. The total chromosome number at the end of meiosis I and II is
   (a) 46 (b) 23
   (c) 44 (d) 92
10. One round of oogenesis produces
   (a) One egg (b) Two eggs
   (c) Three eggs (d) Four eggs
11. Which of the following results in genetic variation
   (a) Independent assortment of chromosomes
   (b) Crossing over
   (c) Random fertilization
   (d) All of these
12. In mitosis, which of the following occurs?
   (a) Chiasmata formation (b) DNA replication
   (c) Synapsis (d) None of these
13. Identify the cells which are divided by mitosis.
   (a) Skin cells (b) Liver cells
   (c) Blood cells (d) All of these
14. Identify the cells which are divided by meiosis.
   (a) Intestinal cells (b) Stem cells
   (c) Gametes (d) None of these
15. Which part of the plants is/are divided by mitosis?
   (a) Stem (b) Flower
   (c) Leaves (d) All of these
16. Identify the cells that are divided by meiosis in plants.
   (a) Root tips (b) Pollen grains
   (c) Ova (d) (b) and (c)

III. Long Answer Type Questions

1. Describe the main stages of cell cycle.
2. In your own words, explain what is meant by homologous pairs of chromosomes.
3. What do you mean by the terms haploid and diploid?
4. In your own words, describe the process of mitosis.
5. In your own words, describe the process of meiosis.
6. Outline the significance of mitosis in cell replacement and tissue repair by stem cells.
7. In your own words, explain how uncontrolled cell division can result in the formation of a tumour.
8. What is the need for reduction prior to fertilization in sexual reproduction?
9. In your own words, explain the importance of effective cell division.
10. Outline the role of meiosis in gametogenesis in humans and in the formation of pollen grain and embryo sacs in flowering plants.
11. Explain how crossing over and random assortment of homologous chromosomes during meiosis and random fusion of gametes at fertilization leads to genetic variation, including the expression of rare recessive alleles.
12. (i) Identify the stage of cell division shown in the figure.
    (ii) Label the structures marked as (1), (2), (3) and (4).
    (iii) Which type of cell is involved in this division?
    (iv) What will happen if the structure marked (3) is not formed?



13. How can you correlate the spread of HIV virus with the process of Mitosis? Knowing the viral disease and its spread, discuss in brief the stigma and discrimination faced by those affected by HIV and AIDS.

Unit 6

Protein Synthesis

Key Unit Competence

To be able to explain the relationship between a gene and the sequence of nucleotides in DNA and to describe the process of protein synthesis in eukaryotes.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- state the features of a genetic code.
- state that a gene is a sequence of nucleotides that form part of a DNA molecule that codes for a specific polypeptide.
- appreciate the importance of the genetic code in determining the structure of a protein.
- describe how the information in DNA is used during transcription and translation to construct polypeptides.
- agree that the way DNA code for polypeptides is central to our understanding of how cells and organisms function.
- be aware that DNA is an extremely stable molecule that cells replicate with extreme accuracy to minimise possibilities of DNA mutations.
- state the roles played by mRNA, tRNA and the ribosomes in the formation of the polypeptide.
- appreciate the role of the genetic code in determining the characteristics of an individual.
- state that ribosomes provide surface area for the attachment of mRNA during polypeptide synthesis.
- state that polysomes consists of up to 50 ribosomes on the same mRNA strand and that they speed up polypeptide synthesis.
- describe the way in which the nucleotide sequence codes for the amino acid sequence with specific reference to Hb^A (normal) and Hb^S(sickle cell) alleles for b-globin poly peptides.
- state that gene mutation is a change in the sequence of nucleotides that may result in an altered polypeptide.
- construct a flow chart, in proper sequence, for the stages of transcription and translation.
- using the evidence, predict the effect of change in genetic code on the structure of the protein manufactured during protein synthesis.
- carry out research to find and understand better about protein synthesis and on genetic diseases.

6.1 GENETIC CODE

ACTIVITY 1

You have studied that codon is made up of three bases and DNAs in human body intermittently open and close up during DNA replication and transcription, but how is it that genetic information is passed on from generation to generation with minimal mistake? Research and discuss your findings, and then list out the best answers. You may look into textbooks, video clips, computer animations, Internet, etc for finding answers.

A gene is 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. In other words, the genetic code is a set of rules that specify how the nucleotides sequence (AUGC) of an m-RNA is translated into the amino acid sequence of a polypeptide chain.

During translation, the process of making proteins, ribosome reads the sequence of an m-RNA (nucleotide sequences) from 5' end to 3' end. Then it makes appropriate amino acids according to the genetic information on the m-RNA. 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 6.1).

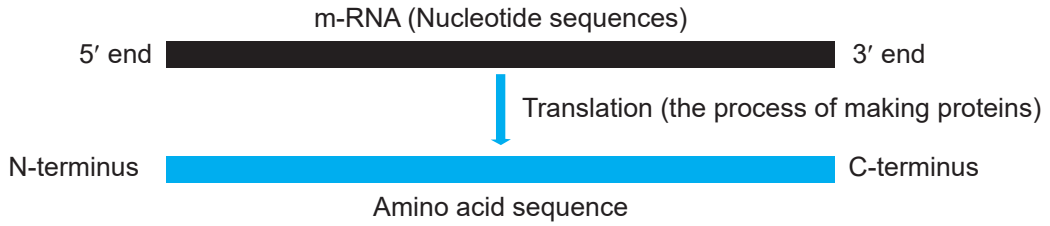


Figure 6.1: The DNA sequence of a single gene is collinear with the amino acid sequence of the polypeptide it encodes

As studied in Unit 3, 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 (m-RNA) into mature functional proteins.

6.1.1 The Characteristics of Genetic Code

The following are some characteristics of genetic code:

1. **The Genetic Code is 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. **The 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. **The Genetic Code is Non-overlapping:** The codons in the m-RNA sequence are read successively without overlapping.
4. **The 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 6.1**). 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 6.1: Genetic Code

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

5. **The 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).

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

1. Firstly, locate and read letter "A" on the **first base** column on the left-hand side of the table.
2. 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.
3. 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.

Figure 6.2: The Genetic Code: 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. **The 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).

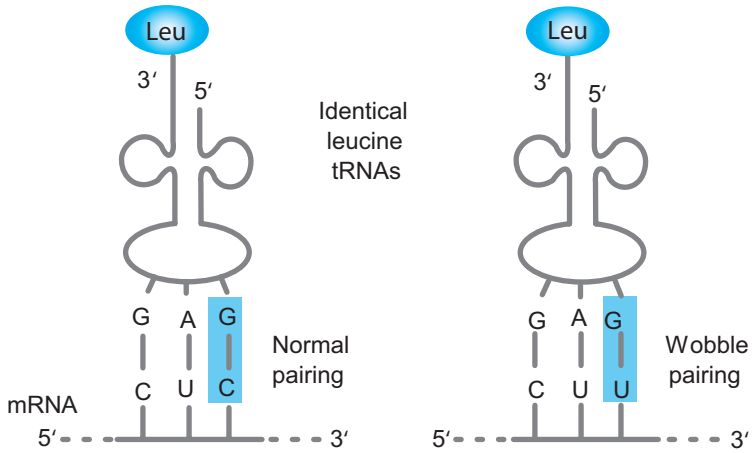


Figure 6.3: Example of base-pairing wobble. The same leucine t-RNA molecule (anticodon GAG) can read two different leucine codons (CUC, CUU)

6.1.2 Importance of the Genetic Code in Determining the Structure of a Protein

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.

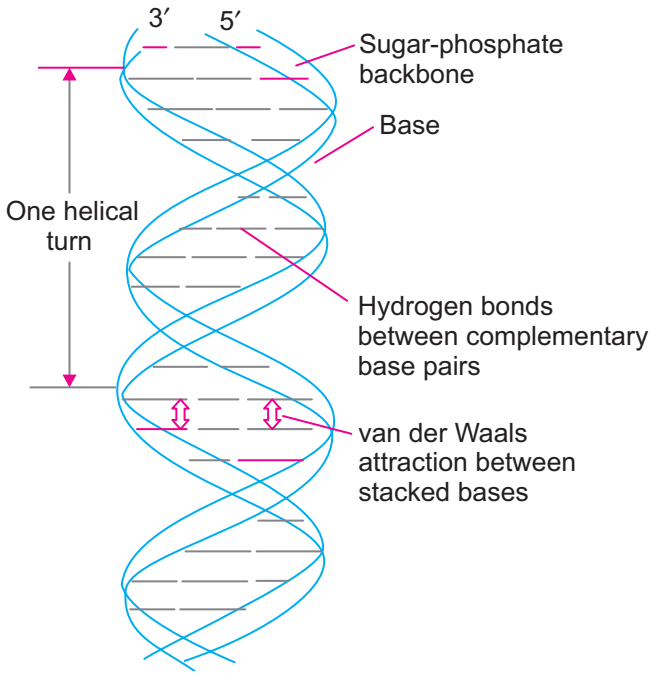


Figure 6.4: Hydrogen bonding and Base stacking enabling stability of DNA

SELF EVALUATION

Complete the sentence with correct word:

(i)A ..... is a sequence of nucleotide which codes for specific polypeptide.

(ii) ..... allows an organisms to translate genetic information into proteins.

(iii) ..... is a start codon.

(iv) ..... and ..... contributes to stability of DNA.

6.2 TRANSCRIPTION

Transcription is the process of copying information from one strand of DNA into a single-stranded RNA.

ACTIVITY 2

Discuss how DNA replication is different from the process of transcription. Make flow chart, diagrams of bacterial and eukaryotic transcriptions. You can use for reference textbooks, video clips, animation and Internet.

6.2.1 Transcription Unit in DNA

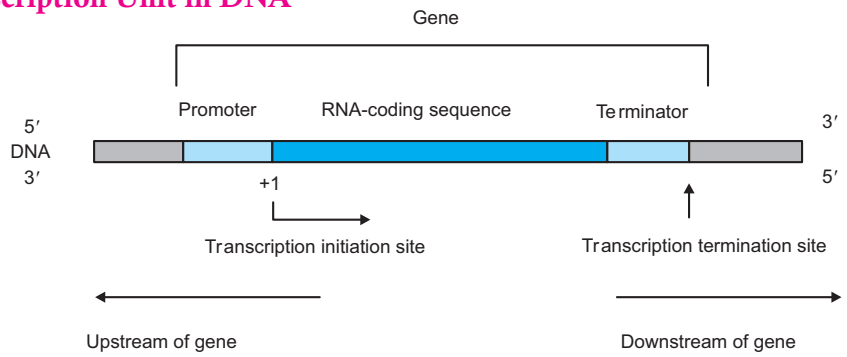


Figure 6.5: A transcription unit of DNA

Note:

- The nucleotide in the template strand at which transcription begins is designated with the number +1.
- Downstream sequences are drawn, by convention, to the right of the transcription start site.

- Nucleotides that lie to the left of the transcription start site, are called the upstream sequences and are identified by negative numbers.

A transcription unit in DNA consists of three main regions (Figure 6.5):

(a) **A promoter:** A promoter is a region of DNA that initiates transcription of a particular gene.

(b) **RNA coding sequence:** It is a DNA sequence that is transcribed by RNA polymerase into RNA transcript (m-RNA).

(c) **A terminator:** It is a DNA sequence which specifies termination of transcription.

6.2.2 RNA Polymerase

In bacteria, RNA polymerase is the only enzyme that is responsible for catalysing the process of transcription. It is a **DNA-dependent RNA polymerase**, as it uses a DNA template strand to synthesize a new RNA chain. During transcription, it synthesizes RNA in **5' to 3' direction** by using 3' to 5' strand of DNA as a **template strand**. The opposite 5' to 3' strand of DNA is not used during transcription and it is called **nontemplate strand**.

RNA polymerase uses RNA precursors for synthesizing RNA chain. The RNA precursors are ribonucleoside triphosphates ATP, GTP, CTP, and UTP. They are collectively known as **NTPs** or **Nucleoside triphosphate**. The synthesis of RNA chain follows complementary base pairing rule i.e., A will pair with U; G will pair with C.

6.2.3 The Process of Transcription in Bacteria

The process of transcription is basically divided into three stages: (a) Initiation (b) Elongation (c) Termination (Figure 6.6).

(a) **Initiation:** RNA polymerase accompanied by sigma (σ) factor binds at the promoter. Sigma factor ensures that RNA polymerase binds accurately and stably on the promoter. Then RNA polymerase unwinds DNA in the promoter region to form **open promoter complex**.

(b) **Elongation:** Once the initiation has commenced, RNA polymerase starts elongating or adding NTPs one after the other using one of the strands of DNA as a template strand. The nontemplate strand is not used for elongation of RNA. Elongation of the new RNA takes place in 5' to 3' direction and follows complementary base pairing rule. For example: If the DNA sequence in the DNA template is 3'-ATACTTGAACTAACTC-5', then the sequence of newly synthesized RNA will be 5'-UAUGAACUUGAUUGAG-3'.

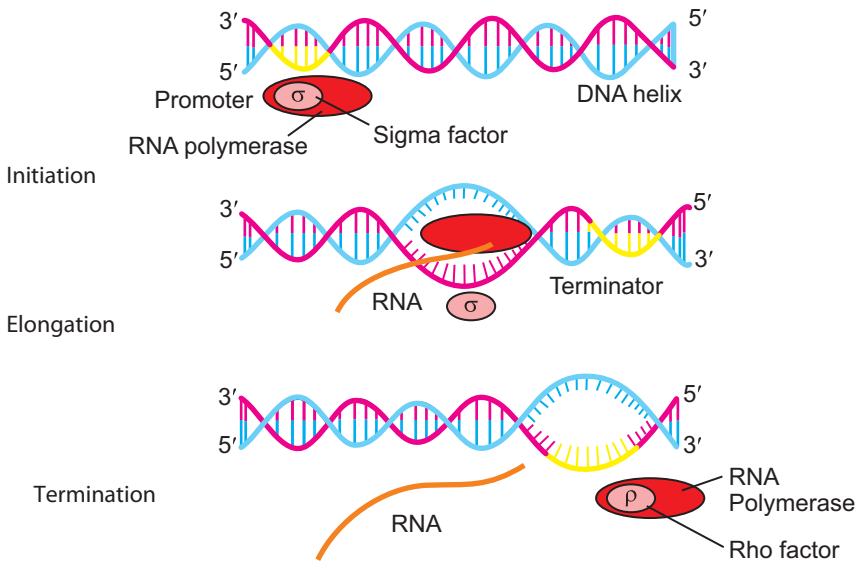


Figure 6.6: The process of transcription in bacteria

(c) **Termination:** Termination of transcription is signalled by **terminator sequence** located downstream from the promoter. It can take place in two ways:

(i) **Rho (ρ) dependent terminators:** In this type, rho protein binds at the terminator sequence and RNA polymerase, and brings the termination of transcription.

(ii) **Rho (ρ) independent terminators:** Rho independent terminators consist of an inverted repeat sequence that is about 16 to 20 base pairs upstream of the termination point. The inverted repeat sequence forms a **hairpin loop structure** that causes transcription to terminate.

6.2.4 Transcription in Eukaryotes

Unlike the situation in prokaryotes, transcription in eukaryotes occurs within the nucleus and mRNA moves out of the nucleus into the cytoplasm for translation. In eukaryotes, there are two additional complexities:

1. There are at least three RNA polymerases in the nucleus (in addition to the RNA polymerase found in the organelles). There are RNA polymerase I, II and III. The RNA polymerase I transcribes rRNAs (285, 185 and 5.8S), whereas RNA polymerase III is responsible for transcription of tRNA, RNA, 5s rRNA and sn RNAs (small nuclear RNAs). The RNA polymerase II transcribes precursor of mRNA (pre-mRNA) or hnRNA (heterogenous nuclear RNA). Thus, there is a division of labour in the functioning of the three types of RNA polymerase.

2. The second complexity is that the primary transcript contains two types of segments, the non-coding **introns** or **intervening sequences** and the coding **exons.** The primary eukaryotic mRNA transcript is much longer and is non-functional. Hence, it is subjected to a process called **'splicing',** where the introns are removed and exons are joined in a definite order. Hn RNA (primary of RNA transcript) undergo two additional processing called **'capping'** and **'tailing'.** In capping an unusual nucleotide, **methyl guanosine triphosphate** ($^{m}G_{ppp}$) is added to the 5′ end of hn RNA. In 'tailing' adenylate residues (200-300) are added (polyadenylation at 3′-end to hn RNA in a template independent manner (i.e., without a template). The fully processed hnRNA is now called mRNA, that is transported out of the nucleus for translation (Figure 6.7).

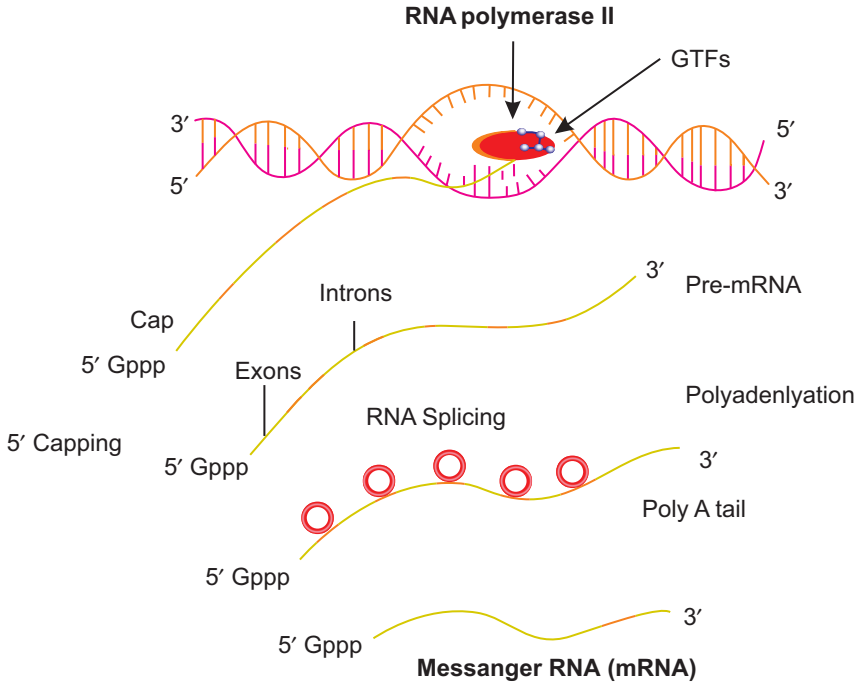


Figure 6.7: Transcription in eukaryotes

ACTIVITY 3

Read the process of translation carefully and know all the important steps. After finishing your reading, put the steps of the process of translation in separate boxes in the form of flow chart. Start the flow chart from the production of pre-m-RNA and end with the proteins (ultimate product). Compare your chart with that of your classmates.

SELF EVALUATION

Complete the sentence with correct word:

(i)..... is a DNA dependent polymers.

(ii) The base pairs of eukaryotic gene are ..... with the bases of transcribed mRNA.

(iii) mRNA coding information for more than one gene is called .....

(iv) ..... is a process of adding poly A tails to pre mRNA.

(v) ..... are removed by RNA splicing.

6.3 TRANSLATION/PROTEIN SYNTHESIS

6.3.1 Role of Transfer RNA in the Formation of Polypeptide Chain

Though there are specific codons on m-RNA for specific amino acids, nucleic acids (m-RNA) and proteins (amino acids) are written in two different languages. Therefore, there has to be a mediator that can decode the message in m-RNA and direct the formation corresponding proteins. This is where the role of t-RNA comes into play. The primary role of transfer RNA (t-RNA) is to decode (translate, like an interpreter) the codons on m-RNA and use the message

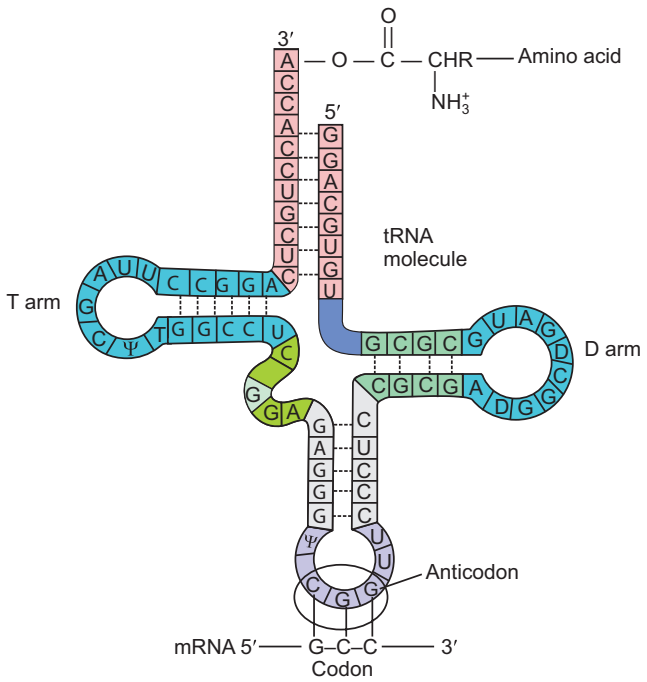


Figure 6.8: A diagram showing t-RNA molecule linking amino acid at its 3' end and codon on m-RNA at its anticodon site.

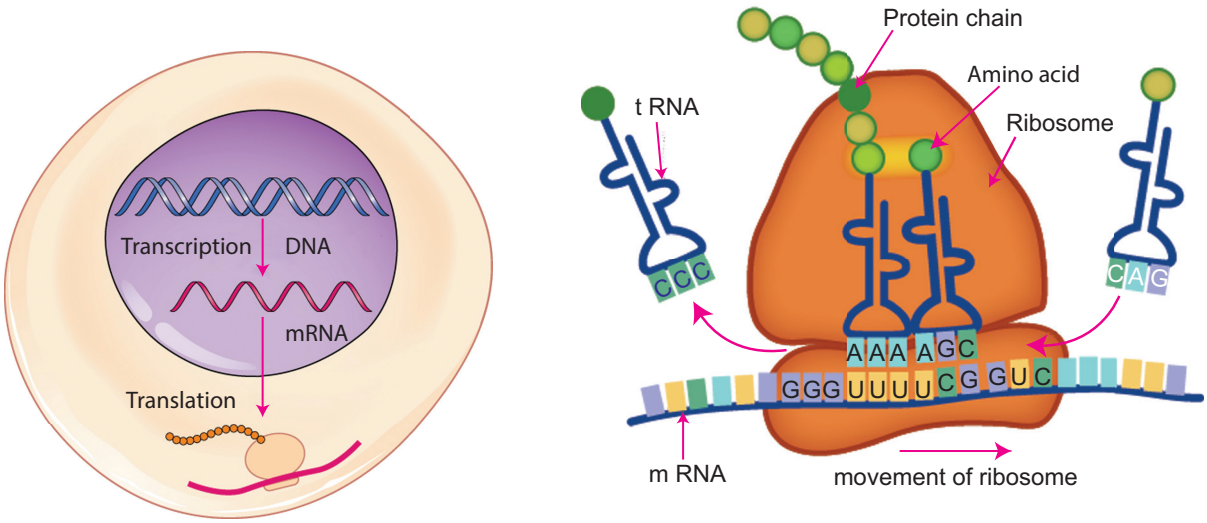
in codons to direct the process of synthesising polypeptide chain. Thus, t-RNA acts as an **adaptor or intermediaries**. Since interpretation of the language between m-RNA and amino acids is involved, the process of protein synthesis is called **translation**.

During translation, t-RNA links to a specific amino acid at its 3' end giving rise to charged aa-t-RNA, while the opposite end (anti-codon region) recognizes a particular codon in the m-RNA (Figure 6.8). Depending upon the interaction between codons in m-RNA and specific charged aa-t-RNAs, polypeptide chain (long amino acids) are synthesized during translation.

Transfer RNA is composed of 73–93 nucleotides, 10 of which are modified from the standard 4 nucleotides of RNA (A, G, C, and U) (Figure 6.8). Because of complementary base pairing, the various t-RNAs become folded in a similar way to form a structure that can be drawn in two dimensions as a **cloverleaf**.

6.3.2 The Role of Messenger RNA in the Formation of Polypeptide Chain

During transcription, the genetic information in DNA is copied and encoded in the intermediate product called **messenger RNA** (m-RNA), which along with t-RNA will be used by ribosome for protein synthesis/translation (Figure 6.9). Thus, the primary role of messenger RNA is to carry the genetic information copied from DNA in the form of a series of codons (three-base code), each of which specifies a particular amino acid.



(A) (B)

Figure 6.9: (A) A simplistic diagram representing transcription and translation. (B) A diagram showing m-RNA carrying genetic information copied from DNA in the form of codons. Examples: UUU, UCG codons are shown in the diagram

The series of codons in m-RNA code for specific amino acids. For example, as shown in Figure 6.2, UUU codon will code for phenylalanine amino acid; similarly, UCG codon will code for serine amino acid.

6.3.3 Role of Ribosomes in the Formation of Polypeptide Chain

Ribosomes are machines that carry our protein synthesis or translation. The main role of ribosomes is to orient the m-RNA and amino acid carrying t-RNAs in such a position that the genetic code can be read accurately and catalyse peptide bond formation.

Ribosomes are particles made up of ribosomal RNA (r-RNA) and proteins. In prokaryotes, they are present in cytoplasm, while in eukaryotes they occur both free in the cytosol and bound to membrane of the nuclear envelope. Mitochondria and chloroplast also have ribosomes.

Generally, a 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.

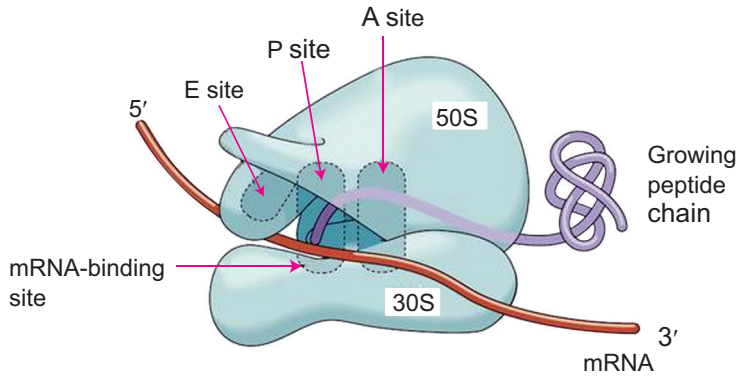


Figure 6.10: A bacterial ribosome

There are four important sites in the ribosome. These four sites are particularly important during protein synthesis (Figure 6.10). These are:

(a) **Messenger RNA-binding site:** It is the site that binds m-RNA.

(b) **A (aminoacyle) site:** It is the site that binds each newly incoming t-RNA with its attached amino acid.

(c) **P (peptidyl) site:** It is the site where the t-RNA carrying the growing polypeptide chain resides.

(d) **E (exit) site:** It is the site from which t-RNAs leave the ribosome after they have discharged their amino acids.

6.3.4 The Way DNA Codes for Polypeptides is Central to Understanding how Cells and Organisms Function

The central dogma of molecular biology is an explanation of the flow of genetic information, from **DNA to RNA,** to make a **functional protein** within a biological system.

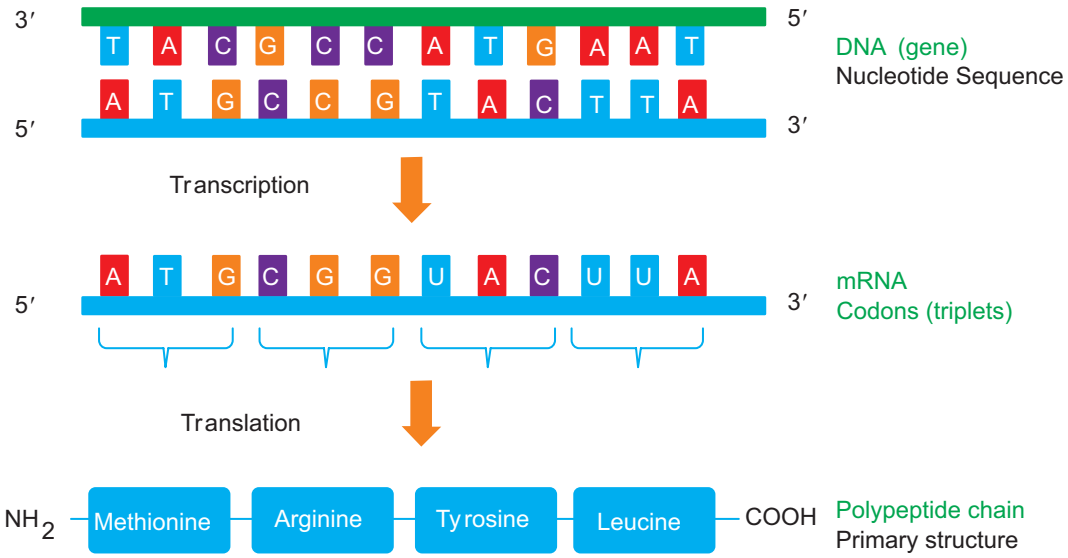
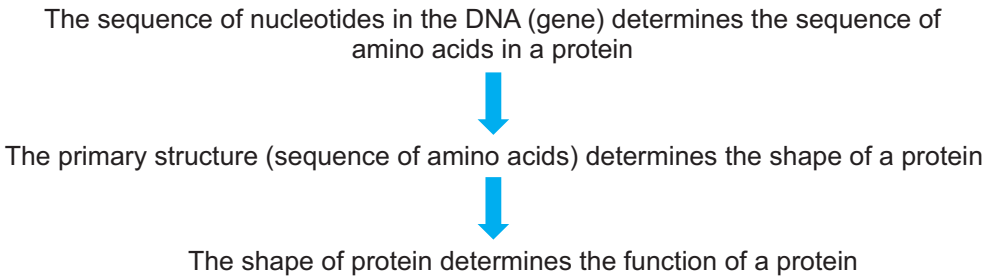


Figure 6.11: Central Dogma-information flow in a biological system

Once a DNA is transcribed into RNA (m-RNA), the genetic code (codon) in an m-RNA specifies the amino acids that are assembled during protein synthesis to make polypeptides. That is why the way DNA codes for polypeptides is central to our understanding of how cells and organisms function.

More specifically, nucleotide sequence in a DNA molecule forms a gene. This particular gene is then transcribed and translated into a specific polypeptide chain (proteins). In other words, the nucleotide sequence in a DNA determines the sequence in which amino acids are linked together when proteins are synthesized (Figure 6.11).

Furthermore, the properties and functions of proteins are determined by the structure of proteins. The primary structure (simple sequence of amino acids) determines its three dimensional shape and, therefore, its properties and functions. For example, the primary structure of an enzyme determines the shape of its active site. And the shape of this active site will consequently determine the substrate with which it can bind.



For proteins to become biological functional, they have to be expressed i.e., two molecules must bind to each other. For examples:–An antibody protein must bind to an antigen to trigger an immune response; an enzyme protein must bind to a substrate to catalyze a reaction. The binding of two molecules involves the two molecules to recognize each other and form a series of non-covalent bonds. Recognition of two molecules for each other is termed "structural complementarity." It can be compared with a key fitting into a lock.

6.4 TRANSLATION IN BACTERIA

Translation is the production of protein molecules (polypeptides) by cellular ribosomes with the help of information present on the m-RNA. The m-RNA and protein molecules are like two languages written with different types of letters. The language by which the information on m-RNA is written has to be translated into the language of amino acids in order to use it to direct the sequential assembly of amino acids into a polypeptide chain. That is the reason why protein synthesis is appropriately referred to as **translation**.

Charging of t-RNA

Prior to translation, each t-RNA molecule must be attached to the correct amino acid. Therefore, the covalent linking of a specific amino acid to the 3' end of the correct t-RNA by the enzyme aminoacyl-t-RNA synthetase is called charging of t-RNA. An enzyme **aminoacyl-t-RNA synthetase** catalyzes the linking of amino acids to their corresponding t-RNAs via an ester bond, accompanied by the hydrolysis of ATP to AMP and pyrophosphate. This process is a critical step in translation as it determines the accuracy of translation.

Charging of t-RNA occurs in two steps:

1. **ATP+ amino acid → aminoacyl-AMP + PPi**
2. **Aminoacyl-AMP + t-RNA → aminoacyl-t-RNA + AMP**

6.4.1 The Process of Translation

The process of translation basically consists of three major stages: (1) Initiation, (2) Elongation and (3) Termination (Figure 6.12).

1. **Initiation:** It is the stage where m-RNA is bound to the ribosome and positioned itself for proper translation. It can be further subdivided into three steps:
   - **(a) Binding of initiation factors:** The initiation factors along with GTP first bind to 30S subunit.
   - **(b) Binding of m-RNA and t-RNA:** Now the m-RNA and the charged t-RNA with the first amino acid bind to the 30S ribosomal subunit.
   - **(c) Formation of 70S Subunit:** The 30S ribosomal subunit now binds to a free 50S ribosomal subunit forming the 70S initiation complex. During this step, all the initiation factors are released.
2. **Elongation:** It is the stage where amino acids are sequentially joined together to form a polypeptide chain via peptide bonds. The sequence of polypeptide chain is formed in an order specified by the arrangement of codons in m-RNA. Elongation can be subdivided into three steps:
   - **(a) Binding of an aminoacyl-t-RNA:** The binding of an aminoacyl-t-RNA to 70S ribosome brings a new amino acid into a position on the ribosome that can be joined to the polypeptide chain. In bacteria, normally the first incoming aminoacyl-t-RNA is N-formylmethionine (fMet).
   - **(b) Peptide bond formation:** The newly incoming amino acid is linked to the growing polypeptide chain by peptide bond formation.
   - **(c) Translocation:** It is a process in which the m-RNA is moved by a distance of three nucleotides (codon) to bring the next codon on the ribosome.

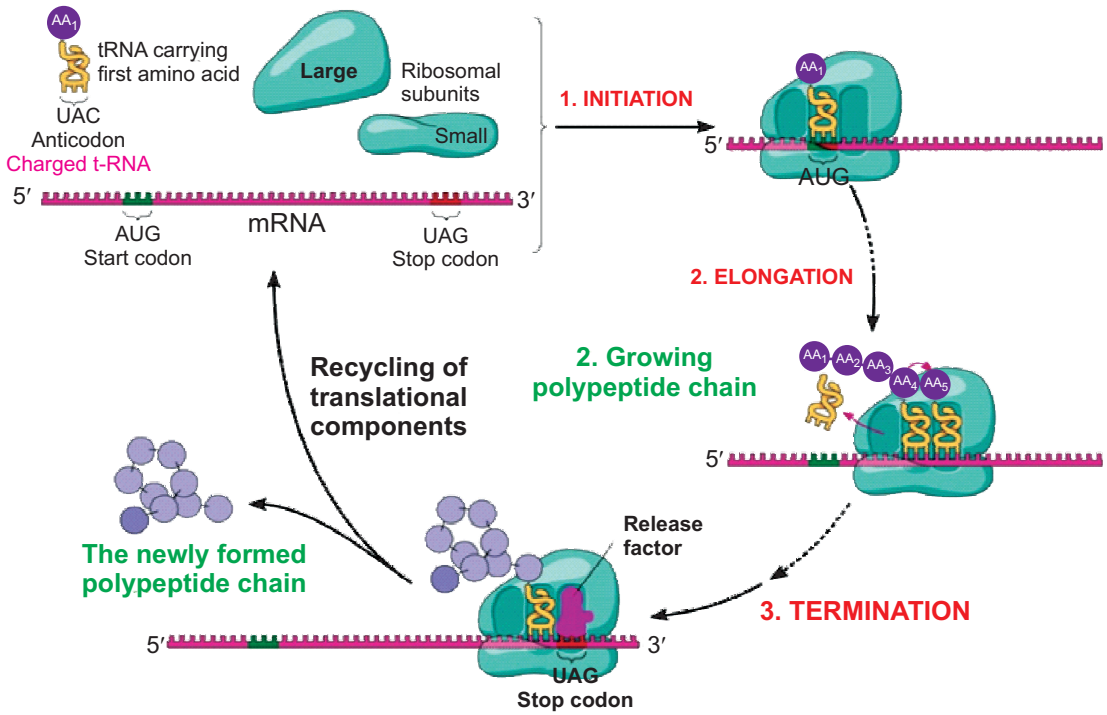


Figure 6.12: The process of Translation

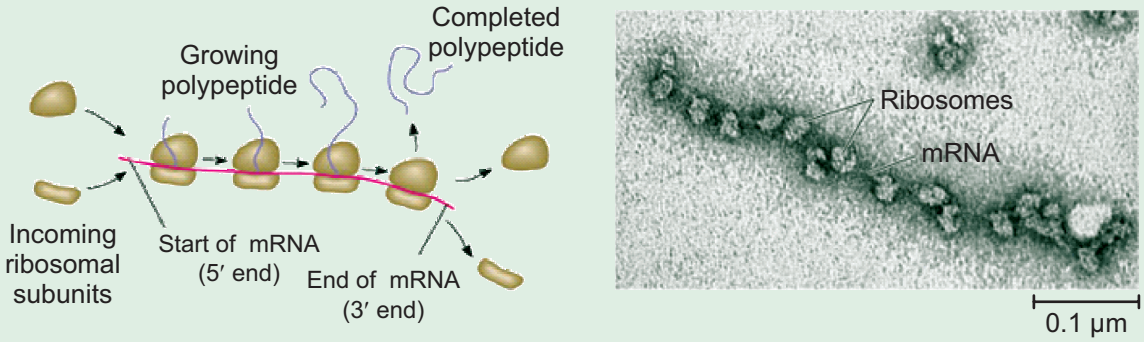
3. **Termination:** It is the process of ending translation. At this stage, the newly formed polypeptide chain and the m-RNA are released from the ribosome. Termination happens when the ribosome comes across one of the stop codons (UAG, UAA, UGA) on the m-RNA. The stop codons are not recognized by any t-RNA; rather, they are recognized by **release factors (RF)**. These release factors along with GTP bind on the stop codons and initiate the termination process. RF1 recognizes UAA and UAG, while RF2 recognizes UAA and UGA.

Polyribosomes/Polysomes

Polyribosomes or polysomes are also known as ergosomes. It was first discovered and characterized by Jonathan Warner, Paul Knopf, and Alex Rich in 1963. As the name goes, 'poly' means **many**. Therefore, polyribosomes are complex of an m-RNA molecule and multiple ribosomes that are simultaneously translating it.

Normally a single ribosome does not alone translate the m-RNA. But there are multiple ribosomes, probably about **50 ribosomes**, which come and bind on the m-RNA one after the other as the preceding ribosomes move from the initiation codon (5' end) towards 3'

end until it comes across terminating codons. Most importantly, these multiple ribosomes that bind on m-RNA simultaneously carry on the translation process (Figure 6.13). As a result, polyribosomes enable a large number of polypeptides to be produced **faster and efficiently** from a single m-RNA compared to a single ribosome translating alone.



(a) An mRNA molecule is generally translated simultaneously by several ribosomes in clusters called polyribosomes.

(b) This micrograph shows a large polyribosome in a prokaryotic cell (TEM).

Figure 6.13: Polyribosomes

6.5 TRANSLATION IN EUKARYOTES

Translation in eukaryotes is much more complex than that of the translation in bacteria. However, the basic process of bacterial translation remains the same in eukaryotes. Some of the major differences between the bacterial and eukaryotic translations are:

1. **Initiation:**
   (a) The first amino acid that binds on AUG start codon is methionine amino acid rather than N-formylmethionine.
   (b) It has 80S ribosomal initiation complex instead of 70S ribosomal initiation complex; it is formed by small 40S ribosomal subunit and 60S ribosomal subunit.
   (c) There are many more initiation factors (eIFs) in eukaryotes than in bacteria.
   (d) A complex of 40S ribosomal subunit + charged Met-t-RNA + several eIFs + eIF proteins move along the m-RNA and scan for the AUG start codon. This process is called **Scanning Model for initiation**. Once the AUG start codon is located, the 60S ribosomal subunit joints the complex to form 80S ribosomal initiation complex.
2. **Elongation:** Elongation in eukaryotes requires about nine eukaryotic elongation factors (eEFs).

3. **Termination:** The process of termination is similar to that in bacteria. But in the case of eukaryotes, a single release factor, called eukaryotic release factor 1 (e-RF1), recognizes all the three stop codons (UAG, UAA, UGA). And the e-RF1 also stimulates the process of termination.

ACTIVITY 4

Watch video clips using the Internet on the process of protein.

Synthesis: Using chart papers of different colours, prepare a model of protein synthesis. You should be very particular about shapes of structure made like with student of DNA, tRNA. You may use the following internet links: - https://www.youtube.com/watch?v=xEF8shaU_34 or https://www.youtube.com/watch?v=pwymX2LxnQs

SELF EVALUATION

Complete sentences with correct words

(i) Process of translation occurs in three stages as ....., ... and ..... .

(ii) tRNA is also known as ..... .

(iii) ..... consists of upto 50 nitrozones in same mRNA and they speed up polypeptide synthesis.

(iv) Eukaryotes have ..... ribosomal complex.

6.6 THE EFFECT OF CHANGE IN GENETIC CODE ON THE STRUCTURE OF PROTEIN DURING PROTEIN SYNTHESIS

ACTIVITY 5

Make a minilab report to demonstrate how gene mutations affect protein synthesis using a sequence of bases of one strand of an imaginary DNA molecule. You may use the examples shown in the text below.

Research and present the findings in journal form on how genetic drugs can be used to stop the expression of genetic diseases with specific reference to how they may interfere with activities of nucleic acids in the nucleus and the cytoplasm of the cell. You may look upto research papers, Internet and magazines.

Mutations are changes in genetic codons caused by changes in nucleotide bases. Some mutations do not have much effect. However, some mutations can have a huge effect on genetic code, which can eventually affect the proteins they code for. The proteins produced in turn can have a profound effect on cellular and organismal function.

Mutations occur in two ways:

A. **A base-pair substitution:** It is a change from one base pair to another base pair in DNA.

B. **Base-pair insertions or deletions:** It is a change in which a base-pair is either incorrectly inserted or deleted in a codon.

(A) A Base-Pair Substitution

Consider the following changes in the DNA from

$$\begin{matrix} 5'\text{-AAA-}3' \\ 3'\text{-TTT-}5' \end{matrix} \longrightarrow \begin{matrix} 5'\text{-GAA-}3' \\ 3'\text{-CTT-}5' \end{matrix}$$

This change in base pair brings changes in the m-RNA codon from one purine to the other purine. In this case, the m-RNA codon is changed from 5'-AAA-3' (lysine) to 5'-GAA-3' (glutamic acid). This is missence mutation.

Now look at the changes in DNA from

$$\begin{matrix} 5'\text{-AAA-}3' \\ 3'\text{-TTT-}5' \end{matrix} \longrightarrow \begin{matrix} 5'\text{-TAA-}3' \\ 3'\text{-ATT-}5' \end{matrix}$$

This change in base-pair in DNA results in change in m-RNA codon from 5′-AAA-3′ (lysine) to 5′-UAA-3′, which is a stop codon. This is a nonsense mutation. It causes premature termination of polypeptide chain synthesis, thereby releasing shorter polypeptide fragments than the normal length of polypeptide fragments during translation. These shorter fragments are often non-functional.

$$\begin{matrix} 5'\text{-AAA-}3' \\ 3'\text{-TTT-}5' \end{matrix} \longrightarrow \begin{matrix} 5'\text{–AAG-}3' \\ 3'\text{–TTC -}5' \end{matrix}$$

A silent mutation results from AT-to-GC transition mutation that changes the codon from 5′-AAA-3′ to 5′-AAG-3′. Both of these codons 5′-AAA-3′ to 5′-AAG-3′ specify the same amino acid, lysine. It is worth mentioning that silent mutation often occurs by changes at the third wobble position of a codon. Refer wobble hypothesis in Genetic code.

(B) Base-Pair Insertions or Deletions

ACTIVITY 6

Consider a statement that is made up of the following words each having three letter like genetic code.

RAM HAS RED CAP

If we insert a letter B in between HAS and RED and rearrange the statement, it would read as follows:

RAM HAS BRE DCA P

Similarly, if we now insert two letters at the same place, say BE. Now it would read.

RAM HAS BIR EDC AP

Now we insert three letters together, say BIG. The statement would read.

RAM HAS BIG RED CAP

The same exercise can be repeated, by deleting the letters R, E and D, one by one and rearranging the statement to make a triplet word.

RAM HAS EDC AP

RAM HAS DCA P

RAM HAS CAP

The conclusion from the above exercise is very obvious. Insertion or deletion of one or two bases changes the reading frame from the point of insertion or deletion. Insertion or deletion of three or its multiple bases insert or delete one or multiple codon hence one or multiple amino acids and reading frame remains unaltered from that point onwards, mutations are referred to as **frame-shift insertion** or **deletion mutations**.

6.7 EFFECTS OF ALTERATION 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 it in the next section.

Another example is Albinism. Albinism occurs due to mutation in the gene for tyrosinase, an enzyme which converts tyrosine to DOPA (dihydroxyphenylalanine) (Figure 6.14). 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.

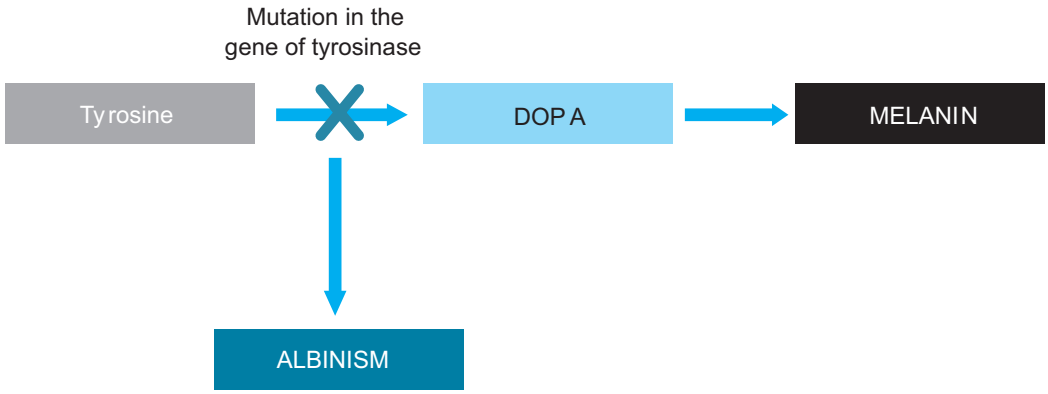


Figure 6.14: Mutation of tyrosinase gene results in albinism, lack of melanin pigment

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 (Figure 6.17). 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 α-globin polypeptides** and **two β-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)** (Figure 6.15). 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 (Figure 6.16). This defective form of haemoglobin in persons with sickle cell anaemia is referred to as **HbS**.

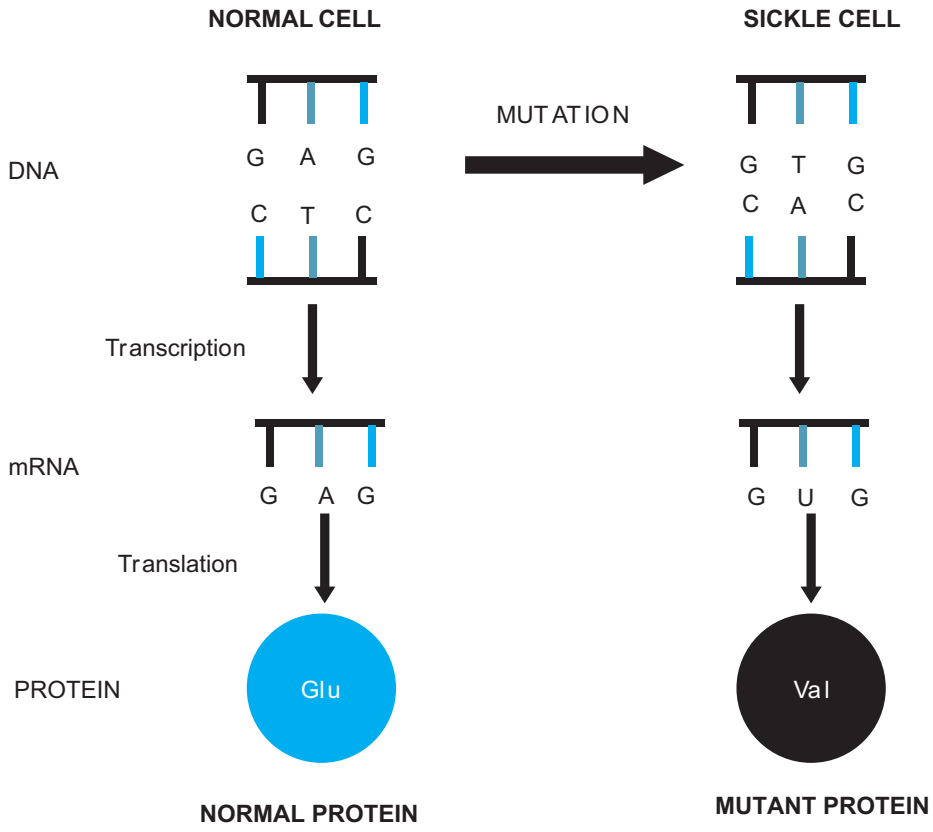


Figure 6.15: A single nucleotide substitution in haemoglobin gene resulting into replacement of glutamic acid by valine amino acid

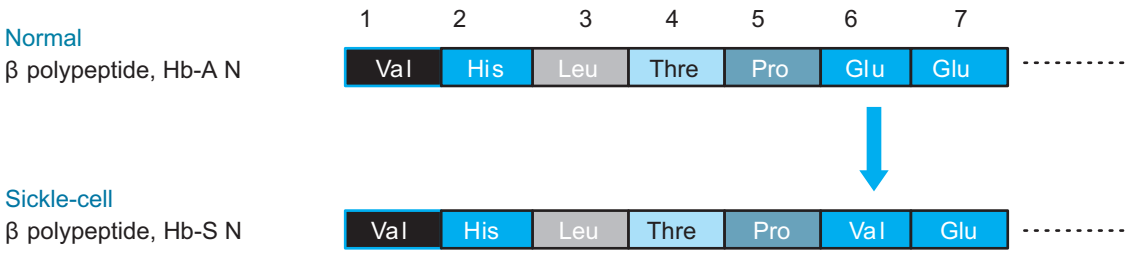


Figure 6.16: A diagram showing replacement of glutamine (Glu) by valine (Val) at 6th position from N-terminus in the sickled haemoglobin polypeptide

The amino acid valine makes the haemoglobin molecules stick together, forming long fibres which convert the normal disc-shape of red blood cells into sickle-shaped red blood cells.

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 (Figure 6.17). 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.

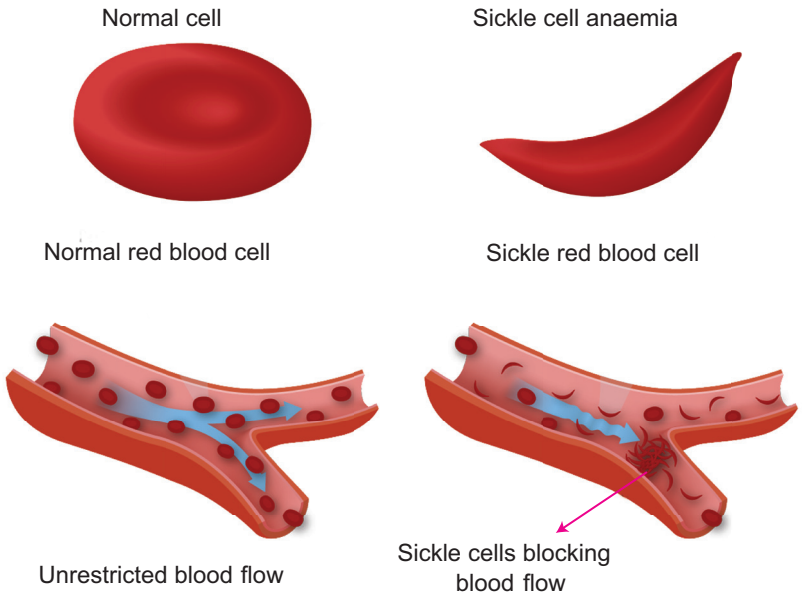


Figure 6.17: Difference between normal and sickle red blood cells

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** (Figure 6.18). 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.

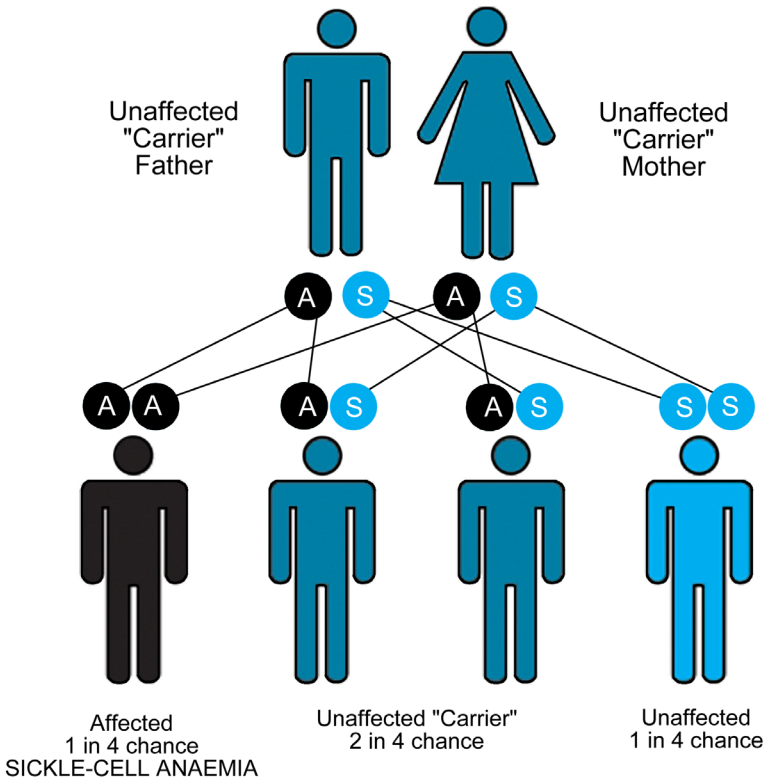


Figure 6.18: A diagram showing sickle-cell anaemia as autosomal recessive disorder

SELF EVALUATION

Complete sentences with correct words:

(i)..... distorts red blood cells and cause sickle-cell anaemia.

(ii) ..... people are sensitive to light.

(iii) Mutations are of two types ..... and ..... .

(iv) Sickle cell anaemia is an ..... disorder.

6.8 SUMMARY

- Genetic Code is the set of rules by which information is encoded in genetic material (DNA or RNA sequences) is translated into proteins (amino acid sequences) by living cells.
- A codon is made up of three nucleotides or triplets. Out of 64 codons, 61 codons are sense codons and 3 codons are non-sense codons.

- Genetic code is almost universal; it shows degeneracy.
- It is through genetic code that the genetic information found in m-RNA is translated to mature functional proteins.
- DNA molecule is a stable structure and replicates accurately in order to avoid any mutation or change in nucleotide sequences in DNA.
- Transcription is the process of copying information from one strand of DNA into a single stranded RNA (mRNA).
- A transcription unit in DNA is composed of a promoter, RNA coding sequence, and a terminator.
- **The process of transcription in bacteria includes —**
  - Initiation — a process of initiating transcription where a complex of RNA polymerase with sigma factor binds at the promoter.
  - Elongation — the process in which RNA polymerase synthesizes a complementary RNA sequence of the DNA template strand.
  - Termination — the process of ending transcription; and it can be carried out either in rho dependent manner or rho independent manner.
- **The process of transcription in eukaryotes involves —**
  - Initiation involves a complex of RNA polymerase II and general transcription factors.
  - Elongation is similar to that of bacteria. But eukaryotic genes do not have terminator sequences.
  - The newly formed pre-m-RNA has to undergo RNA processing.
- Translation is the production of protein molecules (polypeptides) by cellular ribosomes with the help of information present on the m-RNA.
- The covalent linking of a specific amino acid to the 3' end of the correct t-RNA by the enzyme aminoacyl-t-RNA synthetase is called charging of t-RNA.
- **Translation in bacteria includes —**
  - Initiation is a stage where m-RNA is bound to the ribosome and positioned itself for proper translation. It involves three steps.
  - Elongation is a stage where amino acids are sequentially joined together to form a polypeptide chain via peptide bonds.
  - Termination is the process where the newly formed polypeptide chain and the m-RNA are released from the ribosome.
  - Polyribosomes are complex of an m-RNA molecule and multiple ribosomes that are simultaneously translating it. It enables a large number of polypeptides to be produced faster and efficiently.

- **Translation in eukaryotes includes —**
  - Initiation differs from that of bacteria by: the first amino acid is methionine; it has 80S initiation complex; it locates start codon by scanning model for initiation.
  - Elongation is characterized by the involvement of nine eukaryotic elongation factors.
  - Termination codes are recognized only by e-RF1.
  - Change in genetic code is known as mutation.
  - Mutation is of two types: A base-pair substitution and base-pair insertions or deletions.
  - Some mutations do not have much effect such as silent mutation. However, some mutations can have a huge effect on genetic code such as frameshift mutation.
  - Any change in the nucleotide sequence of a gene can result into producing wrong or different polypeptide chain. The outcomes can be detrimental to the affected organisms.
  - Example: Sickle cell anaemia; albinism.

6.9 GLOSSARY

- **Albinism:** It is a disease caused by alteration of nucleotide sequence. It occurs due to mutation in the gene for tyrosinase, an enzyme which converts tyrosine to DOPA.
- **Charging t-RNA:** It is the process of attaching the correct amino acid to t-RNA with the help of aminoacyl-t-RNA synthetase enzyme.
- **Degeneracy:** The coding of the same amino acid by multiple codons. Example:UUU and UUC codons code for the same specific phenylalanine amino acid.
- **Frameshift mutation:** It is a gene mutation in which addition or deletion of one base-pair shifts the m-RNA's downstream reading frame by one base so that incorrect amino acids are added to the polypeptide chain after the mutation site.
- **Missense mutation:** It is a gene mutation in which change in base-pair (nucleotide sequence) of DNA results in change in an m-RNA codon, which codes for different amino acid.
- **Polyribosomes:** They are complex of an m-RNA molecule and multiple ribosomes that are simultaneously translating it.
- **Rho protein:** It is a protein that binds to the terminator sequence and RNA polymerase to end the process of transcription in bacteria.
- **RNA processing:** It is the process where pre-m-RNA undergoes modification to become a functional m-RNA.
- **Sickle cell anaemia:** 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).

- **Stop codon:** It is a nonsense codon, meaning it does not specify any amino acid. It rather stops translation.
- **Transcription:** It is the process of copying information from one strand of DNA into a single-stranded RNA (m-RNA).
- **Translation:** It is the production of protein molecules (polypeptides) by cellular ribosomes with the help of information present on the m-RNA.
- **Translocation:** It is a process in which the m-RNA is moved by a distance of three nucleotides (codon) to bring the next codon on the ribosome (A site).
- **Wobble hypothesis:** The reading of two or more different codons by the same t-RNA molecule. Example: The two different leucine codons (CUC, CUU) can be read by the same leucine t-RNA molecule, contrary to regular base-pairing rules.

6.10 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. Genetic code is composed of A, C, G, and T nucleotides.
2. The main role of t-RNA is to decode the codons on m-RNA.
3. The main role of m-RNA is to carry genetic information in a series of codons.
4. Ribosomes are made up only by proteins.
5. TATA box is found 10 base pairs downstream from +1 start site.
6. RNA polymerase doesn't need any factor to initiate transcription.
7. Hairpin loop structure is formed in rho dependent terminators.
8. Pre-m-RNA needs to undergo RNA processing to become functional m-RNA.
9. In prokaryotes, the first amino acid to bind at the P-site is N-formylmethionine.

II. Multiple Choice Questions

1. Sickle-cell anaemia is caused due to change in
   (a) Nucleotide T by A in the DNA (b) Nucleotide A by T in the DNA.
   (c) Nucleotide G by U in the DNA (d) Nucleotide U by G in the DNA.
2. Which of the following are the characteristics of genetic code?
   (a) Triplet code (b) Almost Universal
   (c) Nonoverlapping (d) All of these.
3. The wrong stop codon is
   (a) UUA (b) AUU
   (c) UAG (d) UGA

4. The word "wobble" means
   (a) Jumping (b) Synthesis
   (c) Unsteady (d) Stable
5. Which of the following is located in the upstream of a bacterial gene?
   (a) Promoter (b) Terminator
   (c) RNA-coding sequence (d) None of the above
6. RNA polymerase I doesn't catalyze the synthesis of
   (a) 28S molecule (b) 5S molecule
   (c) 5.8S molecule (d) 18S molecule
7. Which of the following components is not involved in eukaryotic transcription?
   (a) General transcription factors (b) RNA polymerase II
   (c) Sigma factor (d) Enhancers
8. Which of the following are related to eukaryotes?
   (a) RNA Processing (b) Introns & exons
   (c) Poly (A) tail (d) All of these
9. Scanning model is related to
   (a) Charging of t-RNA (b) Initiation
   (c) Elongation (d) Termination
10. In sickle-cell anaemia, valine amino acid replaces
   (a) Serine (b) Threonine
   (c) Glutamic acid (d) Tyrosine

III. Long Answer Type Questions

1. In your own words, state features of a genetic code.
2. Describe the process of transcription in bacteria.
3. Using diagrams, compare the process of bacterial and eukaryotic transcriptions.
4. Describe the process of translation in bacteria.
5. State the roles of t-RNA, m-RNA, and ribosomes in the formation of polypeptides.
6. What is sickle-cell anaemia? Explain its cause and symptoms.
7. In Genetic code (Figure 6.2), CUU codes for leucine (leu) amino acid. If we change the third letter of CUU i.e., U with C, A, G, which amino acid will the changed codon code for during translation?

Original codon	Change codon	Amino acid
CUU	CUC	
CUU	CUA	
CUU	CUG	

8. UUU codon codes for phenylalanine (Phe). If we change the third base "U" with C, A, G, which amino acid will the changed codon code for during translation?

Original codon	Change codon	Amino acid
UUU	UUC	
UUU	UUA	
UUU	UUG	

9. During translation, what will happen if there is mutation on a codon UAU (codes for tyrosine) where the third letter "U" is replaced by either one of the bases A or G or C?

Original codon	Change codon	Amino acid
UAU	UAA	
UAU	UAC	
UAU	UAG	

10. State that ribosomes provide surface area for the attachment of mRNA during polypeptide synthesis.
11. Construct a flow chart, in proper sequence, for the stages of transcription and translation.
12. Using the evidence, predict the effect of change in genetic code on the structure of the protein manufactured during protein synthesis.
13. Briefly describe the alteration of nucleotide sequence attacking the deadly AIDS. Also show how it can be an essential step towards poverty alleviation.

Unit 7

Autotrophic Nutrition

Key Unit Competence

To be able to describe the process of photosynthesis and explain the various environmental factors that influence the rate of photosynthesis.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- state and explain the types of autotrophic nutrition.
- explain the role of light in autotrophic nutrition.
- state the pigments involved in light absorption.
- appreciate the importance of photosynthesis as an energy transfer process that produces complex organic compounds using light energy absorbed by chloroplast pigments.
- recall the structure of the leaf in relation to photosynthesis.
- use their knowledge of plant cells and leaf structure from the section on cell structure while studying photosynthesis.
- state the sites and stages of photosynthesis in chloroplasts.
- describe the role of chloroplast pigments (chlorophyll a, chlorophyll b, carotene and xanthophylls) in light absorption in the grana.
- describe the relationship between the structure and function in the chloroplast, using diagrams and electron micrographs.
- interpret absorption and action spectra of chloroplast pigments.
- carry out an investigation of limiting factors.
- outline the three main stages of the Calvin cycle.
- describe and outline the conversion of the Calvin cycle intermediates to carbohydrates, lipids and amino acids and their uses in the plant cell.
- relate the anatomy and physiology of the leaves of C4 and CAM plants to high rates of carbon fixation and low rates of transpiration.
- explain the term limiting factor in relation to photosynthesis and the effects of the changes in the limiting factors on the rate of photosynthesis.
- apply knowledge and understanding of limiting factors to increase crop yields in protected environments, such as glasshouses.

- Investigate the effect of light intensity or light wavelength on the rate of photosynthesis.
- Acknowledge that environmental factors influence the rate of photosynthesis and investigation shows how they can be managed in protected environments used in crop production.
- Differentiate between C4, CAM and C3 plants during carbon dioxide fixation.

ACTIVITY 1

The term 'autotroph' consists of two words 'auto' and 'troph'. 'Auto' means 'self' and 'troph' means 'nutrition'. Search from the internet and using books about autotrophic nutrition. Make report on the same and present it to the class.

All organisms require macromolecules like carbohydrates, proteins and fats for their growth and development. Some organisms produce these organic compounds from inorganic sources on their own. Such organisms are called **autotrophs** or **producers** and the process of synthesizing complex compounds from simple inorganic sources is called **autotrophic nutrition**. While others including humans are heterotrophs or consumers, which depend on autotrophs for source of chemical energy. Green plants are autotrophs and require chlorophyll, sunlight, oxygen and minerals for preparing their own food.

7.1 TYPES OF AUTOTROPHIC NUTRITION

Chemoautotrophic: An autotrophic nutrition where organisms get energy from oxidation of chemicals, mainly inorganic substances like hydrogen sulphide and ammonia.

$$2H_2S + O_2 \longrightarrow 2H_2O + 2S$$

Photoautotrophic: An autotrophic nutrition where organisms get energy from sunlight and convert it into usable form like sugars. Green plants and some bacteria like, green sulphur bacteria can make their own food from simple inorganic substances by a process called **photosynthesis.**

$$6CO_2 + 6H_2S \xrightarrow[\text{Bacteriochlorophyll}]{\text{Light energy}} C_6H_{12}O_6 + 6S \qquad \text{(Green sulphur bacteria)}$$

$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light energy}} C_6H_{12}O_6 + 6O_2 \qquad \text{(Green plants)}$$

7.2 TESTS FOR STARCH AND FOR OXYGEN

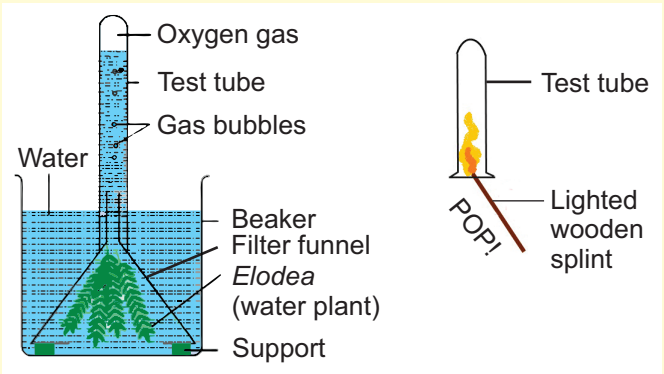
ACTIVITY 2

Aim: To show that starch is important for photosynthesis in terrestrial plants.
Materials Required: Two potted plants, ethyl alcohol, iodine solution, sauce pan and burner.
Procedure: Take two potted plants. Keep one in dark and other in well illuminated condition. After 24 hrs, take leaves from each plant. Boil ethyl alcohol in a sauce pan and dip leaves for 30 s. Place them in a beaker of ethyl alcohol until they turn white. Take leaves out and cover with iodine solution.
Observation: Leaf taken from well illuminated condition plant turned bluish-black while other tested negative.
Discussion: This shows that starch is present in terrestrial plants that carry out photosynthesis.
After performing the experiment, try to answer the following questions:

- What is the role of ethyl alcohol in experiment?
- What made leaves turn blue-black?

ACTIVITY 3

Aim: To show that oxygen is required by aquatic plants.
Materials Required: Beaker, funnel, aquatic plant *Elodea*/*Hydrilla* and boiling tube.
Procedure: Take a few fresh twigs of aquatic plant *Elodea*/*Hydrilla* with one end intact and put in a beaker full of water. Keep an inverted funnel on the plant such that all plants are inside the funnel and their cut ends facing up. Now take a boiling tube full of water and invert it on the funnel. Put the whole apparatus in sunlight.



Observation: Observe the air bubbles accumulating in the boiling tube.
Discussion: The air shows positive test for oxygen gas.
After performing the experiment, answer the following questions:

- What is the positive test for oxygen?
- How is oxygen available for aquatic plants?

7.2.1 Importance of Autotrophic Nutrition

Photosynthesis is a process by which plants and other organisms, such as algae and bacteria synthesize their own food using the energy of light for their growth and development. The food produced by plants is in the form of carbohydrates. In preliminary studies, Julius von Sachs

proposed that glucose is the first product of photosynthesis. It is stored in chloroplasts within plant cells. It provides energy in the form of food to organisms that feed on plants. It has been rightly said "ALL FLESH IS GRASS", as all organisms (herbivores, carnivores and omnivores) are directly or indirectly dependent on plants as a source of energy. It is the means by which solar energy is captured by plants for use by all organisms. In 1782, Jean Senebier proved that green plants can produce oxygen in presence of light and carbon dioxide. It is the single most important biological process that can replenish oxygen which is required for existence of all other organisms. *Have you ever thought about what will happen if there is no photosynthesis*? This unit focuses on the photosynthetic machinery, the reactions in this physiochemical process and the factors affecting photosynthesis.

7.3 ADAPTATION OF PLANTS FOR PHOTOSYNTHESIS

Photosynthesis occurs not only in eukaryotic organisms such as green plants but also in prokaryotic organisms like blue green algae and green sulphur bacteria.

In higher plants, photosynthesis occurs in the green part of the plant (Figure 7.1). Leaves are adapted to carry photosynthesis efficiently. Most leaves are broad and flat to capture maximum light. Also the bifacial nature of the leaf allows it to collect incident light on the upper surface and diffuse light on the lower surface. The photosynthetic tissue is located between the upper and lower epidermis. It consists of one to three layers of compactly arranged, elongated and cylindrical palisade mesophyll cells, and loosely arranged, irregular and isodiametric spongy mesophyll cells. In monocotyledonous leaf, there is no distinction of palisade and spongy parenchyma.

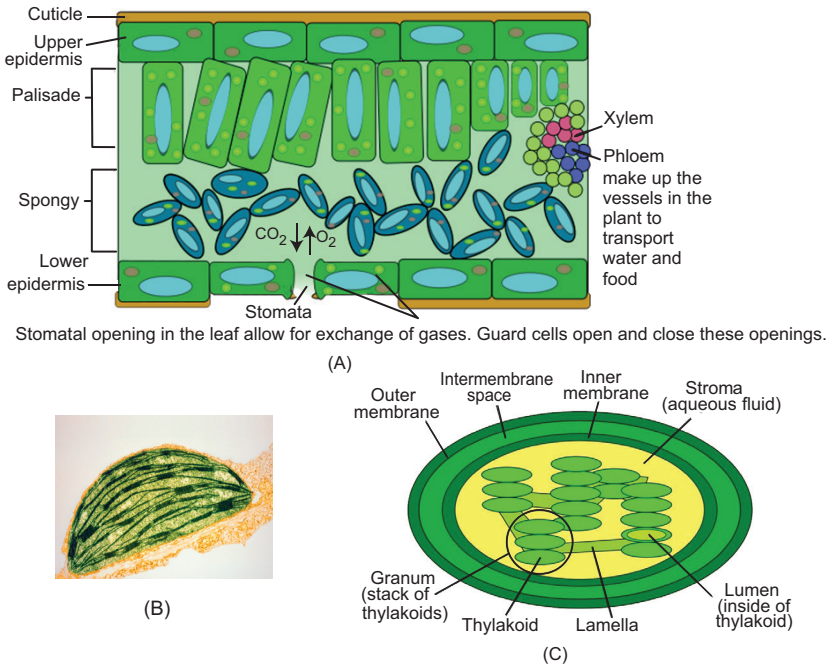


Figure 7.1: (A) Structure of leaf showing photosynthetic cells; (B) EM of chloroplast cells; (C) Sectional view of chloroplast.

The mesophyll cells in leaves contain large number of chloroplasts that transform light energy into ATP and NADPH which are then used to convert CO_2 into sugars.

7.4 STRUCTURE OF CHLOROPLAST–THE ORGANELLE FOR PHOTOSYNTHESIS

Chloroplast is the photosynthetic machinery. It is a double membrane organelle that contains series of parallel membranes called **thylakoids** or **lamellae**, suspended in fluid like matrix called **stroma**. The thylakoids are flattened discs arranged in stacks called **grana**. In a typical chloroplast as many as 40-60 grana may be present and each granum may contain 2-100 thylakoids. The stroma contains DNA, ribosomes, soluble proteins and enzymes, while pigments are confined to thylakoids. Thylakoids have large surface for absorption of light and the space within them '**lumen**' allows rapid accumulation of protons.

7.4.1 Pigments of Chlorophyll

A **pigment** is a substance that absorbs light of different wavelengths. Pigments are involved in absorption of light of certain wavelength. While some wavelengths are absorbed, other are reflected or scattered, which imparts them colour. The absorbed wavelength of light has the correct energy to excite specific transitions of electrons in the pigments. Photosynthesis depends on light absorption by pigments in leaves. However, it can be carried out in isolated chloroplast but not in isolated pigments.

ACTIVITY 4

Aim: To perform chromatography to separate and identify chloroplast.

Materials Required: Whatmann's filter paper No.1, mortar and pestle and solvent.

Procedure: Cut a vertical strip (10 cm) × (2.5 cm) of Whatmann's filter paper No.1. Make it V-shaped at one end. Draw a horizontal line with a pencil (not pen) about half an inch from the bottom.

Make leaf extract by crushing 20 g leaves in 20 mL acetone. With the help of capillary tube load a small drop of leaf extract at the centre of pencil mark and air dry. Repeat the previous step for 5-6 times. Insert paper strip in chromatographic chamber pre-saturated with solvent (1:9:: benzene:petroleum ether) such that only tip of paper is dipped into solvent. *Do not dip the loaded pigment into solvent*. Allow it to run for few (1-2) hours. Take out strip and mark solvent front and different coloured separated pigments.

Observation: Different bands of different colours are formed.

Discussion: Discuss and label the different bands formed on the filter paper. Also answer why there are different bands formed.

Chlorophyll a is the major pigment involved in trapping light energy. It is the principal pigment involved in photosynthesis. It is of universal occurrence. It is a large molecule composed of four pyrrole rings with Mg at centre, and a long hydrocarbon phytol chain. It absorbs maximum wavelengths of 430 nm and 660 nm.

Chlorophyll b constitutes one-fourth of the total chlorophyll content. It has a similar structure as that of Chlorophyll a, except that the $-CH_3$ group in chlorophyll a is replaced by –CHO group in chlorophyll b. It absorbs maximum wavelengths of 460 nm and 680 nm.

Carotenes are tetraterpenes or polyunsaturated hydrocarbons containing 40 carbon atoms and variable number of hydrogen atoms and no other elements. β-carotene is the common form found abundantly in orange, yellow and green fruits and vegetables. Carotenes protect plant against **photo-oxidation.**

Xanthophylls are yellow coloured pigments. They are structurally similar to carotenes, but contain oxygen atoms. These are more common in young and etiolated leaves.

7.4.2 Absorption and Action Spectra

A plot showing absorption of light of different wavelengths of a pigment is called absorption spectrum.

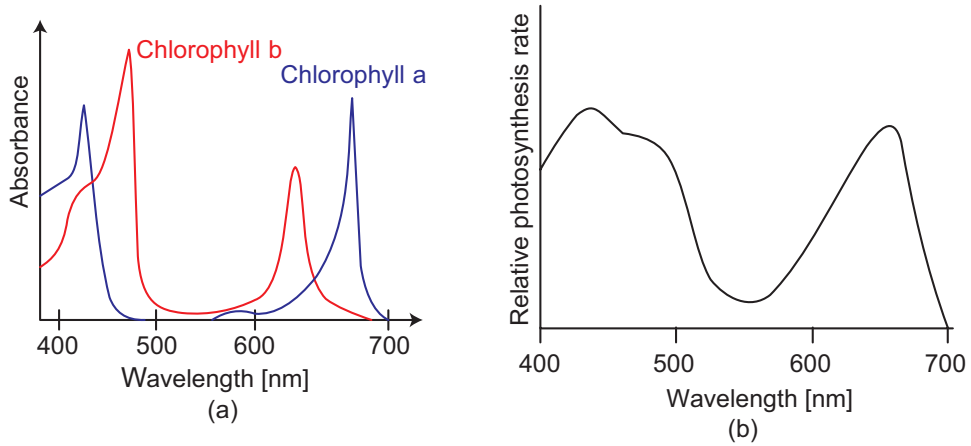


Figure 7.2: (a) Absorption spectrum of chloroplast pigments;
(b) Action spectrum of green plants.

Each pigment absorbs a specific wavelength. We can plot an absorption spectrum showing the ability of pigments to absorb lights of different wavelengths. From Figure 7.2(a), it can be concluded that chlorophyll a and b show absorption peaks at blue and red light. On the other hand, action spectrum is the plot of graph depicting the rate of a light sensitive process at

different wavelength of light. The action spectrum of photosynthesis shows that most of the photosynthesis also takes place in blue and red light. The absorption spectrum of a pigment when compared with action spectrum of photosynthesis, gives the function of the pigment. Therefore, it can be concluded that chlorophyll a is the chief photosynthetic pigment. The other pigments like chlorophyll b, carotenes and xanthophylls are called accessory pigments and form the antenna complex. They collect light of different wavelength and transfer it to reaction centre (basic model of energy transfer). This is called Light Harvesting Complex (Figure 7.3). LHC is made up of hundreds of pigment molecules bound to proteins.

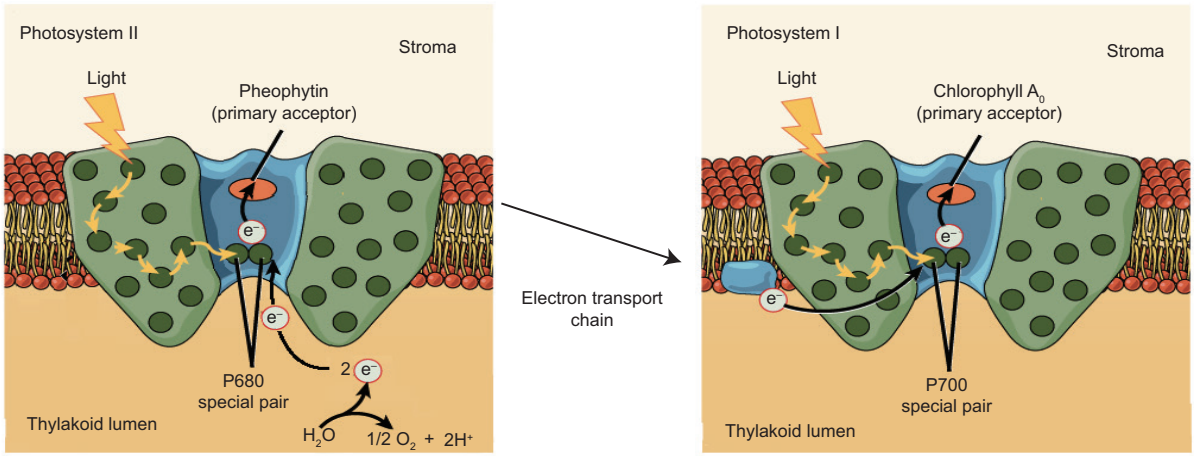


Figure 7.3: Light harvesting complex

In 1985, R Huber, H Michael and J Dissenhofer crystallized and worked on of light harvesting complex of *Rhodobacter*, and got Nobel Prize in 1988. In green plants, pigments are organized into two discrete photochemical complexes: **Photosystem I (PSI)** and **Photosystem II (PSII),** named after their sequence of discovery. Each photosystem has all the pigments which help in more efficient absorption of light. The **chlorophyll a** molecule forms the reaction centre. In PSI, the reaction centre **chlorophyll** a molecule has absorption maxima at 700 nm, hence called $\mathbf{P_{700}}$ and in PSII it has absorption maxima at 680 nm, called $\mathbf{P_{680}}$.

7.4.3 Role of Light

Light has two components: wave and particle. A wave is characterized by a wavelength, denoted by a Greek letter lambda (λ), which is the distance between two successive wave crests, and the number of wave crests that pass an observer in given time is called frequency (ν). Light is also a particle called **photon**. Sunlight is like rain of photons with different frequencies. The energy content of light photon is not continuous rather delivered in discrete packets, the **quanta**.

When a light photon is absorbed, an electron is excited from pigment molecule to a higher energy level (triplet state). It remains there for 10^{-9} s and then fall to ground state. Sometimes, it can emit the energy in the form of light and heat as it reaches the ground state. This process is called **fluorescence**. When electron remains at triplet state for more than 10^{-9} s and then comes back to ground state, the energy is lost in the form of heat and light. This happens even after the source is put off. Such a process is called **phosphorescence**.

SELF EVALUATION

Complete the sentences by correct terms:

(i) Chloroplast is a double membrane organelle that contains a parallel membrane called ..... .

(ii) ..... is the yellow coloured pigment found in young and etiolated leaves.

(iii) Most of the photosynthesis takes place at ..... and ..... light.

(iv) PSII has absorption maxima at ..... .

7.5 MECHANISM OF PHOTOSYNTHESIS

ACTIVITY 5

Aim: Investigation to determine the effect of light intensity or light wavelength on the rate of photosynthesis using a redox indicator.

Materials Required: Pestle and mortar, centrifuge, filter paper, test tube, sucrose buffer, DCPIP dye.

Procedure: Crush the interveinal portion of leaves in chilled sucrose buffer using pestle and mortar. Filter it and centrifuge the filtrate at 200-300 rpm for 2-3 minutes. Collect the supernatant and again centrifuge at higher speed above (5000 rpm). Collect pellet and dissolve in small amount of buffer. Take a test tube and to each test tube add sucrose buffer, chloroplast extract, DCPIP dye according to following table and keep in different light conditions for 10-20 minutes.

Observation:

S.No.	Chloroplast suspension	Sucrose buffer	DCPIP dye	Light condition	Note the colour change
1.	0.5 mL	9 mL	0.5 mL	Sunlight	
2.	0.5 mL	9 mL	0.5 mL	Low light	
3.	0.5 mL	9 mL	0.5 mL	Dark	
4.	0.5 mL (Boiled)	9 mL	0.5 mL	Sunlight	
5.	0.5 mL	9 mL	0	Sunlight	

Discussion: Discuss the change in colour obtained. Also state the role of DCPIP in the experiment.

The process of photosynthesis takes place in two major phases: **Light reaction** and **Dark reaction**. Both these phases are interdependent. Green plants convert light energy to chemical energy. The light energy is used to transfer electron from water to reduce NADP, which in reduced form, can further be used to fix carbon dioxide. Thus, carbon fixation does not need light directly and is called dark reaction. Both light and dark reactions take place in chloroplasts.

Table 7.1

Light reaction	Dark reaction
It is the photochemical reaction where water breaks down in presence of light to produce oxygen, $NADPH_2$ and ATP. H_2O ----------$NADPH_2$ + ATP + $1/2O_2$	It is the carbon reduction reaction where carbon dioxide uses chemical energy to produce sugars. CO_2 +$NADPH_2$ + ATP ---------- $C_6H_{12}O_6$
It includes photolysis of water and evolution of oxygen and assimilatory power	It includes fixation of carbon dioxide to produce hexoses
It takes place in thylakoids of chloroplast	It takes place in stroma of chloroplast
It requires light directly	It does not require light directly
It is temperature independent	It is temperature dependent
It is dependent on dark reaction for ADP and NAPD	It is dependent on light reaction for ATP and NAPDH

Light Reaction

Photochemical phase or **Light reaction** in which solar energy is trapped by chlorophyll and stored in the form of **chemical energy of ATP** and as **reducing power in NADPH2**. The ATP and NADPH2 together constitute the **assimilatory power** of the plant. Oxygen is evolved in the light reaction by splitting of water **(photolysis of water)**.

Mechanism of Light Reaction

The two photosystems (PS I and PS II) absorb different wavelengths of light. The light energy absorbed anywhere in the harvesting zone of a photosystem is passed to its photocentre. When the photocentre acquires a sufficient quantum of energy, it emits an electron. This electron with high potential energy moves down to an **electron transport chain**, and results in the formation of ATP. Thus, the primary function of the two photosystems which interact each other, is to trap light energy and converts it to the chemical energy (ATP). This chemical energy stored in the form of ATP is used by the living cells.

7.6 DARK REACTION/CARBON ASSIMILATION/CARBON FIXATION

7.6.1 Calvin Cycle

It is carbon assimilation process which utilizes assimilatory power generated from light reaction to produce sugars. It occurs in stroma of chloroplasts. Melvin Calvin got Nobel Prize for his outstanding work on carbon assimilation. Melvin Calvin, Andrew Benson and James Bassham gave the **Calvin cycle** of dark reaction. They used autoradiography to detect path of cycle, and chromatography to separate constituents. The first product that showed radioactivity was a three carbon (3-C) compound Phosphoglyceric acid (PGA) and hence the cycle is also called **C-3 cycle**.

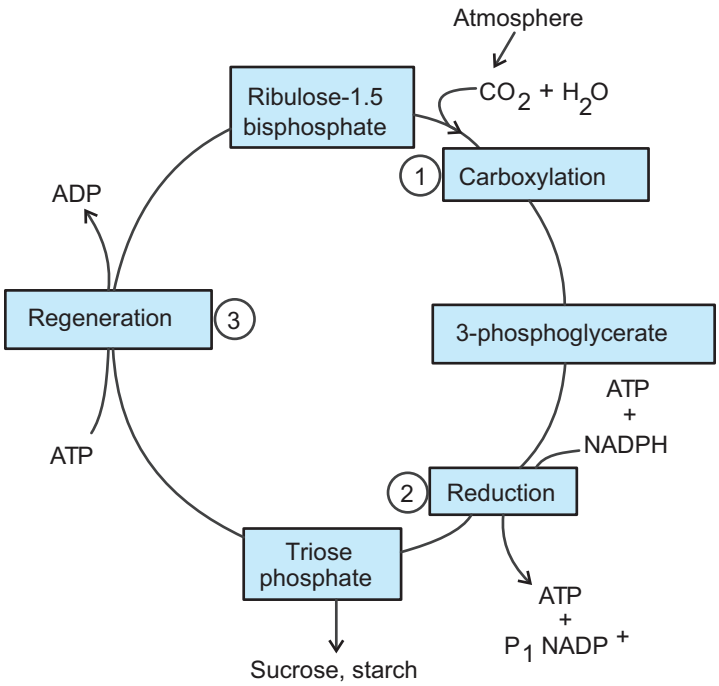


Figure 7.4: Calvin cycle

The process of carbon assimilation can be described under three stages: carboxylation, reduction and regeneration (Figure 7.4).

Carboxylation: It is the process of fixation of carbon in stable organic intermediate, phosphoglyceric acid. This reaction is catalyzed by an enzyme called **RuBPcarboxylase-oxygenase (RUBISCO)**. Rubisco-bis-phospahte (RuBP) is the initial acceptor or substrate for dark reaction.

$$6\ RuBP + 6\ CO_2 + 6H_2O \xrightarrow{\text{RUBISCO}} 12\ \text{Phosphoglyceric acid}$$

Reduction or **Glycolytic Reversal:** It is the process involving reduction of carbon. It is a multistep process that utilizes 12 ATP molecules and 12 NADPH for release of one molecule of glucose. The glucose can further be converted into starch for storage or sucrose for transport.

$$12\ \text{Phosphoglyceric acid} + 12ATP \longrightarrow 12\ \text{Di-phosphoglyceric acid} + 12ADP$$

$$12\ \text{Di-phosphoglyceric acid} + 12NADPH \longrightarrow 12\ \text{Phosphoglyceraldehyde} + 12NADP + H_3PO_4$$

$$5\ \text{Phosphoglyceraldehyde (PGAL)} \rightleftharpoons 5\ \text{Dihydroxy acetone phosphate (DHAP)}$$

$$3\ PGAL + 3\ DHAP \longrightarrow 3\ \text{Fructose1,6-diphosphate}$$

$$\text{Fructose1,6-diphosphate} \longrightarrow \text{Fructose 6-phosphate}$$

$$\text{Fructose 6-phosphate} \longrightarrow \text{Glucose 6-phosphate}$$

Regeneration: This process requires 6 ATP molecules to regenerate 6 molecules of RuBP, which is crucial for continuity of Calvin cycle.

$$2\ \text{Fructose1,6-diphosphate} + 2\ PGAL + 2\ DHAP + 6ATP \longrightarrow 6\ RuBP + 6ADP$$

During complete cycle, ATP, NADPH and CO_2 are used up. For one molecule of glucose six molecules of carbon dioxide, 18 ATP and 12 NADPH are required. The dark reaction is therefore dependent on light for the production of high amount of ATP and NADPH.

In	Out
Six CO_2	One glucose
18 ATP	18 ADP
12 NADPH	12 NADP

Another important requirement is high concentration of CO_2. The efficiency of photosynthesis declines at low concentration of CO_2. This is because the enzyme RUBISO has low affinity with carbon dioxide as compared to oxygen. At low CO_2 concentration, RUBISCO catalyzes the reaction between RuBP and oxygen. The oxygenation of RuBP in presence of light and oxygen is called **Photorespiration**. It occurs in chloroplast, peroxisome and mitochondria. It is a wasteful process as during this process carbon dioxide is released and efficiency of photosynthesis decreases (Figure 7.5).

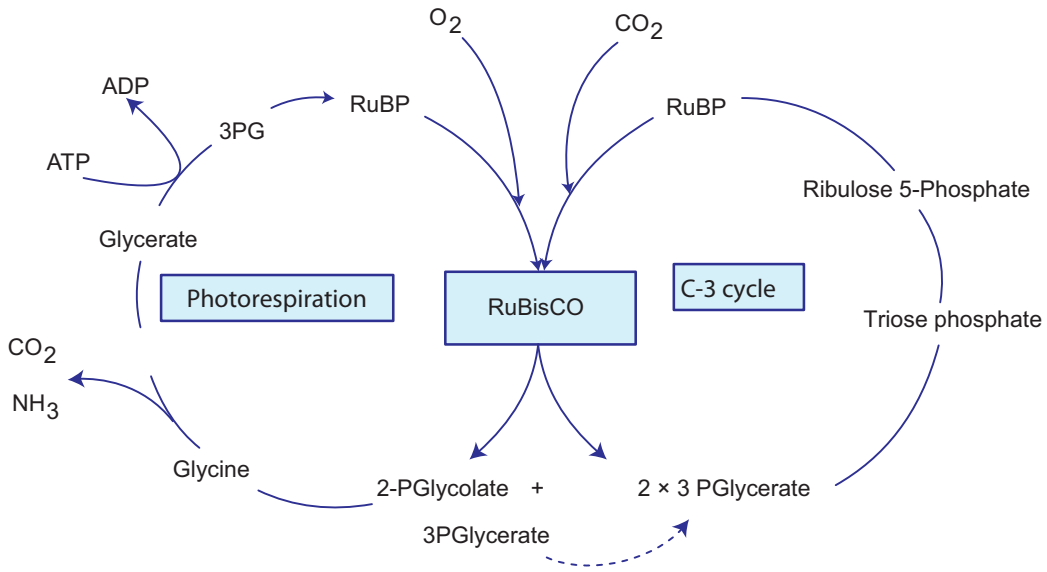


Figure 7.5: Photorespiration and C-3 cycle

7.6.2 Hatch and Slack Cycle

In some temperate plants such as wheat, rice, potato and bean only Calvin cycle occurs. Such plants are called C-3 plants. While in some other plants dual carboxylation takes place: (1) carboxylation of phosphoenol pyruvate (PEP) and (2) carboxylation of RuBP. Such plants are called C-4 plants e.g. maize, sugar cane and sorghum. In these, the first product formed during carbon dioxide fixation is a four carbon compound oxalo acetic acid (OAA). C-4 plants have special type of leaf anatomy called **Kranz** Anatomy. They have special large cells around vascular bundles called bundle sheath cells. These are characterized by having large number of chloroplasts, thick walls and no intercellular spaces. The shape, size and arrangement of thylakoids in chloroplasts are also different in bundle sheath cell as compared to mesophyll cell chloroplasts.

Table 7.2

Mesophyll cell chloroplast	Bundle sheath cell chloroplast
Chloroplasts are small and oval to round	Chloroplasts are large and elongated
Thylakoids are arranged in grana	Thylakoids are stromal
They are evenly distributed in cells	They are centripetally arranged in cell
C-4 cycle takes place	C-3 cycle takes place
Starch absent	Starch present

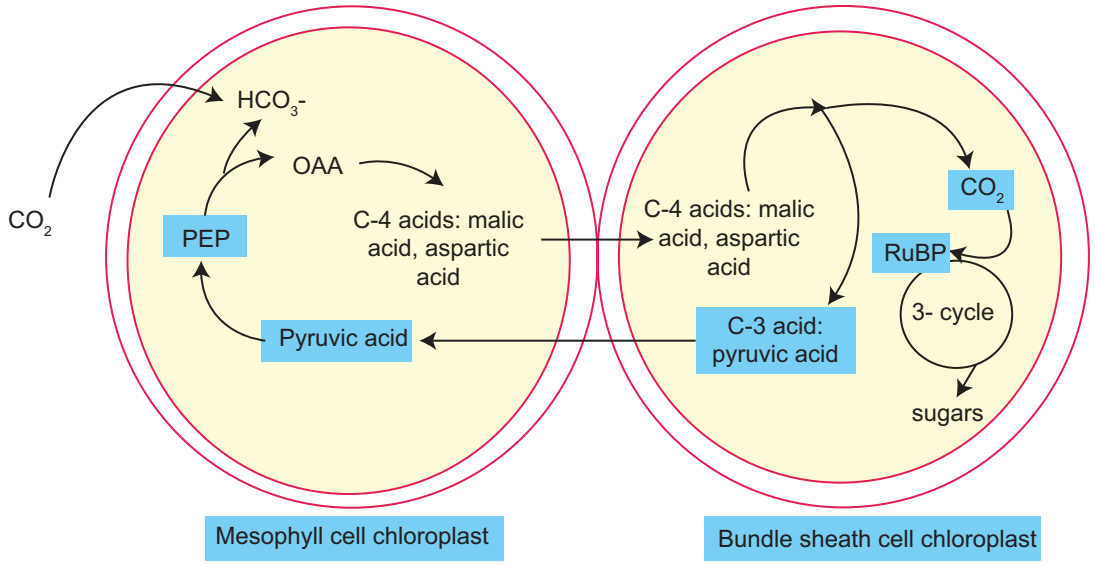


Figure 7.6: Hatch and slack pathway

The pathway followed by C-4 plants is called **C-4 cycle** or **Hatch and Slack pathway**. This was discovered by Hatch and Slack in sugar cane. The primary CO_2 acceptor is a 3-carbon molecule phosphoenol pyruvate (PEP). The reaction is catalyzed by **PEPcarboxylase** or **PEPcase** in mesophyll cell chloroplast. It forms 4-carbon compounds like OAA, malic acid or aspartate, which are transported to the bundle sheath cells. In bundle sheath cells, these acids are broken down to release CO_2 and 3-carbon molecule. The 3-carbon molecule is transported back to mesophyll cells and converted to PEP again, while CO_2 enters into C-3 cycle to form sugars (Figure 7.6). C-4 plants are more efficient than C-3 plants as in C-4 plants, photosynthesis can occur at low concentration CO_2 and photorespiration is negligible or absent.

Table 7.3

C-3 Plants	C-4 Plants
These are mostly temperate plants	These are mostly tropical plants
They show C-3 cycle	They show both C-3 and C-4 cycle
Initial acceptor of CO_2 is RuBP	Initial acceptor of CO_2 is PEP
First product of carbon assimilation is a 3-carbon compound	First product of cycle is a 4-carbon compound
Kranz anatomy is absent	Kranz anatomy or chloroplast dimorphism (different types of chloroplast in mesophyll cell and in bundle sheath cells) is present

SELF EVALUATION

Complete with appropriate terms:

(i) Photorespiration occurs in ....., ... and ..... .

(ii) C4 plants have special type of leaf anatomy called ..... .

(iii) In C3 plants, initial acceptor of CO_2 is ..... .

(iv) Hatch and Slack pathway occurs in ..... and ..... of chloroplast.

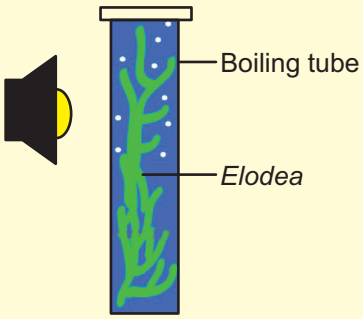
7.7 FACTORS AFFECTING PHOTOSYNTHESIS

ACTIVITY 6

Aim: To investigate the effect of carbon assimilation on the rate of photosynthesis.

Materials Required: *Elodea* plant, glass rod, sodium bicarbonate.

Procedure: Take a fresh, healthy twig of *Elodea* plant with one end intact and tie it gently to a glass rod. Put the glass rod with plant in a boiling tube containing water and add 1mg/mL sodium bicarbonate and keep it in moderate light condition. Note the numbers of bubbles escaping from cut end per minute. Again add same amount of sodium bicarbonate and note the number of bubbles escaping from cut end per minute. Do you find the number of bubbles increasing? Repeat this step until bubbles escaping per minute do not increase. Then take set up under high light intensity and note the numbers of bubbles.



Observation: The bubbles evolved gradually.

Discussion: Discuss what the bubbles are and why they evolved.

Carbon assimilation is directly related to the productivity of plants. It carries implications for the sustainability of the human population. The total carbon assimilation is known as Gross primary productivity and the one available for increase in biomass is known as net primary productivity. Net primary productivity is determined by deleting loss due to respiration by plants. It is the biomass available for animals. By studying factors affecting photosynthesis, one can learn to manage world resources in time. The rate of photosynthesis can be influenced by many factors like number, size, orientation and age of leaf, sunlight, temperature, carbon dioxide and water. However, when several factors can affect a process, the rate of reaction is governed by the factor which is limiting. This is called Blackman's (1905) **law of limiting factor**. For example, despite the presence of green leaf, optimal carbon dioxide, the plant may not photosynthesize if light

intensity is very low. Thus, light behaves as limiting factor and controls the rate of photosynthesis (Figure 7.7). Hence, rate will be determined by the factor available at sub-optimal level.

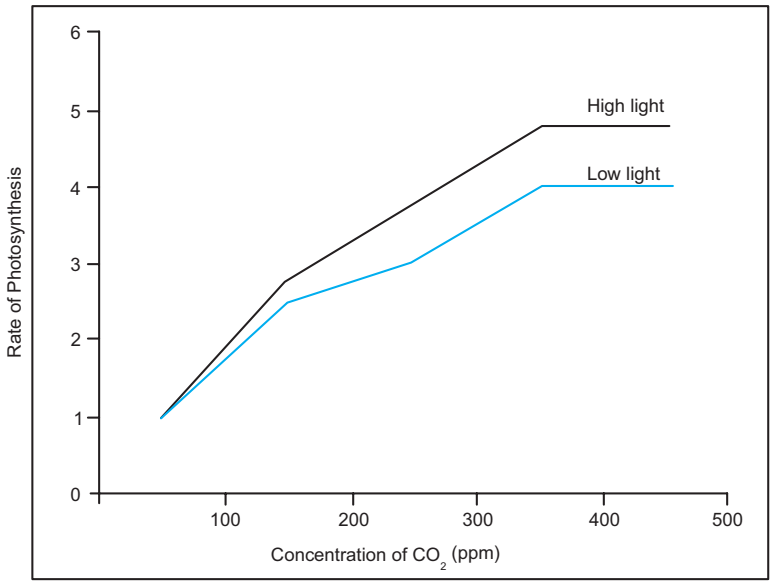


Figure 7.7: Graph depicting Blackmann's law of limiting factor.

7.7.1 External Factors

ACTIVITY 7

Aim: To show effect of carbon dioxide on the rate of photosynthesis.

Materials Required: *Elodea*, beaker, $NaHCO_3$, lamp.

Procedure: Place a pond weed *Elodea* upside in a test tube containing water at 25°C. Place the tube in a beaker of fresh water. Place excess sodium bicarbonate ($NaHCO_3$) in the water to give a constant saturated solution of CO_2. Place the lamp at a fixed distance from the plant. Maintain the room temperature at 20°C. Count the number of oxygen bubbles given off by the plant in a one minute period.

Observation: The bubbles are formed of oxygen.

Discussion: Discuss why was $NaHCO_3$ added to water.

CO_2 concentration: Carbon dioxide is the inorganic substrate for photosynthesis. Increase in concentration up to 0.05% in atmosphere can cause an increase in CO_2 fixation. Carbon dioxide is the major limiting factor, especially in C-3 plants; C-4 plants are more productive even at low concentration of CO_2. Nevertheless, both C-3 and C-4 plants show increase in rate of photosynthesis

at high CO_2 concentration and high light intensities. The fact that C-3 plants respond to higher CO_2 concentration by showing increased rates of photosynthesis leading to higher productivity has been used for some green house crops such as tomatoes and bell pepper. They are allowed to grow in carbon dioxide enriched atmosphere as in glasshouses leading to higher yields.

ACTIVITY 8

Aim: To show the effect of light intensity on photosynthesis in terrestrial plants.

Materials Required: Spinach, sodium bicarbonate solution, detergent, lamp.

Procedure: Take out uniform size discs from fresh leaves of spinach. Place discs in 0.2% sodium bicarbonate solution and a drop of liquid detergent in a syringe. Plunge out air present in between tissue, such that intercellular spaces are occupied by sodium bicarbonate and all leaf discs sink to bottom. Then put leaf discs in the beaker containing water exposed to on lamp. Count the number of leaves that then float on surface at regular interval of time. Similarly, repeat the experiment with increasing light condition.

Observation: Count and note the number of leaves floating.

Discussion: Discuss why the leaves floated.

ACTIVITY 9

Aim: To show the effect of light intensity on aquatic plants.

Materials Required: *Elodea*, glass rod, sodium bicarbonate.

Procedure: Take a fresh, healthy twig of *Elodea* plant with one end intact and tie it gently to a glass rod. Put the glass rod with plant in a tube or jar containing water and a pinch of sodium bicarbonate. Keep it in under a light source at a distance of 50 cm/ low light condition. Note the numbers of bubbles escaping from cut end per minute. Place the apparatus at distance of 30 cm from the light source and count the number of bubbles evolving per minute. Similarly, place the apparatus at variable distances from light source.

Observation: Count the number of bubbles evolving per minute.

Discussion: Discuss any change in the number of bubbles.

Light: Light is an important factor to carry out photosynthesis. It is rarely a limiting factor in nature as photosynthesis can occur even at low light intensities. There is a direct relation between light and CO_2 fixation. With increase in light intensity the rate of photosynthesis increases. However, at higher light intensities, rate does not increase linearly but light saturation occurs. At very high light intensity, there is breakdown of chlorophyll molecules called photo-oxidation and the rate of photosynthesis decreases. The quality of light and

time of exposure also governs photosynthesis. Green plants show high rate of photosynthesis at red and blue light.

ACTIVITY 10

Aim: To show effect of temperature on photosynthesis.

Materials Required: *Elodea* plant, boiling tube, sodium bicarbonate.

Procedure: Take a fresh, healthy twig of *Elodea* plant with one end intact and tie it gently to a glass rod. Put the glass rod with plant in a boiling tube containing water and a pinch of sodium bicarbonate. Keep it in under moderate light condition. Note the temperature and numbers of bubbles escaping from cut end per minute. Heat or cool the water in a boiling tube.

Observation: Count the number of bubbles at different temperatures.

Discussion: Discuss the change in number of bubbles.

Temperature: The dark reactions are dependent on temperature as they are enzymatic. Rate of photosynthesis is best at optimum temperature. Different plants have different temperature optima that also depend on their habitats.

Water: Only about 1% of water absorbed by plants is used in photosynthesis. It is an important factor for various metabolic processes in plant. Water may not have direct affect on photosynthesis even though it is one of the reactants in light reaction. In water stress plants wilt and their stomata close. Thus reducing availability of carbon dioxide and decreasing the rate of photosynthesis. Water stress will also alter the hydration of enzymatic proteins, affecting their activities.

Oxygen concentration: Atmospheric oxygen content affects photosynthesis directly or indirectly. The decrease in rate of respiration at high oxygen concentration was first observed by O. Warburg in 1920 in *Chlorella*. The phenomenon is called the Warburg effect.

Chemical pollutants: Plant growth has been adversely affected by accumulation of various undesirable chemicals. Heavy metals such as lead, mercury, cadmium seem to be affecting photosynthesis through stomata closure. Air pollutants like SO_2, NO_2 and O_3 are also known to affect photosynthesis at higher concentrations.

7.7.2 Internal Factors

Adaptation of leaf: Leaves are arranged on plants to minimize overlapping. The shape, size, age and orientation of leaf influences the absorption of light and thus effects photosynthesis. Most leaves are broad for more absorption of light. The anatomy of the leaf is also highly specialized for absorption of light. The epidermis is transparent and also acts as convex lens

to focus and intensify light reaching mesophyll cells for maximum absorption. The palisade layer also helps in absorption of more light. Presence of hairs, salt glands and epicuticular wax increase the reflection of light and thereby reducing the absorption.

Absorption of carbon dioxide is also dependent on leaf surface area and number of stomata. Spongy parenchyma has large intercellular space so that carbon dioxide can easily diffuse. Opening and closing of stomata is yet another factor that governs photosynthesis as the exchange of gases is affected when stomata close. In some succulent plants such as *Bryophyllum, Kalanchoe*, stomata open during night and close during day to reduce the rate of transpiration. Such plants have special mechanism for photosynthesis called **Crassulacean Acid Metabolism (CAM)**, where CO_2 fixation takes place in different time (day and night) as per availability of carbon dioxide and light (Figure 7.8). CO_2 is taken up by the plant during night time as stomata open during night. It is fixed and converted to malic acid, which is stored in vacuole. During day time when assimilatory power is available, malic acid is released from vacuole and reverted back to pyruvate by releasing carbon dioxide. This CO_2 then enters C-3 cycle and assimilated. Pyruvate is stored in chloroplast in the form of starch and released during night time through glycolysis.

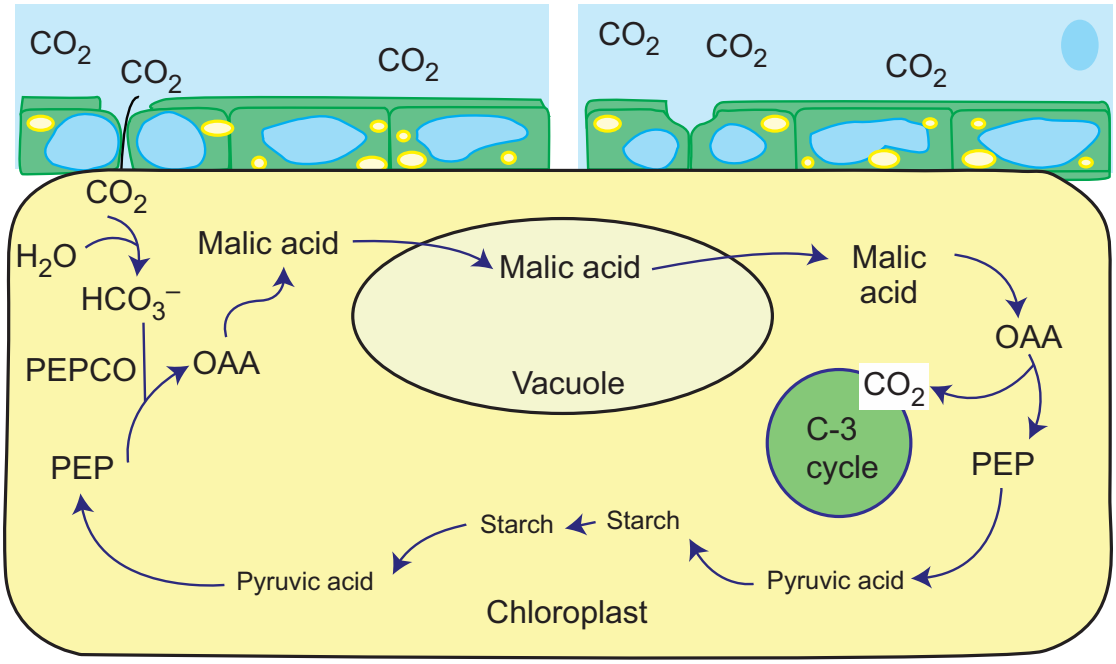


Figure 7.8: Crassulacean acid metabolism in CAM plants

Fill in the columns 2 and 3 in this table to highlight the differences between C_3 and C_4 plants.

Characteristics	C_3 Plants	C_4 Plants	Choose from
Cell type in which the Calvin cycle takes place			Mesophyll/Bundle sheath/both
Cell type in which the initial carboxylation reaction occurs			Mesophyll/Bundle sheath /both
How many cell types does the leaf have that fix CO_2.			Two: Bundle sheath and mesophyll One: Mesophyll Three: Bundle sheath, palisade, spongy mesophyll
Which is the primary CO_2 acceptor			RuBP/PEP/PGA
Number of carbons in the primary CO_2 acceptor			5 / 4 / 3
Which is the primary CO_2 fixation product			PGA/OAA/RuBP/PEP
No. of carbons in the primary CO_2 fixation product			3 / 4 / 5
Does the plant have RuBis CO?			Yes/No/Not always
Does the plant have PEP case?			Yes/No/Not always
Which cells in the plant have Rubisco?			Mesophyll/Bundle sheath/none
CO_2 fixation rate under high light conditions			Low/ high/ medium
Whether photo respiration is present at low light intensities			High/negligible/sometimes
Whether photo respiration is present at high light intensities			High/negligible/sometimes
Whether photo respiration would be present at low CO_2 concentrations			High/negligible/sometimes

Whether photorespiration would be present at high CO_2 concentrations			High/negligible/sometimes
Temperature optimum			30-40°C/20-25°C/above 40°C
Examples			Cut vertical sections of leaves of different plants and observe under the microscope for Kranz anatomy and list them in the appropriate columns.

7.8 SUMMARY

- Organisms that are autotrophic can make their own food from inorganic substances with help of energy.
- Photosynthesis is the process where the source of energy is light. It is carried out by green plants, algae and some bacteria.
- Photosynthesis takes place in green parts of a plant, mainly leaves. Within leaves, chloroplasts in mesophyll cells are the site of photosynthesis.
- Photosynthesis has two stages: light reaction and dark reaction. Light reaction is a photochemical reaction, in which light energy is absorbed by the pigments present in antenna molecules of light harvesting complex. While, in dark reaction carbon is reduced in the stroma of chloroplast.
- Chlorophyll, a molecule is the reaction centre which has two special forms PSI and PSII with absorbance maxima at 700 nm and 680 nm, respectively.
- In temperate plants, C-3 cycle takes place with the help of enzyme RUBISCO. The C-3 cycle includes: carboxylation, reduction and regeneration. In some tropical plants, C-4 cycle takes place.
- C-4 cycle includes dual carboxylation that takes place in mesophyll cells chloroplast and bundle sheath cell chloroplasts.
- Various environmental factors such as light, temperature, carbon dioxide concentration, oxygen concentration and air pollutants are responsible for the plant productivity on account of photosynthesis.

7.9 GLOSSARY

- **Absorption spectrum:** Absorption spectrum is the graph plot that shows the measure of absorption of radiation of different wavelengths.
- **Action spectrum:** Action spectrum is the graph plot that shows rate of physiological activity at different wavelengths of light.
- **ATP synthase:** It is an important lipid binding protein. It is used to generate ATP from ADP. It is present on thylakoid membrane.
- **Autotrophs:** An autotroph is an organism that produces complex organic compounds such as carbohydrates, fats and proteins from simple inorganic substances.
- **Chemoautotrophs:** Chemoautotrophs are organisms that obtain energy by the oxidation of electrons donors in their environment.
- **Emerson enhancement effect:** Increase in rate of photosynthesis when two wavelengths of light: 680 nm and 700 nm are given simultaneously.
- **Fluorescence:** Emission of light of higher wavelength (usually red) by a substance or system when exposed to light.
- **Kranz anatomy:** Occurrence of wreath of bundle sheath cells around vascular bundles in leaves is called Kranz anatomy. The mesophyll cells and bundle sheath cells show chloroplast dimorphism.
- **Law of limiting factor:** If a chemical process is affected by more than one factor, the rate of process will be determined by the factor which is nearest to minimal value.
- **Light Harvesting Complex:** It is a complex of proteins subunits and photosynthetic pigments. It collects light energy and transfers it to the reaction centre.
- **Phosphorescence:** Emission of light of higher wavelength (usually red) by a substance or system even after light is put off.
- **Photoautotrophs:** Photoautotrophs are the organisms that carry out metabolism by using light energy. They can carry out photosynthesis.
- **Photon:** The elementary particle of light.
- **Photorespiration:** The oxygenation of Ribulose bisphosphate in presence of light and oxygen in green plants is called photorespiration.
- **Photosynthesis:** A process of synthesizing organic compounds from inorganic substances in presence of light in green plants.
- **Photosystems:** Photosystems are functional and structural units of protein complexes involved in photosynthesis. There are two types of photosystems : PSI and PSII.
- **Pigment:** A pigment is a material that changes the colour of reflected or transmitted light as a result of wavelength selective absorption.

- **Quantum:** Quantum is the minimum amount of any physical entity involved in interaction. A photon is a single quantum of visible light and referred as light quantum.
- **Red drop phenomenon:** Decrease in rate of photosynthesis beyond 680 nm of light.
- **Redox potential:** It is the measure of tendency of a chemical species to acquire electrons and thereby reduced. It is also called reduction potential.

7.10 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. Organisms that are heterotrophic can make their own food.
2. Photosynthesis has two stages—light reaction and dark reaction.
3. CAM cycle includes triple carboxylation.
4. Environmental factors improve crop yield.
5. Pigment is a material that changes colour of reflected or transmitted light.
6. Within leaves, chloroplasts are responsible for respiration.

II. Multiple Choice Questions

1. Green plants require which of the following for photosynthesis?
   (a) Sunlight (b) CO_2
   (c) O_2 (d) Water
2. C-4 cycle occurs in
   (a) Wheat (b) Rice
   (c) Sugar cane (d) All of the above
3. What is true about action spectrum?
   (a) It can be carried out in isolated pigments
   (b) It gives the function of pigments
   (c) It is used to identify pigments
   (d) It does not involve light
4. By looking at which internal structure, you can tell whether a plant is C-3 or C-4?
   (a) Mesophyll cell (b) Bundle sheath cells
   (c) Vascular bundles (d) Epidermal cells
5. How many ATP are required to produce 2 molecules of glucose?
   (a) 12 (b) 24
   (c) 18 (d) 36

6 Autotrophs are commonly called producers because they
   (a) produce young plants
   (b) produce CO_2 from light energy
   (c) produce sugars from chemical energy
   (d) produce water from light energy

III. Long Answer Type Questions

1. State and explain the types of autotrophic nutrition. Also explain the role of light in autotrophic nutrition.
2. Analyse and appreciate the importance of photosynthesis as an energy transfer process.
3. State the role of chloroplast and structure of leaf in photosynthesis. Giving illustrative diagrams, explain your answer.
4. State the pigments involved in light absorption. Throw light on absorption and action spectra of chloroplast pigments.
5. Outline the three main stages of the Calvin cycle. State the uses of Calvin cycle intermediaries in plant cell.
6. Summarize the limiting factors affecting photosynthesis. Also state how this can help yield crop production.
7. Compare anatomy of C4 and CAM plants.
8. Differentiate between C4, CAM and C3 plants during carbon dioxide fixation.
9. Investigate the effect of light intensity or light wavelength on the rate of photosynthesis.
10. Describe the relationship between the structure and function in the chloroplast, using diagrams and electron micrographs.
11. Acknowledge the importance of autotrophic nutrition in sustaining the balance of life on Earth. Also state the ways to keep the environment sustained. Predict various facts related to photosynthesis that state the importance of nutrition for all living beings.

Unit 8

Transport System in Plants

Key Unit Competence

To be able to describe the structure of the transport tissues in plants and the mechanisms by which substances are moved within the plant.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- recall that plants have two transport tissues: xylem and phloem.
- appreciate the importance of transport systems in plants.
- observe, draw and label, from prepared slides, plan diagrams of transverse sections of stems, roots and leaves of herbaceous dicotyledonous plants to show the tissues in correct proportion.
- draw and label, from prepared slides, the cells in roots, stems and leaves using transverse and longitudinal sections.
- recognise, from prepared slides, using the light microscope to draw and label the structure of xylem vessel elements, phloem sieve tube elements and companion cells.
- acknowledge that plants do not have systems for transporting oxygen and carbon dioxide. Instead, these gases diffuse through air spaces within stems, roots and leaves.
- show resilience when setting apparatus and making observations using microscopes and solutions of different concentration to ensure improved reliability.
- relate the structure of xylem vessel elements, phloem sieve tube elements and companion cells to their functions.
- explain the movement of water between plant cells, and between them and their environment, in terms of water potential.
- recall the term transpiration and understand that transpiration is an inevitable consequence of gas exchange in plants.
- experimentally investigate and explain the factors that affect transpiration rate using simple potometers, leaf impressions, epidermal peels, and grids for determining surface area.
- make annotated drawings, using prepared slides of cross-sections, to show how leaves of xerophytes are adapted to reduce water loss by transpiration.
- explain how hydrogen bonding is involved with the movement of water in the xylem by cohesion-tension in transpiration pull and adhesion to cellulose cell walls.

- state that assimilates, such as sucrose and amino acids, move between sources and sinks in phloem sieve tubes.
- explain how transport systems in plants move substances from where they are absorbed or produced to where they are stored or used.
- show concern when selecting crop plants to reflect adaptations to environments e.g., where they grow well, and when under water or not under water stress.
- explain how sucrose is loaded into phloem sieve tubes by companion cells using proton pumping and the co-transporter mechanism in the cell surface membranes.
- explain mass flows in phloem sap down a hydrostatic pressure gradient from source to sink.
- carry out an investigation to demonstrate mass flow hypothesis.

8.1 NEED FOR A TRANSPORT SYSTEM

ACTIVITY 1

Have you ever thought about 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 on these and discuss your findings in the class.

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 a 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.

8.2 TRANSPORT TISSUES

To understand the movement of various substances in plants, one needs to recall what substances are transported in plant systems and what structures are involved in the transport. Vascular system in flowering plants or angiosperms is highly evolved. It is represented by complex tissue system having xylem and phloem elements. There is a division of labour between the two tissue complexes.

Xylem is involved in uptake of water and minerals. Phloem is involved in uptake of food material. These complex tissues are composed of various cell types that play very important role in the transport of water, mineral elements and photosynthates.

8.3 TRANSPORT OF WATER AND MINERALS

8.3.1 Structure of Xylem Tissue

ACTIVITY 2

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:

Take a fresh green plant.

Give a cut at the basal end.

Put the cut segment in water with natural food colours.

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 coloured? Explain why.

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 a 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 a 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).

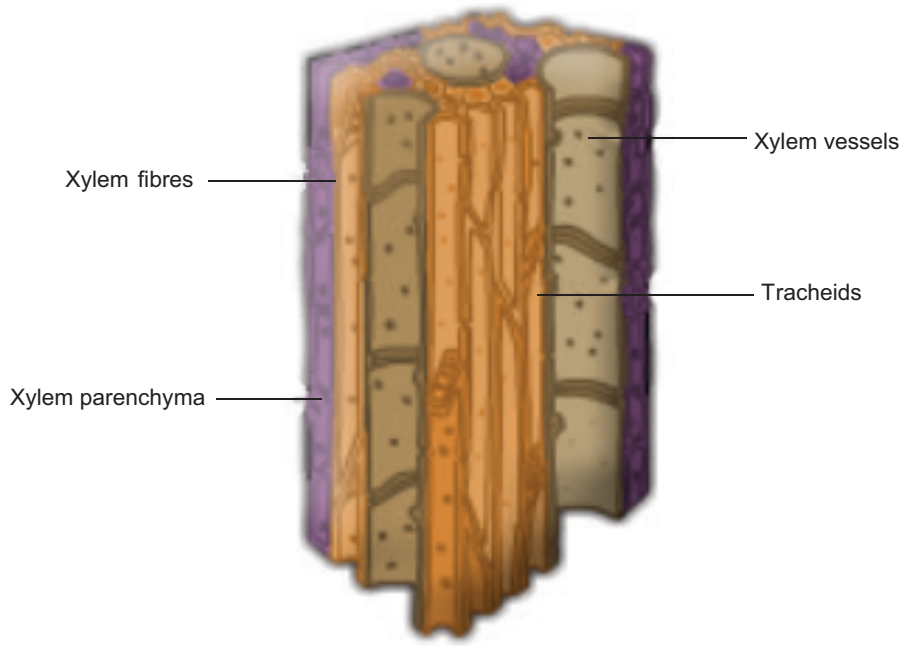


Figure 8.1: Diagram showing xylem elements fibres, parenchyma cells, tracheids and vessels (macerated material)

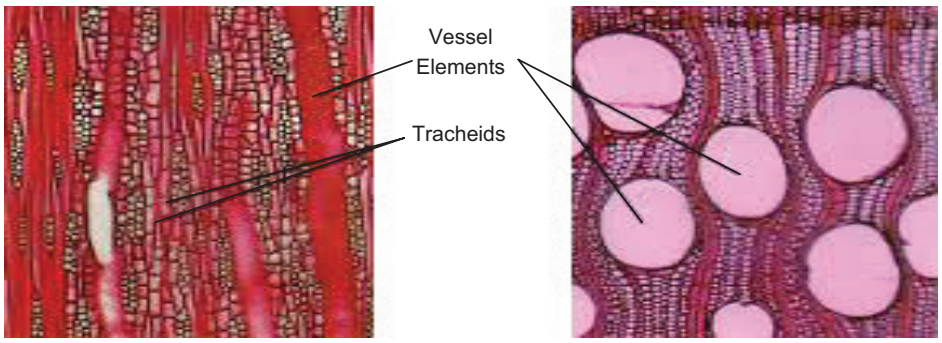


Figure 8.2: R.LS of stem showing tracheids and vessels elements

8.3.2 Absorption of Water Through Roots

ACTIVITY 3

Aim: To demonstrate the water moves through xylem vessels.

Requirements: A small potted plant of tomato, eosine solution, beaker, stand, microscope, slide, razor and water.

Method:

Dig out a small tomato plant.

Cut the stem at the base 1 to 2 cm above roots under water.

Immerse the cut end in eosine solution contained in a beaker.

Fix the shoot erect with the help of a stand.

Keep it for a day or two without disturbing.

Cut the transverse sections of stem.

Observe it under the microscope.

- Could you see that xylem and tracheids in the section looks red?
- Can you say why?

Observations and results: Xylem and tracheids in the section turn red indicating water moves up in the xylem.

Observing plants in different situations allows learners to make inferences about water movement through the plant material.

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** (Figure 8.3).

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**.

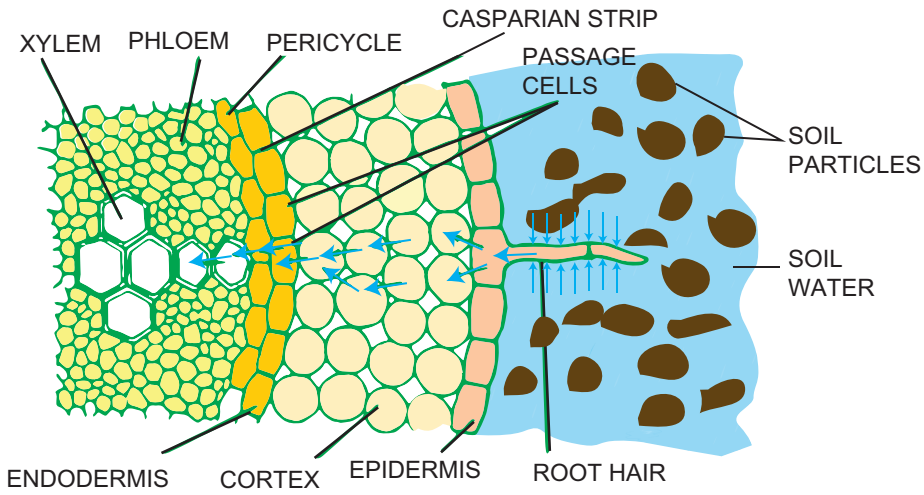


Figure 8.3: Diagram showing entry of water in the root system

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 the non-living continuum (Figure 8.4). The other pathway is the **symplast,** in which water moves across the root hair membrane and through the cells themselves. Plasmodesmata act as channels to transport water between the cells (Figure 8.4).

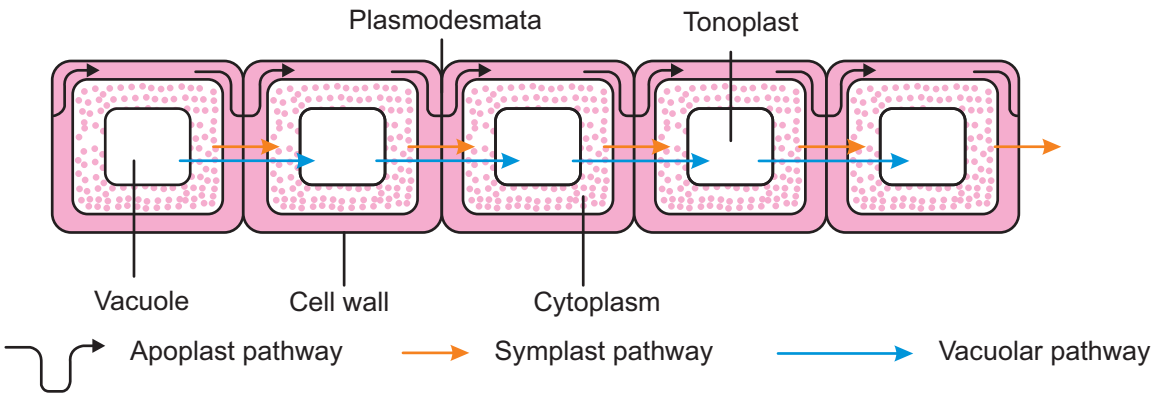


Figure 8.4: Path of water through apoplast, symplast and vacuolar

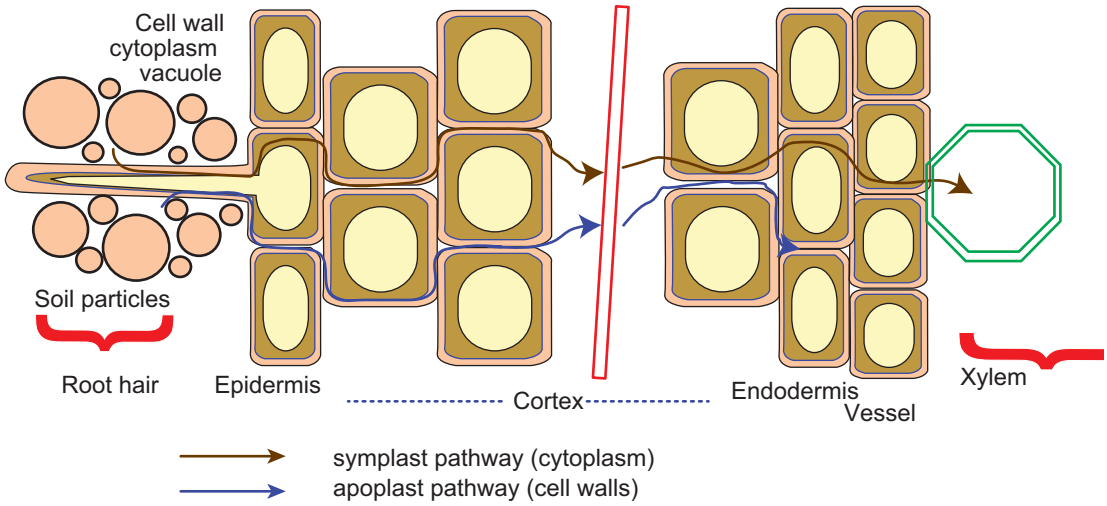


Figure 8.5: Diagram showing the movement of water through various pathways and through various cell layers in the roots

In natural conditions, the apoplastic and symplastic pathway do not separate and are operating simultaneously within the system (Figure 8.5). 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.

8.3.3 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 8.6).

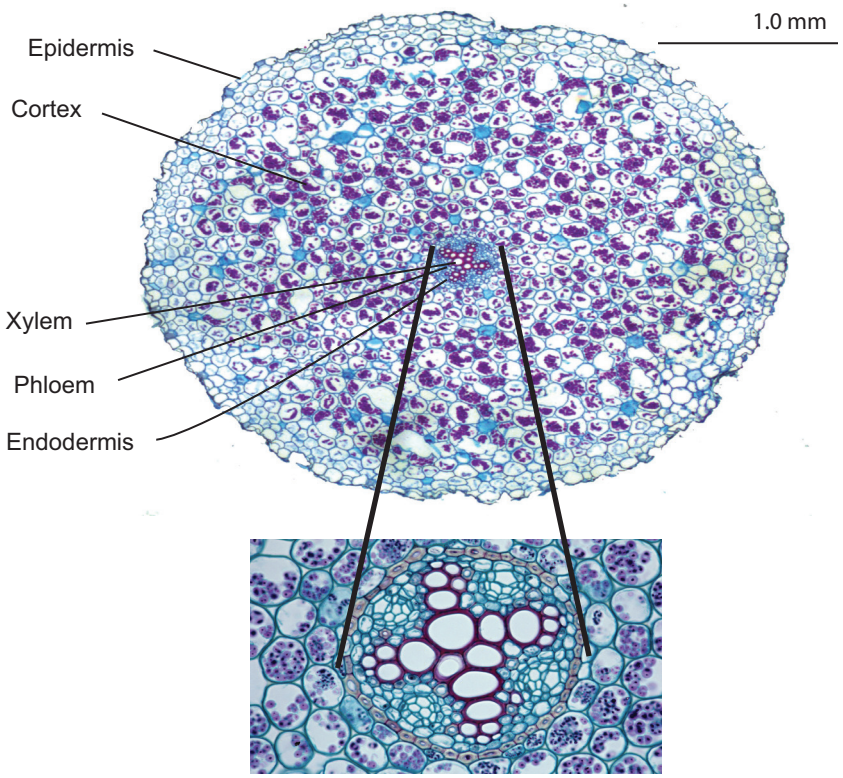


Figure 8.6: Anatomy of ranunculus root

8.3.4 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.

Water absorption in plants takes place with the expenditure or energy or without use of energy. The two processes involved are: **passive and active absorption.**

Passive absorption: Root does not play an active role in water uptake. The root system merely acts as a physical absorbing system. Energy is not spent for absorption. Passive absorption accounts for most of the water absorbed by plants.

Active absorption: Water is absorbed as a result of activity of the root. Root hairs take in minerals by expenditure of energy. Then water moves from low solute concentration to high solute concentration across the membrane.

SELF EVALUATION

Complete sentences with appropriate terms:

(i)Xylem tissue is composed of four types of cells:
....., ..., ... and ..... .

(ii) Plants ..... water from soil and ..... it to aerial parts.

(iii) Two pathways regulating uptake of water from roots are ..... and ..... .

8.3.5 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.

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

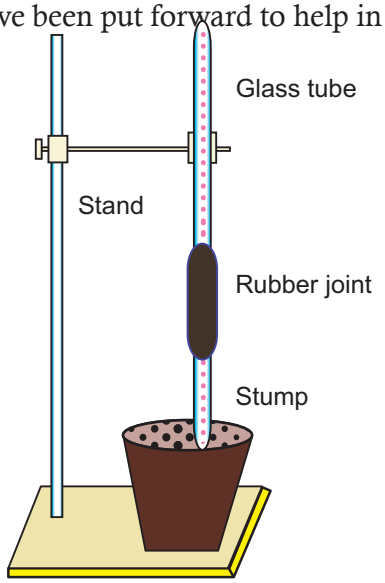


Figure 8.7: Root pressure

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 (Figure 8.7).

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 transpiration pull.

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 (Figure 8.8). But, what generates this transpirational pull?

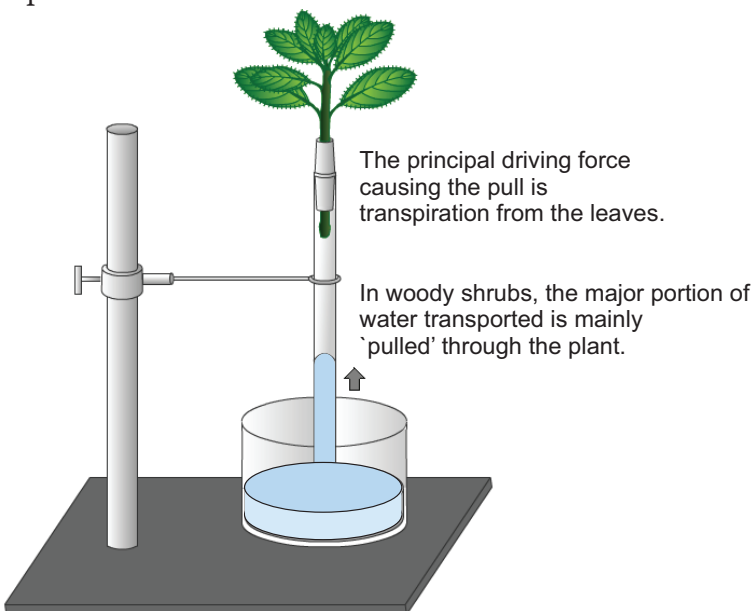


Figure 8.8: Transpiration pull

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 the cortex found in epiphytes such as orchid that absorb water through the hanging roots.

ACTIVITY 4

Aim: To observe various parts of a leaf.

Requirements: A fresh leaf (Bryophyllum), foreceps, needles, watch glass, slides, a razor blade and compound microscope.

Methods: Cut a vertical section of the leaf.

Stain with a fast green and safranin.

Mount in glycerine.
Observe it under a microscope. What do you observe?

Discussion: Do you see some small openings in the lower layer of the leaf? What are these openings called?

Do you see any green coloured pigments in the leaf?

What are these pigments called?

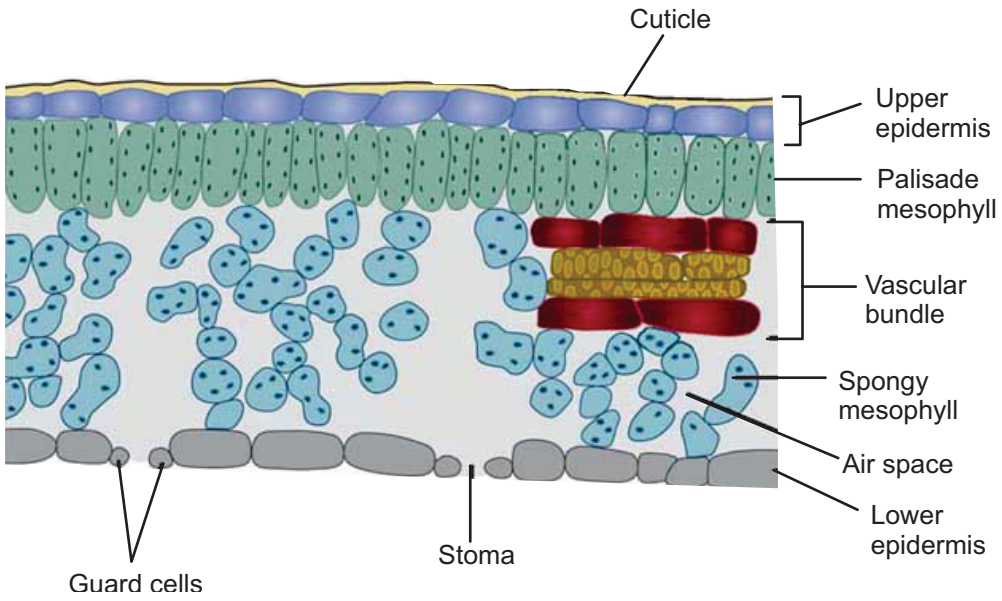


Figure 8.9: Verticle Section of the leaf showing various parts

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 (Figure 8.7).

Plants do not have systems for transporting oxygen and carbon dioxide. Instead, these gases diffuse through air space within stems, roots and leaves.

8.4 TRANSPIRATION IN PLANTS

ACTIVITY 5

Aim: To demonstrate the phenomenon of transpiration by bell jar method.

Requirement: A potted plant, glass plate, bell jar, oilcloth, grease and thread.

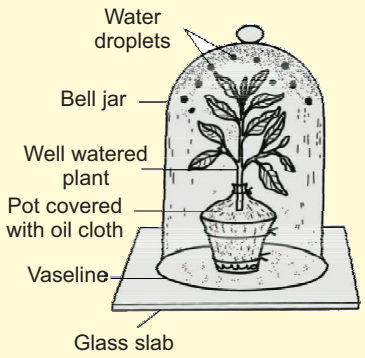
Methodology: Take a watered healthy plant. Cover the soil by cloth to avoid evaporation.

Place the pot on a glass plate and cover with a bell jar.

Leave the apparatus for some time and observe.

What do you see at the inner side of the bell jar? Where do these come from?

Results: Small drops of water start appearing on the inner side of bell jar due to condensation of water vapour transpired from the plant.



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 the 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 (Figure 8.10). 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**.

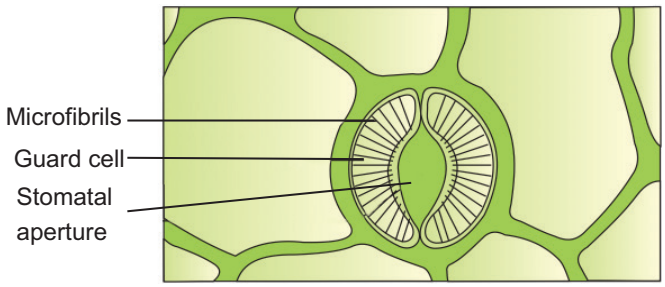


Figure 8.10: Transpiration occurs through stomatal aperture

8.4.1 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 (Figure 8.11). **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.

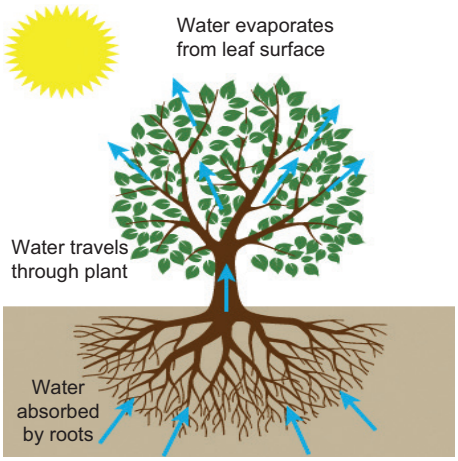


Figure 8.11: Diagram showing process of transpiration on a sunny day

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.

ACTIVITY 6

Aim: To study the effect of different light intensities on the rate of transpiration using a 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 (Figure 8.12).

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.

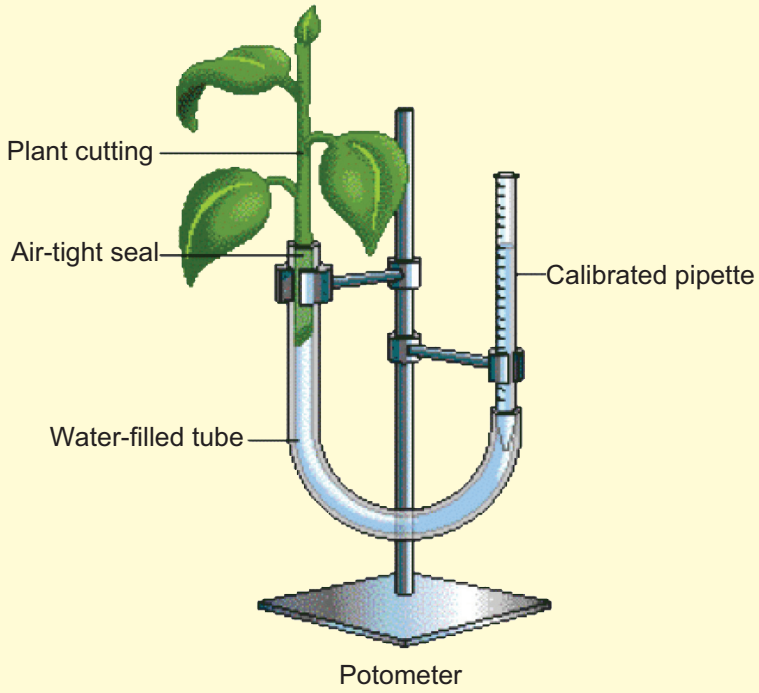


Figure 8.12: Study the effect of light intensities on rate of transpiration using potometer

8.4.2 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.

8.4.3 Adaptations of Xerophytes to Reduce Water Loss

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 act as water storage areas. These stems are also called succulent stems.

SELF EVALUATION

Complete with appropriate terms:

(i)The association of Mycorrhizal fungi is …….. .

(ii) …….. is the loss of water from plants.

(iii) …….. is used to study the rate of transpiration.

(iv) Xerophytes have …….. stomata.

(v) Xerophytes exhibit …….. metabolism.

8.5 TRANSPORT OF FOOD

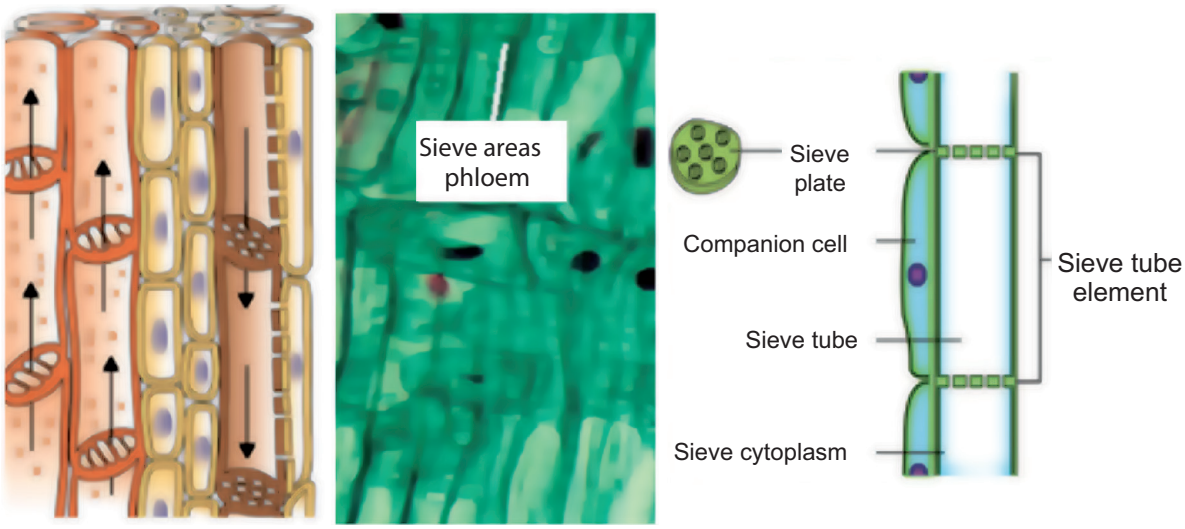
Process of the movement of food synthesized during photosynthesis from the leaves to the roots and other parts of a plant through the phloem is called **translocation**. This is carried out by another conducting tissue phloem.

8.5.1 Structure 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 (Figure 8.13).

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.



(a) (b)

Figure 8.13: (a) and (b) A Structure of phloem: RLS of the stem showing various parts of phloem

8.5.2 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 8.14).

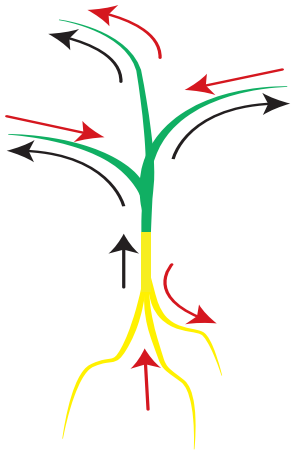


Figure 8.14: Phloem Transport can be bidirectional represented by red arrows

8.5.3 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 8.15).

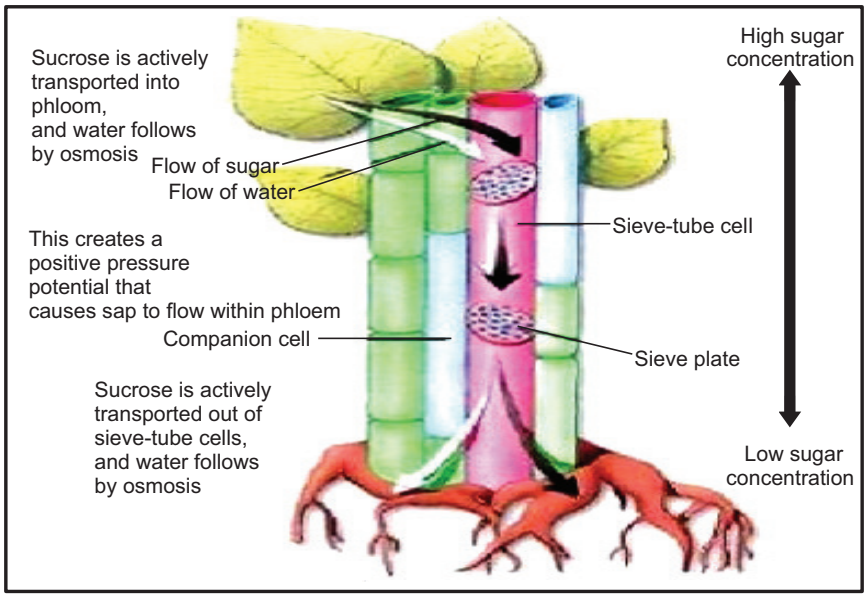


Figure 8.15: Illustrated account of the phloem transport in plants

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 8.16: (a) Girdling in trees

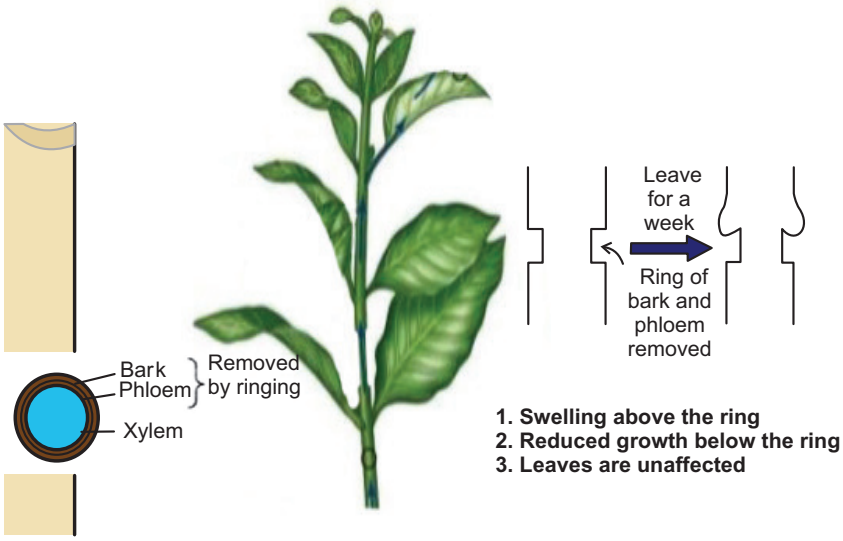


Figure 8.16: (b) Picture showing the role of phloem in translocation of food

A simple experiment, called girdling, was used to identify the tissues through which food is transported (Figure 8.16(a)). 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 (Figure 8.16(b)). 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.

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.

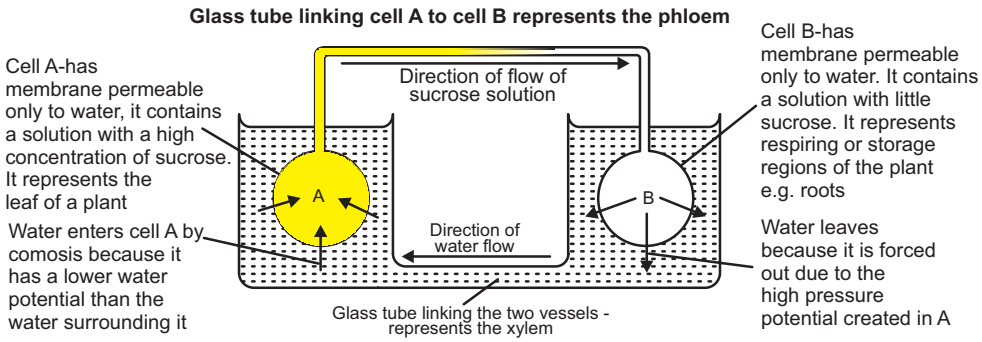


Figure 8.17: Demonstration of mass flowhypathesis

SELF EVALUATION

Complete with the appropriate terms:

(i)…… is the process to show food flows from leaves to roots.

(ii) Phloem transports phloem sap from …… to …… .

(iii) Phloem …….. gives mechanical strength to cells.

(iv) Movement from sileve elements to recipient sink cells is called …….

8.6 SUMMARY

- Water is an important solvent and acts as a reagent in various chemical reactions in the plants.
- It helps to maintain turgidity of cells and is important for growth of plants as it serves as a raw material for photosynthesis.

- Transport of water is an important process in plants and has been well understood.
- Several physical phenomena such as imbibition, diffusion, osmosis, turgor and water potential facilitate uptake of water in plants.
- Forces of cohesion and adhesion also play an important role in transport of the water upstream.
- Water enters the plants through active or passive absorption process. The upward movement of water through stem is called the ascent of sap.
- Practically most of the water absorbed by plants is lost into the atmosphere through the process of transpiration.
- A variety of internal and external stimuli govern the rate of transpiration in plants.
- Atmospheric humidity, temperature, light, wind velocity, leaf area, leaf structure and availability of water affect the process.
- Plants also take up inorganic nutrients from the soil with water. The sugars synthesized in leaves are translocated downwards, upwards and to lateral organs mostly through phloem.
- Experiments have been conducted to demonstrate the movement of food through phloem. Besides sugars that are end products of photosynthesis, amino acids are also transported through phloem.

8.7 GLOSSARY

- **Active transport:** Transport of ions or molecules across a cell membrane against a concentration gradient.
- **Adhesion:** Attraction of water molecules to polar surfaces is called adhesion.
- **Apoplast:** Intercellular spaces, excluding the protoplasts is called apoplast.
- **Aquaporins:** Protein channels for transport across membranes.
- **Casparian strips:** A band like structure in endodermis of root cells that contain suberin and lignin.
- **Cohesion:** Mutual attraction between water molecules is called cohesion.
- **Cuticle:** A three layered structure present on the epidermis that prevents movement of gases and water to move into or out of the plants.
- **Diffusion:** Movement of substance from high concentration to low concentration.
- **Lignin:** An aromatic polymer that rigidifies may secondary cell walls.
- **Lenticels:** Pores on woody stems and roots for gaseous exchange.
- **Osmosis:** Movement of water from area of low to area of high solute concentration.
- **Phloem:** the photosynthate-conducting tissue of plants.
- **Plasmodesmata:** Connection between protoplasts of adjacent cells through cell walls.
- **Plasmolysis:** Shrinkage of cytoplasm under the influence of hypotonic solution.
- **Root pressure:** Hydrostatic pressure created inside the roots due to absorption of water.
- **Root:** The portion of a plant axis produced by the root apical meristem.
- **Stem:** The portion of a plant axis produced by the shoot apical meristem.
- **Leaf:** A lateral appendage of the stem produced by the shoot apical meristem.
- **Sieve element:** a conducting cell in the phloem.

- **Surface tension:** Any liquid has a tendency to occupy the least possible surface area. This property is called surface tension.
- **Symplast:** The continuous system of protoplasts connected by plasmodesmata.
- **Tensile strength:** It is a measure of maximum force per unit area that would be needed to break a continuous column of water.
- **Tracheid:** A conducting cell of the xylem characterized by an elongated shape and lignified secondary cell wall.
- **Turgor Pressure:** Hydrostatic pressure developed inside cell vacuole that presses cytoplasm against the cell wall.
- **Vascular tissue system:** Tissues derived from the procambium or vascular cambium that transports water and photosynthates.
- **Vessels:** Tracheary element with perforation plates.
- **Water potential:** Chemical potential of water in relation to pure water.
- **Xylem:** The water-conducting tissue of plants.

8.8 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

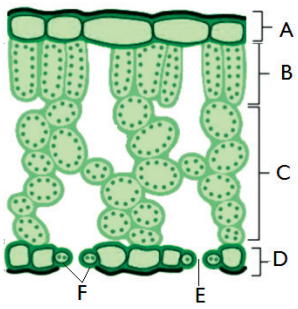
I. Multiple Choice Questions

1. Much of the transpiration takes place through
   (a) stomata (b) lenticels (c) cuticle (d) epidermis
2. The roots absorb water through
   (a) epidermal hairs (b) root hairs (c) root xylem (d) root phloem
3. The ascent of sap in plants takes place due to
   (a) root pressure (b) transpiration pull
   (c) osmosis (d) both (a) and (b)
4. Stomata open and close due to
   (a) presence of valves (b) hormonal control
   (c) turgor pressure of guard cells (d) concentration gradient of the gases
5. The food is transported in the phloem in the form of
   (a) glucose (b) sucrose (c) amino acids (d) fats
6. The movement of particles from the region of their higher concentration to the region of their lower concentration is called
   (a) osmosis (b) diffusion (c) active transport (d) ascent of sap
7. Plant transport system does not transport
   (a) CO_2 (b) organic salts (c) water (d) plant hormones
8. The strongest force to pull water up the xylem and into the leaf is
   (a) capillary action (b) root pressure
   (c) transpiration pull (d) active transport

9. The loss of water in the form of vapours by the leaves and stem of a plant is called
   (a) translocation (b) osmosis
   (c) active transport (d) transpiration
10. The transport of sugar from the leaf to the rest of the plant is called
   (a) translocation (b) osmosis
   (c) active transport (d) transpiration

II. Long Answer Type Questions

1. Name the two transport tissues present in the plant.
2. What are the factors affecting the rate of diffusion?
3. Explain why pure water has the maximum water potential.
4. Differentiate between the following:
   (i) Diffusion and Osmosis
   (ii) Active and Passive Transport
   (iii) Osmosis and Diffusion
   (iv) Transpiration and Evaporation
5. Discuss the factors responsible for ascent of xylem sap in plants.
6. How is turgor pressure created in the sieve elements?
7. What is the difference between apoplast and symplast?
8. Explain in detail the absorption of water through root hairs up to the xylem.
9. Discuss the structure of phloem and its components in plants.
10. Explain how food prepared in the leaves reaches the other parts of the plant.
11. Explain the hypothesis proposed by Munch regarding translocation of food in plants.
12. Appreciate the importance of transport systems in plants.
13. Draw and label, from prepared slides, the cells in roots, stems and leaves using transverse and longitudinal sections.
14. There are a million processes that account for life on Earth. All these processes play a major role in balancing the climate of Earth. Investigate in the same regard the role of transport in plants in regulating the environment of surroundings. Also necessitate the presence of plants or a wholesome regulation of atmosphere.
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

Gas Exchange in Animals

Key Unit Competence

To be able to describe structures of gas exchange in different groups of animals.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- describe the tracheal system of insects and relate to its function.
- describe the structure of the gills in relation to function.
- explain the significance of counter current flow in bony fish.
- dissect an insect, fish and a small mammal to study gaseous exchange organs.
- relate the structure of gas exchange organs to function.
- differentiate between the gaseous exchange in bony fish and that in cartilaginous fish.
- describe the mode of gaseous exchange in amphibians.
- describe the structure of the human gas exchange system.
- appreciate the similarities and differences in gas exchange surfaces of animals.
- interpret a graph of human lung volumes measured with a spirometer.
- calculate the volume of air in the lungs and in the alveoli.
- describe the distribution of tissues within the trachea, bronchi, bronchioles and alveoli and relate each tissue to its function.
- explain the mechanism of ventilation in humans.
- explain the process of gas exchange in alveoli with emphasis on diffusion.
- describe the role of the brain in controlling gas exchange in humans.
- appreciate the role of the brain in controlling gas exchange.
- define terms related to the lung capacities (tidal, reserve volume, vital capacity, residual volume, and dead air space).
- describe how a spirometer can be used to measure vital capacity, tidal volume, breathing rates, and oxygen uptake.

9.1 INTRODUCTION

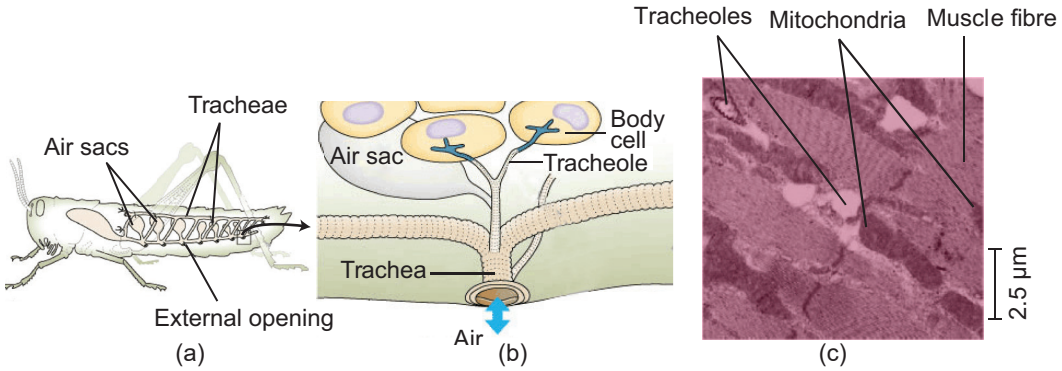
ACTIVITY 1

Place your hands on your chest: You can feel the chest moving up and down. You know it is due to breathing. How do you breathe? What happens during breathing? Discuss.

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. This process of gas exchange is vital for their survival. This continuous 'exchange' of oxygen and carbon dioxide with the animal and the environment is known as **gas exchange**. For a surface to be able to exchange gases in living system, it should be moist, have large surface area, and highly vascular i.e., richly supplied with blood vessels. Exchange of gases through the biological membrane occurs by a process known as **diffusion**. Diffusion is movement of gas molecules from a region of higher concentration to a region of lower concentration.

9.2 GASEOUS EXCHANGE IN INSECTS

Insects have a specialised system of 'tubes' called the **tracheal system** for exchange of gases (Figure 9.1). This system consists of a vast network of **cuticular** (i.e., made of chitin, a



(a) The respiratory system of an insect consists of branched internal tubes. The largest tubes, called tracheae, connect to external openings spaced along the insect's body surface. Air sacs formed from enlarged portions of the tracheae are found near organs that require a large supply of oxygen.

(b) Rings of chitin keep the tracheae open, allowing air to enter and pass info smaller tubes called tracheoles. The branched tracheoles deliver air directly to cells throughout the body. Tracheoles have closed ends filled with fluid (blue-gray). When the animal is active and using more O_2, most of the fluid is withdrawn into the body. This increases the surface area of air-filled tracheoles in contact with cells.

(c) The TEM above shows cross sections of tracheoles in a tiny piece of insect flight muscle. Each of the numerous mitochondria in the muscle cells lies with about 2.5 µm of a tracheole.

Figure 9.1: Tracheal system in insect (Grasshopper). Note that the fine tubes called bronchioles innervating at cellular level. (*Source*: Campbell Biology, 2011)

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.

Air enters the tracheal system of the animal through special openings called **spiracles**. These are present mostly on the lateral side of the animal. These are usually guarded by valves, operated by muscles and sometimes provided with filters. Tracheal tubes are **invaginations** (infoldings) of the body surface. Thus, their walls are similar in structure and composition to the general body surface (integuments) of the animals. Sometimes larger tracheas have thickenings called **taenidia**. These are spiral cuticular layers which give strength and elasticity. The tubes become progressively smaller and thinner to form tracheoles or air capillaries (Figure 9.2). The smaller tubes may have incomplete taenidial support. They have a diameter of less than 1 μm (1 μm = 1×10^{-6} m). Tracheoles are the most important physiological unit of this gas exchange system. It is because they make numerous close contacts with the individual cells for gas exchange to take place. They sink into cell's plasma membrane bringing oxygen very close to the mitochondria of the cells.

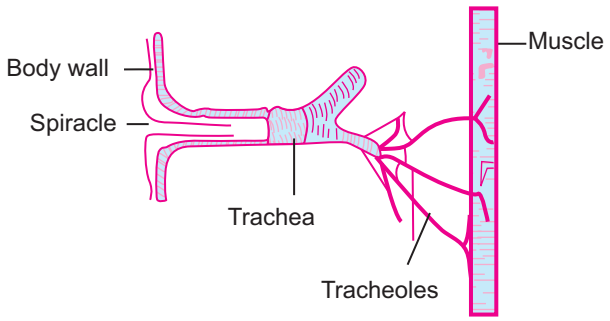


Figure 9.2: Detail structure of the tracheal system in insects

9.2.1 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.

ACTIVITY 2

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, thoraxic spiracles are used for inspiration while abdominal spiracles are used for expiration.

9.3 GASEOUS EXCHANGE IN FISH: GILLS

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. 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 (Figure 9.3). 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.

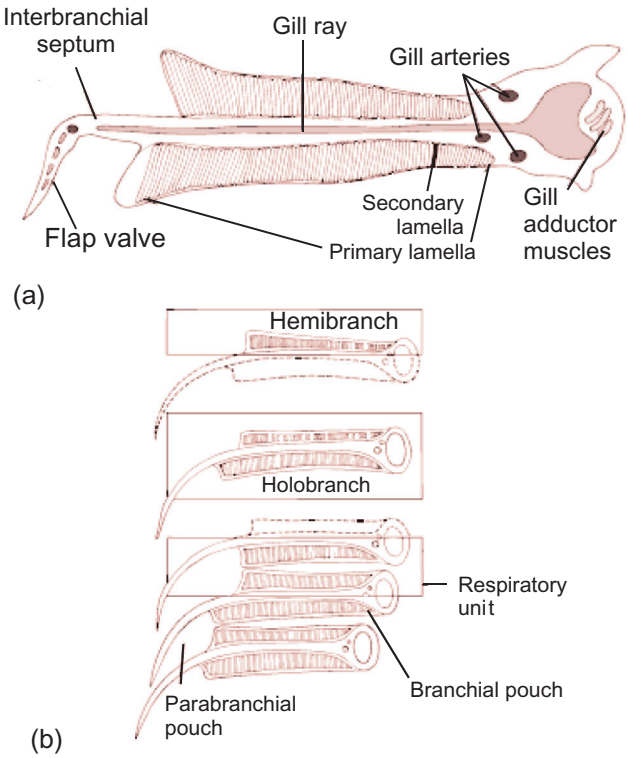


Figure 9.3: Structure of gills in shark. (*Source:* Kardong, Vertebrates: Comparative anatomy, Function, Evolution, 2012)

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** (Figure 9.4). 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 (Figure 9.5).

ACTIVITY 3

Aim: To observe and study the structure of gills in freshwater fish.

Materials Required: Fish (Tilapia), dissecting microscope, surgical scissors, chloroform, forceps, scalpels, pins, dissecting tray, etc.

Procedure:

1. Obtain a live fish Tilapia from a local fish market and anaesthesize it with chloroform.
2. Locate the gill on the lateral side of the head by lifting the operculum. Cut out the operculum and expose the red coloured gills.
3. Dissect out the gills and observe it under the microscope.
4. Draw a detail sketch structure of the gill and it lamellae and label it different parts with the help of your teacher.

Observation: Can you see the gill lamellae and the gill rakers?

9.3.1 Mechanism of Gill Ventilation

ACTIVITY 4

Aim: To observe and study the ventilation mechanism in fish.

Materials Required: Fish in an aquarium, notebook and pencil timer, etc.

Procedure:

Observe the movement of the mouth and operculum of a fish in the aquarium. Note the number of times the mouth and operculum opens in a minute and record it in your notebook.

Observation: Record the rate at which ventilation occurs in the fish.

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 the 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.

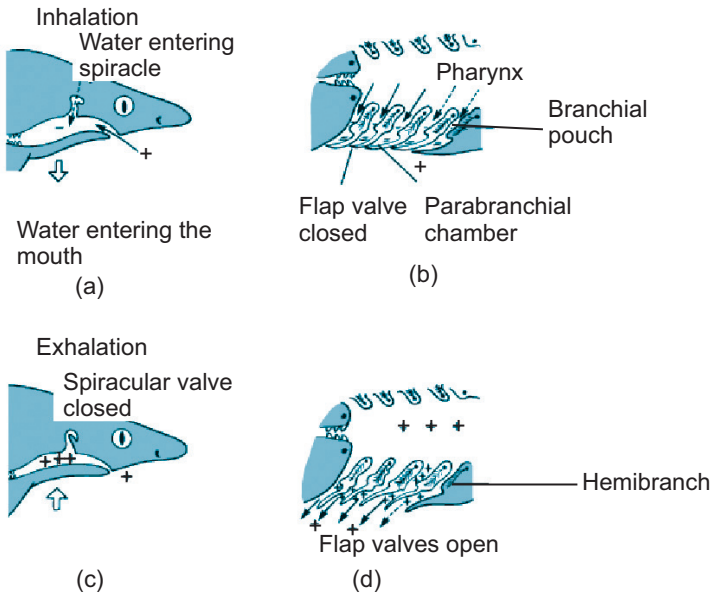


Figure 9.4: Gill ventilation in sharks. Lateral (a, c) and frontal view (b, d). Relative positive and negative pressures indicated by + and –, respectively (*Source:* Kardong, Vertebrates: Comparative anatomy, Function, Evolution, 2012)

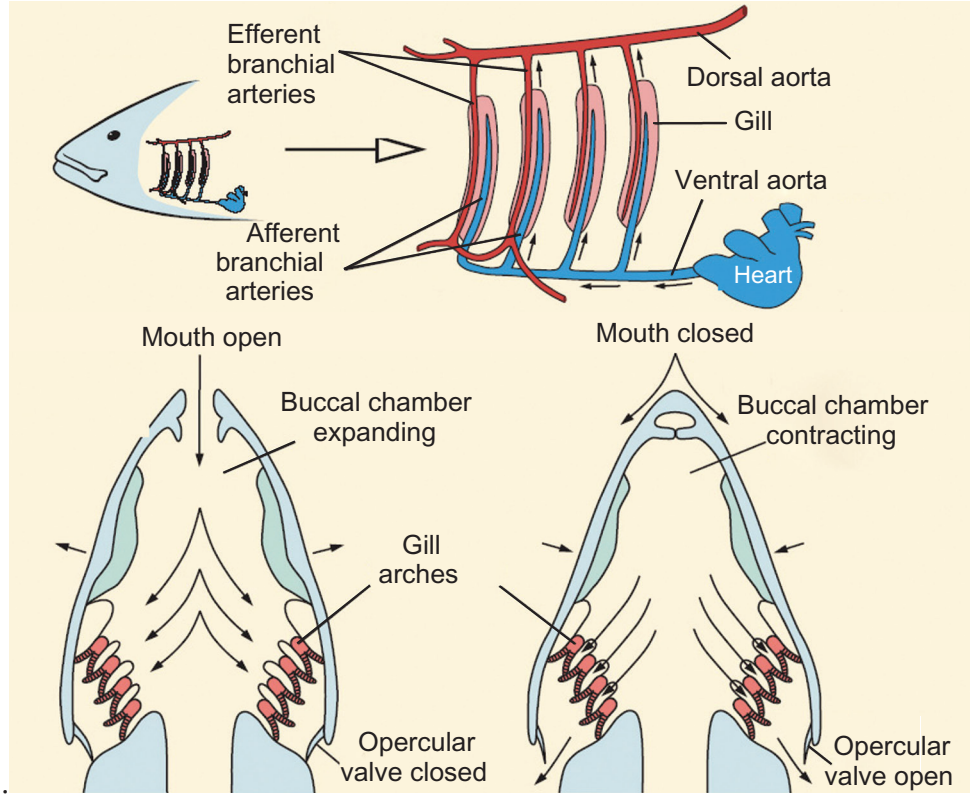


Figure 9.5: Mechanism of gill ventilation in Tilapia

Difference between gaseous exchange of cartilaginous and bony fish

S. No.	Cartilaginous fish	S. No.	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 maintained 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.

ACTIVITY 5

To study counter current flow and parallel flow.

Use the internet or textbooks to make a chart diagram of countercurrent and concurrent flow of fluids. Using arrows of different colours indicate the direction of flow of fluid in both the flow system. Download videos/animations from the internet depicting the countercurrent flow and exchange of gases through this system. Ask each of the students to give an advantage to each of countercurrent flow over concurrent flow.

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 (Figure 9.6). In such a system,

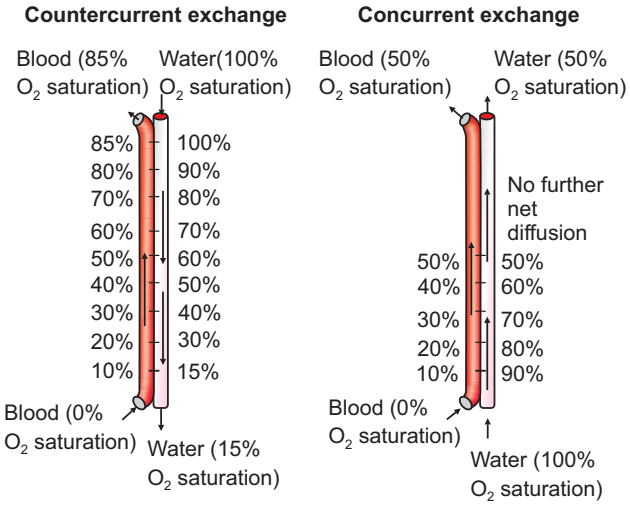


Figure 9.6: Current and counter current fluid flow.

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. 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. As we can see in Figure 9.7, 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.

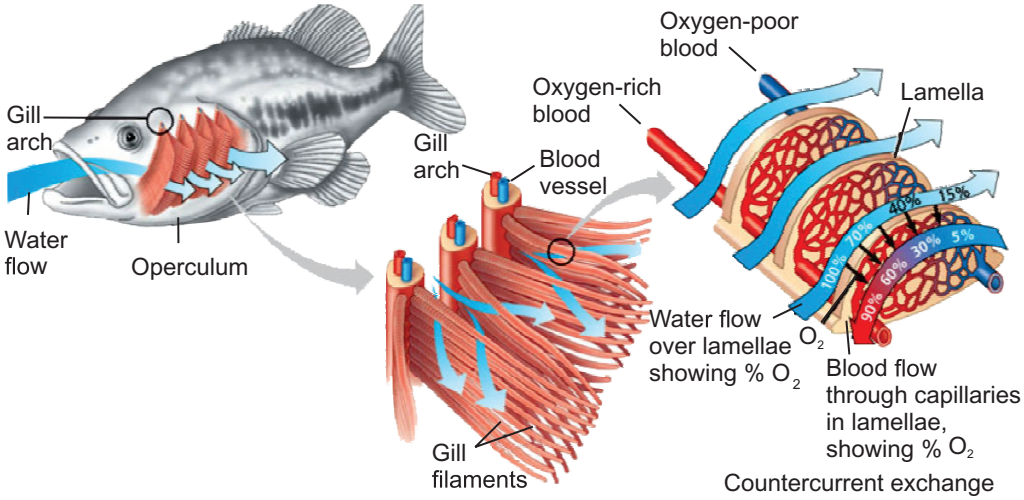


Figure 9.7: Countercurrent mechanism of gas exchange in bony fishes

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.

9.4.1 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.

SELF EVALUATION

Complete with appropriate terms:

(i) Two gases involved in gas exchange are ..... and ..... .

(ii) The high efficiency of tedeost gills is due to ..... .

(iii) ..... fish have exposed gill slits.

(iv) Taenidia are thickening of larger trachea in ..... .

(v) Active ventilation in insects is brought about by ..... and ..... .

9.5 GASEOUS EXCHANGE IN AMPHIBIANS

ACTIVITY 6

Aim: To observe a live frog or toad in a glass tank and discuss its gas exchange surfaces.

Materials Required: A live frog/toad, aquarium/glass tank, notebook and pen etc.

Procedure:

1. Obtain a live frog and put it in an aquarium or glass tank slowly. Take care to handle the animal gently and the animal should not be harmed.
2. Now observe carefully how it keeps itself ventilated and frequently comes to the surface, etc.
3. While on land observe carefully the movement of the buccal chamber for ventilation.
4. Touch the surface of the frog and examine the skin whether it is dry or wet.

Observation:

Did you observe the wet slimy condition of the skin of the frog? Try to explain why is it so? 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 (Figure 9.8). 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.

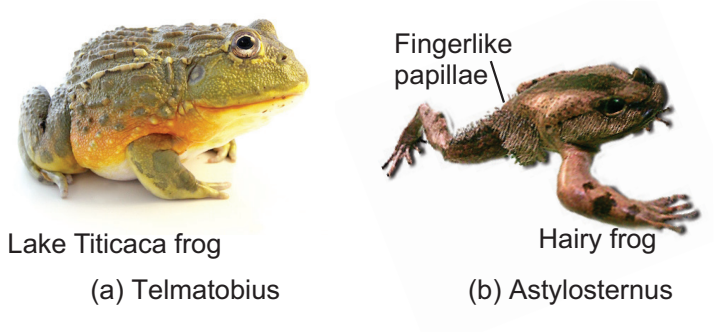


Figure 9.8: Cutaneous respiratory structures in some amphibians

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 (Figure 9.9). 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 (Figure 9.10). 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.

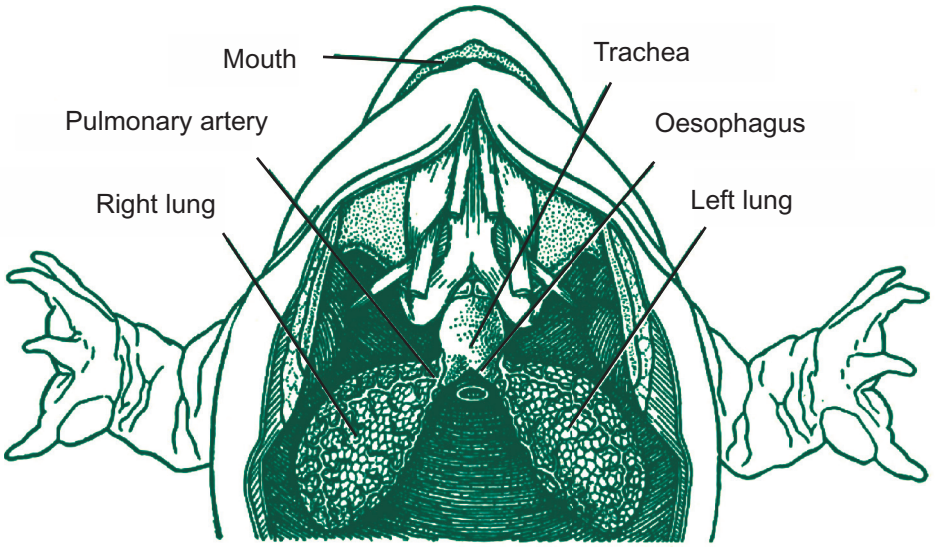


Figure 9.9: Structure of lungs in frog (amphibians).

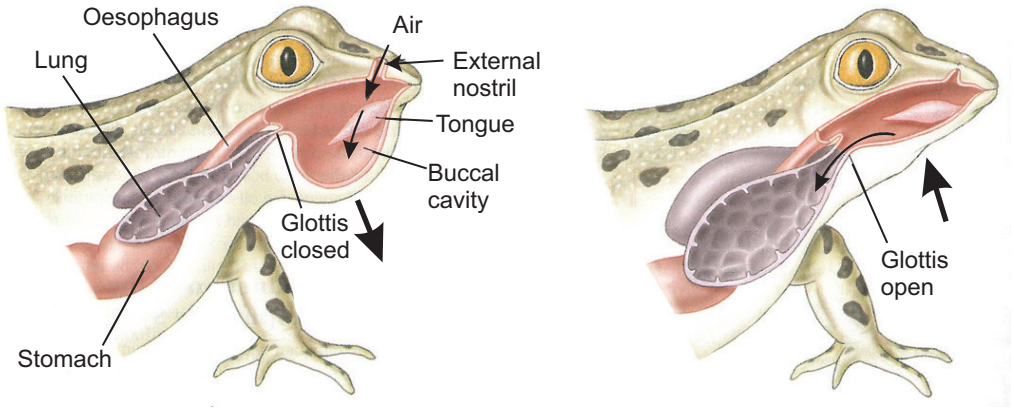


Figure 9.10: Mechanism of ventilation in frog (amphibians)

SELF EVALUATION

Complete with appropriate terms;

(i) Gas exchange occurring through skin is called ..... respiration.

(ii) Amphibians develop ..... to increase surface area for gaseous exchange.

(iii) Partitions of inner lungs in Amphibians are known as ..... .

9.6 GASEOUS EXCHANGE IN HUMANS

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*.

9.6.1 Structure of Gaseous Exchange in Humans

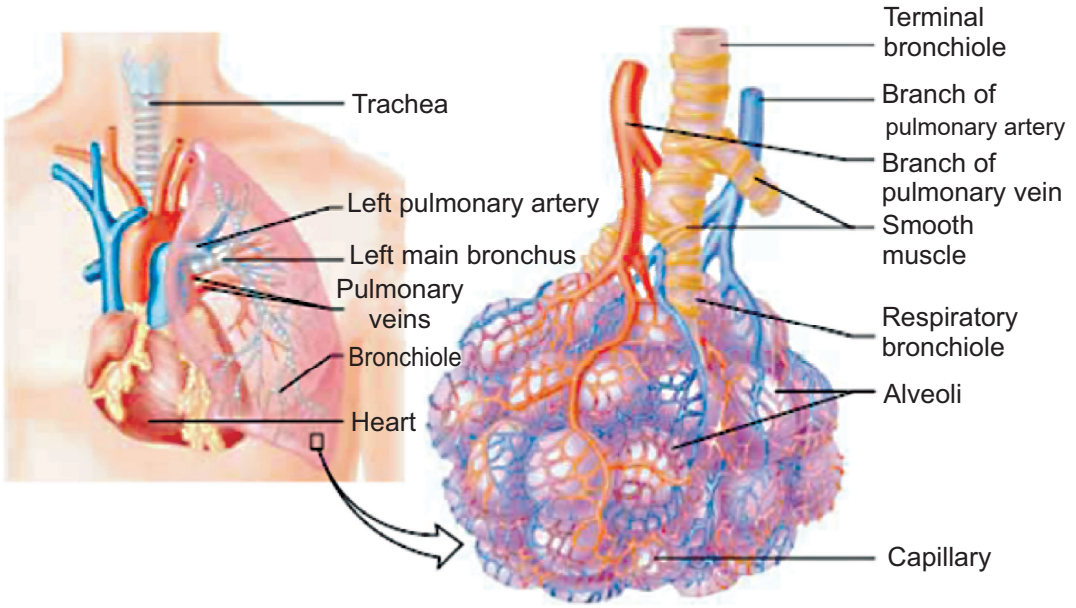
ACTIVITY 7

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 parts and surfaces of the gas exchanges system in humans. Also study the process of gas exchange and the mechanism of ventilation. Now, a small presentation on the same topic. You can also clay models of the respiratory system in humans.

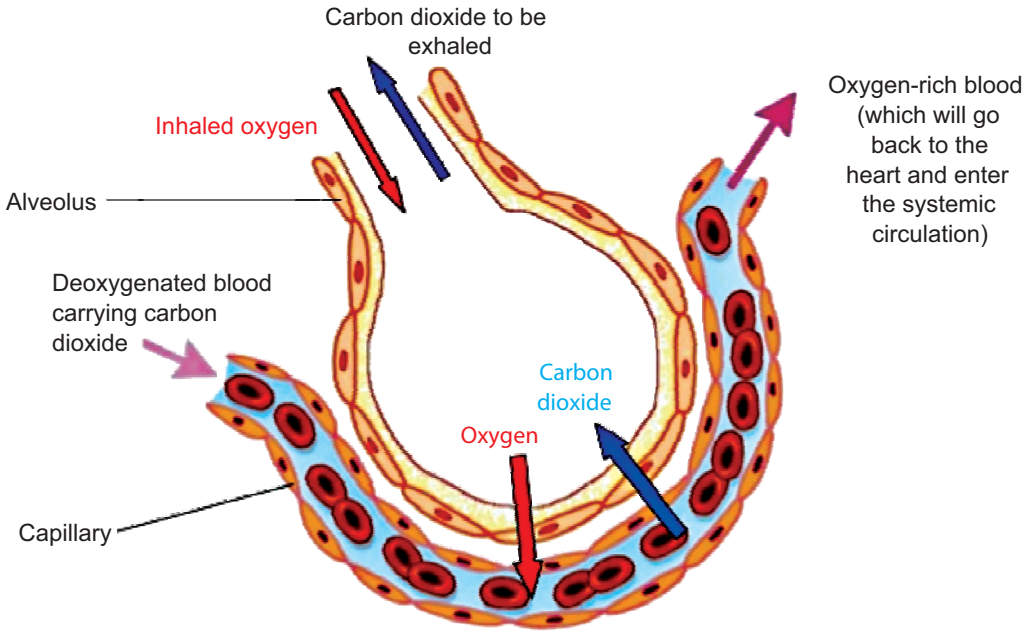
Air is inhaled through the nose into the **pharynx** (throat). Pharynx is a common passage for both air and food. The pharynx branches into two tubes, the **oesophagus** or **food pipe** and the **larynx**. The larynx is part of the airways and it houses the vocal cords. The nose, mouth, pharynx, and 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 (Figure 9.11a).

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**. Bronchioles 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 (Figure 9.11(a)). 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 (Figure 9.11 (b)). Alveoli are approximately 300 million in number in an adult and are the actual sites for gas exchange.



(a)



(b)

Figure 9.11: (a) Detail structure of human respiratory system: the lungs and the alveoli (*Source*: Vander et. al., Human Physiology, 2001) (b) gas exchange in the alveoli

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.

9.6.2 Functions of Tissues within the Gas Exchange System

The respiratory system consists of four main layers (Figure 9.12):

(i) The respiratory mucosa (epithelium and supporting lamina propria)

(ii) Submuscosa

(iii) Cartilage and/or muscle layer

(iv) Adventitia

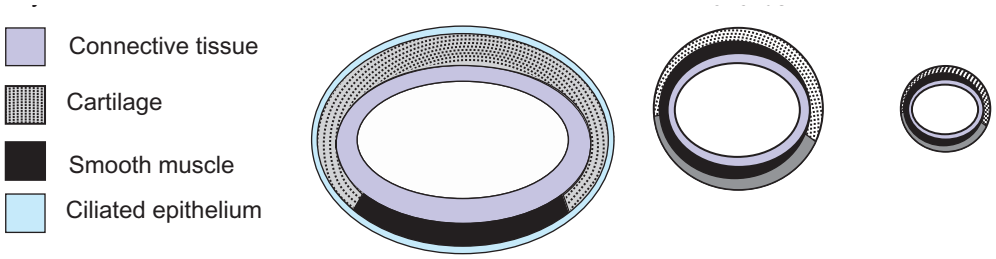


Figure 9.12: Diagrammatic representation of cross section of airways showing distribution of tissues (not to scale)

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. These 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 **mucous secreting glands** (Figure 9.13). 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 in 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	Pseudostrat-ified	Pseudostrat-ified	Columnar	Columnar	Cuboidal
Clara cells	Absent	Absent	Absent	+	+
Goblet cells	+++	++	++	+	Absent
Muscularis mucosa	Absent	+	++	+++	+++
Mucous glands	+++	++	+	Absent	Absent
Cartilage	+++	++	+	Absent	Absent

Figure 9.13: Table showing different tissue layers of the gas exchange system

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.

SELF EVALUATION

Complete with appropriate terms:

(i)Tiny air containing sacs found in the human gaseous exchange system are ..... .

(ii) ..... is a wide flexible tube in human gas exchange.

(iii) Respiratory mucosa in humans is made up of ..... and ..... .

(iv) Alveoli are lined up by ..... and ..... .

9.6.3 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.

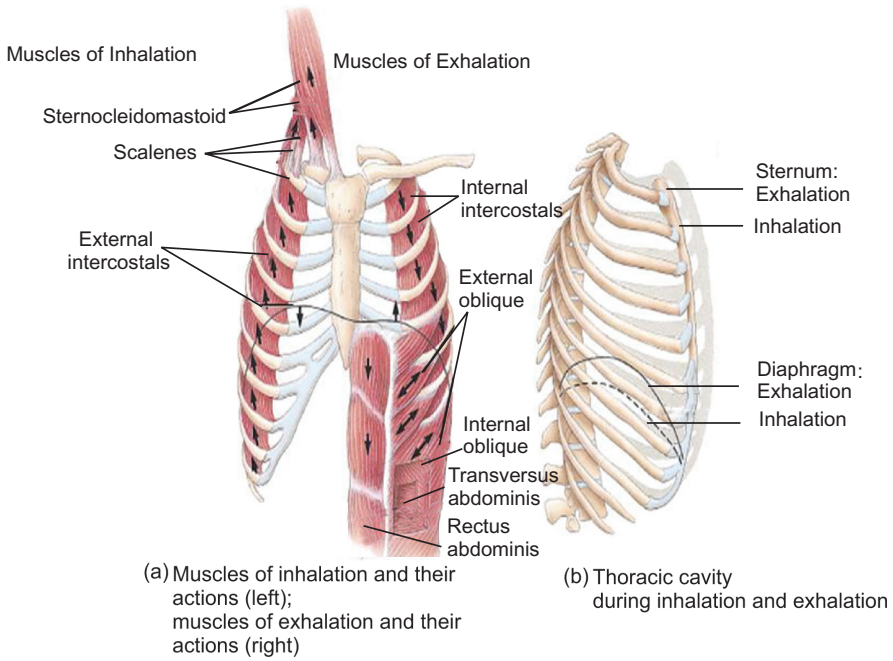


Figure 9.14: Structure and mechanism of lung ventilation in human

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 (Figure 9.14). 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.

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

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 (Figure 9.15).

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.

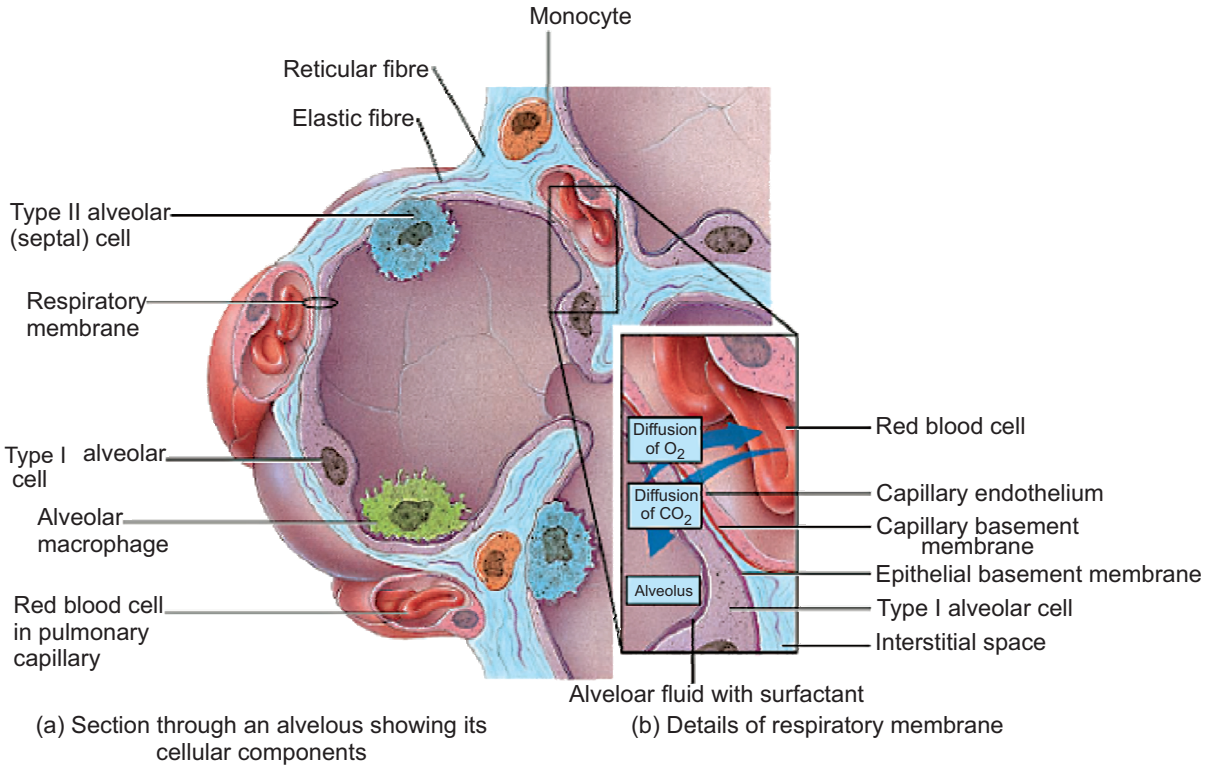


Figure 9.15: Detail structural components of an alveolus: (a) section through alveolus and (b) details of respiratory membrane

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.

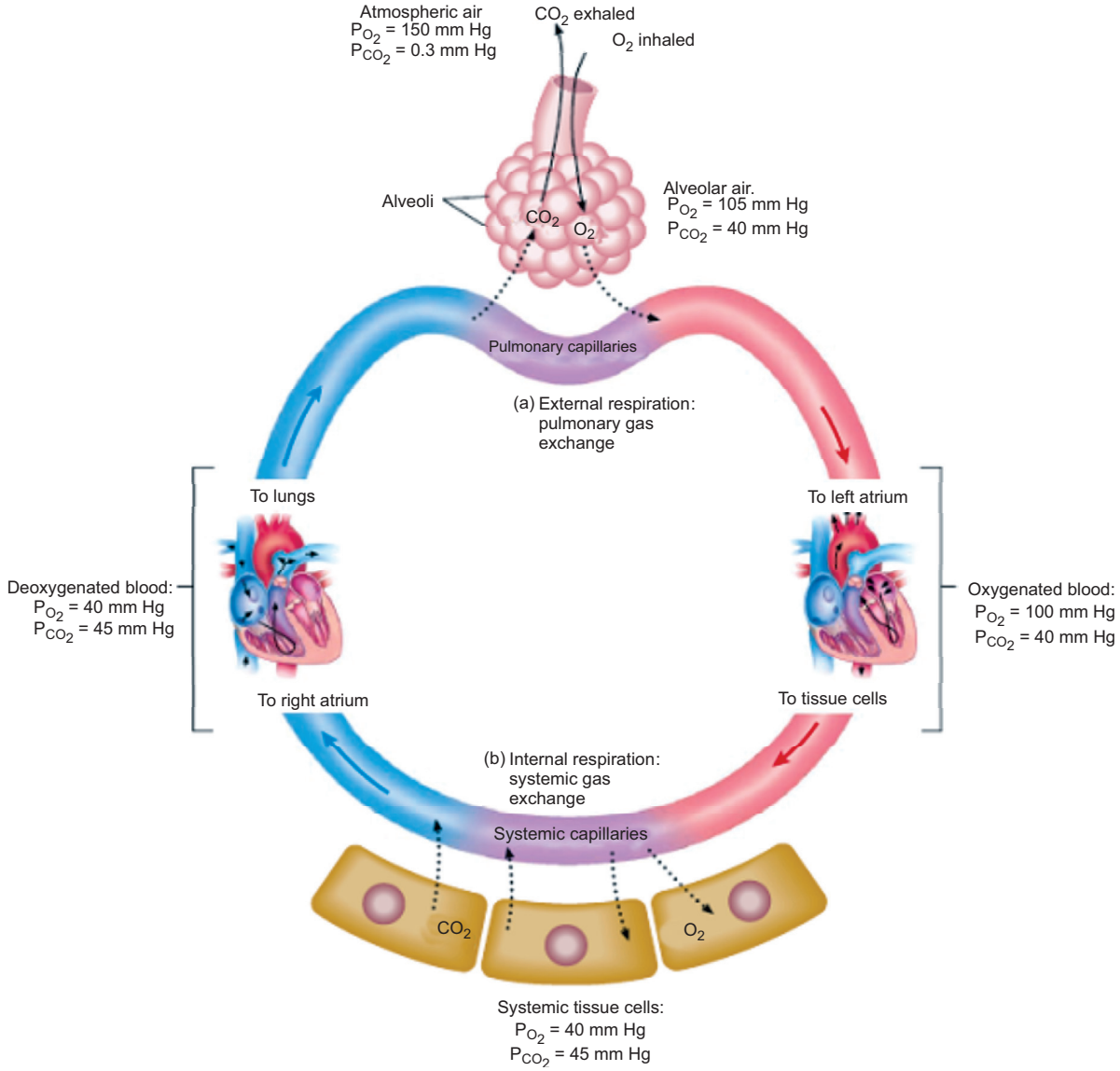


Figure 9.16: Exchange of gases in alveoli of humans

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 9.16).

9.6.4 Lung Volume and Capacities

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 sixfold 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,

$$\text{Alveolar ventilation (ml/min)} = \underset{\text{(ml/breath)}}{\text{(Tidal volume}} - \underset{\text{(ml/breath)}}{\text{Dead space)}} \times \underset{\text{(breath/min)}}{\text{Respiratory rate}}$$

$$= (500 - 150)\ \text{ml/breath} \times 12\ \text{breath/min}$$

$$= 350 \times 12 = 4200\ \text{ml/min}.$$

ACTIVITY 8

Calculate pulmonary ventilation (PV) and alveolar ventilation (AV) from the data provided.

(i) Tidal volume = 550 ml, Dead space = 185 ml, Respiratory rate = 17/min, inspiratory reserve volume = 2500 ml, tidal volume = 550, and expiratory reserve volume = 1450.

(ii) Tidal volume = 600 ml, Dead space = 195 ml, Respiratory rate = 15/min, inspiratory reserve volume = 2800 ml, tidal volume = 600, and expiratory reserve volume = 1350.

(iii) Tidal volume = 550 ml, Dead space = 175 ml, Respiratory rate = 20/min, inspiratory reserve volume = 2500 ml, tidal volume = 500, and expiratory reserve volume = 1500.

Hint: What is formula for calculation of pulmonary ventilation (PV) and alveolar ventilation (AV)?

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.

SELF EVALUATION

Complete with appropriate terms:

(i) Maximum volume of air that a person can expire after a maximal inspiration is called ..... .

(ii) Diffusion of O_2 from air to expillaries and CO_2 in opposite direction is called .....

(iii) During ..... volume of lungs increases in humans.

Spirometry

The **spirometer** is an apparatus for measuring inspired and expired volumes during breathing and the respiratory rate (Figure 9.17). The record is called a spirogram (Figure 9.18).

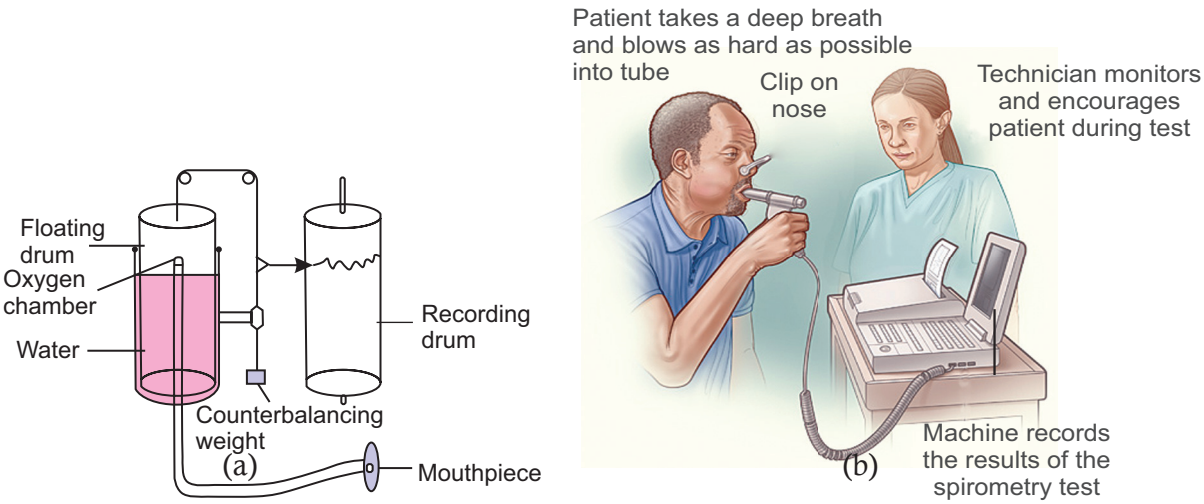


Figure 9.17: (a) A basic model of a spirometer; and (b) a patient taking readings on a modern spirometer

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* (Figure 9.17a) 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.

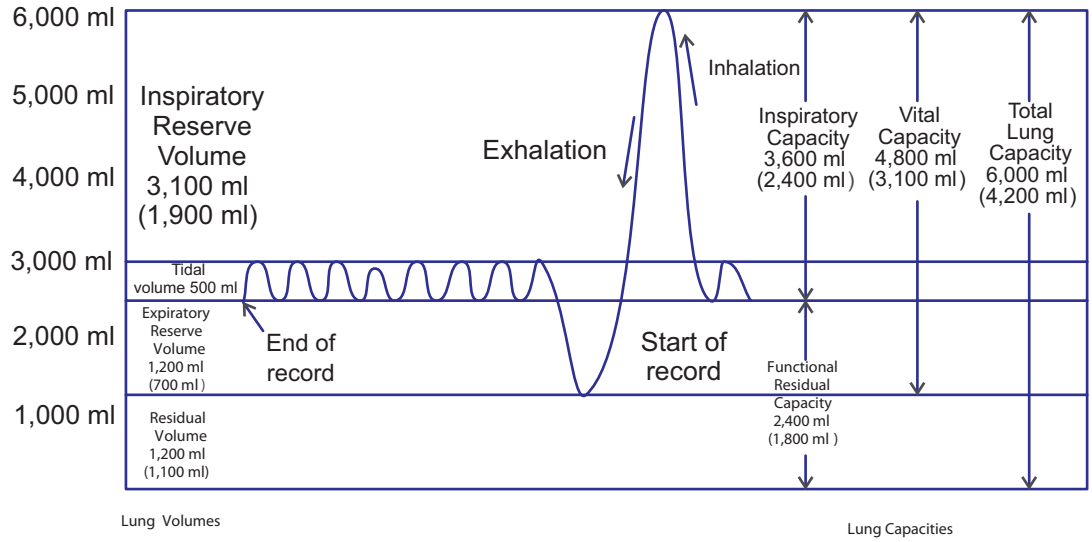


Figure 9.18: Spirogram of lung volumes and capacities in a healthy man and woman (within parentheses). The spirogram is read from the right (i.e., start of record) to the left (i.e., end of record)

ACTIVITY 9

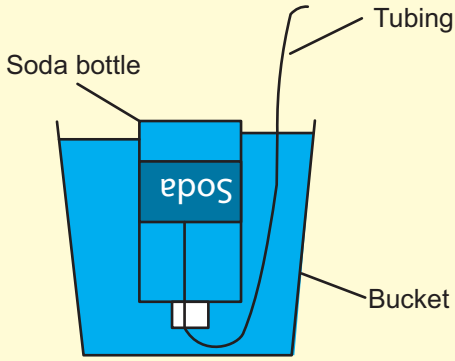
Aim: To design a model of the spirometer based on its main features.

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.
4. Open the bottle underwater to prevent any unwanted air from entering the bottle.
5. Place one end of the tubing into the soda bottle in the water, and leave the other end outside of the water.
6. Use the tubing to blow into, for determining lung capacity.
7. Remember to place the bottle in the water upside down before removing the cap.
8. Don't forget to insert one end of the hose in the bottle after you open the cap underwater
9. Before you exhale into the tubing, your spirometer should resemble the picture below.



10. 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.

(v) Again note the amount of air you exhaled by looking at the lines on the soda bottle.

(vi) This volume is your "**inspiratory reserve**." The inspiratory reserve is the amount of air that your lungs can hold in.

(vii) Refill the bottle with water and reinsert the tubing. One student holds the bottle while the other takes a few normal breaths to get himself back to a normal breath. **Then exhale as much air as you can into the end of the tubing** outside of the water.

(viii) Note the amount of air you exhaled by looking at the lines on the soda bottle.

(ix) This is your "**expiratory reserve**." The expiratory reserve is the amount of air that your lungs can blow out after a normal breath.

Observations:

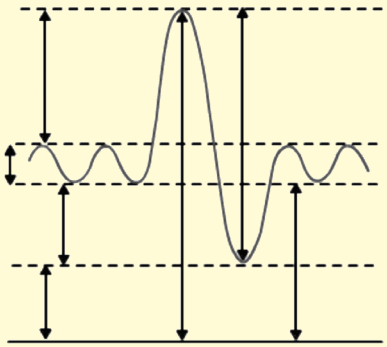
The vital capacity is the greatest change in volume that can occur in the lungs.

Inspiratory Reserve + Expiratory Reserve + Tidal Volume = Vital Capacity

ACTIVITY 10

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 if any.

9.7 NERVOUS CONTROL OF BREATHING

ACTIVITY 11

Inform the class about the function or role of a particular part of the brain controlling the process of respiration in humans viz. the medullary rhythmicity area and the pneumotaxic area in the pons.

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 (Figure 9.19):

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 breathing during 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.

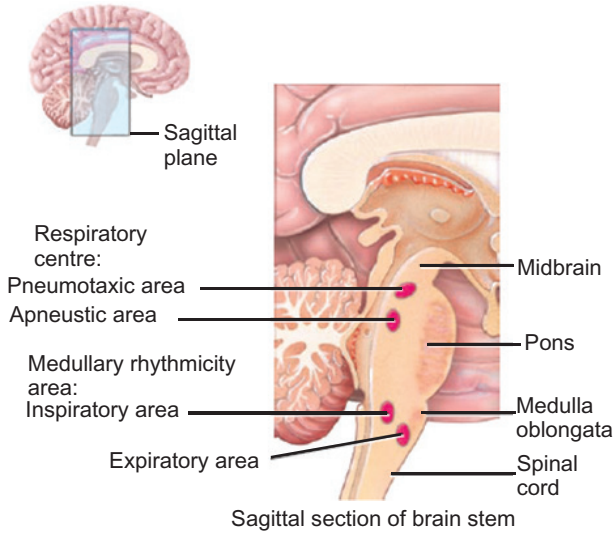


Figure 9.19: Respiratory centre in the human brain

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 muscles. 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.

SELF EVALUATION

Complete with appropriate terms:

(i)..... is used to measure inspired and expired volumes of air.

(ii) Respiratory centre is a cluster of neurons located bilaterally in ..... and ..... of brain stem.

(iii) ..... in brain prolongs inhalation.

9.8 SUMMARY

- Aerobic animals require a continuous supply of oxygen for metabolic processes and also removal of metabolic waste (CO_2) from its body.
- This is achieved by developing a complex system of gas exchange in every animal.
- Gases exchange takes place by the process of diffusion where it moves from a place of higher concentration to a place of lower concentration.
- Small invertebrates like insects have a vast network of 'tubes' made of chitin called the tracheal system spread all over their body which is used for exchange of gases.
- The tubes or trachea branches and interbranches to form fine tubes called tracheoles innervating tissues at cellular level. Air enters and leaves through openings called spiracles.
- In aquatic animals like fish and some amphibian larvae exchange of gases takes place through special structures called gills.
- Gills can be external or internal depending on its location in the body. Gills are highly vascular, thin and always ventilated with water.
- A holobranch or complete gill refers to a branchial arch and the lamellae on both anterior and posterior faces of its septum. A gill arch with lamellae on only one face is a hemibranch.
- Ventilation of gills in fish is achieved by the coordinated action of the buccal cavity and the operculum or gill cover.
- Countercurrent mechanism of gas exchange is present in gills of teleost. It is a very efficient mechanism of gas exchange and almost 85% of oxygen is extracted from water.
- Amphibians can respire through skin (cutaneous respiration), gills or the lungs.
- Exchange of gas in the skin, gills or the lungs takes place by diffusion of gas (O_2) from air or water to the blood capillaries in the skin or the septal walls of faveoli.
- In humans, exchange of gases takes place through the lungs. The lungs are elastic structures. The lungs, the airways leading to them, and the chest structures responsible for movement of air into and out of the lungs.
- The conducting zone of the airways consists of the trachea, bronchi, and terminal bronchioles. The respiratory zone of the airways consists of the alveoli, which are the sites of gas exchange.
- The alveoli are lined mostly by type I cells along with some type II cells, which produce surfactant.
- The lungs are covered by pleura and between the two pleural layers is an extremely thin layer of intrapleural fluid.
- During inspiration, the contractions of the diaphragm and inspiratory intercostal muscles increase the volume of the thoracic cage causing atmospheric air to rush into the lungs.
- During expiration, the inspiratory muscles cease contracting, allowing the elastic recoil of the chest wall and lungs to return them to their original between-breath size resulting in the air moving out of the lungs through the nose.

- The vital capacity is the sum of resting tidal volume, inspiratory reserve volume, and expiratory reserve volume.
- Gases diffuse from a region of higher partial pressure to a region of lower partial pressure. Exchange of gases in lungs and tissues takes place though the process of diffusion because of the differences in partial pressures of gases.
- There is net diffusion of oxygen from alveoli to blood and of carbon dioxide from blood to alveoli when systemic venous blood flows through the pulmonary capillaries.
- In certain conditions like when the alveolus capillary surface area is decreased or when the alveolar walls thicken inadequate gas exchange between alveoli and pulmonary capillaries may occur.

9.9 GLOSSARY

- **Alveoli:** The plural of alveolus. The alveoli are firy air sacs within the human lungs where exchange of gases takes place.
- **Breathing:** The process of taking air in and expelling it from lungs through the nose or mouth.
- **Bronchi:** The plural of bronchus. It is any of the major air passages of lungs which diverge from windpipe.
- **Counter current mechanism:** Maintenance of equilibria in the concentration of any permeable materials under two conditions.
- **Cutaneous respiration:** The process of respiration through skin.
- **Exhalation:** It is the process or act of exhaling out air, generally CO_2.
- **Gills:** These are the paired respiratory organ of fish and some amphibians, by which oxygen is extracted from water.
- **Inhalation:** It is the process or act of inhaling in air, generally O_2.
- **Paveoli:** A small pit or cavity resembling a cell of a honey comb alveola.
- **Spirometer:** An apparatus for measuring inspired and expired volumes of air during breathing.
- **Trachea:** A large membranous tube of cartilage extending from larynx to bronchial tubes and conveying air to and air from the lungs.
- **Ventilation:** The bodily process of inhalation and exhalation.

9.10 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. Insects have a specialised system of 'tubes' called the **tracheal system** for exchange of gases.
2. There is active ventilation in most treacheates (i.e., animals possessing trachea).

3. Fish gills consist of thousands of highly specialised **gill lamellae** enclosed in a gill cavity.
4. Amphibians use the moist skin, gills or the lungs for gas exchange.
5. Modern amphibians do not rely heavily on cutaneous respiration.
6. Most adult amphibians have lungs for breathing air.
7. Internal (tissue) respiration is the exchange of gases between blood in systemic capillaries and tissue cells.
8. Alveoli are the structure for gas exchange in humans.
9. The apparatus for measuring inspired and expired volumes during breathing is a spirometer.
10. The sum of inspiratory reserve volume, tidal volume, and expiratory reserve volume is called residual volume.

II. Long Answer Type Questions

1. Describe the tracheal system of insects and relate to its function.
2. Describe the structure of the gills in relation to its function.
3. In your own words, explain the significance of counter current flow in bony fish.
4. Describe the mode of gaseous exchange in amphibians.
5. Describe the structure of the human gas exchange system.
6. Describe the distribution of tissues within the trachea, bronchi, bronchioles and alveoli and relate each tissue to its function.
7. Explain the mechanism of ventilation in humans.
8. Explain the process of gas exchange in alveoli with emphasis on diffusion.
9. Describe the role of the brain in controlling gas exchange in humans.
10. Define the following terms related to the lung capacities:
    (i) Tidal volume (ii) Reserve volume
    (iii) Vital capacity (iv) Residual volume
    (v) Dead air space
11. Describe how a spirometer can be used to measure vital capacity, tidal volume, breathing rates, and oxygen uptake.
12. Calculate vital capacity and alveolar ventilation from the data provided.
    Tidal volume = 550 ml, Dead space = 185 ml, Respiratory rate = 17/min, inspiratory reserve volume = 2500 ml, tidal volume = 550, and expiratory reserve volume = 1450.
13. What contribution does exchange of gases make on global warming? Discuss your answer with relevant data. Also throw light on the dialect "Global warming: a myth or truth."

Unit 10

Smoking and Related Diseases

Key Unit Competence

To be able to describe the effects of tobacco smoking on the gas exchange system.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- state the features of a genetic code.
- describe the effects of tar and carcinogens in tobacco smoke on the gas exchange system.
- describe the signs and symptoms of lung cancer and chronic obstructive pulmonary diseases (COPD).
- describe the effects of nicotine and carbon monoxide on the cardiovascular system.
- explain how tobacco smoking contributes to atherosclerosis and coronary heart disease.
- interpret photographs to differentiate healthy lungs from infected lungs.
- interpret data linking cigarette smoking to disease and early death.
- observe and interpret research statistics linking to tobacco smoking.
- evaluate the epidemiological and experimental evidence linking cigarette smoking to disease and early death.
- influence the campaign against cigarette smoking.

10.1 CIGARETTE SMOKING

ACTIVITY 1

To observe the effect of tobacco on animals.

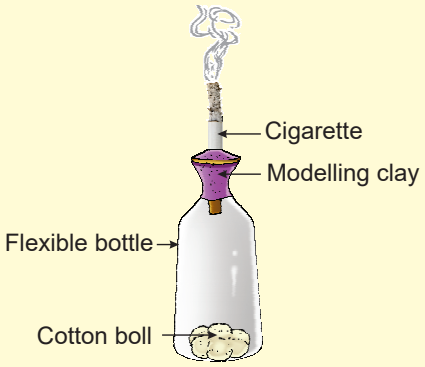
Collect some tobacco leaves or cigarette butts and boil them with water. Allow the solution to cool. Now filter it with a stainer. Pour the solution into a large squirt bottle. Spray the solution on a plant infested with aphids. Wait for a while. Do you find the aphids stay on the plant? What makes them leave the plant? This is the tobacco that forces the pests to leave the plant.

Tobacco leaves contain toxins which are harmful to human.

ACTIVITY 2

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 coloured tar on the bolls? Where does this tar come from?



This is how cigarette smoke harms the lungs. Cigarette smoking is very harmful for health, and it nearly affects every organ of the body, causes many diseases, and reduces the health of smokers in general.

Cigarette smoking is the leading preventable cause of death in the United States.

- Smoking causes more deaths each year than the following causes combined:
  - Human immunodeficiency virus (HIV)
  - Illegal drug use
  - Alcohol use
  - Motor vehicle injuries
  - Firearm-related incidents
- Smoking causes about 90% (or 9 out of 10) of all lung cancer deaths in men and women. More women die from lung cancer each year than from breast cancer.
- About 80% (or 8 out of 10) of all deaths from chronic obstructive pulmonary disease (COPD) are caused by smoking.
- Cigarette smoking increases risk for death from all causes in men and women.

Tobacco Control

ACTIVITY 3

Discuss the steps to control the use of tobacco. Everyone knows the detrimental effects of tobacco but still it is used. Write a journal stating why the youth need to control tobacco.

Tobacco control is a field of international public health science, policy and practice to reduce the tobacco use which causes high morbidity and mortality due to tobacco smoke. Tobacco control is a priority area for the World Health Organization (WHO), through the Framework

Convention on Tobacco Control. It has started to protect present and future generations from the devastating health, social, environmental and economic consequences of tobacco consumption and exposure to tobacco smoke. Progress was initially notable at a state or national level, particularly the pioneering smoke-free public places legislation introduced in New York City in 2002 and the Republic of Ireland in 2004, and the UK effort for tobacco control in 2004.

WHO produced an internationally-applicable and now widely recognised summary of the essential elements of tobacco control strategy, publicised as the mnemonic MPOWER tobacco control strategy. The 6 components are:

Monitor tobacco use and prevention policies

Protect people from tobacco smoke

Offer help to quit tobacco use

Warn about the dangers of tobacco

Enforce bans on tobacco advertising, promotion and sponsorship

Raise taxes on tobacco

10.2 DANGEROUS CHEMICALS IN TOBACCO SMOKE

Smokers inhale about 7,000 chemicals in cigarette smoke. Many of these chemicals come from burning tobacco leaf. Some of these compounds are chemically active and trigger profound and damaging changes in the body. Tobacco smoke contains over 60 known cancer-causing chemicals. Smoking harms nearly every organ in the body, causing many diseases and reducing health in general.

The most damaging components of tobacco smoke are:

1. **Tar:** Tar is the collective term describing toxins produced by smoking cigarettes and the coating they place on the lungs. Tar is sticky and brown, and stains teeth, fingernails and lung tissue. Tar contains the carcinogen benzo(a)pyrene. When inhaled, these toxins form a particulate matter that coats lungs much the same way that soot from log fires coats chimneys. But unlike chimneys, which are made of stone or brick, human lungs are made of thin, delicate tissue not intended for toxic smoke intake.

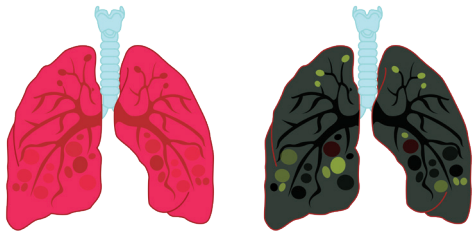


Figure 10.1: Healthy (Left) and tar coated lung (Right)

2. **Nicotine** is the addictive drug in tobacco smoke that causes smokers to continue to smoke and affects the brain activity. Addicted smokers need enough nicotine over a day to 'feel normal'—to satisfy cravings or control their mood.

How Nicotine Affects the Brain

- Brain is made up of billions of nerve cells. They communicate by releasing chemical messengers called neurotransmitters. Each neurotransmitter is like a key that fits into a special "lock," called a receptor, located on the surface of nerve cells. When a neurotransmitter finds its receptor, it activates the receptor's nerve cell.
- The nicotine molecule is shaped like a neurotransmitter called **acetylcholine**. Acetylcholine and its receptors are involved in many functions, including muscle movement, breathing, heart rate, learning, and memory. They also cause the release of other neurotransmitters and hormones that affect your mood, appetite, memory, and more. When nicotine gets into the brain, it attaches to acetylcholine receptors and mimics the actions of acetylcholine. Nicotine also activates areas of the brain that are involved in producing feelings of pleasure and reward. Recently, scientists discovered that nicotine raises the levels of a neurotransmitter called dopamine in the parts of the brain that produce feelings of pleasure and reward. Dopamine, which is sometimes called the pleasure molecule, is the same neurotransmitter that is involved in addictions to other drugs such as cocaine and heroin. Researchers now believe that this change in dopamine may play a key role in all addictions.

3. **Carbon monoxide (CO):** This odourless gas is fatal in large doses because it takes the place of oxygen in the blood. It is also called **'Silent killer'**. Each red blood cell contains a protein called haemoglobin that transports oxygen molecules around the body. However, carbon monoxide binds to haemoglobin better than oxygen. In response, the body makes more red blood cells to carry the oxygen it needs, but it makes the blood thicker. This means that when the body demands more oxygen during exercise, less oxygen reaches the brain, heart, muscles and other organs.

How it Affects to the Body

- Carbon monoxide poisoning occurs when carbon monoxide builds up in your bloodstream. When too much carbon monoxide is in the air, your body replaces the oxygen in the red blood cells with carbon monoxide. This prevents oxygen from reaching your tissues and organs. This leads to serious tissue damage, or even death.

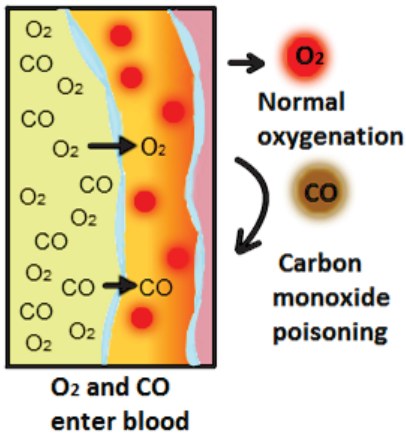


Figure 10.2: Carbon monoxide poisoning

Carbon monoxide poisoning can be especially dangerous for people who are sleeping or intoxicated. People may have irreversible brain damage or even be killed before anyone realizes

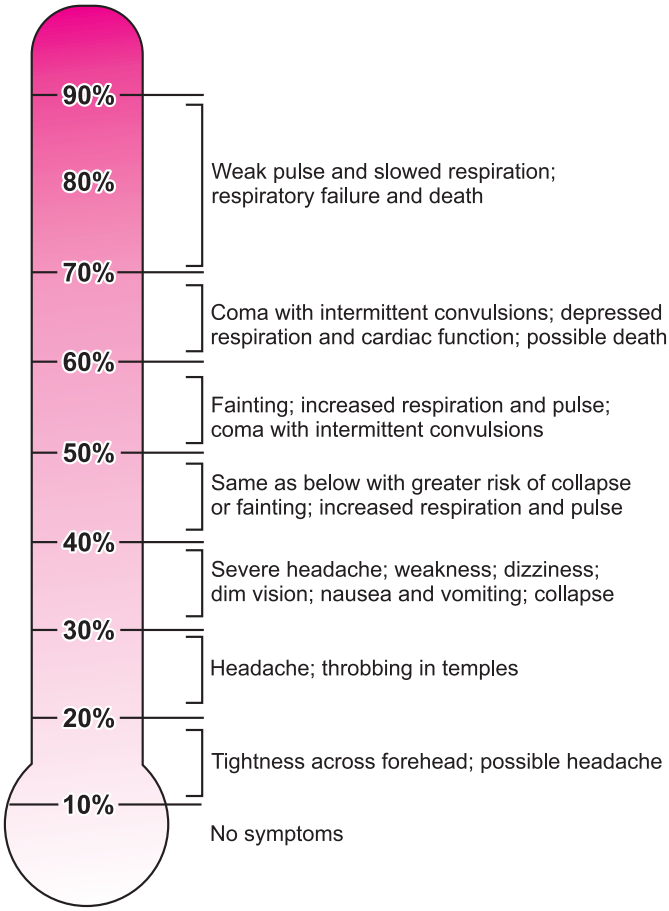


Figure 10.3: Typical symptoms of carbon monoxide poisoning (increasing percentage of CO in blood).

- **Hydrogen cyanide** – The lungs contain tiny hairs (cilia) that help to clean the lungs by moving foreign substances out. Hydrogen cyanide stops this lung clearance system from working properly, which means the poisonous chemicals in tobacco smoke can build up inside the lungs. Other chemicals in smoke that damage the lungs include hydrocarbons, nitrous oxides, organic acids, phenols and oxidising agents.
- **Oxidizing chemicals** – These highly reactive chemicals (which include free radicals) can damage the heart muscles and blood vessels. They react with cholesterol, leading to the build-up of fatty material on artery walls. Their actions lead to heart disease, stroke and blood vessel disease.
- **Metals** – Tobacco smoke contains dangerous metals including arsenic, cadmium and lead. Several of these metals are carcinogenic.
- **Radioactive compounds** – Tobacco smoke contains radioactive compounds that are known to be carcinogenic.

SELF EVALUATION

Complete with appropriate terms:

(i)..... is also called Silent killer.

(ii) ..... is the addictive drug found in cigarette.

(iii) Tar contains carcinogen .....

(iv) Radiation compounds present in tobacco smoke are .....

(v) Carbon monoxide poisoning ..... percentage of CO in flood.

10.3 LUNG CANCER AND SMOKING

Lung cancer is strongly correlated with cigarette smoking, with about 90% of lung cancers arising as a result of tobacco use. The risk of lung cancer increases with the number of cigarettes smoked over time. If someone smokes one pack of cigarettes per day, he/she has a risk for the development of lung cancer that is 25 times higher than a non-smoker. Among those who smoke two or more packs of cigarettes per day, one in seven will die of lung cancer. But even though the risk is higher; the more you smoke, there is no safe level of exposure to tobacco smoke.

Passive smoking, or the inhalation of tobacco smoke from other smokers sharing living or working quarters, is also an established risk factor for the development of lung cancer. Research has shown that non-smokers who reside with a smoker have a 24% increase in risk for developing lung cancer when compared with other non-smokers.

Lung cancer is the uncontrolled growth 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.

Primary lung cancer originates in the lungs, while secondary lung cancer starts somewhere else in the body, metastasizes, and reaches the lungs. They are considered different types of cancers and are not treated in the same way.

According to the World Health Organization (WHO), 7.6 million deaths globally each year are caused by cancer; cancer represents 13% of all global deaths and lung cancer is by far the number one cancer killer.

10.3.1 Signs and Symptoms of Lung Cancer

The most common symptoms of lung cancer are:

- A cough that does not go away or gets worse
- Chest pain that is often worse with deep breathing, coughing, or laughing
- Hoarseness
- Weight loss and loss of appetite
- Coughing up blood or rust-coloured sputum (spit or phlegm)
- Shortness of breath
- Feeling tired or weak
- Infections such as bronchitis and pneumonia that don't go away or keep coming back
- 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.

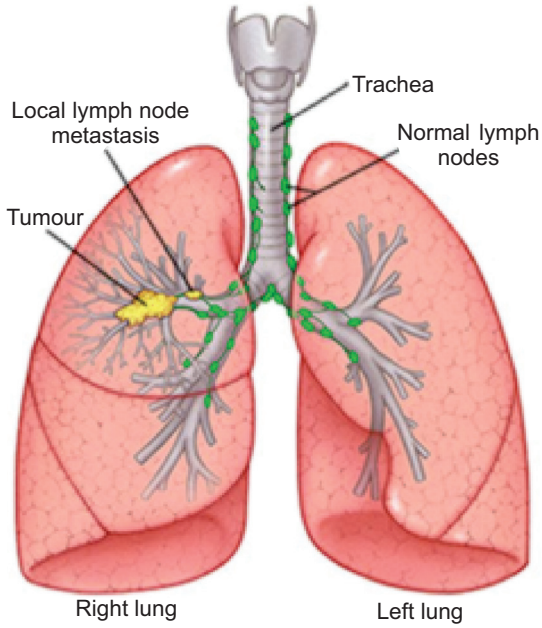


Figure 10.4: Tumour formation in lung (right) and healthy lung (left)

10.3.2 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.

10.4 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:

- A long-lasting (chronic) cough.
- Breathing difficulty, especially during physical activities.
- Cough.
- Sputum production.
- Wheezing.
- Blueness of the lips or fingernail beds (cyanosis).
- Frequent respiratory infections.
- Lack of energy.

As 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 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 COPD. It causes airway obstruction in the lungs.

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 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.

The main cause of COPD in developed countries is tobacco smoking. In the developing world, COPD often occurs in people exposed to fumes from burning fuel for cooking and heating in poorly ventilated homes.

Only about 25 per cent of chronic smokers develop clinically apparent COPD, although up to half have subtle evidence of COPD. Some smokers develop less common lung conditions. They may be misdiagnosed as having COPD until a more thorough evaluation is performed.

Risk factors for COPD include:

- **Exposure to tobacco smoke.** The most significant risk factor for COPD is long-term cigarette smoking. The Pipe smokers, cigar smokers and marijuana smokers are at risk, as are people exposed to large amounts of secondhand smoke.
- **People with asthma who smoke.** The combination of asthma, a chronic airway disease, and smoking increases the risk of COPD even more.
- **Occupational exposure to dusts and chemicals.** Long-term exposure to chemical fumes, vapours and dusts in the workplace can irritate and inflame your lungs.
- **Age.** COPD develops slowly over years, so most people are at least 35 to 40 years old when symptoms begin.
- **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:

- **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.
- **Heart problems:** COPD increases the risk of heart disease, including heart attack.
- **Lung cancer:** Smokers with chronic bronchitis have a greater risk of developing lung cancer than those smokers who don't have chronic bronchitis.
- **High blood pressure:** COPD may cause high blood pressure in the arteries that bring blood to your lungs (pulmonary hypertension).
- **Depression:** Difficulty in breathing and dealing with serious illness can contribute to development of depression.

10.5 SMOKING CONTRIBUTES TO CARDIOVASCULAR DISEASE

Athrosclerosis (Artherosclerosis) and Coronary Heart Disease (CHD):

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 10.5). The disease disrupts the flow of blood around the body, posing serious cardiovascular complications. The plaque clogs up the artery, disrupting the flow of blood around the body. This potentially causes blood clots that can result in life-threatening conditions such as heart attack, stroke and other cardiovascular diseases which are the usual causes of heart attacks, strokes, and peripheral vascular disease — what together are called "**cardiovascular disease**." Carbon monoxide exposure has been implicated in the process of atherosderosis.

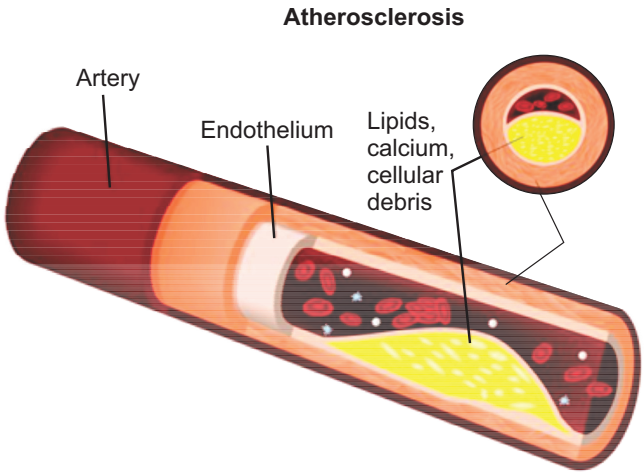


Figure 10.5: Showing plaque formation around the artery wall in Atherosclerosis

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 (Figure 10.6). The most common symptoms of coronary artery disease are angina (say "ANN-juh-nuh" or "ann-JY-nuh") and shortness of breath when exercising or doing other vigorous activity. Women are somewhat more likely than men to have other symptoms like nausea and back or jaw pain.

10.5.1 Effect of Carbon Monoxide and Nicotine in Cardiovascular Diseases

You have already studied that both carbon monoxide and Nicotine along with other carcinogens affect the 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 the heartbeat faster and raises the blood pressure, making the heart work harder.

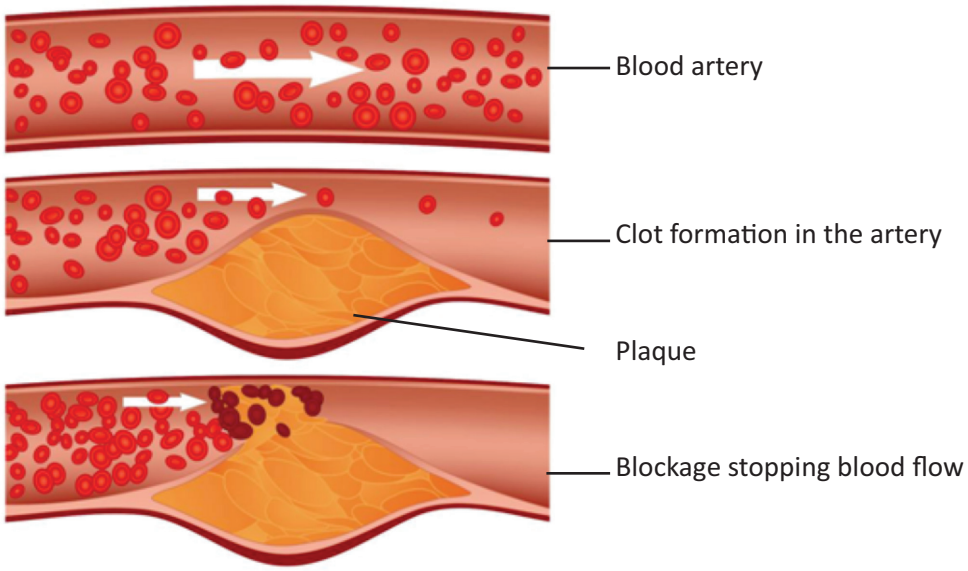


Figure 10.6: The process of blocking arteries by plaque in coronary heart disease

10.6 SMOKING AND HEALTH RISKS

ACTIVITY 4

Research on the effects of smoking on gas exchanges system and its health risks. You may take help of magazines, books and the internet. Present your findings in class.

Smokers are more likely than non-smokers to develop heart disease, stroke, and lung cancer.

- Smoking is estimated to increase the risk—
  - For coronary heart disease by 2 to 4 times
  - For stroke by 2 to 4 times
  - Of men developing lung cancer by 25 times
  - 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.

10.6.1 Smoking and Cardiovascular Disease

Smokers are at greater risk for diseases that affect the heart and blood vessels (cardiovascular disease).

- Even people who smoke fewer than five cigarettes a day can have early signs of cardiovascular disease.
- Smoking damages blood vessels and can make them thicken and grow narrower. This makes your heart beat faster and your blood pressure go up. Clots can also form.
- A stroke occurs when a clot blocks the blood flow to part of your brain or when a blood vessel in or around your brain bursts.
- Blockages caused by smoking can also reduce blood flow to your legs and skin.

10.6.2 Smoking and Respiratory Disease

Immediate Effects of Smoking on the Breathing System

Smoking is bad for health from the very first cigarette, because some of the chemicals in the smoke have an immediate effect on the body.

- Carbon monoxide from the smoke is taken into the blood instead of oxygen. The cells get less oxygen for respiration, especially during exercise. This is particularly damaging during pregnancy because a developing baby can be starved of oxygen.

- The cilia in your trachea and bronchi are anaesthetised so they no longer move mucus and pathogens away from the lung and lungs become more likely to get infections of the breathing system. Long-term smokers may also develop a 'smoker's cough' as your body tries to get rid of the mucus which builds up in the lungs.

The effects of tobacco smoke on the respiratory system include:

- Irritation of the trachea (windpipe) and larynx (voice box)
- Reduced lung function and breathlessness due to swelling and narrowing of the lung airways and excess mucus in the lung passages
- Impairment of the lungs' clearance system, leading to the build-up of poisonous substances, which results in lung irritation and damage
- Increased risk of lung infection and symptoms such as coughing and wheezing
- Permanent damage to the air sacs of the lungs.

Smoking can cause lung disease by damaging your airways and the small air sacs (alveoli) found in your lungs.

- Lung diseases caused by smoking include COPD, which includes emphysema and chronic bronchitis.
- Cigarette smoking causes most cases of lung cancer.
- In condition of asthma, tobacco smoke can trigger an attack or make an attack worse.
- Smokers are 12 to 13 times more likely to die from COPD than non-smokers.

10.6.3 Smoking and Other Health Risks

Smoking harms nearly every organ of the body and affects a person's overall health.

- 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.
  - Stillbirth (death of the baby before birth).
  - Low birth weight.
  - Sudden infant death syndrome (known as SIDS or crib death).
  - 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.
  - Women past childbearing years who smoke have weaker bones than women who never smoked, and are at greater risk for broken bones.

- Smoking affects the health of your teeths 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).

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 (Figure 10.7).

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.

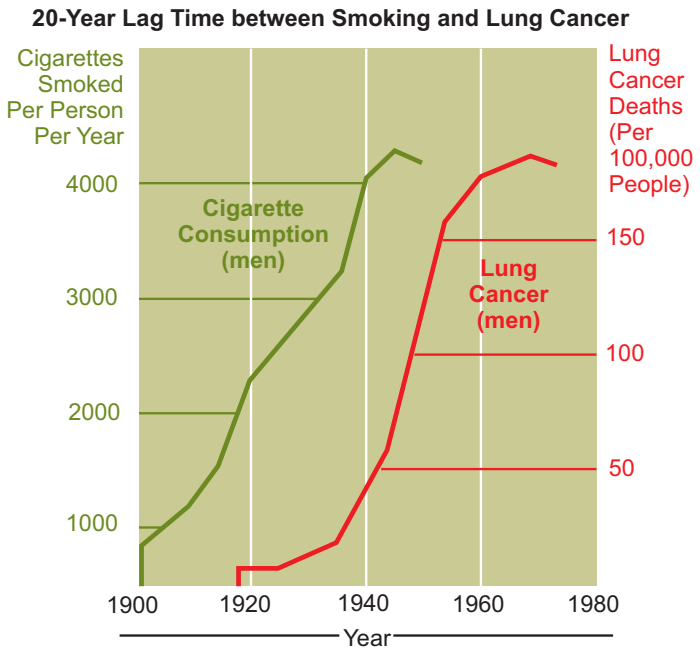


Figure 10.7: Lag time between smoking and lung cancer

Cigarette smoke contains over 4,000 chemicals, including 43 known cancer-causing (carcinogenic) compounds and 400 other toxins. These cigarette ingredients include nicotine, tar, and carbon monoxide, as well as formaldehyde, ammonia, hydrogen cyanide, arsenic, and DDT. Nicotine is highly addictive

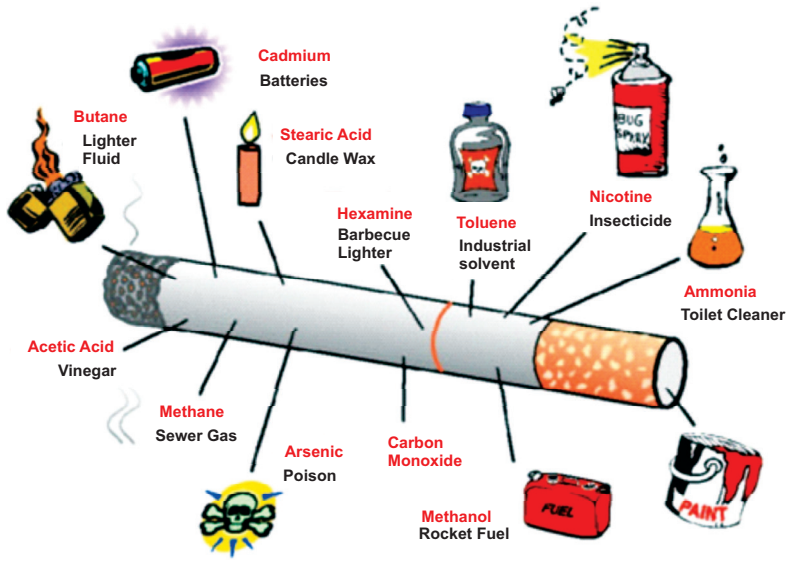


Figure 10.8: Cigarette ingredients

Anti-smoking Campaigns

We will continue to run 'smoke-free' campaigns to encourage people to change their behaviour. The campaigns are aimed at:

- Making people aware of the health dangers of smoking.
- Stopping young people from taking up smoking.
- Encouraging smokers to try and quit, and to do so in the most effective way.
- Encouraging people to stop smoking in their homes and family cars—emphasising how it affects children.

10.7 SUMMARY

- Smoking harms nearly every bodily organ and organ system in the body and diminishes person's health and smokers are more likely than non-smokers to develop heart disease, stroke, and lung cancer.
- Smoking is a leading cause of lung cancer and death from cancer.
- It causes stroke and coronary heart disease, which are among the leading causes of death in the United States.

- Atherosclerosis and coronary heart disease results in damaging of blood vessels and make them thick and grow narrow, when a clot blocks the blood flow to part of brain or when a blood vessel in or around your brain bursts, it causes stroke.
- Chronic Obstructive Pulmonary Disease (COPD) is a chronic inflammatory lung disease caused by smoking which damage the airways and the small air sacs (alveoli) found in the lungs. Emphysema and Chronic bronchitis condition also contributed to COPD which obstruct the airways of the lung.
- People with COPD are at higher risk of developing heart disease, lung cancer and a variety of other conditions. They suffer from breathing difficulty, suddenly lose weight and feel low energy.
- Cigarette smoking and tobacco smoking contain number of harmful and carcinogenic chemicals like:
- Nicotine — not carcinogenic but highly addictive. Smokers find it very hard to quit because they are hooked on nicotine. Nicotine is an extremely fast-acting drug. It reaches the brain within 15 seconds of being inhaled. Nicotine is used as a highly controlled insecticide. Exposure to sufficient amounts can lead to vomiting, seizures, depression of the CNS (central nervous system), and growth retardation.
- Carbon Monoxide — a poisonous gas with no smell or taste. The body finds it hard to differentiate carbon monoxide from oxygen and absorbs it into the bloodstream. Carbon monoxide decreases muscle and heart function, it causes fatigue, weakness, and dizziness. It is especially toxic for babies still in the womb, infants and individuals with heart or lung disease.
- **Tar** — Tar' describes the particulate matter which, generated by burning tobacco, forms a component of cigarette smoke. Each particle is composed of a large variety of organic and inorganic chemicals consisting primarily of nitrogen, oxygen, hydrogen, carbon dioxide, carbon monoxide, and a wide range of volatile and semi-volatile organic chemicals. In its condensate form, tar is a sticky brown substance that is the main cause of lung and throat cancer in smokers. Tar can also cause unsightly yellow-brown stains on fingers and teeth.

10.8 GLOSSARY

- **Atherosclerosis:** A condition where the arteries become narrowed and hardened due to an excessive build up of plaque around the artery wall.
- **Benign tumour:** Tumour that remains in one place and does not appear to spread.
- **COPD:** Chronic Obstructive Pulmonary Disease is a chronic inflammatory lung disease caused by smoking which damage the airways and the small air sacs (alveoli) found in the lungs.
- **Cardiovascular disease:** It includes all types of heart and blood vessel diseases.

- **Malignant tumour:** Tumour that spreads to other parts of the body either through the bloodstream or the lymphatic system.
- **Tar:** A sticky, dark brown substance that can accumulate and coat the airways and lungs.

10.9 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. Smoke from cigarettes can make non-smokers sick.
2. Smoking can affect a person's ability to smell and taste food.
3. Secondhand smoke kills about 3,000 non-smokers each year from lung disease.
4. It takes about ten seconds for nicotine absorbed into the bloodstream to reach the brain.
5. Smoking is a difficult habit to quit.
6. Nicotine, the chemical found in cigarettes, is an addictive drug.
7. A smoker is twice as likely to have a heart attack as a non-smoker is.
8. Cigarette brands that are heavily advertised on TV, in magazines, on billboards, and on T-shirts are the brands more teens buy.
9. One out of every ten smokers will die of a smoking-related sickness.
10. More germs get into your lungs when you smoke.

II. Multiple Choice Questions

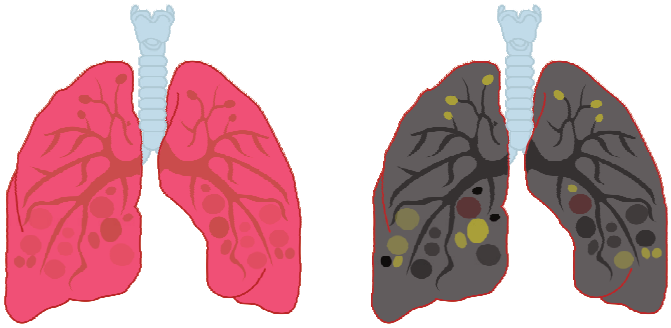
1. Smoking causes
   (a) Lung cancer (b) Heart disease
   (c) Respiratory disease (d) All of above
2. Atherosclerosis is a condition where,
   (a) Body needs more energy
   (b) Lungs get filled with mucus
   (c) Plaque clogs up the artery, disrupting the flow of blood around the body
   (d) Brain becomes dead
3. Chronic Obstructive lung disease occurs due to
   (a) Chronic bronchitis (b) Emphysema
   (c) None of these (d) Both of these

4. COPD stands for
   (a) Cuticular Obstetric Pelvic Disease
   (b) Critical Obstructive Pituarity Disorder
   (c) Chronic Obstructive Pulmonary Disease
   (d) Chronic Obesity Personal Decision
5. Emphysema is caused due to
   (a) Bursting of alveoli (b) A decrease in the surface area of gas exchange
   (c) Both A and B (d) None of above
6. Gas exchanging system cannot be damaged by
   (a) Carcinogens (b) CO
   (c) Nicotine (d) Any of these
7. The blood is not oxygenated well enough due to
   (a) Asthma (b) Emphysema
   (c) Chronic Bronchitis (d) All of above
8. Common causes of Chronic Obstructive Pulmonary Disease (COPD) does not include
   (a) Smoke from the factory furnace (b) Vehicle pollution
   (c) Industrial pollution (d) Water pollution
9. Chronic Obstructive Pulmonary Disease (COPD) does not include
   (a) Asthma (b) Chronic Bronchitis
   (c) Emphysema (d) Retinoblastoma
10. The smoker's cough is
   (a) A sign of recovery
   (b) An attempt to move the mucus up the airways
   (c) An attempt to move the air down the airways
   (d) A mixture of bacteria and BCs

III. Long Answer Type Questions

1. What are the dangerous components of tobacco smoke?
2. In your words, describe the effects of tar and carcinogens in tobacco smoke on the gas exchange system.
3. How can you control the use of tobacco in your society? Explain briefly.
4. Describe the signs and symptoms of lung cancer and chronic obstructive pulmonary diseases (COPD).

5. Describe the effects of nicotine and carbon monoxide on the cardiovascular system.
6. Explain how tobacco smoking contributes to atherosclerosis and coronary heart disease.
7. Interpret data linking cigarette smoking to disease and early death.
8. Comment on smoking gender disparities prevalent in the community. Also state the effect of smoking on a pregnant woman. How does it affect the infant?
9. Correlate smoking to behavioural economics and health behavioural changes. Support your answer with examples.
10. Differentiate between:
    (a) Emphysema and chronic bronchitis
    (b) Atherosclerosis and coronary heart disease
11. Look at the pictures and answer the questions that follow:



(A) (B)

(a) Which of these is healthier? (b) How is it different from the other one?

Unit 11

General Principles of Homeostasis

Key Unit Competence

To be able to explain general principles of homeostatic mechanisms.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- explain the significance of a constant internal environment.
- state the factors that must be kept constant in the internal environment of the body.
- carry out research on homeostasis and deduce the findings.
- appreciate the importance of maintaining a constant internal environment.
- relate organisms' ways of life to their environmental conditions.
- discuss the role of the negative feedback mechanism.
- explain the feedback mechanism in relation to the endocrine and nervous system.
- identify the main internal and external causes of change in the internal environment.
- describe the formation, composition and movement of tissue fluid in relation to blood and lymphs.
- appreciate the adaptations of animals to different environmental conditions in relation to homeostasis.

11.1 SIGNIFICANCE OF CONSTANT INTERNAL ENVIRONMENT

ACTIVITY 1

Have you ever thought about how your body maintains the same body temperature even if it is too hot or cold outside? Do you know about homeostasis and why it is required? Use library and Internet sources to collect information about homeostasis and various factors that must be kept constant in the human body. Learn, write and draw diagrams of homeostatic mechanisms and present your findings in the class.

All living organisms have an ability to maintain stable internal conditions. It requires continuous adjustments to the changes occuring in both internal and external environments. 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.

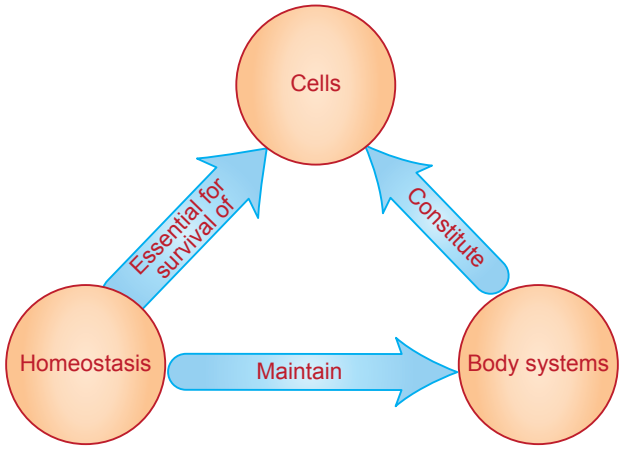


Figure 11.1: Homeostasis

A living body ensures stable internal conditions in order to survive, grow and develop. The homeostatic mechanisms are inevitable for proper functioning of the body. Many systems of the body operate together to maintain a steady state. The cells, tissues, and organs may perform very different functions; however, all the cells in the body are similar in their metabolic needs. Homeostasis continuously provides the necessary ingredients of survival, for example, oxygen and nutrients to cells and thus, to complete the body. The metabolic activities and cellular processes can continue even though the external environment fluctuates substantially. Therefore, the regulation of an optimal internal environment enables an organism to live in wider range of environmental conditions (Figure 11.1).

Automatic systems such as thermostats or air conditioners maintain constant internal (room) conditions.

11.1.1 Factors of Homeostasis to be Kept Constant in the Body

ACTIVITY 2

Have you ever read or heard about some persons having diabetes or high blood pressure. Do you know why such conditions occurred in these people while others have no problems? Discuss and find out the appropriate answers.

Note: Refer to negative feedback mechanism to learn about high blood pressure.

Homeostasis can be considered as dynamic equilibrium rather than a constant, unchanging state. The body mechanisms maintain various fluctuating physical and chemical variables within tolerable limits. These important variables include temperature, glucose, pH, water, ions, respiratory gases and osmotic pressure of body fluids among others.

Some principal homeostatic mechanisms in humans to be kept constant are as follows:

- 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.
- The human body constantly works to maintain a normal glucose level in blood. 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.
- 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.
- When high amount of salt and ions are present in the body, the kidneys produce concentrated urine. This process removes extra amount of salt and ions while conserving water, and return the body to normal metabolic range. In contrast, when the salt and ions concentration is low in the human body, kidneys produce dilute urine and conserve salt and ions.
- 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 fulfill 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.
- 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.

All the body systems in humans are interdependent and function invariably to keep fluctuating factors within tolerable limits.

11.1.2 Components of Homeostatic Mechanisms

All homeostatic control mechanisms have three interdependent components for regulation of any type of change or variable. 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/integration centre"**, the component that sets the range at which a variable is maintained. The control centre determines an appropriate response to the stimulus. The control centre then sends signals to an **effector,** which can be muscles, organs, or other structures that receive signals from the control centre. After receiving the signal, a change occurs to correct the deviation by opposing or enhancing the stimulus. This ongoing process continuously works to restore and maintain homeostasis. For example, in order to regulate body temperature, thermo-*receptors* are present in the skin which communicates information to the brain, the *control centre*. The control centre commands the *effectors* i.e., blood vessels and sweat glands to function accordingly (Figure 11.2).

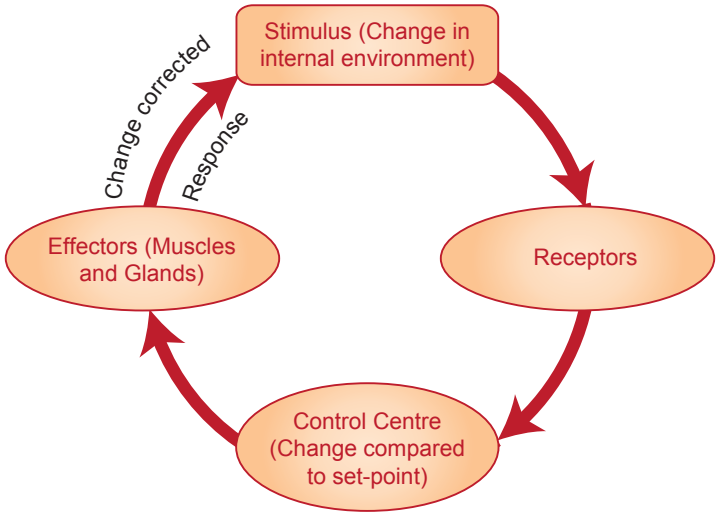


Figure 11.2: Components of homeostatic mechanisms

11.2 NEGATIVE AND POSITIVE FEEDBACK REGULATION

ACTIVITY 3

Have you ever thought how the body brings itself to the normal state after any change in its system/s? How the signal that brings any change in body is regulated either stopped or amplified? With the help of charts, discuss the feedback mechanism(s) and their role in maintaining homeostasis in the body.

Feedback regulation is a type of response to a stimulus which determines the effect of original stimulus. When a change of variable occurs, there are two main types of feedback mechanisms to which the system reacts: ***Negative feedback*** is a response in which the system functions in such a way as to reverse the direction of change. This response system tends to keep things constant allowing the maintenance of homeostasis. The regulations of body temperature, pH, ionic balance and blood pressure are the most common type of negative feedback systems. ***Positive feedback*** is the response to amplify the change in the variable. Blood clotting and events in childbirth are the types of positive feedback system. Both types of feedback mechanisms are equally important for the proper functioning of a body. If any or both these mechanisms are affected or altered somehow, it can lead to many complications.

11.2.1 Negative Feedback Mechanisms

Negative feedback consists of reducing the output or activity of any system or organ back to its normal range of functioning. This change either raises or lowers the variable to its normal set point automatically by counteracting. Here, negative means 'opposite, not bad'. This can be understood by the controlling process that regulates blood pressure. Blood pressure is the measure of the force of blood pushing against blood vessel walls. The heart pumps blood into the arteries (blood vessels), which carry the blood throughout the body. Whenever the blood pressure increases, the blood vessels can sense the resistance of blood flow against the walls. The blood vessels act as the receptors and relay the change to the brain. The brain acts as control centre and transmits the signal to the heart and blood vessels, both of which act as the effectors. The heart rate would decrease as the blood vessels increase in diameter, known as vasodilation. This change would cause the blood pressure to fall back to its normal range. The opposite would happen when blood pressure decreases, leading to vasoconstriction (decrease in diameter of blood vessel) (Figure 11.3).

Several factors/conditions interfere with the normal process of regulation of blood pressure. Smoking, obesity, high salt concentration in diet, alcohol consumption, stress, hormonal disorders affect the heart and blood vessels. This leads to high blood pressure or hypertension which causes the heart to work harder to pump blood in the body. This can further damage the heart, blood vessels and other organs.

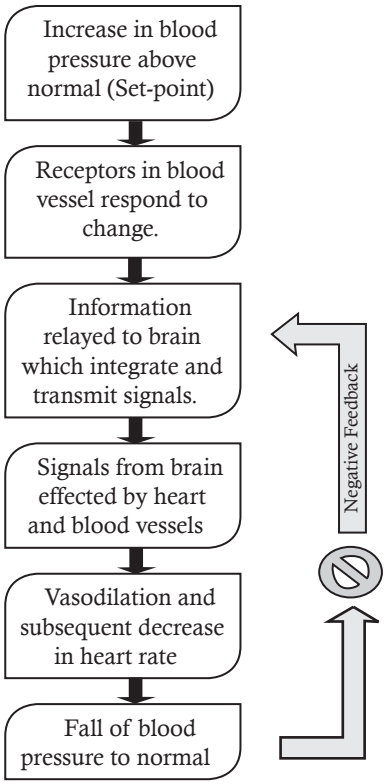


Figure 11.3: Negative feedback mechanism

Negative feedback mechanisms are most common in living organisms, working in a specific manner sequence.

11.2.2 Nervous and Endocrine Control Mechanisms

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 11.4 (a)).

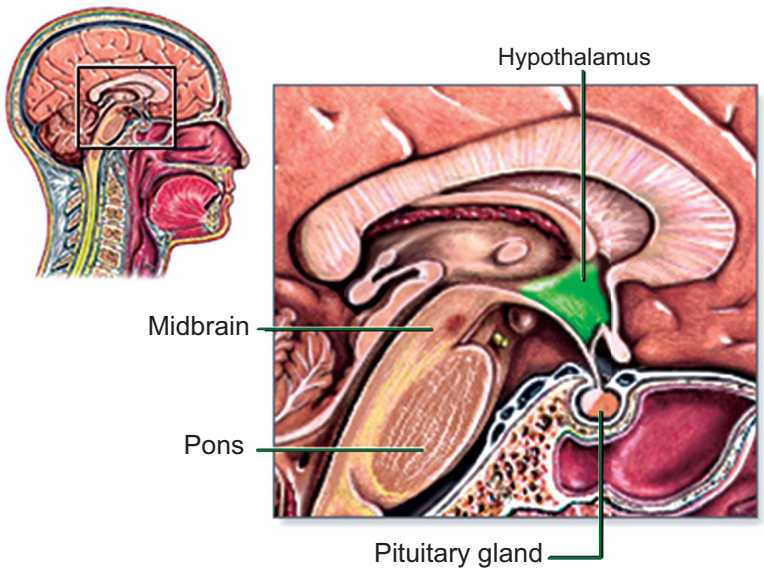


Figure 11.4: (a) Hypothalamus and Pituitary gland

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 11.4 (b)).

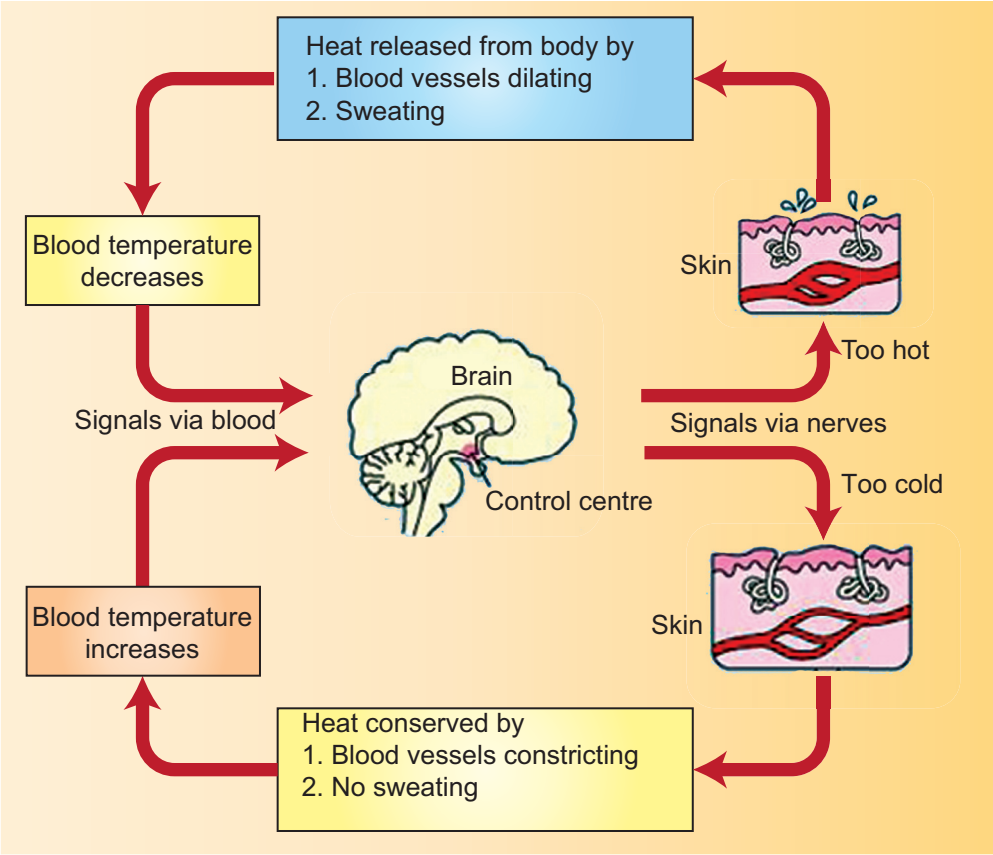


Figure 11.4: (b) Homeostatic regulation of body temperature

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 (Figure 11.5).

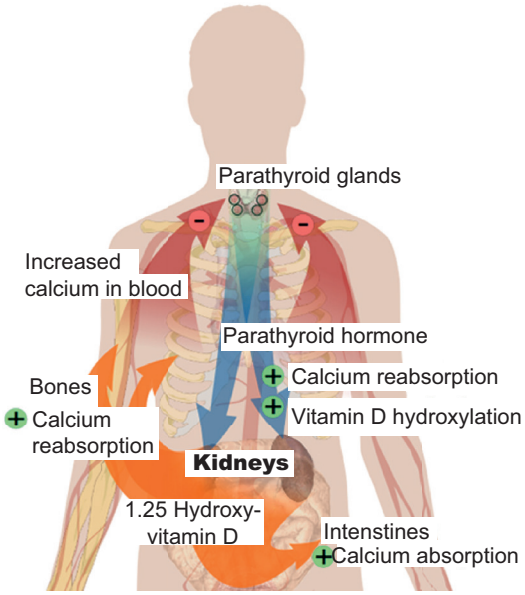


Figure 11.5: Calcium regulation

Both the nervous and endocrine system of the human body co-ordinate to ensure a balance between fluid gained and fluid loss. The **ADH** (Anti-diuretic Hormone) or **vasopressin** is the principal compound that controls water balance by decreasing water output by the kidney. Vasopressin is formed in the hypothalamus and get stored in the posterior pituitary (a part of endocrine system). If the body becomes fluid-deficient, osmoreceptors (monitor blood plasma osmolality) in the hypothalamus signals for the release of vasopressin from posterior pituitary. An increase in the secretion of vasopressin causes retention of fluid by the kidneys and subsequent reduction in urine output. Conversely, if fluid levels are excessive, release of vasopressin is suppressed resulting in less retention of fluid and resulting increase in the volume of urine produced.

SELF EVALUATION

Complete with appropriate terms:

(i) The tolerable pH level in human body ranges from ..... to ..... .

(ii) ..... provides necessary ingredients for survival.

(iii) Endocrine system consists of ..... which secretes hormones.

(iv) ..... is a response in which the system functions in a way to reverse the direction of change.

(v) ..... and ..... are mechanisms to maintain body temperature.

11.3 CAUSES OF CHANGES IN HOMEOSTASIS ENVIRONMENT

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.

11.3.1 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.

11.3.2 External Causes: Lifestyle

Nutrition: A diet lacking specific vitamin or mineral leads to 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 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.

11.3.3 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 the 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.

ACTIVITY 4

Aim: To observe and analyze the pressure flow of liquid coming out from the perforated rubber tubes.

Materials Required:

1. A rubber tube (1 cm width and 50 cm in length)
2. Two beakers
3. One bucket.

Procedure:

1. Take a rubber tube of about 1 cm width and 50 cm in length and make two set of tiny holes on at a distance of 10 cm before both ends.
2. Attach tube to a water tap tightly. Try to adjust the tubular part with holes towards downside so as to collect the liquid in beakers or trays.
3. At the other end, put a collecting vessel such as a bucket. Adjust the rubber tube in horizontal position and open the tap for 10-20 seconds and collect the water coming out of rubber holes in beakers placed under the holes in the tube.
4. Measure the collected liquid in two beakers separately by glass cylinders. Note the readings and compare the volume of water collected in the beakers.

Discussion:

1. Do you find any difference in volume of water collected in beakers?
2. Where do you think high and low pressure end on rubber tubes?
3. Does the high pressure end expel more water than low pressure end?

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 litres of interstitial fluid making 16% of the total body weight.

11.4.1 Formation

The formation of the tissue fluid is based on the difference in pressure of flowing (Starling's law) 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).

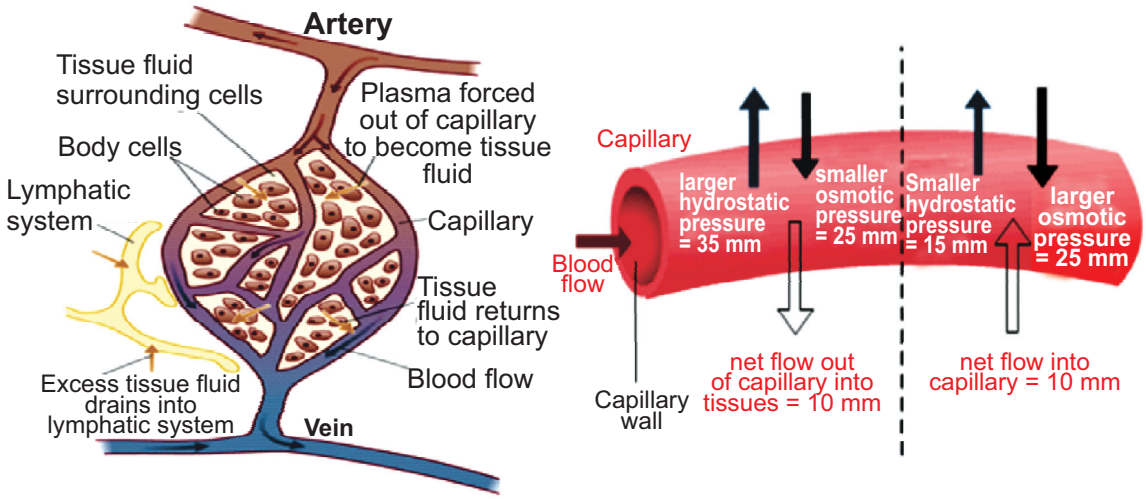


Figure 11.6: Formation of interstitial fluid from blood

11.4.2 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.

11.4.3 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.

The formation, composition and movement of tissue fluid are important processes for the development of immunity in the human body.

11.5 ADAPTATIONS OF ORGANISMS TO ENVIRONMENTAL CONDITIONS

ACTIVITY 5

A field trip to a zoo/wildlife sanctuary/national park can be organized under the guidance of a teacher. The students/learners should observe, understand and discuss the various environmental conditions in which animals live and survive. Different groups of animals which live on land, water and other places can be studied for the adaptations in their habitat. Learners should write their observations about the different features/characteristics of animals, timing of appearance, season, place/location as well as behaviour of different animals. A report should be submitted about the field trip describing the observations along with the diagrams/images/photographs taken and computer aided material.

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.

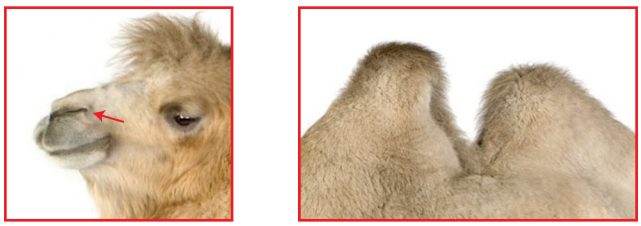
Different organisms have adapted to the great diversity of habitats and distinct conditions in the environment. Although, the adaptations are many and varied, they can be categorized into mainly three types: Structural, physiological and behavioural.

11.5.1 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 the 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 11.7: 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 11.8: Camel's adaptations in desert environment: (a) Nostrils and (b) Hump

Similarly, the long necks of giraffes allow them to feed among treetops and spot predators. Also, they have tough and long tongues (upto 18 inches) enabling to pull leaves from branches without being hurt by the thorns. Spotted coat camouflages giraffes among the trees.

In tropical areas, natural radiators are an efficient way of lowering the body's temperature: for instance, the ears of the elephant and the rabbit are full of blood vessels, helping the animal cool its body in the heat. Rabbits living in Arctic areas have smaller ears.

Figure 11.9: Giraffe

11.5.2 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. In contrast, Arctic fish (cold-blooded animals) lives easily in temperatures lower to sub-zero level. Such temperatures results in the formation of ice crystals in the organism's cells that may cause irreversible damage and ultimately, death. However, arctic fishes living in the same freezing waters survive due to an antifreeze protein in the blood that prevents ice crystals formation in their cells and maintains metabolic functions.

11.5.3 Behavioural Adaptations

Behavioural adaptations are learned 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.

SELF EVALUATION

Complete with appropriate terms:

(i) Micro organisms employ ..... to surpass hostile conditions for a long time.

(ii) ..... is a type of mammal having fins and a streamlined body.

(iii) ..... and ..... influences/tends to disturb homeostatic mechanisms.

(iv) RBCs, platelets and plasma cannot pass through ..... .

(v) ..... fishes have an antifreeze protein in the blood to prevent formation of ice crystals.

11.6 SUMMARY

- Homeostasis is the ability of a living body to maintain a relatively stable internal environment.
- Homeostasis is an important characteristic of living things requiring continuous adjustments due to the changes occurring in internal and external environment.
- Variables that must be kept constant and regulated to the normal level (set points) in a body are temperature, glucose, pH, water, ions, respiratory gases and osmotic pressure of body fluids.
- Homeostatic control mechanisms have three interdependent components: receptor, integration centre and effectors.
- Negative feedback occurs when the response to a stimulus reduces the original stimulus.
- Positive feedback occurs when the response to a stimulus increases the original stimulus.
- The nervous system controls the activities of body parts quickly to external and internal stimuli.
- The endocrine system regulates body activities slowly with long lasting effects.
- The hypothalamus is a part of brain and links the nervous system and endocrine system.
- The homeostatic mechanisms are altered or interrupted based on internal (genetic) and external (lifestyle choices and environmental exposures) factors.
- Interstitial/tissue fluid is formed from blood plasma and it surrounds and bathes the cells in tissue spaces.
- Tissue fluid provides nutrients and removes waste products from the cells of the body.
- Tissue fluid is formed due to the pressure difference in flow of the blood through the blood capillaries.
- Tissue fluid contains sugars, salts, fatty acids, amino acids, coenzymes, ions, hormones,

neurotransmitters, as well as metabolic waste products from the cells in a water medium.

- Tissue fluid moves from tissue spaces to lymph vessels (lymph), to lymph nodes and finally returns to the blood.
- Adaptation is a feature/characteristic of an animal which enables it to survive in its habitat.
- Different organisms have adapted to distinct habitats and environmental conditions.
- Three categories of adaptations are structural, physiological and behavioural. Each type of adaptation has its own survival value.

11.7 GLOSSARY

- **Adaptation:** A feature or characteristic of an organism which helps in its survival in a particular habitat.
- **Control centre or integration centre:** Receives and processes information from the receptor.
- **Effector:** Responds to the command of the control centre by either opposing or enhancing the change.
- **Homeostasis:** A balancing act which maintains a particular internal condition.
- **Receptor:** Receives information about a change in its environment.
- **Negative feedback:** A response system which reverses the direction of change.
- **Positive feedback:** A response system which amplifies the change in the variable.

11.8 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. A living body ensures stable internal conditions in order to survive, grow and develop.
2. The property of living beings to maintain a constant internal environment is termed as **'homeostasis'**.
3. Blood pressure is the measure of the force of blood pushing against blood vessel walls.
4. The endocrine system controls the activities of body parts by reacting quickly to external and internal stimuli.
5. Organisms living in various habitats need different adaptations in order to maintain homeostasis.
6. Behavioural adaptations are related to the working of an organism's metabolism.

7. The chemical messengers secreted from the endocrine system affect on specific target organs.
8. The thick fur layer on the skin of polar bears protects them from sunlight.
9. Whales migrating to oceanic waters can maintain a constant body temperature.
10. Colonial animals, if being separated, can survive easily in their habitats.
11. Camel's hump is an adaptation to store water in desert climate.

II. Multiple Choice Questions

1. An example of positive feedback mechanism is:
   (a) maintaining stable blood glucose levels
   (b) the production of milk in a nursing mother
   (c) maintaining a stable body temperature
   (d) all of the above
2. Which hormone increases the glucose level in the blood?
   (a) glucose (b) glucagon
   (c) insulin (d) glycogen
3. Which is the proper sequence of events in maintaining homeostasis?
   (a) Signal, Receptor, Stimulus, Response
   (b) Stimulus, Response, Signal, Receptor
   (c) Receptor, Stimulus, Signal, Response
   (d) Stimulus, Receptor, Signal, Response
4. Which is an example of negative feedback?
   (a) maintaining stable blood glucose levels
   (b) the production of milk in a nursing mother
   (c) contractions of the uterus during childbirth
   (d) all of the above
5. The principal systems controlling and regulating body activities are:
   (a) nervous and respiratory system (b) endocrine and digestive system
   (c) nervous and endocrine system (d) respiratory and digestive system
6. Which of the following statements best describes homeostasis?
   (a) keeping the body in a fixed and unaltered state
   (b) dynamic equilibrium

(c) maintaining a relatively constant internal environment
(d) altering the external environment to accommodate the body's needs

7. Tissue fluid is different from blood in terms of:
   (a) red blood cells (b) platelets
   (c) plasma proteins (d) all of the above
8. The human body's "thermostat" is found in:
   (a) nervous system (b) integumentary system
   (c) endocrine system (d) urinary system
9. Which statement is not correct about calcium homeostasis?
   (a) parathyroid hormone increases blood calcium level
   (b) calcitonin decreases calcium levels in blood
   (c) both hormones (PTH and calcitonin) are secreted by same gland
   (d) calcium regulation is an example of negative feedback mechanism
10. Which statement is correct about vasopressin?
   (a) an increase in secretion of vasopressin decreases fluid volume in the body
   (b) a decrease in secretion of vasopressin increases fluid volume in the body
   (c) an increase in secretion of vasopressin increases fluid volume in the body
   (d) none of the above

III. Long Answer Type Questions

1. Giving suitable examples, in your own words, explain the significance of a constant internal environment.
2. State the factors that must be kept constant in the internal environment of the body.
3. Discuss the role of the negative feedback mechanism.
4. Explain the feedback mechanism in relation to the endocrine and nervous system.
5. What are the main internal and external causes of change in the internal environment?
6. Describe the formation, composition and movement of tissue fluid in relation to blood and lymphs.
7. Giving examples, relate organisms' ways of life to their environmental conditions.
8. How do pollutants alter homeostasis of an organism? What role does homeostasis play in environmental protection?

Unit 12

Regulation of Glucose

Key Unit Competence

To be able to explain the mechanism of the regulation of blood glucose level.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

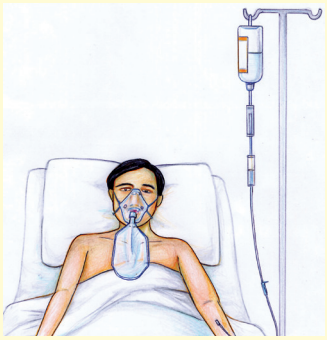
- describe the role of hormones in sugar regulation.
- describe the detailed structure of a liver lobule and the Islet of Langerhans.
- explain the negative feedback mechanism in the process of blood glucose control.
- discuss the causes and effects of blood sugar imbalances in the body.
- appreciate the importance of a controlled diet for diabetics.
- assist diabetics and people having hypertension in coping with their situation.
- relate the structure of the liver and the pancreas to their functions.
- relate the microstructure of the liver and the pancreas to sugar regulation.
- describe the functions of the liver and pancreas in the regulation of glucose in the body.
- describe the three main stages of cell signalling in control of blood glucose by adrenaline as follows:
  - hormone-receptor interaction at the cell surface.
  - formation of cyclic AMP that binds to kinase protein.
  - an enzyme cascade involving activation of enzymes by phosphorylation to amplify the signal.
- make research using internet or articles on the role of adrenaline in the control of blood sugar.
- explain the principles of the operation of dip sticks and biosensors for quantitative measurements of glucose in the blood and urine.
- explain how urine analysis is used in diagnosis with reference to glucose, protein and ketones.

12.1 IMPORTANCE OF GLUCOSE

ACTIVITY 1

Visit a nearby hospital to see the patients.

You will notice many patients lying on the bed with a bottle hanging from a stand by the side of their bed as shown in the picture.



Ask the doctor, what is inside the bottle and why is it given to the patients?

Record the answer.

Note: In the hospital, patients are generally given glucose by drip instead of food because, the drip directly deposits the glucose into the blood stream and hence the body cells get it in matter of minutes, but if it is given through food, the glucose's energy would reach the body parts only after the digestion process and this will take a longer time.

Glucose is one of the most important carbohydrates molecules in our body. Body requires glucose to carry out some of its most important functions. Glucose is synthesized in green plants, from carbon dioxide, CO_2 and water, H_2O with the help of energy from sunlight. This process is known as **photosynthesis**. The reverse of the photosynthesis reaction i.e., breakdown of glucose in the presence of oxygen to form carbon dioxide and water releasing the energy, is the main source of power for all the living organisms. The excess glucose in plants is stored in the form of starch which serves as foods for various animals.

12.1.1 Glucose as Energy Source

Almost 80 per cent of carbohydrates in our food are converted to glucose during digestion in the alimentary canal. Fructose and galactose is the other main product of carbohydrates digestion. After absorption from the alimentary tract, fructose and galactose are converted into glucose in the liver. And therefore, glucose constitutes more than 95 per cent of all the carbohydrates circulating in the blood.

Body cells require glucose continuously for its various metabolic activities. These cells directly absorbed glucose from the blood. Once inside the cells, glucose combines with a phosphate moiety to form **Glucose-6-phosphate** with the help of enzyme **glucokinase** in liver and **hexokinase** in most other cells. This phosphorylation reaction is irreversible and helps to retain the glucose

inside the cells. However, in liver cells, renal tubular epithelial cells and intestinal epithelial cells, an enzyme **glucose phosphatase** converts the glucose-6-phosphate back to glucose.

$$\text{Glucose + ATP} \underset{\text{Glucose phosphatase (liver, kidney and intestine)}}{\overset{\text{Glucokinase/Hexokinase}}{\rightleftharpoons}} \text{Glucose-6-phosphate + ADP}$$

Complete oxidation of one molecule of glucose into carbon dioxide and water inside the cells produce as many as **38 molecules of ATP** (2 from glycolysis, 2 from Krebs cycle and 34 from oxidative phosphorylation).

12.1.2 Glucose as Structural Component

As we discussed above, glucose is the main source of energy in all the living cells. Besides being regarded as the universal fuel, glucose also acts as the source of carbon for all the carbon containing compounds of the body. For example, ***ribose***, a pentose monosaccharides used in the synthesis of nucleotides and nucleic acids is synthesized from glucose through **Pentose Phosphate Pathway (PPP)**. Other important compounds include, **glycoprotein**, a protein with oligosaccharide chains (glycans) covalently attached to their polypeptide side chain; **proteoglycans**, a special class of glycoproteins which contain about 95% polysaccharide (glycosaminoglycans) and 5% protein and various other polysaccharides like cellulose, chitin, glycogen etc.

Glycoproteins are integral membrane proteins which play an important role in the cell-cell interactions. For example, antigen-antibody interaction in blood-type compatibility is mediated by glycoproteins which determine the blood type of the individual. Proteoglycans, on the other hand are major components of extracellular matrices.

12.1.3 Glycogen

Glycogen is a homopolymer of glucose in which each molecule is linked to each other by $1 \rightarrow 4$ glycosidic bond and branching through $1 \rightarrow 6$ linkages. It is synthesized in the liver cells. The process of biosynthesis of glycogen from glucose with the help of enzyme **glycogen synthase** is known as glycogenesis. In response to decrease in blood glucose concentration, glycogen breaks down to glucose-1-phosphate and glucose in the liver and muscle. This process is known as **glycogenolysis**. The enzyme **glycogen phosphorylase** removes the glucose residue sequentially from the glycogen to yield glucose-6-phosphate. Other enzymes, **glucan transferase** and **glucosidase** help in breaking the branch forming α $(1 \rightarrow 6)$ glycosidic

bonds of the glycogen molecule. The overall final product of the glycogenolysis is glucose-6-phosphate which is converted back to glucose by **glucose phosphatase** and release into the blood stream.

12.2 ROLE OF LIVER AND PANCREAS IN GLUCOSE REGULATION

ACTIVITY 2

Discuss functions of various organs of our body.

Note down the organ and its functions which helps in the regulation of blood glucose level.

Find the particular organ(s) which has/have the major role in glucose metabolism.

Our body maintains a narrow range of glucose concentration in the blood between 70 mg/dL to 130 mg/dL which may increase upto 180 mg/dL after a meal containing high amount of carbohydrates. The hormones responsible for the regulation of blood sugar level—insulin and glucagon are secreted by the pancreas. The excess glucose in our blood is converted into glycogen in the liver. Therefore, pancreas and liver play a vital role in the regulation of blood sugar concentration.

12.2.1 Role of Liver in Glucose Regulation

The liver is the largest internal solid organ in the body second to the skin as the largest organ overall. It performs various functions in our body, including synthesis and storage of proteins and fats, carbohydrates metabolism, formation and secretion of bile, detoxification and excretion of potentially harmful compounds. Liver contains two main cell types: Kupffer cells and Hepatocytes.

1. **Kupffer cells** are a type of macrophage that capture and break down old, worn out red blood cells passing through liver sinusoids.
2. **Hepatocytes** are cuboidal epithelial cells that line the sinusoids and make up the majority of cells in the liver. Hepatocytes perform most of the liver's functions—metabolism, storage, digestion, and bile production.

Hepatocytes cells contain various enzymes which help in the regulation of blood glucose. These are:

1. **Glycogen synthase**; responsible for glycogen biosynthesis (Glycogenesis). When the concentration of glucose in the blood increases beyond the normal value, the excess glucose is converted to glycogen in the liver with the help of enzyme glycogen synthase.
2. **Glycogen phosphorylase**; responsible for breaking down of glycogen (Glycogenolysis). When the blood glucose level drops, the enzyme glycogen phosphorylase convert glycogen to glucose-6-phosphate. Other two enzymes, glucan transferase and glucosidase also help in glycogenolysis.
3. **Glucose phosphatase**; responsible for conversion of glucose-6-phosphate to glucose in the liver. Glucose is then released into the blood stream, thereby increasing the blood glucose level.

12.2.2 Role of Pancreas in Glucose Regulation

Pancreas is the most important endocrine organ for the regulation of blood glucose. It secretes insulin and glucagon, the two main hormones responsible for the regulation of blood glucose.

1. **Insulin:** When the blood glucose concentration increases rapidly, for example after a meal with high carbohydrates content, pancreas secretes insulin hormone into the blood stream. Insulin binds to its receptors and increases the rate of glucose uptake, storage and utilization by almost all tissues of the body resulting in lowering of blood glucose level. Besides, insulin also stimulates glycogenesis, lipid and proteins biosynthesis which helps in decreasing blood glucose concentration.
2. **Glucagon:** In response to decrease in blood glucose concentration, pancreas secretes glucagon which activates the enzyme glycogen phosphorylase responsible for degradation of glycogen to glucose-6-phosphate. Glucose-6-phosphate is then dephosphorylated to form glucose and finally released into the blood stream thereby increasing the blood glucose level. Glucagon also stimulates gluconeogenesis i.e., biosynthesis of glucose from non-carbohydrate compounds like pyruvate and amino acids.

12.3 DETAILED STRUCTURE OF LIVER LOBULE AND ISLET OF LANGERHANS

ACTIVITY 3

Observe permanent slides of transverse section of liver and pancreas under the light microscope in low magnification followed by higher magnification.

Observe the liver lobules and islet of Langerhans and draw your observation on your record.

Discuss the structure and relate the observed structure with the function of liver and pancreas.

Note: Care should be taken while focussing the slide under the microscope. Focussing should be done starting from the lower magnification to avoid any unwanted damage to the lens.

12.3.1 Liver and Liver Lobules

The liver is a roughly triangular in shape and extends across the entire abdominal cavity under the diaphragm. Most of the liver's mass is located on the right hypochondrium (i.e., upper part of the abdomen) as well as part of the abdomen (Figure 12.3). The liver is made of very soft, pinkish-brown tissues encapsulated by a connective tissue capsule. This capsule is further covered and reinforced by the peritoneum of the abdominal cavity, which protects and holds the liver.

The liver consists of 4 distinct lobes—the left, right, caudate, and quadrate lobes. The Falciform ligament divides the liver into two main lobes, right and left. The larger right lobe is again sub-divided into three lobes, the right lobe proper, the caudate lobe and the quadrate lobe (Figure 12.1). Each liver lobe is made up of about 100,000 small hexagonal functional units known as lobules. A typical liver lobule comprises rows of liver cells, hepatocytes, radiating out from a central vein. The six angles of the hexagon are occupied by a portal triad comprising a hepatic portal vein, a hepatic artery and a bile duct. The portal veins and arteries are connected to the central vein through a network of capillary-like tubes called sinusoids (Figure 12.2). Blood flows out of the sinusoids into the central vein and is transported out of the liver.

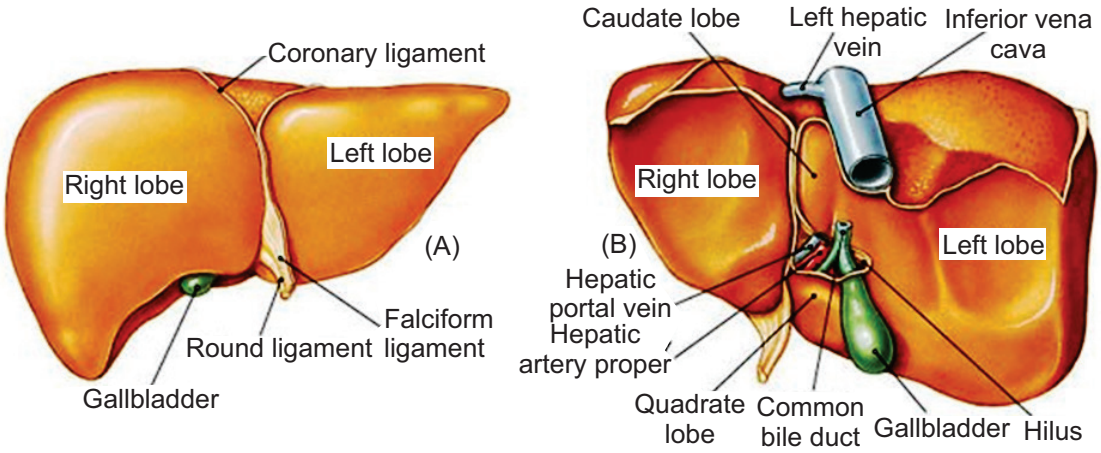


Figure 12.1: Anatomy of Liver—(A) Anterior view (B) Posterior view

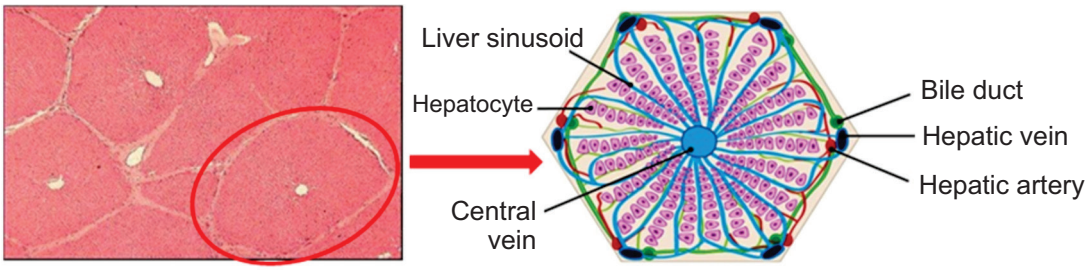


Figure 12.2: Transverse section of Liver showing liver lobules and diagrammatic representation of a typical liver lobule

12.3.2 Pancreas

The pancreas is an elongated, tapered organ, located in the abdominal region, behind the stomach and next to the duodenum—the first part of the small intestine (Figure 12.3). The right side of the organ, called the head, is the widest part of the organ and lies in the curve of the duodenum. The tapered left side which extends slightly upward is the body of the pancreas. The tail of the pancreas ends near the spleen.

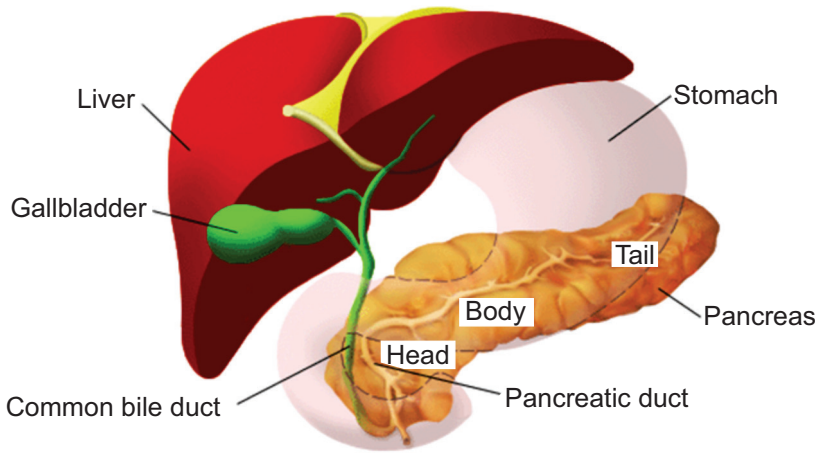


Figure 12.3: Diagrammatic representation of the location of pancreas and liver in the body

Structure and Function of Pancreas

Pancreas has two main functional components:

1. **The Exocrine cells, the acini**—Cells that release digestive enzymes into the gut via the pancreatic duct. These enzymes include trypsin and chymotrypsin to digest proteins; amylase for the digestion of carbohydrates; and lipase to break down fats. The pancreatic duct joins the common bile duct to form the **ampulla of Vater** in the duodenum. The pancreatic juices and bile (from gallbladder) released into the duodenum help the body to digest fats, carbohydrates as well as proteins.
2. **The Endocrine pancreas**—Highly vascularized groups of cells known as the **Islets of Langerhans** within the exocrine tissue constitute the endocrine pancreas (Figure 12.4). The human pancreas has 1–2 millions islets of Langerhans. It contains four different types of cells which are distinguished from one another by their morphology and staining characteristics;
   (i) **Alpha cells:** Which secrete **glucagon**, constitute about 25 per cent of all the cells of islet of langerhans.
   (ii) **Beta cells:** The most abundant of the islet cells constitute about 60% of the cells. They release **insulin** and **amylin** hormones with unknown function, secreted in parallel to the insulin.
   (iii) **Delta cells:** Constitute about 10 per cent of total cells and secrete **somatostatin** which regulates both the alpha and beta cells.

(iv) **F cells or PP cells:** Are present in small number and secrete a polypeptide known as **pancreatic polypeptide** which inhibits the digestive enzymes produced by the exocrine pancreas.

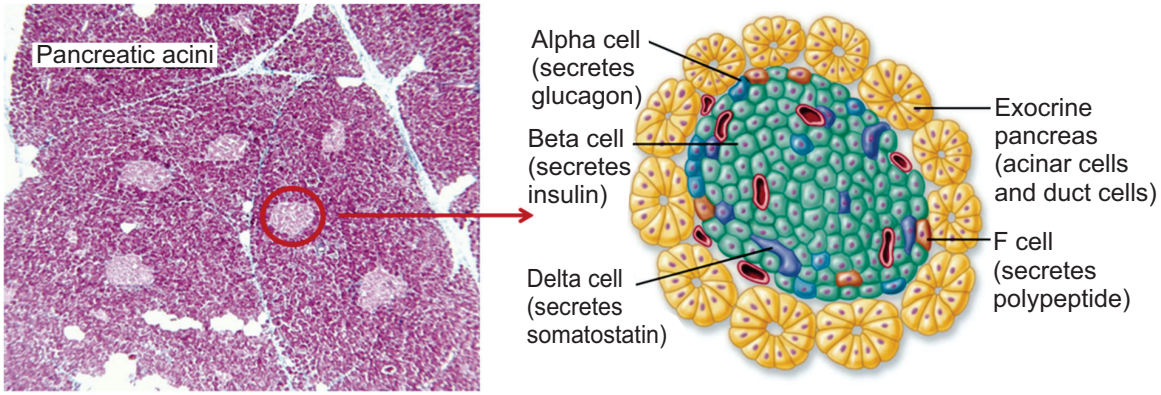


Figure 12.4: Transverse section of Pancreas showing the acini and Islet of Langerhans and Diagrammatic representation of an Islet of Langerhans

SELF EVALUATION

Complete the sentence with appropriate terms:

(i)..... is a homopolymer of glucose synthesized in liver cells.

(ii) Complete oxidation of one molecule of glucose yields ..... molecules of ATP.

(iii) The liver consists of four distinct lobes ....., ..., ..., and ..... .

(iv) The endocrine pancreas consists of highly vascularized groups of cells called ..... .

12.4 HOMEOSTATIC CONTROL OF BLOOD GLUCOSE CONCENTRATION BY INSULIN AND GLUCAGON

ACTIVITY 4

Discuss the mechanism of glucose regulation. Prepare a PowerPoint presentation using internet available resources. Show your presentation to the class.

Insulin and glucagon are the major hormones responsible for the regulation of blood glucose. Both insulin and glucagon are secreted by the pancreas, and are referred to as pancreatic endocrine hormones.

12.4.1 Insulin

Insulin was first discovered in 1922 by Banting and Best. Although there is always a low level of insulin secreted by beta cells of pancreas, the amount secreted into the blood increases as the blood glucose level rises. In the blood, it circulates entirely in an unbound form with plasma half-life of about 6 minutes. Only a small portion of the insulin binds with the insulin receptors of the target cells while the rest is degraded by the enzyme insulinase, mainly in liver and to a lesser extends in kidney and muscles.

Function of Insulin

Binding of insulin to the receptors stimulates the rate of glucose uptake, storage and utilization by almost all tissues of the body mainly in muscles, adipose tissue and liver. Other important functions of insulin include:

1. Insulin promotes glycogenesis by activating enzyme glycogen synthase.
2. Insulin inactivates liver phosphorylase, the key enzyme of glycogenolysis.
3. Insulin promotes lipid synthesis by increasing the conversion of excess glucose into fatty acids in the liver. These fatty acids are transported as triglycerides to the adipose tissue where it is deposited as fat.
4. Insulin inhibits the enzymes responsible for gluconeogenesis in liver.
5. Insulin promotes protein synthesis by increasing the rate of transcription and translation. It also stimulates transport of many amino acids into the cells.
6. Insulin inhibits breakdown of lipids and proteins.

Regulation of Insulin Secretion

The secretion of insulin by beta cells of islet of Langerhans depends on the following factors:

1. **Blood glucose level:** Increased in the blood glucose level stimulates the insulin secretion while decreased in the blood glucose concentration inhibits the secretion.
2. **Blood fatty acids and amino acids concentration:** Insulin secretion is also stimulated by increased in the concentration of blood's fatty acids and amino acids concentration and inhibited when its concentration decreased.
3. **Gastrointestinal hormones:** Insulin secretion increases moderately in response to several gastrointestinal hormones—gastrin, secretin, cholecystokinin and gastric inhibitory peptide.

These hormones are released after the person takes meal and the increased in insulin secretion can be regarded as preparation for the glucose and amino acids uptake by cells.

4. **Other hormones:** Other hormones that are associated with the increase in the insulin secretion are glucagon, growth hormone, cortisol, progesterone and estrogen.

12.4.2 Glucagon

Glucagon is secreted by the alpha cells of the pancreatic islets in response to low blood glucose levels and to events whereby the body needs additional glucose, such as in response to vigorous exercise.

Functions of Glucagon

The effect of glucagon in regulating blood glucose level is exactly opposite to insulin.

1. The most important function of glucagon is activation of glycogen phosphorylase enzyme responsible for degradation of glycogen to glucose-6-phosphates. The glucose-6-phosphate is then dephosphorylated to glucose and finally released into the blood stream resulting in increase in blood glucose concentration.
2. Glucagon also stimulates the increase in rate of amino acid uptake and its conversion into glucose, i.e., gluconeogenesis.
3. Glucagon activates adipose cell lipase enzyme which stimulates lipids metabolism.
4. Glucagon also inhibits the storage of triglycerides in the liver by preventing the liver from removing fatty acids from the blood.
5. Glucagon also enhances the strength of the heart; increases blood flow in some tissues, especially the kidneys; enhances bile secretion; and inhibits gastric acid secretion.

Regulation of Glucagon Secretion

Glucagon secretion increases with the decrease in the concentration of blood glucose level while the increasing concentration of glucose inhibits its secretion. Other factors which stimulate glucagon secretion are, increase in the concentration of amino acids in blood and vigorous physical exercise.

12.4.3 Negative Feedback Mechanism

Negative feedback is an important regulatory mechanism for physiological function in all living cells. It occurs when a reaction is inhibited by increased concentration of the product. Regulation of blood glucose level is an excellent example of homeostatic control through negative feedback mechanism (Figure 12.5).

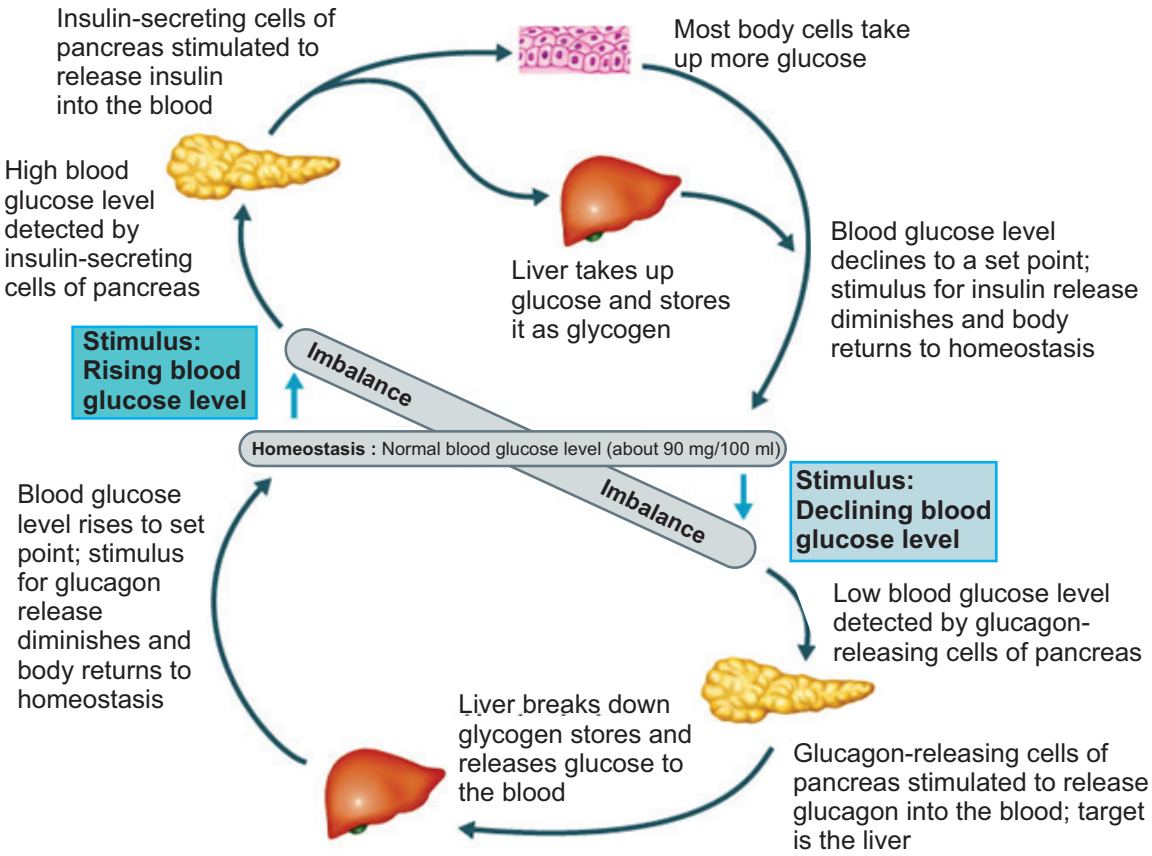


Figure 12.5: Negative feedback regulation of blood glucose level by insulin and glucagon

Response to an Increase in Blood Glucose

When there is increase in blood glucose level, the beta cells of the pancreatic islets of langerhans increase the release of insulin into the blood. Insulin binds to receptors on the cell membrane and stimulates the cells to increase glucose absorption. This led to a decrease in blood glucose level. Besides, insulin also stimulates glycogenesis and glycolysis while inhibiting glycogenolysis, gluconeogenesis, lipolysis etc. which all contributes in reducing blood glucose levels.

Response to a Decrease in Blood Glucose

Decreased in blood glucose level stimulates the alpha cells of pancreas islets to increase the secretion of glucagon. Glucagon activates enzyme glycogen phosphorylase in the liver and muscle cells which start glycogenolysis. It also promotes gluconeogenesis, lipid metabolism etc. The overall effect of glucagon is an increase in the concentration of blood glucose.

12.5 INTERACTION OF GLUCOSE CONTROL MECHANISMS BY OTHER HORMONES

ACTIVITY 5

Using the internet, find research papers on the role of adrenaline in regulating blood glucose level.

Make a PowerPoint presentation of the research paper.

Show the presentation to the class.

12.5.1 Hormones Involved in Glucose Regulation

Other than insulin and glucagon, there are many hormones which contribute to the regulation of blood glucose level (Figure 12.6). They are:

1. **Somatostatin:** It is secreted by delta cells of pancreatic islet of langerhans in response to many factors related to ingestion of food like increased concentration of glucose, amino acids, fatty acids and several gastrointestinal hormones released from the upper gastrointestinal tract. Somatostatin acts locally within the islets of Langerhans and inhibits the secretion of both insulin and glucagon. It also reduces the motility of the stomach, duodenum, and gallbladder and decreases the secretion and absorption in the gastrointestinal tract. Hence, lowers overall blood glucose level.
2. **Epinephrine:** Commonly known as Adrenaline, it is secreted by the medulla of the adrenal glands in response to strong emotions such as fear or anger. It causes increases in the heart rate, muscle strength, blood pressure and sugar metabolism. In response, it enhances the process of glycogenolysis, increasing the overall blood glucose concentration.
3. **Cortisol:** It is also known as stress hormone and is secreted by the adrenal cortex of the adrenal gland in response to stress. Cortisol enhances gluconeogenesis and increases the concentration of glucose in the blood.
4. **Adrenocorticotropic Hormone (ACTH):** In response to various stresses, hypothalamus secretes corticotropin-releasing hormone which stimulates anterior pituitary to secrete ACTH. It stimulates the the adrenal cortex to release the cortisol hormones.

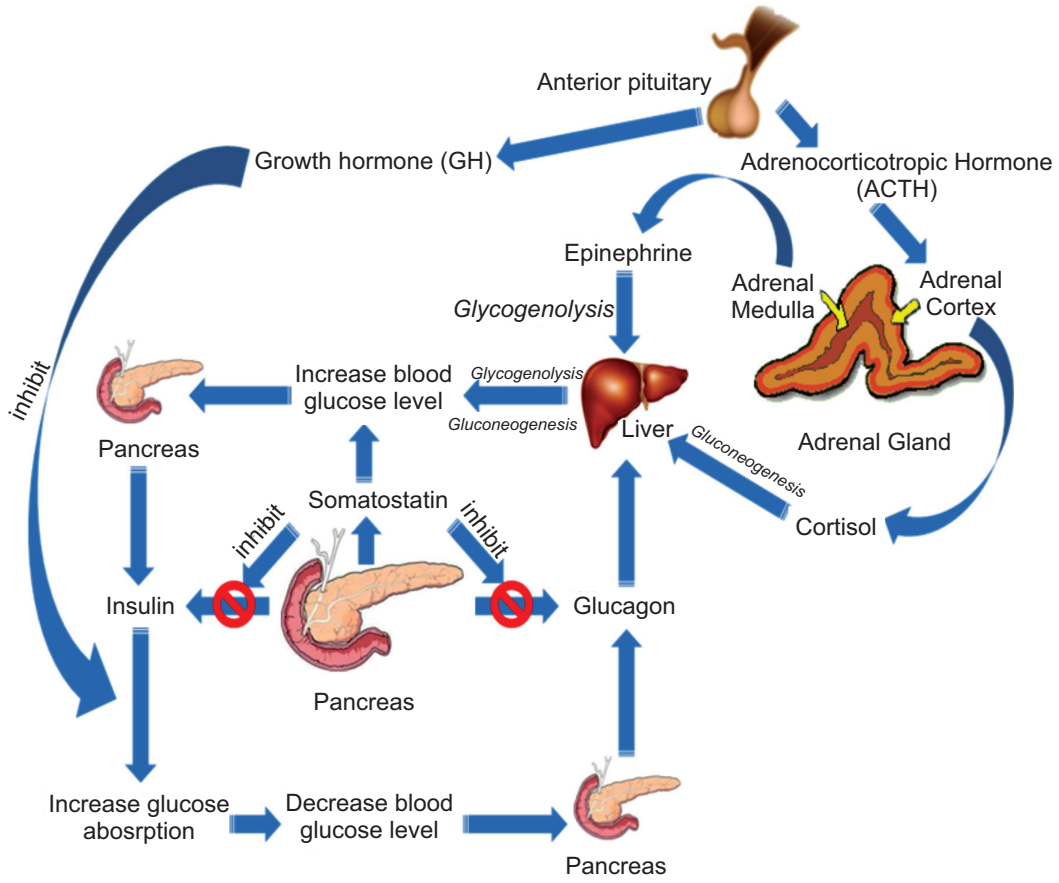


Figure 12.6: Hormonal regulation of blood glucose level

5. **Growth hormone (GH):** It is another anterior pituitary hormone which antagonizes the action of insulin by inhibiting the glucose uptake by cells and increasing the blood glucose level.
6. **Gastrointestinal hormones:** The hormones released by gastrointestinal tract such as gastrin, secretin, cholecystokinin and gastric inhibitory peptide etc. increase the digestion and absorption of nutrients in the gastrointestinal tracts. These hormones stimulate the pancreas to secrete insulin in anticipation of the increase in blood glucose level.

12.5.2 Mechanism of Hormonal Regulation

Our body maintains certain variables like temperature, pH etc. within a safe range so that it does not cause any harm to the body and the internal environment remains stable and relatively constant. This is known as **homeostasis**. Hormones are chemical messenger that are directly released into the blood stream. They play a very important role in maintaining the homeostasis.

Steps of Hormonal Signalling

Hormonal signal transduction is a complex process which involves the following steps:

1. Hormones are the first synthesis in particular cells of an organ and stored for secretion in response to certain stimulus.
2. When the organ receives the stimulus; hormones are secreted directly into the blood stream.
3. Blood carries the hormone to the target cell(s).
4. The hormone is recognized by the specific receptor in the cell membrane or by the intracellular receptor protein.
5. The hormonal signal is relayed and amplified through a series of signal transduction process in the target cells which lead to cellular response.

Cell Signalling Mechanism Involves in Glucose Regulation—Glycogenolysis

As mentioned earlier, several hormones affect glycogenolysis. Among these, glucagon and epinephrine are the most important hormones which trigger the breakdown of glycogen. Epinephrine is released in response to rigorous muscular activity from the adrenal medulla and stimulates the breakdown of glycogen in muscle to a larger extent than in the liver. The liver cells are more responsive towards glucagon. Both epinephrine and glucagon can bind to common receptor and through a series of other enzymes; activate the enzyme glycogen phosphorylase necessary to initiate glycogenolysis.

The whole process of signal transduction epinephrine and glucagon can be divided into three main steps (Figure 12.7).

1. **Hormone-receptor interaction at the cell surface**

   The hormone epinephrine and glucagon act as a ligand and bind to specific receptors known as 7TM, found in the plasma membranes of muscle and liver cells. The binding activate the alpha-subunit of the Gs protein.

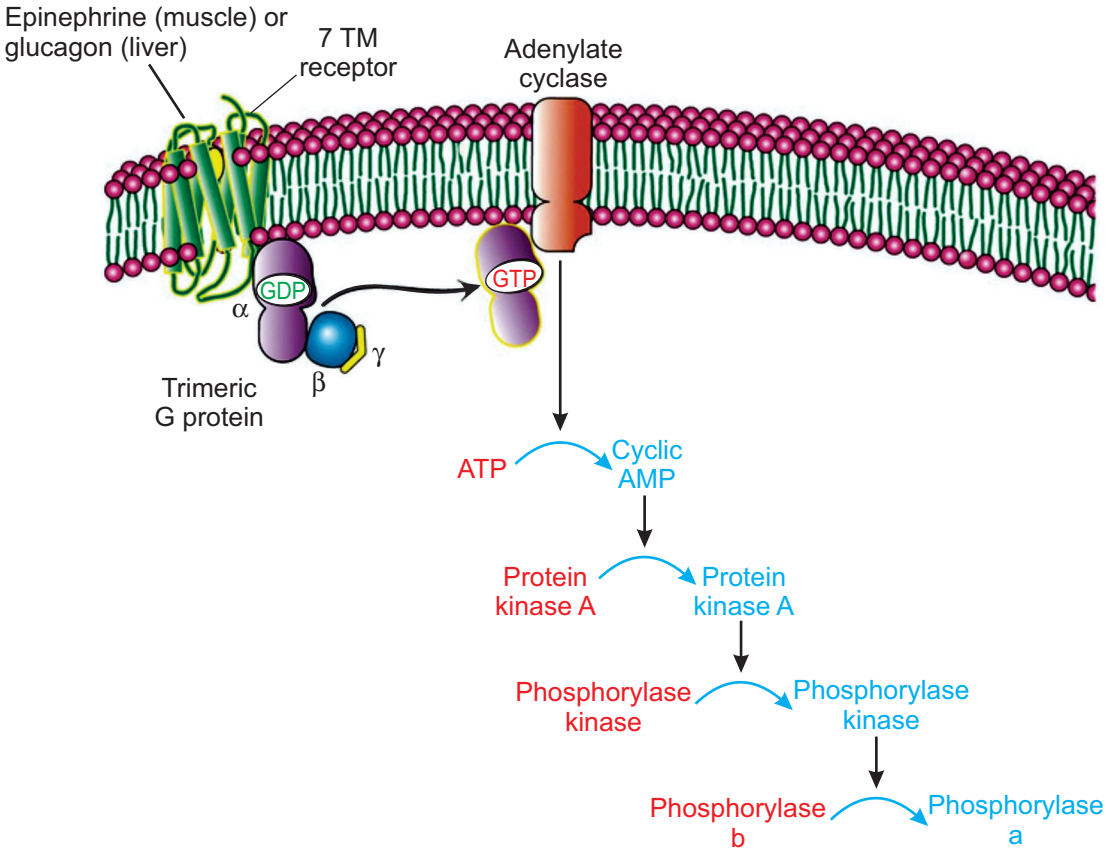


Figure 12.7: Hormonal signal transduction pathway in the activation of glycogen phosphorylase enzyme during glycogenolysis

2. **Formation of cyclic AMP that binds to kinase protein**

   The activated alpha-subunits of Gs protein activate the adenylate cyclase, a transmembrane protein. Adenylate cyclase catalyzes the formation cyclic AMP (cAMP) which acts as the second messenger in the signal transduction pathways.

3. **Activation of an enzyme cascade by phosphorylation and amplification of the signal**

   As level of cyclic AMP increases in the cytoplasm, it binds to the regulatory subunits of protein kinase A and activates protein kinase A. The activated protein kinase A phosphorylates and activates another enzyme phosphorylase kinase which finally activates glycogen phosphorylase and initiates the glycogenolysis.

Once activated, cyclic AMP cascade can highly amplify the effects of hormones through the number of enzymes. Therefore, binding of a small number of hormone to cell-surface receptors can lead to the release of a very large number of sugar molecules.

SELF EVALUATION

Complete with appropriate terms:

(i) Insulin was first discovered in 1922 by ..... .

(ii) Glucagen is secreted by ..... cells of pancreatic islets.

(iii) Epinephrine commonly known as ..... .

(iv) Hormone ..... enhances glycogenolysis and increases concentration of glucose in the blood.

(v) ..... catalyzes the formation of cycle AMP.

(vi) ..... activates glucagon phosphorylase and initiates the glycogenolysis.

12.6 CAUSE OF BLOOD SUGAR IMBALANCES IN THE BODY

ACTIVITY 6

Draw the diagram of the negative feedback mechanism of glucose regulation on the chart paper.

Illustrate the effect of various hormones on each step.

Highlight the important steps which can cause or affect the blood sugar balance.

Our body obtains glucose from various food sources or synthesis in the liver and muscles from other compounds like pyruvate, lactate, glycerol, and glucogenic amino acids. The blood carries glucose to all the cells in the body where it is metabolized to produce energy.

Blood sugar levels keep on fluctuating throughout the day increasing after meals and decreasing in between the meals. When the blood glucose level rises beyond the normal value, the condition is known as **hyperglycaemia**. On the other hand, hypoglycaemia or low blood sugar is the condition in which the blood glucose level is below normal (~70 mg/dL).

12.6.1 Hyperglycaemia

High blood glucose level can be caused due to various reasons like:

1. **Carbohydrates:** Eating food containing too much carbohydrates. The body of a person cannot process high levels of carbohydrates fast enough to convert it into energy.
2. **Insulin control:** The pancreas of the individual are unable to produce enough insulin.
3. **Stress:** Stress stimulates the secretion of certain hormones like cortisol and epinephrine etc., which increases the blood glucose level.

4. **Low levels of exercise:** Daily exercise is a critical contributor to regulating blood sugar levels.
5. **Infection, illness, or surgery:** With illness, blood sugar levels tend to rise quickly over several hours.
6. **Other medications:** Certain drugs, especially steroids, can affect blood sugar levels.

A high blood sugar level can be a symptom of diabetes. If hyperglycaemia persists for several hours, it can lead to dehydration. Other symptoms of hyperglycaemia include dry mouth, thirst, frequent urination, blurry vision, dry, itchy skin, fatigue or drowsiness, weight loss, increased appetite, difficulty breathing, dizziness upon standing, rapid weight loss, increased drowsiness and confusion, unconsciousness or coma.

12.6.2 Hypoglycemia

Hypoglycaemia is generally defined as a serum glucose level below 70 mg/dL. Symptoms typically appear when the blood glucose levels reaches below 60 mg/dL and levels below 50 mg/dL can be fatal.

Common causes of low blood sugar include the following:

1. Overmedication with insulin or antidiabetic pills
2. Use of alcohol
3. Skipped meals
4. Severe infection
5. Adrenal insufficiency
6. Kidney failure
7. Liver failure, etc.

Common symptoms of hypoglycemia include trembling, clammy skin, palpitations (pounding or fast heart beats), anxiety, sweating, hunger, and irritability. If the brain remains deprived of glucose for longer period, a later set of symptoms can follows like difficulty in thinking, confusion, headache, seizures, and coma. And ultimately, after significant coma or loss of consciousness, death can occur.

12.7 DIABETES MELLITUS

ACTIVITY 7

Using the internet, study the different symptoms and causes of diabetes mellitus.
Prepare a PowerPoint presentation and present to the class.

Diabetes mellitus (commonly referred to as diabetes) is a chronic condition associated with abnormally high levels of sugar in the blood due to impaired carbohydrate, fat, and protein metabolism. It can be due to absence or insufficient production of insulin by the pancreas, or inability of the body to properly use insulin. Hence, there are two types of diabetes mellitus – **Type I** causes by lack of insulin secretion and **Type II**, caused by reduced sensitivity of target cells to insulin.

12.7.1 Type I Diabetes

It is known as insulin dependent diabetes mellitus (IDDM) and cause due to insufficient insulin production by the beta cells of pancreatic islet of langerhans or due to absence of the beta cells itself. Since the pancreas makes very little or no insulin at all, glucose cannot get into the body's cells and remain in the blood leading to hyperglycemia. The concentration of blood glucose level can be as high as 300 – 1,200 mg/dL. The symptoms of Type I diabetes includes:

1. **Loss of glucose in urine**; due to increase in blood glucose, concentration goes beyond 180 mg/dL.
2. **Dehydration**; due to osmotic loss of water from cells and inability to reabsorb water in kidney.
3. **Tissue injury**; due to damages blood vessels in many tissues.
4. **Metabolic** acidosis; due to increased fat metabolism.
5. **Depletion of body's protein**; due to increase protein metabolism.

Treatment of Type I Diabetes

Persons with Type I diabetes require treatment to keep blood sugar levels within a target range which includes:

1. Taking insulin from external source everyday either through injections or using an insulin pump.
2. Monitoring blood sugar levels several times a day.
3. Eating a healthy diet that spreads carbohydrates throughout the day.
4. Regular physical activity or exercise. Exercise helps the body to use insulin more efficiently. It may also lower your risk for heart and blood vessel disease.
5. Not smoking.
6. Not drinking alcohol if you are at risk for periods of low blood sugar.

12.7.2 Type II Diabetes

Also known as **non-insulin dependent diabetes mellitus (NIDDM)**, it is caused due to the inability of cells to take up glucose from the blood. It can be either due to defective insulin receptors over cell surfaces or abnormality of blood plasma protein, amylin. Due to decrease

sensitivity of cells to insulin, a condition known as **insulin resistance**, the beta cells secrete large amount of insulin into the blood stream resulting in increase concentration of insulin in blood. This condition is known as **hyperinsulinemia**. Type II diabetes are more common and account for almost 80–90 per cent of the total diabetes mellitus cases.

The symptoms of type II diabetes include:

1. **Obesity**, especially accumulation of abdominal fat;
2. **Fasting hyperglycemia;**
3. **Lipid abnormalities** such as increased blood triglycerides and decreased blood high-density lipoprotein-cholesterol; and
4. **Hypertension.**

Treatment of Type II Diabetes

There's no cure for diabetes, so the treatment aims to keep the blood glucose levels as normal as possible and to control the symptoms and prevent health problems developing later in life. In type II diabetes, the pancreas is still working but our body develops insulin resistance and is unable to effectively convert glucose into energy leaving too much glucose in the blood. Therefore, Type II diabetes can be managed through lifestyle modification including:

1. Healthy diet as eating well helps manage our blood glucose levels and body weight.
2. Regular exercise helps the insulin work more effectively, lowers your blood pressure and reduces the risk of heart disease.
3. Regular monitoring of blood glucose levels to test whether the treatment being followed is adequately controlling blood glucose levels or we need to adjust the treatment.

12.7.3 Importance of Controlled Diet in Diabetes

Controlled diet is very important for diabetic patients because blood sugar is mostly affected by the food one eats. The glycaemic index of a food measures how the food affects the blood glucose level. The higher the **glycemic index** of the food, the greater the potential of increasing blood glucose. Therefore, in order to control glucose levels in the blood, it is important that diabetic primarily chooses low glycaemic index carbohydrates like dried beans and legumes such as lentils and pintos, non-starchy vegetables, fruits, whole grain bread and cereals, sweet potatoes etc. Foods like white bread, white rice, cornflakes, white potatoes, popcorn, pineapple, and melons are high glycaemic index foods and should be eaten moderately.

Because people with diabetes are at risk of high blood pressure, it makes sense to also choose foods that are heart healthy (i.e., lean, low-fat) and the ones that are low in salt. Increasing the amount of fibre in diet and reducing fat intake, particularly saturated fat, can help prevent diabetes or manage the diabetic condition from developing any complications. Therefore, one should:

1. Increase the consumption of high-fibre foods, such as wholegrain bread and cereals, beans and lentils, and fruits and vegetables.
2. Choose foods that are low in fat for example, replace butter, ghee and coconut oil with low-fat spreads and vegetable oil.
3. Choose skimmed and semi-skimmed milk, and low-fat yoghurts.
4. Eat fish and lean meat rather than fatty or processed meat, such as sausages and burgers.
5. Grill, bake, poach or steam food instead of frying or roasting it.
6. Avoid high-fat foods, such as mayonnaise, chips, crisps, pasties, poppadoms and samosas.
7. Eat fruit, unsalted nuts and low-fat yoghurts as snacks instead of cakes, biscuits, bombay mix or crisps etc.

12.7.4 Coping with Situation of Diabetics and Hypertension

Blood pressure is the measure of the force of blood pushing against blood vessel walls. The heart pumps blood into the arteries, which carry the blood throughout the body. The normal plod pressure is less than 120 (systolic) over 80 (diastolic). High blood pressure, also called **hypertension**, is dangerous because it makes the heart work harder to pump blood out to the body and contributes to hardening of the arteries, or **atherosclerosis**, to stroke, kidney disease, and to the development of heart failure. Diabetics are more likely to develop high blood pressure and other heart and circulation related problems, because diabetes damages arteries and makes them targets for hardening (atherosclerosis). Obesity is another main factor which is responsible for hypertension.

When it comes to preventing diabetes complications, normal blood pressure is as important as good control of blood glucose levels. Therefore, to treat and help prevent high blood pressure, one should control their blood glucose, stop smoking, eat healthy, maintain a healthy body weight, limit alcohol and salt consumption and exercise regularly.

Assisting Hypertension Patients

The following first aid tips are recommended when a person experiences hypertension:

1. Make the patient to lie on the bed and rest adequately. Tell the patient to take deep breaths and reassure them.
2. Do not allow them to walk about, accompany the patient if it is really needed.
3. If the patient is in a stressful situation, try to comfort and reduce anxiety, as anxiety alone can increase blood pressure.
4. If the patient is vomiting or having seizures, turn to lateral side to prevent aspiration.
5. Keep monitoring breathing, pulse rate, blood pressure, level of consciousness and for any other dangerous signs (e.g., paralysis of body in stroke, convulsions, etc.)
6. Do not give anything by mouth to eat/drink if there is suspicion of stroke.

7. If the patient's nose is bleeding, administer appropriate first aid.
8. Give drinks that are high in potassium to help balance the amount of sodium (salt) in the body to lower blood pressure levels.

12.8 MONITORING OF BLOOD GLUCOSE LEVELS

ACTIVITY 8

Aim: To perform blood glucose quantification test.

Materials Required:

1. Glucose meter
2. Test strips
3. Lancets (small needles used to prick the skin) and lancet device that holds the lancet.

Procedure:

1. Wash your hands with soap and water and dry them properly.
2. Prepare the blood glucose meter with the test strip according to the manufacturer's instructions.
3. Use the lancet device to prick the side of your fingertip with a lancet.
4. Place a drop of blood onto the correct part of the test strip.
5. The strip will draw up the blood into the meter and show a digital reading of the blood glucose level within seconds.
6. Note the reading.
7. Use a clean cotton ball to apply pressure to the fingertip for a few moments until the bleeding stops.
8. Similarly, measure the blood glucose level of your friends.
9. Compare your blood glucose level with that of your friends.

Discussion:

In general, a fasting blood glucose reading (taken before a meal) should be between 72 mg/dL to 126 mg/dL. And a blood glucose reading 2 hours after a meal should be between 90 mg/dL to 180 mg/dL.

Precautions:

1. Make sure the lancelet is properly sterilized.
2. Insert the test strip properly.

Blood glucose monitoring is a way of testing the concentration of glucose in the blood (glycaemia). As mentioned earlier, the concentration of blood glucose kept on fluctuating throughout the day. Under certain physiological disorders, especially when the person is suffering from diabetes mellitus, the blood glucose concentration can increase well above the normal concentration. Most people with type II diabetes need to monitor their blood sugar levels at home. A blood glucose test is generally performed by piercing the skin (typically, on the finger) to draw blood, then applying the blood to a chemically active disposable 'test-strip' as described (see **activity 8**) or to a biosensor.

Dipstick Test

A **dipstick** or the **reagent strips** is a narrow strip of plastic with small pads attached to it. Each pad contains specific reagents for a different reaction, thus allowing for the simultaneous determination of several compounds. The blood glucose test use enzymes **glucose oxidase** and **hexokinase** which are specific to glucose, embedded on a **test strip** or a **dipstick**. When the blood sample is applied onto the strip, the enzymes catalyzed glucose specific reaction which changes the colour. The chemical reaction involves in the glucose oxidase test is as follows:

$$\text{Glucose} + O_2 \xrightarrow{\text{Glucose oxidase}} \text{Gluconic acid} + H_2O_2$$

$$H_2O_2 + \text{Chromogen} \xrightarrow{\text{Peroxidase}} \text{Oxidized Chromogen}$$

Numbers of chromogen like potassium iodide, tetramethylbenzine, O-tolidinehydrochloride, 4-aminoantipyrine etc. are used in the dipstick. The colour reaction of the dipsticks is kinetic and will continue to react after the prescribed time. Therefore, reading taken after the prescribed time can give false result.

Biosensors

A biosensor is a device which is composed of two elements; a **bio-receptor** that is an immobilized sensitive biological element (e.g. enzyme, DNA probe, antibody) recognizing the analyte (e.g. enzyme substrate, complementary DNA, antigen) and a **transducer**, used to convert biochemical signal resulting from the interaction of the analyte with the bioreceptor into an electronic signal. The intensity of generated signal is directly or inversely proportional to the analyte concentration. For example, the glucose biosensor is based on the fact that the immobilized Glucose oxidase enzyme which catalyzes the oxidation of β-D-glucose by molecular oxygen producing gluconic acid and hydrogen peroxide. An electrochemical transducer converts this reaction into electronic signal which appears on the screen of the glucose meter.

Continuous Glucose Monitoring

Continuous glucose monitoring systems (CGMS) use a glucose sensor inserted under the skin in the form of a small needle. The signal from the sensor is transmitted wirelessly and the result is recorded in a small recording device. The monitor of the device updates and displays the blood sugar level every few minutes. The glucose sensor needs to be removed and replaced at least once per week.

Advantages of continuous glucose monitoring:

1. The monitor displays blood sugar level every few minutes, allowing one to see whether the level is increasing, decreasing, or is stable.
2. The receiver can also be set to alarm if the blood sugar level is above or below a pre-set level.
3. The blood sugar results from the continuous monitor can be downloaded to a computer, allowing you to check blood sugar trends over time.

The only disadvantage of continuous monitor other than the cost is its inaccuracy compared to more traditional accurate dipstick method. Therefore, most experts recommend continuous glucose monitoring along with several finger sticks daily to calibrate the CGMS device and to verify that the sensor readings are accurate.

Roles of Adrenaline in the Control of Blood Sugar Level

Adrenaline, a natural stimulant created in the kidney's adrenal gland, travels through the bloodstream and controls functions of the autonomous nervous system, including the secretion of saliva and sweat, heart rate and pupil dilation. The substance also plays a key role in the human flight-or-flight response.

The "fight or flight" hormone that gives us a quick boost of extra energy to cope with danger — including the danger of low blood glucose. When blood glucose levels drop too low, the adrenal glands secrete epinephrine (also called adrenaline), causing the liver to convert stored glycogen to glucose and release it, raising blood glucose levels. Epinephrine also causes many of the symptoms associated with low blood glucose, including rapid heart rate, sweating, and shakiness. The epinephrine response spurs the liver to correct low blood glucose or at least raise blood glucose levels long enough for a person to consume carbohydrate.

12.9 DETECTION OF GLUCOSE IN URINE

ACTIVITY 9

Aim: To test the presence of glucose in the urine sample using Benedict's test.

Materials Required:

1. Benedict's solution (100 g of anhydrous sodium carbonate, 173 g of sodium citrate and 17.3 g of copper (II) sulfate pentahydrate in 1L dH_2O prepared freshly; not more than 3 months old),
2. Urine sample
3. Dropper,
4. Test-tube,
5. Test-tube holder.

Procedure:

1. Take 5 ml (one teaspoon) of Benedict's solution in the test-tube.
2. Holding the test-tube with the holder, heat it over a spirit lamp till the Benedict's Solution boils without overflowing.
3. Drop 8 to 10 drops of urine into the boiling Benedict's solution.
4. After again boiling the mixture, let it cool down.
   - Do you see any change in the colour of the mixture?
   - Why does it happen?

Discussion:

1. Note down the colour of the mixture after cooling.
2. The colour of the mixture serves as a guide to the amount of sugar in the urine:
   - Blue: sugar absent;
   - Green: 0.5% sugar;
   - Yellow: 1% sugar;
   - Orange: 1.5% sugar;
   - Red brown/Red ppt.: 2 % or more sugar.

Precautions:

1. Care should be taken while heating the Benedict's solution.
2. Use disposable gloves while handling the urine sample.
3. Result should be noted only when the solution cold to the room temperature.

Note: Coloured water sample can be used instead of the urine sample to avoid the cases of infection.

ACTIVITY 10

Aim: To determine the urine glucose concentration using coloured water (simulated urine).

Materials Required:

1. Coloured water (Blue, Green, Yellow, Orange, Red Brown)
2. Test tubes

Procedure:

1. Take a test tube containing coloured water.
2. Write down approximate concentration of glucose depending on the colour of the water.
3. Explain your result.

Discussion:

1. The colour of the water serves as a guide to the amount of sugar in the simulated urine:
   - Blue: sugar absent;
   - Green: 0.5% sugar;
   - Yellow: 1% sugar;
   - Orange: 1.5% sugar;
   - Red brown/Red ppt.: 2% or more sugar.

Urine analysis can be used to test pH, protein, glucose, ketones, occult blood, bilirubin, urobilinogen, nitrite, leukocyte esterase etc. in the urine sample. Simple test for glucose in urine can be used to diagnose diabetes mellitus. Generally, healthy person do not loss glucose in their urine whereas a person with diabetes mellitus loses small to large quantities of glucose in their urine.

Detection of Glucose in Urine

The presence of glucose in the urine is called **glycosuria** (or **glucosuria**). The urine analysis of glucose is based on enzyme **glucose oxidase** which is impregnated in a dipstick (reaction described in previous section).

Detection of Protein in Urine

The glomerular filtrate of a normal kidney contains little amount of low–molecular weight protein. Most of these proteins get reabsorbed in the tubules with less than 150 mg being excreted through urine per day. Therefore, the abnormal increase in the amounts of protein

in the urine, **Proteinuria**, can be an important indicator of renal diseases. There are certain physiologic conditions such as exercise and fever that can lead to increased protein excretion in the urine in the absence of renal disease.

Proteinuria is a symptom of **chronic kidney disease (CKD)**, which can be due to **diabetes, high blood pressure**, and **diseases that cause inflammation** in the kidneys. Therefore, urine analysis for protein is part of a routine medical assessment for everyone. If CKD is not checked in time, it can lead to **end-stage renal disease (ESRD)**, when the kidneys completely stop functioning. A person with ESRD requires a kidney transplant or regular blood-cleansing treatments called **dialysis** to further sustain.

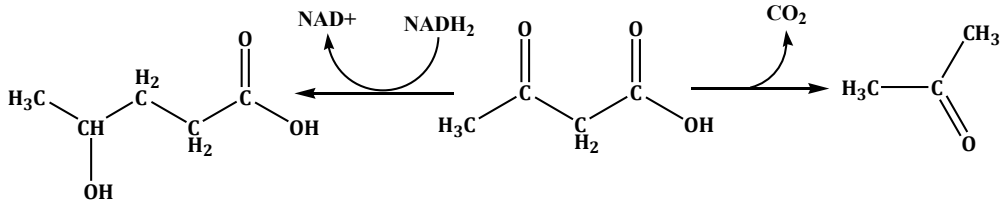
The tests for proteinuria are based either on the "**protein error of indicators**" principle (ability of protein to alter the colour of some acid-base indicators without altering the pH) or on the ability of protein to be precipitated by acid or heat. According to "protein error of indicators" principle, a protein-free solution of **tetra bromophenol blue** at pH 3 is yellow in colour and its colour changes from yellow to blue (or green) when the pH increases from pH 3 to pH 4. However, in the presence of protein (albumin), the colour changes occur between pH 2 and 3 i.e., an "error" occurs in the behaviour of the indicator. The method is more sensitive to albumin than to other proteins, whereas the heat and acid tests are sensitive to all proteins.

The test result may show false-positive results in a highly buffered alkaline urine, which may result from alkaline medication or stale urine. Also, if the dipstick is left in the urine for too long, the buffer could be washed out of the reagent resulting in increase pH and the strip may turn blue or green even if protein is not present. On the other hand, false-negative results can occur in dilute urines or when the urine contains proteins other than albumin in higher concentrations.

Detection of Ketones in Urine

As discussed earlier, **ketones, or ketone bodies** are formed during lipid metabolism. One of the intermediate products of fatty acid breakdown is acetyl CoA. If the lipid metabolism and carbohydrate metabolism are in balanced, Acetyl-CoA enters the citric acid cycle (Krebs cycle) where it reacts with oxaloacetate to form citrate. When carbohydrate is not available in the cells, all available oxaloacetate get converted to glucose and so none is available for condensation with Acetyl- CoA. As such, Acetyl-CoA cannot enter the Krebs cycle and is diverted to form ketone bodies.

The ketone bodies are **acetoacetic acid (diacetic acid), hydroxybutyric acid and acetone**. Acetyl-CoA is first converted to acetoacetic acid which later gets converted to other two ketones through the following reaction:



Hydroxybutyric acid is formed by reversible reduction, and acetone is formed by a slow spontaneous decarboxylation. Acetoacetic acid and hydroxybutyric acid are normal fuels of respiration and are important sources of energy. In fact, the heart muscle and the renal cortex prefer to use acetoacetate instead of glucose. The odour of acetone may be detected in the breath of an individual who has a high level of ketones in the blood because acetone is eliminated through lungs.

Laboratory tests for ketones include **reagent test-strip methods** and **tablet-based tests** such as Acetest. The test strip or dipstick contains the reagents **sodium nitroprusside** and an alkaline buffer, which react with diacetic acid in urine to form a maroon colour, as in the following reaction:

Acetoacetic acid + Sodium nitroprusside + Glycine $\xrightarrow{\textit{Alkaline pH}}$ **Violet-purple colour**

False-positive results may occur when the urine sample is highly pigmented, contains large amounts of levodopa metabolites, have high specific gravity and a low pH or contain sulfhydryl groups.

SELF EVALUATION

Complete with appropriate terms:

(i) Hyperglycaemia is the condition when the blood glucose level is below ..... .

(ii) ..... is caused due to insufficient insulin production by beta cells.

(iii) A ..... diet is important to regulate glucose level in body.

(iv) The test strip or dipstick contains the reagents ..... and ..... .

(v) The presence of glucose in urine is called ..... .

12.10 SUMMARY

- Glucose is the universal fuel which provides energy to all the living cells.
- Glucose is converted to glucose-6-phosphate with the help of enzyme glucokinase in liver and hexokinase in most cells, which help the cells to retain glucose.
- One molecule of glucose yields 38 molecules of ATP.

- Polysaccharides of glucose viz. cellulose, chitin are important structural components of plants and animal cells.
- Excess glucose in the body is stored in the form of glycogen through glycogenesis.
- When the blood glucose level falls, glycogen breaks down into glucose through glycogenolysis.
- Pancreas and liver are the main organs responsible for regulation of blood glucose level.
- Pancreas secretes insulin and glucagon hormones responsible for glucose regulation.
- Exocrine pancreas release digestive enzymes including trypsin, chymotrypsin, amylase and lipase.
- The islet of langerhans is the endocrine component of pancreas and secretes insulin (by beta cells), glucagon (by alpha cells), somatostatin (by delta cells) and pancreatic polypeptide (by F cells).
- Liver is a vital organ of our body which performs various functions ranging from protein synthesis to detoxification of drugs.
- Liver lobes are compost of small units, known as liver lobules.
- Insulin stimulates rapid glucose uptake by cells, promote glycogenesis while inhibiting glycogenolysis and gluconeogenesis resulting in decreasing blood glucose level.
- Glucagon activates enzyme glycogen phosphorylase and initiates glycogenolysis in the liver and muscle cells.
- In liver cells, glucagon increases the rate of amino acid uptake and converts it into glucose.
- Blood glucose level regulation by insulin and glucagon is an excellent example of negative feedback mechanism where the effect of one hormone stimulates the other hormone and vice versa.
- Hormonal regulation of glucose is a three step process which involves hormone-receptor interaction followed by activation of second messenger, cAMP and a series of enzyme cascade.
- Hyperglycemia is a condition when the blood glucose level rises higher than the normal level.
- Hypoglycaemia is the condition when the serum glucose level is below 70 mg/dL.
- Diabetes mellitus is a chronic condition associated with abnormally high levels of glucose in the blood.
- The concentration of insulin increase in the blood (hyperinsulinemia) as more and more insulin is secreted by beta cells in response to decrease sensitivity by cells. This condition is known as insulin resistance.
- Blood glucose monitoring is a very important exercise to keep the glucose level checked and avoids various harmful consequences of high blood sugar due to diabetes mellitus.
- Urine analysis of glucose, ketone bodies and protein, blood glucose test, glucose tolerance test and acetone breath test.

12.11 GLOSSARY

- **Glycosuria:** Presence of glucose in urine.
- **Glycolysis:** Splitting of glucose molecule into two molecules of pyruvic acid.
- **Glycogenesis:** Biosynthesis of glycogen.
- **Glycogenolysis:** Breaking down of glycogen.
- **Gluconeogenesis:** Formation of glucose from non-carbohydrate compounds.
- **Hyperglycemia:** Condition of high blood glucose concentration.
- **Hypoglycemia:** Condition of low blood glucose concentration below 70 mg/dL.
- **Hyperinsulinemia:** High concentration of insulin in blood.

12.12 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

I. State whether the following statements are True (T) or False (F)

1. Excess glucose in the body is stored in the form of glycogen.
2. Trypsin is an enzyme used for carbohydrate digestion.
3. Bile salt is secreted by exocrine liver.
4. Glucagon is secreted by pancreas in response to high blood glucose concentration.
5. Insulin administration is recommended for people with type II diabetes mellitus.
6. Type I diabetes mellitus is due to insufficient secretion of insulin by beta cells.
7. Ketone bodies are formed when our body have excessive fat metabolism.
8. Hyperinsulinaemia is associated with type II diabetes mellitus.
9. Glycogenolysis is the breakdown of glucose to form pyruvate.
10. The binding of hormones to receptors activates cAMP.

II. Multiple Choice Questions

1. Which of the following monosaccharides is not a product of carbohydrate metabolism in our body?
   (a) Glucose (b) Fructose
   (c) Ribose (d) Galactose
2. One molecule of glucose yield …… molecules of ATP.
   (a) 34 (b) 36
   (c) 38 (d) 40
3. Which of the following is not a part of the portal triad?
   (a) Central vein (b) Hepatic artery
   (c) Hepatic portal vein (d) Bile duct.

4. Somatostatin is secreted by
   (a) Alpha cells (b) Beta cells
   (c) Delta cells (d) F cells
5. The process of formation of glucose from non-carbohydrates source in the body is known as
   (a) Glycogenesis (b) Gluconeogenesis
   (c) Glycolysis (d) Glycogenolysis
6. Which of the following hormones is responsible for decreasing blood glucose level?
   (a) Glucagon (b) Insulin
   (c) Somatostatin (d) Adrenaline
7. Which of the following compounds is not a ketone body?
   (a) Acetoacetic acid (b) Hydroxybutyric acid
   (c) Acetone (d) Citric acid
8. In the digestive tract, fructose is absorbed inside the epithelial cells of intestine through
   (a) GLUT1 (b) GLUT3
   (c) GLUT5 (d) SGLUT2
9. The enzyme used in the dipstick for testing concentration of glucose is
   (a) Glucose oxidase (b) Glycogen phosphorylase
   (c) Glucose phosphatase (d) Glucosidase
10. Hypoglycemia is the condition when the blood glucose level reach
   (a) Above 140 mg/dL (b) Below 140 mg/dL
   (c) Above 70 mg/dL (d) Below 70 mg/dL

III. Long Answer Type Questions

1. Glucose is the most important carbohydrate in our body. Justify the statement.
2. Describe the negative feedback mechanism with an example.
3. Describe the functions of liver and pancreas in regulating blood glucose level.
4. What are the causes of sugar imbalance in our body?
5. What is diabetes mellitus? Discuss its cause and effect.
6. Discuss in brief the importance of analysing urine in diagnosis diabetes mellitus.
7. How does glucose regulation effect aging? What possible effects can regulation of glucose have on health of an organism?
8. In your own words, describe three main stages of cell signalling in control of blood glucose by adrenaline.

Unit 13

Regulation of Temperature

Key Unit Competence

To be able to explain the importance and ways by which organisms regulate body temperature.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- explain the importance of temperature regulation.
- describe the morphological, physiological and behavioural adaptations to temperature changes in the environment.
- interpret data related to the effects of temperature on animal behaviour.
- describe the responses to cold and hot conditions by endothermic and ectothermic animals.
- interpret and list the adaptive features shown by plants inhabiting extreme cold and hot environments.
- acknowledge the importance of maintaining fairly constant temperatures for efficient metabolism.
- explain the role of the brain and thermo receptors in temperature regulation.
- research using the internet the role of brain in temperature regulation.
- describe the different processes in which plants minimise overheating.
- design and investigate the effect of temperature.

13.1 IMPORTANCE OF TEMPERATURE REGULATION

ACTIVITY 1

Aim: To investigate the effect of temperature on enzyme activity.

Materials Required:

1. Water bath
2. Ice
3. Test tubes

4. Thermometers
5. Bunsen burners
6. Cornstarch
7. Distilled water

Procedure:

1. Pour some water into the water baths and set the temperature at 37°C and 60°C.
2. Make a starch solution by adding 1 g of cornstarch to 10 ml of distilled water. Pour the mixture into 50 ml of boiling water and stir until the solution becomes transparent.
3. Prepare amylase solution by adding 2 ml of saliva to 12 ml of water.
4. Take three test tubes and label as Ice, 37°C and 60°C.
5. Add 4 ml of the starch solution and 4 ml of amylase solution in the three test tubes.
6. Immediately place one test tube in the ice, one in the water bath at 37°C and other at 60°C.
7. Incubate the test tubes for 15 minutes.
8. Take 4 drops of samples from each test tube on a glass plates.
9. Add 1 drop of iodine to each sample.
10. Note the time taken for the iodine to turn yellow from blue.

Discussion:

Amylase is an enzyme that hydrolyzes starch into its components i.e., glucose. Iodine turns blue when it comes into contact with starch, but it stays yellow in the presence of glucose. Therefore, faster the iodine turns yellow from its blue colour, the faster amylase works on the starch.

Note the time taken for different samples and discuss the result with your teacher.

Precautions:

1. The temperature of the water baths should be properly set.
2. Starch solution should be homogenous.
3. Time should be noted carefully.

Besides water, our body consists of many inorganic and organic compounds including proteins, lipids, carbohydrates etc. Among these, proteins are the most important compounds and are regarded as "workhorse" molecules of life, taking part in essentially every structure and activity of life. Proteins make up about 75 per cent of the dry weight of our bodies and serve four important functions;

1. They are nutritious.
2. They also form the structural components of our body including skin, hair etc. They are building materials for living cells, appearing in the structures inside the cell and within the cell membrane.
3. As haemoglobin, Hb they carry oxygen to all the body organs and
4. They functions as biological catalysts as **enzymes** facilitating and controlling various chemical reactions of our body.

Protein molecules are often very large and are made up of hundreds to thousands of amino acid units. They are of varying shape and size. For examples, keratins, a protein in hair and collagen in tendons and ligaments linear chains of amino acids. Other proteins called globular proteins, fold up into specific shapes and often more than one globular unit are bound together. Enzymes are globular proteins. Though large, enzymes typically have a small working region, known as active site which acts as the binding site of ligands. The shape of globular proteins is held together by many forces, including highly resistant strong covalent bonds. However, there are also many weak forces, like hydrogen bonds, which are susceptible to pH, osmolarity and temperature changes.

Since the function of enzymes is attributed to its shape, small changes in the shape can greatly reduce its function. Every enzyme has an optimal temperature at which it works best and this temperature is approximately the normal body temperature of the body. Therefore, in order to ensure the optimal function of the enzymes within, the core body temperature need to be maintained more or less constant. If the body temperature falls below the normal value, the enzymes catalyzed reactions of the animal will be slowed. Similarly, too much rise in body temperature might result in enzyme denaturation and hence reduced catalytic activities.

Rise in body temperature also reduces the oxygen carrying capacity of haemoglobin. Increasing temperature weakens and denatures the bond between oxygen and haemoglobin which in turn decreases the concentration of the oxyhaemoglobin. This can lead to **hypoxia** – a condition in which tissues receive insufficient oxygen supply from the blood.

13.2 MORPHOLOGICAL, PHYSIOLOGICAL AND BEHAVIOURAL ADAPTATION TO TEMPERATURE CHANGES IN THE ENVIRONMENT

ACTIVITY 2

Use internet to find the pictures of animals living in different temperature conditions like arctic, snow covered mountains, forest, deserts, sea etc.Use the following link: *https://www.youtube.com/results?search_query=animal+habitat&sp=EgIwAQ%253D%253D*

Print the pictures and paste it in your scrapbook.

Write down different morphological, physiological and behavioural adaptations of the animal which help it to live in a particular environment. Discuss various adaptations of your collections.

From deepest corner of the sea to high mountains, living organisms have colonized almost everywhere. However, they are not distributed evenly with different species found in different areas. Many abiotic factors including temperature, humidity, soil chemistry, pH, salinity, oxygen levels etc., influence the availability of species in certain area. Each species has certain set of environmental conditions within which it can best survive and reproduce to which they are best adapted. This is known as limits of tolerance (i.e., the upper and lower limits to the range of particular environmental factors within which an organism can survive). No organism can survive if the environmental factor is below its lower limits of tolerance or above the higher limits. Therefore, organisms having a wide range of tolerance are usually distributed widely, while those with a narrow range have a more restricted distribution. For examples, euryhaline fishes (like salmon) can survive wide range of salt concentration and therefore are found both in freshwater and salt water environment while stenohaline fishes are found only in saltwater or freshwater.

Temperature is one of the most important factors which directly or indirectly influence the distribution of organisms to a large extent. For example, polar bears can survive very well in low temperatures ranges, but would die from overheating in the tropics. On the other hand, a giraffe does very well in the heat of the African savanna, but would quickly freeze to death in the Arctic. Compared to ectotherms or cold blooded animals, endotherms due to their ability to generate their own body heat, are generally more widely distributed. Besides, all the organisms have varying degree of morphological, physiological or behavioural adaptations that helps them to survive the extreme temperature conditions of their habitat.

13.2.1 Effect of Temperature

As discussed above, all the living organisms have a particular range of temperature within which they can best survive and reproduce. Temperature below or above this temperature ranges are harmful to the organism in various ways. Some of well known effects of temperature on living organisms are given below.

1. **Effect of temperature on cells:** If the temperature is too cold, the cell proteins could be destroyed due to the formation of ice, or as the water is lost, the cytoplasm can become highly concentrated. Conversely, extreme heat can coagulate cell proteins.
2. **Effect on metabolism:** Most of metabolic activities of microbes, plants and animals are regulated by enzymes and the functions of enzymes are greatly affected by temperature. Therefore, increase or decrease in the body temperature will greatly affect the various metabolic activities. For example, the activity of liver arginase enzyme upon arginine increases gradually with increase in the temperature from 17°C to 48°C. With the increase in temperature beyond 48°C, the enzymatic activity decreased sharply.

3. **Effect on reproduction:** Changes in temperature affect both the maturation of gonads i.e., gametogenesis and fecundity of animals. For example, some animal species can breed throughout the year, some only in summer or in winter, while some species have two breeding periods, spring and autumn. Therefore, temperature determines the breeding seasons of most organisms. Also, it was observed that female chrotogonus trachypterus an acridid insect lays highest number of eggs per female at of 30°C and decreases with increase in temperature from 30°C to 35°C.
4. **Effect on sex ratio:** In certain animals like copepod **Maerocyclops albidu**, rises in temperature significantly increases the number of male offspring. Similarly in plague flea, **Xenopsylla cheopis**, males' population outnumbered females when the mean temperature is between 21°C to 25°C. However, further decreases in temperature reverse the conditions with the considerable increases in female population.
5. **Effect on growth and development:** In general growth and development of eggs and larvae is more rapid in warm temperatures. For example, Trout eggs develop four times faster at 15°C than at 5°C. On the other hand, seeds of many plants will not germinate and the eggs and pupae of some insects will not hatch until chilled.
6. **Effect on colouration:** Animals generally have a darker pigmentation in warm and humid climates than those found in cool and dry climates. This phenomenon is known as *Gioger* rule. In the frog *Hyla* and the horned toad *Phrynosoma*, low temperatures have been known to induce darkening. Some prawn turn light coloured with increasing temperature.
7. **Effect on morphology:** Temperatures have profound effects on the size of animals and various body parts. Endotherms generally attain a larger body size (reduced surface-mass ratio) in colder temperatures than in warmer temperatures. As such the colder regions harbour larger species. Conversely, the poikilotherms (ectotherms) tend to be smaller in colder regions. We will discuss the various morphological modifications due to extreme climates in the later sections.
8. **Effect on animal behaviour:** Temperature certainly has profound effect on the behavioural pattern of animals. The advantage gained by certain cold blooded animals through thermotaxis or orientation towards a source of heat are quite interesting. Ticks locate their warm blood hosts by a turning reaction to the heat of their bodies. Certain snakes such as rattle snakes, copper heads, and pit vipers are able to detect mammals and birds by their body heat which remains slightly warmer than the surroundings.

9. **Effect on animal distribution:** Since the optimum temperature for many organisms varies, temperature imposes a restriction on the distribution of species. The diversity of animals and plants gradually decrease as we move from equator towards the pole.

13.2.2 Morphological Adaptations

1. **Body size and shape:** Ectotherms or cold-blooded animals whose body temperature depends on the temperature of external environments are usually smaller in size compared to endotherms or warm blooded animals. For instance, compare the size of elephant, blue whales and crocodiles or snakes. Within the same species, individuals living in the colder climates tend to be larger than those living in warmer climates. This is known as **Bergmann's rule**. For example, whitetail deer in the southern part of the United States have a smaller body size than whitetail deer in the for norhtern states (Figure 13.1 (A)) the far northern states (Figure 13.1 (B)).

Figure 13.1: Bergmann's rule: Body size and temperature. White-tailed deer (*Odocoileus virginianus*) extend from Canada through Central America into South America north of the Amazon River basin. There is a strong size gradient, with the largest animals in the temperate north (A) and the smallest in the warm neotropics (B). Antler growth is positively allometric with respect to skull size: the smaller animal has disproportionately small antlers

2. **Body Extremities:** According to Allen's rule, animals living in the colder climates have more rounded and compact form. This is achieved by reducing the size of the body extremities i.e., ears, limbs, tails etc. On the other hand, animals living in the warmer

climates have longer body extremities. For instance, compare the size of the ear of Arctic fox with that of the Desert fox (Figure 13.2). Longer body extremities increase the surface to volume ratio of the desert fox which enable them to lose heat more easily.

Most cold-blooded organisms have either an elongated or a flat body shape. For example, fishes, snakes, lizards, and worms have long and slender body form which ensures rapid heat up and cool down processes.

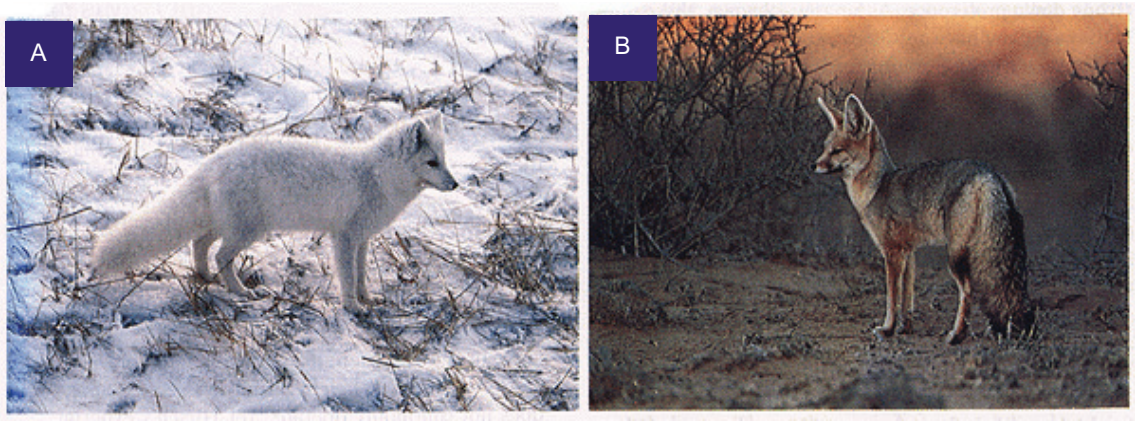


Figure 13.2: Allen's rule: Body extremities and temperature. (A) Arctic fox (Alopax lagopus) with its short tail, ear and legs and (B) Desert fox (Vulpes chama) with longer tail, ear and legs

Both Bergmann's rule and Allen's rule depend on simple principle that "*the ratio of surface area to volume of an object is inversely proportional to the volume of the object*". In other words, the smaller an animal is, the higher the surface area-to-volume ratio. Higher surface area-to-volume ratio ensures these animals to lose heat relatively quickly and cool down faster, so they are more likely to be found in warmer climates. Larger animals, on the other hand, have lower surface area-to-volume ratios and lose heat more slowly, so and they are more likely to be found in colder climates.

3. **Insulation:** All the marine mammals have a thick insulating layer of fat known as **Blubber**, just beneath the skin. It covers the entire body of animals such as seals, whales, and walruses (except for their fins, flippers, and flukes) and serves to stores energy, insulates heat, and increases buoyancy. Thickness of blubber can range from a couple of inches in dolphins and smaller whales, to 4.3 inches in polar bears to more than 12 inches in some bigger whales. To insulate the body, blood vessels in blubber constrict in cold water. Constriction of the blood vessels reduces the flow of blood to the skin and minimizes the heat loss. In such animals, skin surface temperature is nearly identical

to the surrounding water, though at a depth of around 50 mm beneath the skin, the temperature is the same as their core temperature.

Some marine mammals, such as polar bears and sea otters, have a thick fur coat, as well as blubber, to insulate them. The blubber insulates in water while fur insulates in air or terrestrial environment. The feathers of the birds also function in insulating the body from cold temperature.

13.2.3 Physiological Adaptations

1. **Evaporation:** In a colder region, i.e., when the surrounding environment of the animal is cooler than the body temperature, **conduction** and **radiation** are the main ways an animal will dissipate heat. However, in warmer region, the air temperature is often higher than the animal's body temperatures, so the only physiological thermoregulatory mechanism available is **evaporation**. Animals use three evaporative cooling techniques that include **sweating, panting**, and **saliva spreading**.
   (a) **Sweating:** It is the loss of water through sweat glands found in the skin of mammals. The number of sweat glands can vary from none in whales, few in dogs to numerous in humans. Most small mammals do not sweat because they would lose too much body mass if they did. For example, in a hot desert the amount of water a mouse would lose through sweating to maintain a constant body temperature would be more than 20% of its body weight per hour, which could be lethal for the animal. Therefore, smaller mammals use other techniques to cool down their body. On the other hand, sweating is an important thermoregulatory mechanism for primates including humans. An adult human can loss as much as 10–12 litres of water per day through sweating.
   (b) **Panting:** It is rapid, shallow respiration that cools an animal by increased evaporation from the respiratory surfaces. It is a common thermoregulatory technique used by small animals like dogs and rodents to loss heat.
   (c) **Saliva spreading:** It is a means of thermoregulation used by marsupials. Under extreme heat, saliva will drip from animal's mouth and is then wiped on its fore and hind legs. This technique induces the cooling effect of evaporation by wetting the fur. However, since the animal cannot spread saliva while moving, they need to adapt other evaporative techniques during such situations.
2. **Counter current mechanism:** As mentioned above, in addition to its role in the transport of oxygen and food, circulatory system of our body is responsible for distribution of

heat throughout the body. This is true in case of both endotherms and ectotherms. In endotherms, most of the body heat is generated in brain, liver, heart and skeletal muscles. This heat is transported to other parts of the body through blood. On the other hand, in ectotherms, the circulatory system help in transporting heat from skin to others body parts. The counter current heat exchanger is generally located in body extremities like limbs, neck, gills, which are directly in contact to the external environment.

In colder region, when the warm blood flows through the arteries, the blood gives up some of its heat to the colder blood returning from the extremities in the veins running parallel to the arteries. Such veins are located in the deeper side of the body and carry the warm blood to the heart and most of the body heat is retained. Such mechanism can operate with remarkable efficiency. For instance, a seagull can maintain a normal temperature in its torso while standing with its unprotected feet in freezing water (Figure 13.3).

When the external temperature is higher than the body temperature and heat loss is not a problem, most of the venous blood from the extremities returns through veins located near the surface. If the core body temperature becomes too high, the blood supply to the surface and extremities of the body is increased enabling heat to be released to the surroundings.

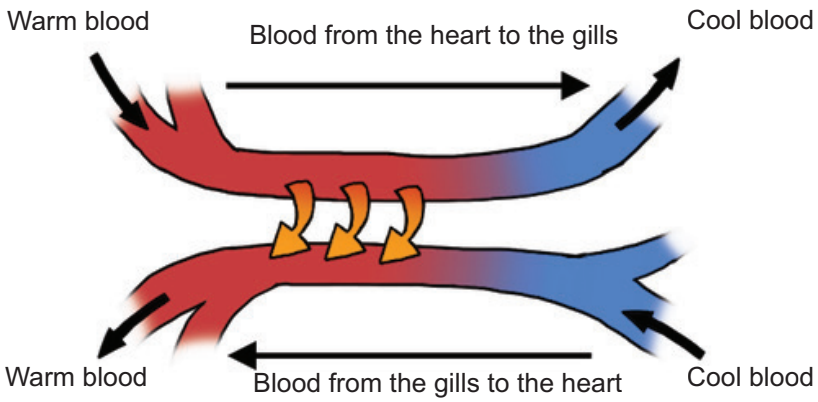


Figure 13.3: Counter current heat exchange mechanism. As warm blood travels from the heart to the gills, an exchange of heat takes place with the colder blood returning from the gills

3. **Hyperthermia:** Hyperthermia is a condition of having the body temperature greatly above the normal. Although all the endotherms can maintain a constant body temperature, some are able to raise their body temperature as a way to decrease the amount of water and energy used for thermoregulation. For example, camels and gazelles can increase their

body temperature by 5–7°C during the day when the animal is dehydrated. Hyperthermia helps in saving water by letting their body temperature increase instead of using evaporative cooling to keep it at a constant temperature.

4. **Water retention:** Human body obtains about 60 per cent of the water they need from ingested liquid, 30 per cent from ingested food, and 10 per cent from metabolism. While rodent adapted to arid conditions obtains approximately 90 per cent from metabolism and 10 per cent from ingested food. The predaceous marsupial Mulgara can go its whole life without ingesting water but by obtaining water from the food they eat and from metabolism. The fawn hopping mouse eats seed, small insects, and green leaves for moisture, and Kowaris eat insects and small mammals to obtain water. These animals have specialized kidneys with extra microscopic tubules to extract most of the water from their urine and return it to the blood stream. And much of the moisture that would be exhaled in breathing is recaptured in the nasal cavities by specialized organs.

   Many desert dwelling insects tap plant fluids such as nectar or sap from stems, while others extract water from the plant parts they eat, such as leaves and fruit. The abundance of insects permits insectivorous birds, bats and lizards to thrive in the desert. Elf owls survive on katydids and scorpions. Pronghorns can survive on the water in cholla fruits. Kit foxes can satisfy their water needs with the water in their diet of kangaroo rats, mice, and rabbits, along with small amounts of vegetable material.

5. **Excretion:** As mentioned above, desert dwelling mammals and birds have specialized kidneys with long loops of Henle compared to animals that live in aquatic environments and less arid regions. A longer tubules help in reabsorbing most of the water from their urine and return it to the blood stream. As a result, the urine becomes highly concentrated. In these animals, most of the water in the faeces gets reabsorbed in the alimentary canals and colon. Camels produce dryer faeces than other ruminants. For example, sheep produce faeces with 45 per cent water after 5 days of water deprivation, while camels produce faeces with 38 per cent water even after 10 days of water deprivation. The ability to excrete concentrated urine and dry faeces is an important adaptation to arid conditions. Desert rodents can have urine five times as concentrated as that of humans.

13.2.4 Behavioural Adaptations

Behavioural adaptations are used to reduce the amount of heat gained or lost by animals, and, thereby, reducing the amount of energy and water to maintain the body temperature. Ectoderms or cold blooded animals rely on their behaviour to maintain a favourable body temperature.

1. **Nocturnality:** It is the simplest form of behavioural adaptation characterized by activity during the night and sleeping during the day. As such, nocturnal animals avoid direct exposure to heat of the day, thereby preventing loss of water needed for evaporative cooling. The night temperatures are generally 15–20°C colder than the daytime, so require much less energy and water to regulate body temperature. Most of the desert animals like quoll, bilby, and the spinifex hopping mouse, are nocturnal. Other large animals like lions prefer to hunt at night are to conserve water.

   Crepuscular animals are those animals that are mainly active during twilight (i.e., the period before dawn and that after dusk). Examples include hamsters, rabbits, jaguars, ocelots, red pandas, bears, deer, moose, spotted hyenas etc. Many moths, beetles, flies, and other insects are also crepuscular in habit. These crepuscular animals take advantage of the slightly cooler mornings and evenings to escape the daytime heat, and to evaporate less water.

2. **Microhabitat:** Among the diurnal animals (animals which are mainly active during the day and rest during night), the use of microhabitat like burrows, shade is another type of behavioural adaptation to avoid the daytime heat. Fossorial animals (digging animals), such as mulgaras, spent much of their time below ground eating stored food. Lizards and snakes seek a sunny spot in the morning to warm up their body temperatures more quickly and remain in shade when the temperature rises.

3. **Migration:** It is the physical movement of animals over a long distance from one area to another. It is found in all major animal groups, including birds, mammals, fish, reptiles, amphibians, insects, and crustaceans. Many factors like climate, food, the season of the year or mating could lead to migration. It helps the animals in avoiding the extreme environmental conditions by moving to more favourable places. For example, many migratory birds like arctic tern (Sterna paradisaea) migrate north-south, with species feeding and breeding in high northern latitudes in the summer, and moving some hundreds of miles south during the winter to escape the extreme cold of north. Monarch butterflies spend the summer in Canada and the Northern America and migrate as far south as Mexico for the winter.

4. **Hibernation and Aestivation:** Warm blooded animals which do not migrate generally survive the extreme cold condition of winter by sleeping. Hibernation is the state of dormancy during the cold conditions, i.e., winter. During hibernation, body temperature drops, breathing and heart rate slows, and most of the body's metabolic functions are put on hold in a state of quasi-suspended animation. This allows them to conserve energy, and survive the winter with little or no food.

Many insects spend the winter in different stages of their lives in a dormant state. Such phenomenon is known as **diapause**. During diapauses, insect's heartbeat, breathing and temperature drop. Some insects spend the winter as worm-like larvae, while others spend as pupae. Some adult insects die after laying their eggs in the fall and eggs hatch into new insects in the spring when the food supply and temperature become favourable.

Aestivation or summer dormancy on the other hand, is a state of animal dormancy, characterized by inactivity and a lowered metabolic rate, in response to high temperatures and arid conditions. It allows an animal to survive the scarcity of water or food as aestivating animal can live longer off its energy reserves due to the lowered metabolism, and reduced water loss though lowered breathing rates. Lung fishes, toad, salamander, desert tortoise, swamp turtles are some of the other non-mammalian animals which undergo aestivation.

5. **Social behaviour:** Among all the adaptations, living together is one of the most important adaptations of the animal kingdom. Animals can derive a lot of benefit from spending time with other members of the same species like finding food, defence against predators and care for their young. For example, emperor penguins can survive the harsh Antarctica winter huddling together in groups that may comprise several thousand penguins. Huddling greatly reduces the surface area of the group compared to individuals and a great deal of warmth and body fat is conserved. Many social mammals, including many rodents, pigs and primates survive extreme cold by huddling together in groups.
6. **Locomotion:** Different types of locomotion require varying amount of energy. Many mammals like kangaroo, hares hop, which is an energy efficient type of locomotion. When animals go from walking to running, there is an increasing energy cost; however, once kangaroos start moving, there is no additional energy cost. This is because when a kangaroo lands, energy is stored in the tendons of its hind legs which is used to power the next hop.

SELF EVALUATION

Complete with correct terms:

(i) ..... is a dormant state experienced by many insects during winters.

(ii) Gioger rule states that animals have ..... colouration in warm climate.

(iii) Individuals of some species living in colder climates tend to be larger than those in warmer climates exhibiting ..... rule.

(iv) Polar bears and sea otters have ..... and ..... for insulation.

(v) Camels and gazelles save water by letting their body temperature ..... .

13.3 RESPONSE TO COLD AND HOT CONDITIONS BY ENDOTHERMIC AND ECTOTHERMIC ANIMALS

ACTIVITY 3

Select an animal to study the temperature regulation mechanism.

Study different morphological, physiological and behavioural adaptation of the animals in different temperature.

Make a PowerPoint presentation and present it in the class.

13.3.1 Endotherms' Response to Temperature Changes

Endothermic organism can maintain relatively high body temperatures within a narrow range. Since most of the body heat is produced as a result of various metabolic activities, thermoregulation in endotherms depends on food and water availability. For example, bear undergoes hibernation during the winter because there is no sufficient food during the cold season. On the other hand, in arid environment like deserts, many deserts animals are nocturnal to avoid the extreme daytime heat to avoid loss of water through evaporation.

Response to Hot Temperature

When the body temperature increases in response to the external temperature, the body's temperature control system uses three important mechanisms to reduce the body heat. These are:

1. **Vasodilation:** The blood vessels in skin become intensely dilated due to the inhibition of the sympathetic centres in the posterior hypothalamus that cause vasoconstriction. Vasodilation increases the rate blood flow to the skin and as a result, the amount of heat transfer from the core of the body increases tremendously.
2. **Sweating:** As discussed in the previous section, sweating is an important adaptation to lose body heat through evaporative cooling. An increase in 1°C in body temperature causes enough sweating to remove ten times the basal rate of body heat production.
3. **Decrease in heat production:** As mentioned above, metabolic activities of the body are the main source of body heat. The mechanisms that cause excess heat production, such as shivering and chemical thermogenesis, are strongly inhibited when exposed to hot temperature.

Response to Cold Temperature

In response to cold temperature, the temperatures control system performs exactly opposite mechanism to that performs in hot temperature. These are:

1. **Vasoconstriction:** The blood vessels in the skin constrict under the influence of posterior hypothalamic sympathetic centres which reduce the blood flow to the skin.
2. **Piloerection:** Piloerection means hairs "standing on end". Sympathetic stimulation causes the arrector pili muscles attached to the hair follicles to contract, which brings the hairs to an upright stance. The upright projection of the hairs allows them to entrap a thick layer of air next to the skin which acts as insulator, so that transfer of heat to the surroundings is greatly depressed.
3. **Increase in heat production (thermogenesis):** Endothermic metabolic rates are several times higher than those of ectotherms. The metabolic heat production of endotherms is regulated in response to fluctuations in the environment temperature. This phenomenon is known as **adaptive thermogenesis** or **facultative thermogenesis**. It can be defined as "*Heat production by metabolic processes in response to environmental temperature with the purpose of protecting the organism from cold exposure and buffering body temperature from environmental temperature fluctuations*". Under cold temperature stress, heat production by the metabolic activities increased tremendously by promoting *shivering, sympathetic excitation of heat production, and thyroxine secretion*. These mechanisms will be discussed later. Extreme shivering can increase the temperature four to five times the normal production.

13.3.2 Ectotherms' Response to Temperature Changes

Ectotherms cannot maintain stable body temperature and their body temperature relies on the external temperature. They depend more on energy assimilation rather than utilizing it for temperature regulation. Therefore, ectotherms regulate their body temperature behaviourally and by cardiovascular modulation of heating and cooling rates. At the same time, metabolism and other essential rate functions are regulated so that reaction rates remain relatively constant even when body temperatures vary. This process is known as **acclimatization** or **temperature compensation**. For example, many fish adjust metabolic capacities to compensate for seasonal variation in water temperature with the result that metabolic performance remains relatively stable throughout the year. Reptiles often regulate their body temperature to different levels in different seasons to minimize the behavioural cost of thermoregulation. At the same time, tissue metabolic capacities are adjusted to counteract thermodynamically-induced changes in rate functions.

Response to Hot Temperature

When the external temperature increases, ectotherms protect their bodies from overheating using various mechanisms. These are:

1. **Use of microhabitat:** Under extreme heat conditions, many ectotherms like lizards and snakes prefer to stay in shade, either beneath the rocks, crevices or underground burrows. Amphibians and fishes enter cold water when their body temperature increases.
2. **Acclimatization:** If a salamander living at 10°C is exposed to 20°C, its metabolic rate increases rapidly. But if the exposure to the higher temperature lasts for several days, the animal experiences a compensating decrease in the metabolic rate. This decrease in the metabolic rate is due to acclimatization. The higher metabolic rate is due to the increase in the enzymes activity with temperature. However, with prolonged exposure to the condition, the metabolic rates decrease to prevent excessive energy loss. Ectotherms also exhibit acclimatization of temperature tolerance range with animal acclimated to high temperature are able to tolerate higher temperature than those exposed only to low temperature. Similarly, cold acclimated animals have better tolerance to low temperature than high temperature acclimated animal.

Response to Cold Temperature

Ectotherms response to cold temperature is exactly opposite to the response shown when exposed to hot temperature. That is:

1. **Basking to sun:** When the body temperature of the ectotherms becomes colder than the normal, the animals either bask to sunlight to warm up the body or move to a warmer place. Under extreme cold conditions, all the metabolic activities may cease and the animals enter the state of torpor (reduced metabolic activities).
2. **Cold Acclimatization:** Decrease in the temperature result in reduced metabolic rate. Therefore as a compensatory measures to meet the require body metabolism, the cold acclimatization of ectotherms is characterized by increase in concentration of various metabolic enzymes. There is also significant increase in the mitochondria and capillaries concentration in the skeletal muscle. This increase the ATP production through aerobic respiration in these tissues. Therefore, in those animals which have prolonged exposure to cold temperature, there may be increase in the locomotion, though the basal rates of metabolism remain below the warm acclimatized animals.

13.4 THE ROLE OF THE BRAIN: HYPOTHALAMUS AND THERMORECEPTORS IN TEMPERATURE REGULATION

ACTIVITY 4

Study the role of hypothalamus and different thermoreceptors in thermoregulation.

Make a PowerPoint presentation and present it in front of the class. Discuss your presentation with your teacher and seek suggestions for any improvements.

So far we have discussed that on the basis of types of thermoregulation, all the living organisms can be classified into two groups – ectotherms and endotherms. Endotherms can regulate their body temperature within a narrow range through various physiological mechanisms while ectotherms being depended on external temperature mostly rely on their behaviour to maintain body temperature. But how do these animals sense and counter the changing temperature of their body will be discussed in the section.

13.4.1 Thermoreceptors

A **thermoreceptor** is a sensory receptor which is basically the receptive portion of a sensory neuron that converts the absolute and relative changes in temperature, primarily within the innocuous range to nerves impulses. **Thermoreception** is the sense by which an organism perceives the temperature of the external and internal environment from the information supply by thermoreceptors. In vertebrates, most of the thermoreceptors are found in skins which are actually free nerve endings. Deep body thermoreceptors are also found mainly in the spinal cord, in the abdominal viscera, and in or around the great veins in the upper abdomen and thorax region.

Mammals have at least two types of thermoreceptors – the **warm receptors**, those that detect heat or temperatures above normal body temperature and **cold receptors**, those that detect cold or temperatures below body temperature. The warm receptors are generally unmyelinated nerves fibres, while cold receptors have thinly myelinated axons and hence faster conduction velocity. Incerasing body temperature results in an increase in the action potential discharge rate of warm receptors while cooling results in decrease. On the other hand, cold receptors' firing rate increases during cooling and decreases during warming. Another types of receptor called **nociceptors**, detect pain due to extreme cold or heat which is beyond certain threshold limits.

A specialized form of thermoception known as distance thermoreception is found in some snakes like pit viper and boa, use a specialized type of thermoreceptor which can sense the

infrared radiation emitted by hot objects. The snake's face has a pair of holes, or pits, lined with temperature sensors. These sensors indirectly detect infrared radiation by its heating effect on the skin inside the pit which helps them to locate their warm blooded prey. The common vampire bat may also have specialized infrared sensors on its nose.

13.4.2 Hypothalamus

The hypothalamus is a very small, but extremely important part of the brain that acts as the link between the endocrine and nervous systems of the body. The hypothalamus plays a significant role in the endocrine system and is responsible for maintaining the body's **homeostasis** by stimulating or inhibiting many key processes, including heartbeat rate and blood pressure, body temperature, fluid and electrolyte balance, appetite and body weight, glandular secretions of the stomach and intestines, production of substances that influence the pituitary gland to release hormones and sleep cycles.

13.4.3 Thermoregulation—Role of Hypothalamus

Thermoregulation is carried out almost entirely by nervous feedback mechanisms, and almost all these operate through temperature-regulating centres located in the hypothalamus (Figure 13.4). The hypothalamus contains large numbers of heat-sensitive as well as cold-sensitive neurons which acts as thermoreceptor, sensing the temperature of the brain. The posterior hypothalamus region contain the thermoregulatory centre which integrate the signals from of all the thermoreceptors found in skin, deep organs and skeletal muscles, as well as from the anterior hypothalamus and control the heat-producing and heat-conserving reactions of the body.

Cooling Mechanism

When the body temperature increases beyond the set-point, the anterior hypothalamus is heated. The posterior hypothalamus senses the heat and inhibits the adrenergic activity of the sympathetic nervous system, which control vasoconstriction and metabolic rate. This causes cutaneous vasodilation and increase heat loss through skin. It also reduces the body metabolic rate resulting in decreasing heat production through metabolic reactions. Under intense heating, the cholinergic sympathetic fibres innervating the sweat glands release acetylcholine, stimulating the secretion of sweat. Many behavioural responses to heat, such as lethargy, resting in shade, lying down with limbs spread out, etc., decreases heat production and increases heat loss.

Heating Mechanism

When the body temperature falls below the set-point, the body regulating mechanism tries to reduce heat loss and increase heat production. The immediate response to cold is vasoconstriction throughout the skin. The result is vasoconstriction of the skin blood vessels, reducing the blood flow and subsequent heat loss through skin. Sympathetic stimulation also causes piloerection and reduces the heat loss from the body by trapping heat within the body hair.

The primary motor centre for shivering is excited by the cold signals from skin and spinal cord which cause shivering of the skeletal muscles. Intense shivering can increase the body heat production four to five times normal. Cooling the anterior hypothalamic due to decrease in body temperature stimulates hypothalamus to increases the production of the neurosecretory hormone **thyrotropin-releasing hormone**. This hormone in turn stimulates the anterior pituitary gland, to secrete **thyroid-stimulating hormone**. Thyroid-stimulating hormone then stimulates thyroid glands to increased output of thyroxine. The increased thyroxine level in the blood increases the rate of cellular metabolism throughout the body and hence increases heat production.

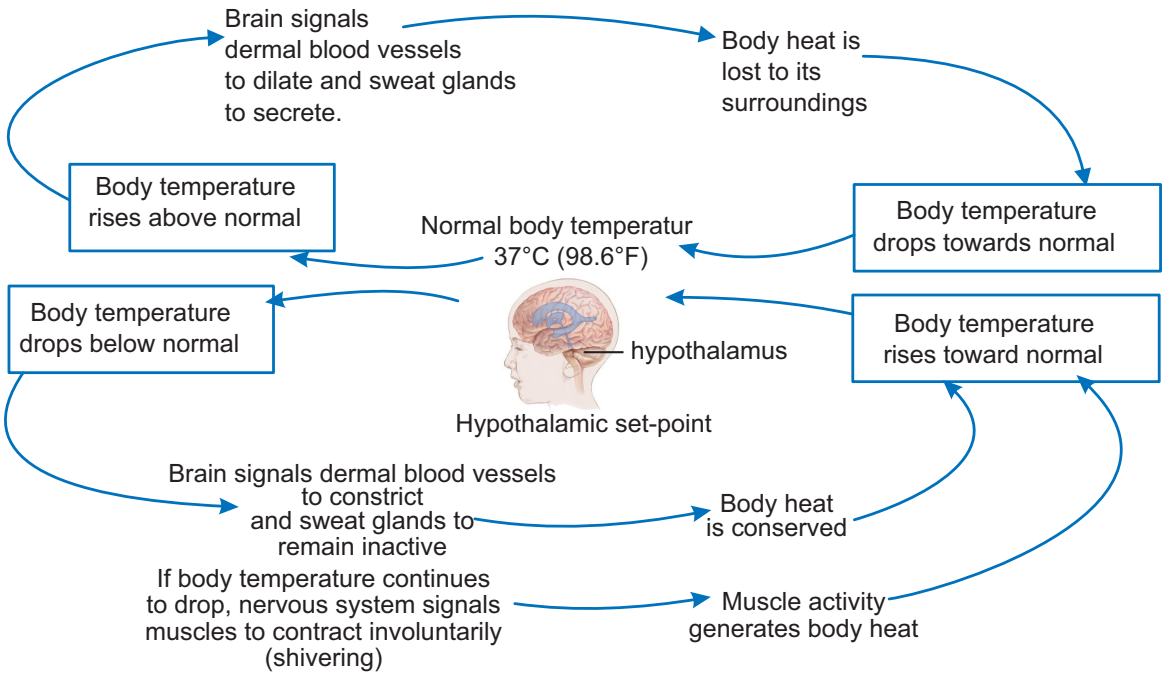


Figure 13.4: Neural feedback mechanism for regulation of body temperature

13.5 EFFECT OF TEMPERATURE CONDITIONS ON ANIMAL BEHAVIOUR

ACTIVITY 5

Aim: To investigate the effect of temperature conditions on animal behaviour.

Materials Required:

1. A long piece of metal at least 1 cm thick
2. Hot plates
3. Ice
4. Crickets/Cockroach
5. Transparent plastic pipe (at least 6 cm in diameter).

Procedure:

1. Cut the transparent plastic pipe longitudinally into two equal halves.
2. Place one end of the metal rod on a hot plate and the other end in ice to form a continuous thermal gradient.
3. Over top the metal rod, place the long half cylinder clear plastic pipe and seal the ends with cotton.
4. Release some 5–10 crickets/cockroachcs into the tunnel.
5. Observe the behaviour of the animals inside the tunnels.
6. Remove the hot plates and ice from the ends of the metal rods.
7. Observe the change in the behaviour of the animals.

Discussion:

1. Observe whether the animals seek out a preferred temperature or do they remain dispersed.
2. Note down the temperature of the point of the tunnels where the animals aggregate.
3. Discuss your result in the class.

Temperature generally influences the behavioural pattern of animals. In temperate waters, the influence of temperature on the behaviour of wood borers is profound. For example, in the winter months in general, both Martesia and Teredo occur in smaller numbers in comparison with **Bankia campanulaia** whose intensity of attack is highest during the winter months. Further, the advantage gained by certain cold blooded animals through thermotaxis or orientation towards a source of heat are quite interesting. Ticks locate their warm blood hosts by a turning reaction to the heat of their bodies. Certain snakes such as rattle snake, copper heads, and pit vipers are able to detect mammals and birds by their body heat which remains slightly warmer than the surroundings.

Even in the dark, these snakes strike on their prey with an unnerving accuracy, due to heat radiation coming from the prey. The arrival of cold weather in temperate zones causes the snakes to coil up and huddle together.

However, changes in temperature conditions affect the normal adaptational behaviour of animals. For example, animal species that hibernate throughout winters end their hibernation sooner than normal due to intense climatic changes. This disruption from normal hibernation could mean life or death for these species. Migration patterns of many animal species have also been affected due to temperature change. One of the reasons for change in migration patterns is loss of habitat at either end of the migratory route. Another reason for change is that some animals are travelling farther towards higher altitudes in search of colder climates, invading the territory of already established species. Many animals cover long distances to reach warmer climates for breeding purposes. However, the devastation of migratory route or loss of habitat has forced these species to either change or not migrate at all. The same is happening for aquatic animals.

13.6 TEMPERATURE CONTROLS IN PLANTS

ACTIVITY 6

Select a plant grown in extreme cold and hot environments.
Study the plant grown in hot climate and the plant grown in cold climate.
Point out various adaptive features of the plants.
Make a PowerPoint presentation and present it in the class.

Like all the other living organisms, plants depend on enzymes catalyzed chemical reactions for their growth and development. For example, plants synthesize their own food from water and carbon dioxide using sunlight through photosynthesis. The process of photosynthesis involves a series of complex enzyme system and other proteins. Therefore, along with carbon dioxide, water, light, nutrients and humidity, temperature is also one of the limiting factors for growth and development of plants.

Unlike animals, plants remain fixed in a particular site and absorb heat from the sunlight. The excess heat from the body is released to the surrounding through radiation and evaporation. The process of evaporation of water from the leaves and stem of plants to the surrounding environment is known as **transpiration**. It occurs through **stomata**, small opening located on

the underside of the leaves. The stomata are specialized cells in the leaves which can open or close, limiting the amount of water vapour that can evaporate. Higher temperature causes the opening of stomata whereas colder temperature causes the opening to close. The opening of the stomata and hence the transpiration rate of plants depends on environmental conditions such as light, temperature, the level of atmospheric CO_2 and relative humidity. Higher relative humidity leads to more opening, while higher CO_2 levels lead to closing of stomata. Under high environmental temperature, the plant body gets heat up. In order to cool down, the plant increases its transpiration rate. The evaporative loss of water from the plant's body lowers the temperature.

Besides transpiration, many plants have different adaptations that help them survive in extreme temperature conditions ranging from hot and arid deserts to cold and snow covered mountains. These adaptations make it difficult for the plant to survive in a different place other than the one they are adapted to. This explains why certain plants are found in one area, but not in another. For example, cactus plants, adapted to desert conditions can't survive in the Arctic. These adaptations will be discussed later in this unit.

13.6.1 Effect of Temperature Changes on Plants

The most obvious effect of temperature on plants is changes in the rate of photosynthesis and respiration. Both processes increase with rise in the temperature upto a certain limits. However, increase in temperature beyond the limits, the rate of respiration exceeds the rate of photosynthesis and the plants productivity decreases.

Another important effect of temperature is during the process of **germination** of seeds. Like most other processes it also depends on various factors including air, water, light, and, of course, temperature. In many plant species, germination is triggered by either a high or low temperature period that destroys germination inhibitors. This allows the plant to measure the end of winter season for spring germination or end of summer for fall germination. For example, winter adapted plant seeds remain dormant until they experience cooler temperatures. Temperature of 4°C is cool enough to end dormancy for most cool dormant seeds, but some groups, especially within the family Ranunculaceae and others, need conditions cooler than –5°C. On the other hand, some plants like Fire poppy (*Papaver californicum*) seeds will only germinate after hot temperatures during a forest fire which cracks their seed coats. The fire does not cause direct germination, rather weakens the seed coat to allow hydration of the embryo.

Pollination is another phenological stage of plants sensitive to temperature extremes across all species. Since pollination is carried out by pollinators like honey bees, butterflies etc., any factors including temperature that affect these pollinators will certainly affect the process.

Heat Adapted Plants

In extremely hot and dry desert region with annual rainfall averages less than 10 inches per year, and there is a lot of direct sunlight shining on the plants, the main strategy for the survival of the plants is to avoid extensive water loss through transpiration. Therefore, in such region many plants called **succulents**, like cactus can store water in their stems or leaves. Some plants are leafless or have small seasonal leaves that only grow after rains. These leafless plants conduct photosynthesis in their green stems. Leaves are often modified into spines to discourage animals from eating plants for water. Also waxy coating on stems and leaves help reduce water loss. Other plants have very long root systems that spread out wide or go deep into the ground to absorb water.

On the other hand, in hot and humid tropical rainforest, the abundance of water can cause problems such as promoting the growth of bacteria and fungi which could be harmful to plants. Heavy rainfall also increases the risk of flooding, soil erosion, and rapid leaching of nutrients from the soil. Plants grow rapidly and quickly use up any organic material left from decomposing plants and animals. The tropical rainforest is very thick, and not much sunlight is able to penetrate to the forest floor. However, the plants at the top of the rainforest in the canopy must be able to survive the intense sunlight. Therefore, the plants in the tropical rainforest usually have large leaves with drip tips and waxy surfaces allow water to run off easily. Some plants grow on other plants to reach the sunlight.

Similarly, in aquatic plants adapted for life in water, the leaves are very large, fleshy and waxy coated. Increase surface area allows plants to lose excess water while the shiny wax coating discourages the growth of microbes. The roots and stems are highly reduced since water, nutrients, and dissolved gases are absorbed from the water directly through the leaves.

Cold Adapted Plants

In extremely cold region like tundra which is characterized by a permanently frozen sub-layer of soil called **permafrost**, the drainage is poor and evaporation slow. With the region receiving very little precipitation, about 4 to 10 inches per year usually in the form of snow or ice, plant life is dominated by small, low growing mosses, grasses, and sedges. Plants are darker in colour, some even red which helps them absorb solar heat. Some plants are covered with hair which helps keep them warm while others grow in clumps to protect one another from the wind and cold.

In a slightly warmer temperate forest, with temperature varies from hot in the summer to below freezing point in the winter, many trees are deciduous that is they drop their leaves in the autumn to avoid cold winter, and grow new ones in spring. These trees have thin, broad,

light-weight leaves that can capture a lot of sunlight to make a lot of food during the warm weather and when the weather gets cooler, the broad leaves cause too much water loss and can be weighed down by too much snow, so the tree drops its leaves. They usually have thick bark to protect against cold winters.

SELF EVALUATION

Complete with appropriate terms:

(i) Piloerection helps in ..... .

(ii) ..... can regulate their body within a narrow range.

(iii) ..... receptors detect pain due to extreme cold or heat.

(iv) ..... is responsible for maintaining homeostasis.

(v) Plants in tropical forests have ....., and ..... .

(vi) Plants in cold regions shed their leaves to ..... .

13.7 SUMMARY

- Endotherms or warm-blooded animals are those animals that actively maintain a stable body temperature by generating heat.
- Ectotherms or cold-blooded animals are those animals whose body temperature depends on their surrounding environment.
- Ectotherms can conserve more energy while endotherms use their energy to maintain body temperature, hence remain active even in wide temperature changes.
- All the enzymes have an optimum range of temperature beyond which they cease to function.
- Temperature is one of the most important factors which directly or indirectly influence the distribution of organisms to a large extend.
- Temperature above or below the limits of tolerance can have various effects on animal's body including cells, metabolism, reproduction etc.
- Bergmann's rule states that animals living in the colder climates tend to be larger than those living in warmer climates.
- According to Allen's rule, animals living in the colder climates have more rounded and compact form which is achieved by reducing the size of the body extremities i.e., ears, limbs, tails etc.
- The counter current heat exchanger is generally located in body extremities like limbs, neck, gills, which are directly in contact to the external environment and helps to conserve or loss body heat.
- Desert dwelling mammals and birds have specialized kidneys with long loops of Henle compared to animals that live in aquatic environments and less arid regions.

- Hibernation is the state of dormancy during the cold conditions, i.e., winter.
- Aestivation or summer dormancy is a state of animal dormancy, characterized by inactivity and a lowered metabolic rate, in response to high temperatures and arid conditions.
- Torpor is the state of decreased physiological activity in an animal, usually by a reduced body temperature and metabolic rate.
- Thermogenesis or mechanisms of heat production, such as shivering and chemical thermogenesis, are strongly inhibited when exposed to hot temperature.
- Ectotherms depends more on their behaviour to regulate their body temperature.
- Ectoderms can adjust metabolism and other essential rate functions so that reaction rates remain relatively constant even when body temperatures vary. This process is known as acclimatization or temperature compensation.
- A thermoreceptor is a sensory receptor which is basically the receptive portion of a sensory neuron that converts the absolute and relative changes in temperature to nerves impulses.
- The hypothalamus is a small, but extremely important part of the brain that acts as the link between the endocrine and nervous systems of the body.
- The primary motor centre for shivering is excited by the cold signals from skin and spinal cord and depress by heat.
- All animals have a preferred range of temperature conditions at which it functions most optimally.
- Changes in temperature conditions affect the normal behavioural adaptations of the animals.
- Plants also depends on enzymes catalyzed chemical reactions for their growth and development.
- The process of evaporation of water from the leaves and stem of plants to the surrounding environment is known as transpiration.
- The stomata are specialized cells in the leaves which can open or close, limiting the amount of water vapour that can evaporate.
- Temperature affects the photosynthesis, respiration, germination as well as pollination of plants.
- Plants adapted to hot and dry climate have reduced leaves and longer roots.
- The large waxy coated leaves of plants in tropical rainforest are waterproof and help in losing water more easily.
- Small, low growing mosses, grasses, and sedges are the characteristics of extremely cold region like tundra.

13.8 GLOSSARY

- **Adaptive thermogenesis:** Heat production by metabolic processes in response to environmental temperature.
- **Aestivation:** State of animal dormancy, characterized by inactivity and a lowered metabolic rate, in response to high temperatures and arid conditions.
- **Hibernation:** State of dormancy during the cold conditions, i.e., winter.
- **Hyperthermia:** Condition when the body temperature is higher than normal.
- **Hypothermia:** Condition of low body temperature.
- **Torpor:** State of decreased physiological activity in an animal, usually by a reduced body temperature and metabolic rate.
- **Transpiration:** The process of evaporation of water from the leaves and stem of plants to the surrounding environment.

13.9 UNIT ASSESSMENT

Do all these exercises in your exercise book.

I. State whether the following statements are True (T) or False (F)

1. All the living organisms have a particular range of temperature within which they can best survive and reproduce.
2. Nocturnality is the simplest form of behavioural adaptation characterized by activity during the day and sleeping during the night.
3. Crepuscular animals take advantage of the slightly cooler mornings and evenings to escape the daytime heat, and to evaporate less water.
4. Body temperature of Ectotherms rely on the external temperature.
5. Thermoregulation in endotherms depends on food and water availability.
6. Invertebrates, most of the thermo receptors are found in skins.
7. Changes in temperature conditions do not affect the normal adaptation behaviour of animals.
8. Hibernation is the state of dormancy during the cold conditions, i.e., winter.
9. Most of the heat in our body is generated through metabolic activity.
10. Larger animals can easily lose their body heat to their surrounding environment.

II. Multiple Choice Questions

1. The physical movement of animals over a long distance from one area to another is known as ..... .
   (a) Hibernation (b) Aestivation
   (c) Migration (d) None of these
2. Large animals like lions prefer to hunt at night to ..... .
   (a) conserve water (b) avoid direct exposure to heat
   (c) utilise less energy (d) All of these
3. With rise in the temperature, the plant's rate of ..... increases.
   (a) respiration (b) photosynthesis
   (c) both (a) and (b) (d) None of these
4. Temperature of ..... depends on the temperature of external environments.
   (a) Ectotherms (b) Endotherms
   (c) Both (a) and (b) (d) None of these
5. The state of reduced metabolic rate on a daily basis is an example of
   (a) Hibernation (b) Aestivation
   (c) Torpor (d) None of the above
6. Reptiles are
   (a) Ectotherms (b) Endotherms
   (c) Homeotherms (d) Heterotherms
7. Animals living in warmer climates have longer ears according to
   (a) Bergmann's Rule (b) Allen's Rule
   (c) Gloger's rule (d) Jordon's rule
8. The process of increasing body temperature in response to the environmental temperature is known as
   (a) Acclimatization (b) Adaptive thermogenesis
   (c) Piloerection (d) Insulation
9. The waxy coating of leaves of aquatic plants helps to
   (a) Conserve water (b) Increase transpiration rate
   (c) Avoid growth of microbes (d) Float in water
10. The rate of transpiration of plants depends on environmental conditions such as
    (a) Temperature (b) Level of atmospheric CO_2
    (c) Relative humidity (d) All the above
11. Increased thyroxin level in our blood increase the rate of
    (a) Metabolism (b) Excretion
    (c) Muscle contraction (d) Food assimilation

III. Long Answer Type Questions

1. In your own words, explain the importance of temperature regulation.
2. Describe the morphological, physiological and behavioural adaptations to temperature changes in the environment.
3. Giving suitable examples, describe the responses to cold and hot conditions by endothermic and ectothermic animals.
4. Explain the role of the brain and thermo receptors in temperature regulation.
5. Describe the different processes in which plants minimise overheating.
6. In your own words, explain the importance of maintaining fairly constant temperatures for efficient metabolism.
7. List few adaptive features shown by plants inhabiting extreme cold and hot environments.
8. Why is thermoregulation assessed with health and disorder? How is thermoregulation correlated to the environment? What changes can help organism's survival?

Unit 14

Behaviour and Responses in Mammals

Key Unit Competence

To be able to explain the different forms of behaviour and responses and their importance in the survival of organisers.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- state the different types of behaviour.
- recall that the nervous system is responsible for coordinating behaviour.
- explain the different types of behaviour in terms of stimulus, receptor, nerves and effectors.
- explain how the types of behaviour result from sequential responses.
- apply knowledge of reflex actions to describe the components of a reflex arc and explain the different reflex behaviours.
- distinguish between simple reflex actions and a fixed action pattern.
- give examples of imprinting and understand its significance.
- explain the value of habituation.
- define the terms: conditioning, habituation, survival, courtship behaviour and migration.
- analyse the forms of conditioning.
- analyse the contribution of innate behaviour and learned behaviour to an animal's overall behaviour and survival.
- distinguish between classical and operant conditioning.
- analyse the significance of latent learning.
- relate learning and response to survival in the environment.
- discuss the advantages and disadvantages to organisms living in societies.
- describe how birds and mammals maintain their territory.
- explain the significance of behavioural rhythms.
- distinguish between migration and dispersion.
- discuss the advantages of bird migration.
- appreciate the importance of animal welfare.
- value the causes and effects of bird and other animal migration.

- show concern for the behaviour of animals in societies.
- acknowledge the need for a territory by some animals for their continued survival.
- show concern for the importance of conditioned reflex in relation to survival.

14.1 INTRODUCTION

ACTIVITY 1

Watch videos of animals from the internet or on television. Try to observe their behaviours and responses. Discuss and make an elaborative report on it. ue the following internet link: *https://www.youtube.com/results?search_query=animal+behavious&sp=EgIwAQ%253D%253D*

Behaviour can be defined more precisely as an internally directed system of adaptive activities that facilitate survival and reproduction. A stimulus is an environmental change that directly influences the activity of an organism. Behaviour is a result of sensory and motor integration in an organism i.e., nervous system includes sensory cells that detect changes in environment. Nerve cells transmit and integrate information, chemical messengers transmit information into body and muscle cells translate information into action.

Orientation behaviours are coordinated movements (walking, flying, swimming, etc.) that occur in response to an external stimulus. These behaviours have adaptive value for survival by helping the organism to locate (or avoid) the source of a stimulus. The simplest behaviours involve input from only a single sensory receptor whereas more advanced behaviours require bilateral input from a pair of receptors.

14.2 TYPES OF BEHAVIOUR

Behavioural activities are divided into two groups: Innate and Learned

14.2.1 Innate Behaviour (Simple Response)

Innate behaviour, also known as inherited behaviour, is genetically programmed. Individuals inherit a suite of behaviours just as they inherit physical traits such as body colour and wing venation. In general, innate behaviours will always be:

1. Heritable — encoded in DNA and passed from generation to generation
2. Intrinsic — present in animals raised in isolation from others
3. Stereotypic — performed in the same way each time by each individual
4. Inflexible — not modified by development or experience
5. Consummate — fully developed or expressed at first performance

Since innate behaviour is encoded in DNA, it is subject to genetic change through mutation, recombination, and natural selection. Just like physical traits, innate behaviours are phylogenetic adaptations that have an evolutionary history.

In general, innate behaviours are viewed as "programmed" responses to external stimuli. They usually fit into one of the following categories:

A. Automatic Innate Behaviour

ACTIVITY 2

Take some moist soil with woodlice and place it on paper. Place earthworm near the light source.

Note the activity of woodlice and earthworm.

Discuss how animals orient in both activities of taxis and kinesis.

Also state and cite any such behaviour.

The most basic unit of innate behaviour is a simple reflex arc. This is a neural pathway that may involve as few as two neurons: a sensory neuron detects a stimulus and is linked with a motor neuron that sets off a response in an effector cell (such as a muscle or a gland cell). More commonly, reflex arcs also include an association neuron spliced between the sensory and motor neurons. The association neuron also synapses with other neurons to relay information to the brain and other parts of the body.

Examples of automatic innate behaviour are:

1. **Reflex arc:** When you touch a hot object, you quickly pull your hand away using the withdrawal reflex (Figure 14.1). Reflex action is different from fixed action pattern Firstly, reflex action is a simple motor action, stereotype and repeatable but fixed action is complex motor act, involving a specific temporal sequence of component acts. Secondly, reflex is elicited by a sensory stimulus and the strength of the motor action being graded with intensity of the stimulus while fixed action pattern are generated internally or elicited by a sensory stimulus. This stimulus acts as a trigger, causing release

of coordinated motor act. Action may be graded in intensity and it may be contingent on the type of sensory stimulus but maintain its basic pattern. Most insects have simple "startle" reflexes triggered by small disturbances as well as more comprehensive "escape" reflexes triggered by larger disturbances.

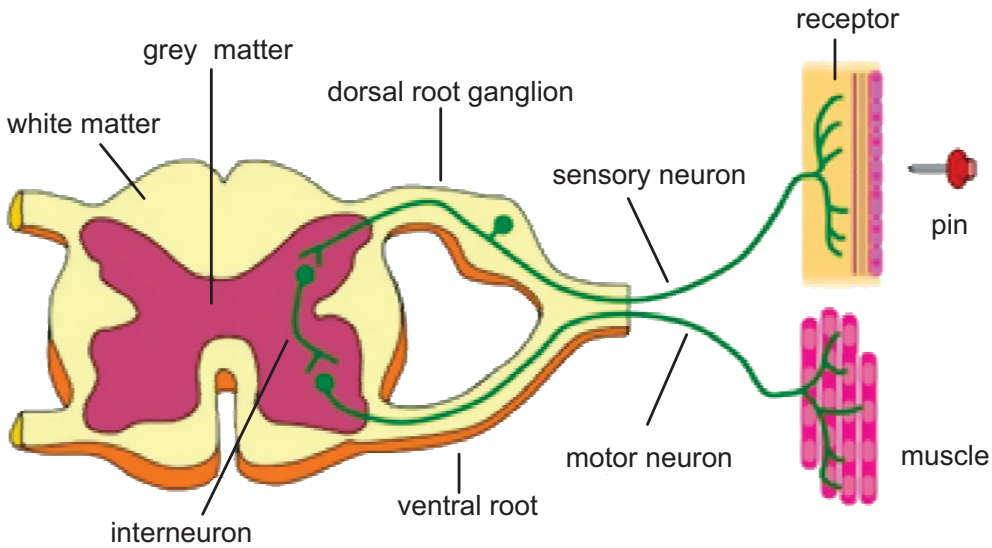


Figure 14.1: Showing the reflex action pattern

While **Fixed Action Pattern (FAP)** is a sequence of coordinated movements that are performed together as a "unit" without interruption. Each FAP is triggered by a unique stimulus variously known as a sign stimulus, a key stimulus, or a releaser. A praying mantis striking at prey is a typical example. The releaser for this FAP is any movement by a small (prey-sized) object within striking distance. Once initiated, the mantis cannot change direction in mid-strike or abort the mission if the prey escapes. Other common examples of FAPs include courtship displays, hunting or food gathering, nest-building activities, and attack or escape movements. Unlike simple reflexes, FAPs may involve a whole-body response and often require a threshold level of internal readiness (drive).

2. **Fight-or-flight response:** It mobilizes the body for greater activity. Your body is being prepared to fight or run from danger (Figure 14.2). It is controlled by hormones and the nervous system.

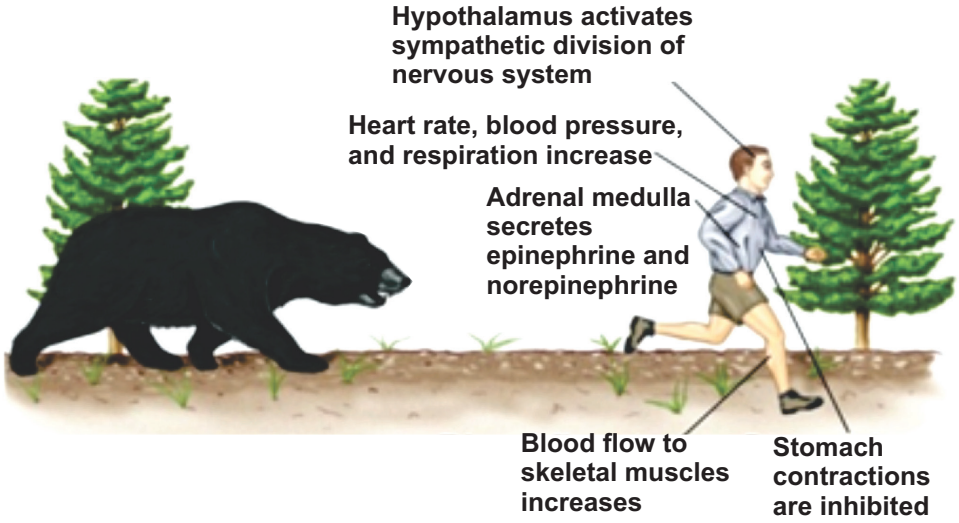
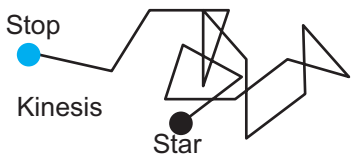


Figure 14.2: A fight-or-flight response

3. **Taxis:** It is a movement directly toward (positive) or away from (negative) a stimulus. A klinotaxis involves side-to-side motions of the head or body with successive comparison of stimulus intensity as the animal moves forward. A tropotaxis requires bilateral input from paired sensory receptors such that the signal is equalized in both receptors. Stimulus intensity increases with movement toward the source and decreases with movement away from the source. For example: Movement of cockroaches away from a light source.
4. **Kinesis:** It is a change in the speed of movement (orthokinesis) or a change in the rate of turning (klinokinesis) which is directly proportional to the intensity of a stimulus. Input from only a single sensory receptor is necessary. A kinesis is non-directed orientation, that is, the animal exhibits a "random walk".

   Example: Locomotion of woodlice in relation to humidity. With increased humidity there is an increase in the percentage time that the woodlice will remain stationary.



B. Instinct Innate Behaviour

An instinct is a complex pattern of innate behaviour. Instinctive behaviour begins when the animal recognizes a stimulus and continues until all parts of the behaviour have been performed. Examples of instinctive behaviour include Courtship, Territoriality and Migration. We will discuss these in detail later.

ACTIVITY 3

Make a list of innate and learned behaviour seen in animals. Note the points related to both behavioural types. Make a report on the same.

14.2.2 Learning

Learning, or learned behaviour, takes place when behaviour changes through practice or experience.

Learning allows an animal to adapt to change, an ability that is important for animals with long life spans (Figure 14.3). In general, learned behaviours will always be:

1. Non-heritable — acquired only through observation or experience
2. Extrinsic — absent in animals raised in isolation from others
3. Permutable — pattern or sequence may change over time
4. Adaptable — capable of modification to suit the changing conditions
5. Progressive — subject to improvement or refinement through practice

Figure 14.3: Learning behaviour: A trainer is teaching the actions to dogs.

A. Habituation

A simple form of learning in which an organism decreases or ceases its response to a stimulus after repeated presentations. It is progressive decrease of the amplitude or frequency of a motor

response to repeated sensory stimulation that is not caused by sensory receptor adaptation or motor fatigue. Habituation provides an important mechanism for filtering sensory information, as it allows filtering out irrelevant stimuli and thereby focusing on important stimuli, a prerequisite for many cognitive tasks.

Example: Horses or cows disregarding noisy cars and scare crow habituation to crows.

Figure 14.4: Crows have habituated to the scare crow

B. Imprinting

It is a form of learning in which an animal, at a specific critical time of its life, forms a social attachment to another animal. During this brief interval, the animal acquires an indelible memory of certain salient stimuli in its "home" environment (taste of the host plant, smell of the nest site, etc.). This memory is retained throughout life and recalled later when needed.

Example: Relation between mother and new born (Figure 14.5).

Figure 14.5: Ducklings showing the imprinting behaviour

Behavioural imprinting acts as an instinct for survival in newborns. The offspring must immediately recognize its parent, because threatening events, such as the attack by a predator or by other adults could occur just after hatching. Thus, imprinting is very reliable to induce the formation of a strong social bond between offspring and parent, even if it is the wrong one. Birds learn the characteristics of their siblings, which later on will influence their mating preferences as adults.

14.3 CONDITIONING AND LATENT LEARNING

Learning that a particular stimulus or a particular response is linked to a reward or punishment is called conditioning.

14.3.1 Classical Conditioning

ACTIVITY 4

Discuss about the Pavlov's experiment.

Write down the interpretation of the experiment in your exercise book.

Cite some examples of classical conditioning.

It is a learning process in which an innate response to a potent stimulus comes to be elicited in response to a previously neutral stimulus; this is achieved by repeated pairings of the neutral stimulus with the potent stimulus. Eventually, the animal learns to respond to the stimulus even in the absence of a reward or punishment. The scientist Ivan Pavlov conducted a famous experiment on classical conditioning in which he trained a dog to salivate at the sound of a bell.

Example: Ivan Pavlov's classical conditioning experiment (Figure 14.6).

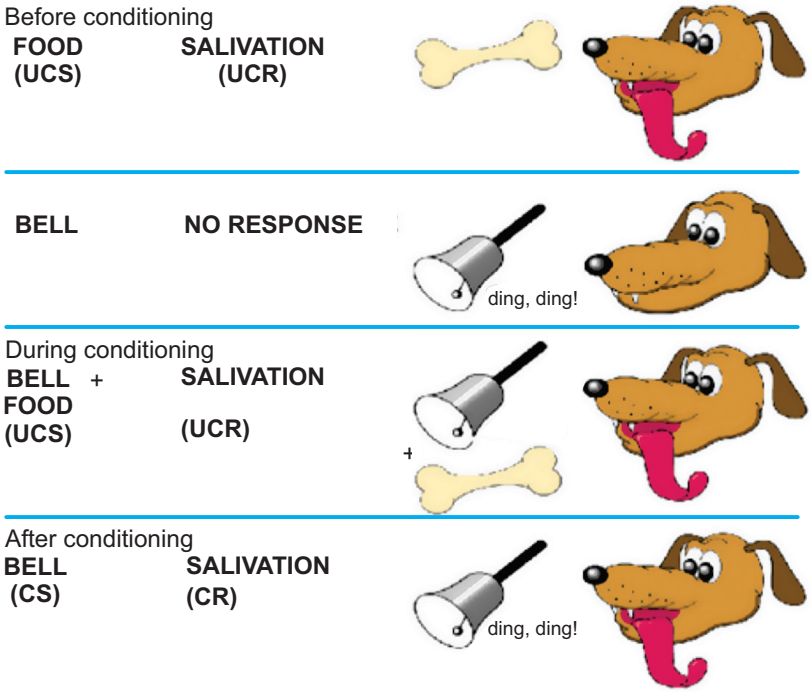


Figure 14.6: Pavlov's experiment showing the classical conditioning

14.3.2 Operant Conditioning (Learning by Trial and Error)

An animal learns to associate one of its own behavioural acts with a positive or negative effect. The animal tends to repeat the response if it is rewarded, but avoids the response if it is harmed. For example, predators quickly learn to associate certain kinds of prey with painful experiences. A coyote may learn the hard way not to attack a porcupine nose-first. Learning by trial and error often reinforces behaviours that are important to survival. In this an animal receives a reward for making a particular response. Motivation is an internal need that causes an animal to act, and is necessary for learning to take place.

Examples: Learning to ride a bike or birds using different materials to build a nest until it is just right (Figure 14.7).

Figure 14.7: Riding a bicycle showing operant conditioning behaviour

14.3.3 Insight Learning

It is most complex type of learning in which an animal uses previous experience to respond to a new situation. It involves the ability to analyze problems and to test possible solutions. Insight is not technically a form of learning. Furthermore, insight may itself be based on trial-and-error experience with related problems.

Example: A chimpanzee was placed in a room with several boxes on the floor and a banana hung high above its head. The chimp eventually "sized up" the situation and then stacked the boxes in order to reach the food (Figure 14.8).

Figure 14.8: Chimpanzee showing Insight learning behaviour.

14.3.4 Latent Learning

ACTIVITY 5

Collect information about the latent learning behaviour. Write down the points related to latent learning.

Discuss the significance of latent learning.

It is a form of learning that is not immediately expressed in an overt response; it occurs without any obvious reinforcement of the behaviour or associations that are learned. Latent learning implies that learning can take place without any behavioural changes being immediately present. This means that learning can be completely cognitive and not instilled through behavioural modification alone. This cognitive emphasis on learning was important in the development of cognitive psychology. Latent learning can be a form of observational learning (i.e., learning

through observing the behaviour of others), though it can also occur independently of any observation.

Example: A rat completes a maze several times, without an incentive. The rat learns the maze very slowly (Figure 14.9). When food is placed at the end of the maze, the rat completes the maze very quickly, demonstrating that latent learning had occurred and a cognitive map of the maze was informed.

Figure 14.9: Rats are showing latent learning behaviour

SELF EVALUATION

Complete with approprite terms:

(i) ..... is a sequence of coordinated moments that are performed together as a unit.

(ii) Animal exhibiting a random walk is an example of animal showing ..... or non-directed orientation.

(iii) Ducklings show ..... behaviour.

(iv) ..... is a learning that a particular response in linked to a reward or punishment.

(v) ..... learning involves previous experience to respond to a new situation.

(vi) Birds show ..... behaviour while building nests with different materials until it is right.

14.4 SOCIAL BEHAVIOUR

Social behaviour is any action directed by an individual towards a member of its species. It includes competitive behaviour such as fighting, threat and submission and co-operative interactions like parental care and mating. All mammals show social behaviour.

14.4.1 Social Communication

It is defined as the passage of information from one individual to another and usually results in the modification of the recipient's behaviour or physiological state. A social signal is a

behaviour which has evolved to convey information to a non-specific receiver with the object of modifying its behaviour for the benefit of the signaller.

Types of social signal

1. Discrete
2. Graded

Examples: For discrete social signal: alarm call of a ground squirrel, a chemical signalling oestrus or the territorial song of a gibbon.

For graded signal: aggressive vocalizations and threats displays.

14.4.2 Altruism

When an individual expends energy or runs risks in helping another, its behaviour is termed as altruistic. Altruistic behaviour lowers the fitness of the altruist, while increasing that of the recipient.

Three theories have been suggested in attempts to accommodate altruism within current evolutionary theory.

1. **Group selection:** In this group of people who support and help one another may have an advantage over the groups whose members are selfish. Major drawback is that it is not a stable strategy because some selfish individuals in an altruistic group would inevitably increase their own fitness at the expense of altruistic group members.
2. **Kin selection:** Proposed by Hamilton, the evolutionary strategy which favours the reproductive success of an organism's relatives, even at a cost to the organism's own survival and reproduction. Kin altruism is an altruistic behaviour whose evolution is driven by kin selection. Kin selection is an instance of inclusive fitness, which combines the number of offspring produced with the number an individual can produce by supporting others, such as siblings.

   Example: In humans, it depends how closely related they are to the recipient.

Vervet monkeys use allo-mothering, where related females such as older sisters or grandmothers often care for young-ones, according to their relatedness.

14.4.3 Reciprocate (Reciprocal Altruism)

It is a behaviour whereby an organism acts in a manner that temporarily reduces its fitness while increasing another organism's fitness, with the expectation that the other organism will act in a similar manner at a later time.

Conditions for reciprocal altruism:

1. The behaviour must reduce a donor's fitness relative to a selfish alternative;
2. The fitness of the recipient must be elevated relative to non-recipients;
3. The performance of the behaviour must not depend on the receipt of an immediate benefit;

Example: In primates, Vervet monkey shows that among unrelated individuals, grooming induces higher chance of attending to each other's calls for aid. However, Vervet monkeys also display grooming behaviours within group members, displaying alliances.

Advantages of living in social groups

1. Animals are more successful in finding food if they search as a group. Foraging in a group makes it easier to capture a prey. Example: Dolphins are known to surround a school of fish and to take turns darting into the centre to eat the fish that are trapped in the middle. Many carnivores will band together when they try to capture large prey.
2. Animals live in social groups to get protection. Example: One baboon might not be able to fight off a leopard; a troop of baboons often are able to do so.
3. More individuals cooperating together, some can serve as sentries looking for danger while the other group members are eating or sleeping. Example: Prairie dogs normally have some individuals acting as sentries, which makes it nearly impossible to sneak up on a prairie dog town.
4. Many prey species travel in groups because their movements are highly coordinated. Example: Schools of fish and flocks of shorebirds. This behaviour creates confusion for the predator.
5. Some animals form social groups to make travel easier. Example: Canada geese and other bird species typically fly in a V formation in order to reduce wind resistance.
6. Some animals congregate in close proximity in cold weather in an effort to stay warm.

Disadvantages of living in social groups

1. Increased sickness and disease: Animals living in groups face higher risks of infection than others.
2. Increased vulnerability to predators: Animals living in social groups get protection but they also have difficulty seeking hide during attack.
3. Increased competition for food.
4. Increased competition for mates.

14.5 COURTSHIPS, TERRITORIALITY AND DOMINANCE HIERARCHIES

14.5.1 Courtship

It is the behaviour that males and females of a species carry out before mating. It communicates to each of the potential mates that the other is not a threat. It also reveals information to each animal that the species, gender, and physical condition of the other are suitable for mating. Courtship allows one or both sexes to select a mate from several candidates.

Examples:

(a) **Rabbits:** Female usually secretes an airborne hormone scent, called **pheromone.** Once the male detects this scent, courtship behaviour could begin. The male and female sniff each other, possibly to make sure of each other's sex and mating receptivity. One bunny then dashes off with the other in hot pursuit. Once they stop playing hard to get, the bunnies stomp their feet and may do a little "dance" by kicking their feet in the air as they run.

(b) **Ferrets:** Courtship and mating in ferrets can be a bit noisy, prolonged and even ferocious event. Ferrets respond to the length of daylight and their natural breeding season is from March to August. When the female goes into estrus (heat) and is receptive, the male grabs her by the back of the neck. The male continues to bite the nape of the neck and the ferrets are pressed together. Mating occurs and may last for around one hour.

14.5.2 Territoriality

ACTIVITY 6

Research about the animal that lives in territories.

Study how they maintain their territories.

Write down the points about them in your exercise book.

Territoriality refers to the exclusive use of fixed space, which entails obtaining, defending, or advertising occupancy of the space. Animals divide geographical area around them into four broad regions:

1. Total range (entire area covered)
2. Home range (large area for all activities – feeding, sex and roaming is done)
3. Territory (small area within home ranges, driving away intruders and visited in days
4. Core area (within territory but much smaller)

Sizes of Territories

This varies from species to species depending on body size, group size, and habitat and food requirement. Size of territory depends on size and diet of animals.

Larger species have larger territories e.g., wildebeest, zebras. Predators have larger territories than plant eaters. Territories are smaller when food is found in abundance and distribution is not spread far. Territorial animals patrol their outer limits.

Functions of Territoriality

1. Well shaped aggregation of local population.
2. Well defined area for parental care.
3. Limitation of breeding population and control beyond carrying capacity.
4. Adequate food.
5. Reserve of unmated males and females for prompt replacement.
6. Reduction in rate of contracting parasites or diseases.
7. Helps intending against predators and share resources.
8. Collectively defence nests and young from predators.
9. Porters separate after breeding for short periods.

Example: Wolves maintain territories in which they hunt and live. These areas are aggressively defended from other group members. The male cougar has a large territory that may overlap with the territories of several females but is defended against other males. Responding to scent marks, the inhabitants of the overlapping ranges also avoid each other, except for breeding.

Figure 14.10: Wolves showing the territoriality behaviour

How they Mark their Territory

- **Scent marking:** Scent marking, also known as territorial marking or spraying when this involves urination, is a behaviour used by animals to identify their territory. Strong-smelling substances are present in urine, faeces, or secreted from scent glands located on various areas of the body. These scents contain pheromones or proteins that produce odours. These odours not only for communication, but can also mark the presence of territory.

  For example, leopards and jaguars mark their territory by rubbing themselves against vegetation. New World monkeys use urine washing to communicate.

In Blue wildebeest scent markings are secreted from two glands, the pre-orbital gland and a scent gland in the hoof.

- **Visual:** Ring-tailed lemurs hold their distinctive tails high in the air during territorial scent marking. They also engage in "stink fights" with intruding males.

  To mark the territory, visual sign-posts may be short-term or long-term. Short-term communication includes colouration or behaviour of the animal, which can only be communicated when the resident is present. But in case of long-term visual signals, faecal matter is deposited on the vegetation or ground.

  Some animals have prominent "badges" or visual displays to mark their territory with scent marking or auditory signals.

  The ring-tailed lemur (Lemur catta) marks its territory with urine scent. When it is urinating for marking purposes, it holds its extremely distinctive tail high in the air adding a visual component to the advertisement; when it is urinating for eliminative purposes; its tail is only slightly raised.

  After leaving urination mark, some animals scrape or dig the ground nearby, thereby leaving a visual advertisement of the territory. This includes domestic dogs.

- **Auditory:** Many animals use vocalizations to mark their territory. These are short-term signals transmitted only when the animal is present, but can travel long distances and over varied habitats.

  Examples of wolves marking their territories to other packs through a combination of scent marking and howling. Under certain conditions, wolf howls can be heard over areas of up to 130 km^2 (50 sq mi). When howling together, wolves harmonize rather than chorus on the same note, thus creating the illusion of there being more wolves than there actually are. Wolves from different geographic locations may howl in different fashions– the howls of European wolves are much more protracted and melodious than those of North American wolves, whose howls are louder and have a stronger emphasis on the first syllable.

Ways to Defend their Territories

(a) Ritualized aggression: Animals use a range of behaviours to intimidate intruders and defend their territories, but without engaging in fights which are expensive in terms of energy and the risk of injury. This is ritualized aggression. Such defence frequently involves a graded series of behaviours or displays that include threatening gestures such as vocalizations, spreading of wings or gill covers, lifting and presentation of claws, head bobbing, tail and body-beating, and finally, direct attack.

Examples:

(i) Domestic cats (Felis catus) are very territorial and will defend this with ritualized body-posturing, stalking, staring, spitting, yowling and howling (Figure 14.11).

Figure 14.11: Two domestic cats posturing during ritualised aggression over a territory

(ii) Spider monkeys (genus Ateles) defend their territory by screams, barks, rattling or dropping branches, and urinating and defecating on intruders below.

(iii) Male ring-tailed lemurs have scent glands on their wrists, chests, and in the genital area. During encounters with rival males, they may perform ritualised aggression by having a "stink fight".

(b) Aggressive behaviour threatens other animals: Aggressive behaviour is used to intimidate another animal of the same species (Figure 14.12).

Figure 14.12: Aggressive behaviour of dog

14.5.3 Dominance Hierarchies

It is defined as a form of animal social structure in which a linear or nearly linear ranking exists, with each animal dominant over those below it and submissive to those above it in the hierarchy. It is present in mammals like baboons, wolves, etc.

Types of Dominance Hierarchies

Linear Hierarchy

This kind of dominance hierarchy can be depicted with the help of a hierarchy pyramid. Here, individuals on a particular level use their power to dominate on other individuals that are in lower order or level but at the same time, they tend to be submissive to individuals in orders above them. Such individuals can be seen to get influenced by social interactions and they also tend to have a much better access to food and other facilities.

Despotic Hierarchy

In this, one single individual is dominant on the rest of the group or clan. The orders and instructions given by the pack leader or the troupe leader are followed submissively by the rest of the group members. There is no fight for superiority between the followers.

Effects of Dominance Hierarchy

Individuals in higher order have a better and prior access to food. Individuals in the lower order get the left over feed after the dominant individual has had its feed. This alpha position also brings better mating opportunities thereby increasing the chances of reproductive success and a healthier offspring. In case of species, where a single female mates with multiple males, the males naturally tend to be more aggressive to gain the dominant or alpha position.

An important aspect connected to dominance hierarchy is that of territorial advantage in favour of dominant individuals. This territorial advantage is important from point of view of nesting place, mating locations and ample supply of food.

In case of weakening or death of a dominant individual, the alpha position is assumed by one of the individuals of the immediate next order to the alpha position after a reasonable tussle between competing individuals. Once the dominant individual is selected, the aggression gradually subsides and the rest of the members turn submissive.

Examples: Pack Animals

Animals that move around in packs such as wolves, wild dogs, hyenas, etc. Wolves or wild dogs that are in dominant position have a habit of marking their territories or dens by spraying their urine at prominent locations around their territory. This is an instant signal for other pack members that this territory is off limits for them. Similarly, such marking helps keep prey animals

away from the dominant individual's territory. It is easy to identify the dominant male when the pack is defending itself from a rival pack. At such times, the dominant male is usually the one with long puckered up ears and a straight vertical tail. Amongst the hyenas however, the alpha position is always assumed by females.

SELF EVALUATION

Complete with appropriate terms:

(i) Animals living in groups face ..... risk of infection.

(ii) Courtship and mating in ferrets is ....., ... and ..... .

(iii) Territorial marking is also known ..... .

(iv) Aggressive behaviour ..... other animals.

(v) ..... hierarchy involves one single individual dominance.

14.6 BEHAVIOURAL RHYTHMS AND BIOLOGICAL CLOCKS

ACTIVITY 7

Observe all the activities which are regulated by biological clocks.

You may watch downloaded videos of animals exhibiting such behaviour.

Write down and discuss them in your exercise book.

14.6.1 Behavioural Rhythms

They are periodic biological fluctuation in an organism that corresponds to, and is in response to, periodic environmental change. These rhythms are the repeating patterns of biochemical, physiological, and behavioural processes. They are found in most living things, including plants, animals and many microorganisms.

These rhythms allow animals of different species to share the same food sources without direct competition because some animals are active only during hours of darkness (i.e., they are nocturnal) while others are active only during the day (diurnal). The advantage to having a built-in method of responding to light and darkness, rather than relying on actual changes in light as a cue, is that, in effect, the organism is prevented from "sleeping late" and missing the optimal time of day for foraging.

Most common biological rhythm is the **circadian rhythm** (circa- *about* plus dian- day). The circadian rhythm is a rest-activity cycle that is centered on light, meaning when a preset amount of light occurs, an animal will be active; and at another time the animal will rest. Humans are

active when there is a lot of light, which is usually during the day and rest when there is less light, usually at night. These circadian rhythms control the core human body temperature, sleep-wake cycle and secretion of hormones.

Hibernation and migration are the examples of biological rhythms.

Examples: Ground squirrels gather rations and pack on fat reserves in the fall in preparation for cold winters spent underground.

Moose reproductive cycles match the birth of fawns in the spring to the rich emergence of forage at that time.

Human core body temperature cycles with a low during the middle of their sleep cycle and highs around lunch time and early evening.

14.6.2 Biological Clocks

Biological Clocks are self-sustaining oscillators which will continue to a period of free-running cycling even in the absence of external cues. Biological Clocks exhibit a high degree of inheritance, independence of temperature and social conditions, strong resistance to pharmacological and chemical disruption, may even be expressed at the level of single cells.

When an animal that functions according to such a clock is rapidly translocated to a geographic point where the environmental cycle is no longer synchronous with the animal's cycle, the clock continues for a time to function synchronously with the original environmental cycle. Humans similarly transported over great distances often experience fatigue and lowered efficiency for several days, a phenomenon known as "jet lag," or jet syndrome (Figure 14.13).

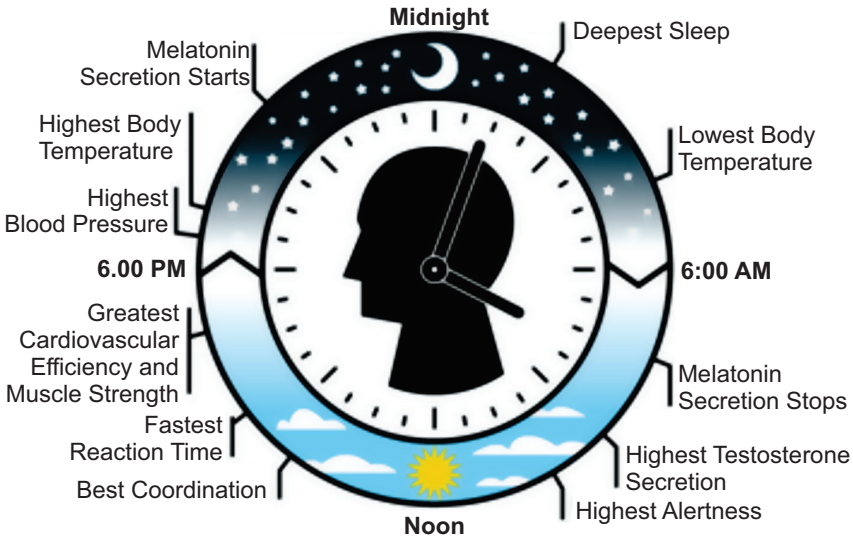


Figure 14.13: Biological clocks of human being

14.7 ANIMAL MIGRATION

ACTIVITY 8

Research about the migratory birds.Using the following internet link: *https://www.google.com/search?as_st=y&tbm=isch&hl=en&as_q=animal+migration&as_epq=&as_oq=&as_eq=&imgsz=&imgar=&imgc=&imgcolor=&imgtype=&cr=&as_sitesearch=&safe=images&as_filetype=&tbs=sur%3Afmc*

Note the activities for which migratory birds do migrate.

Write down the advantages of the migration.

It is termed as periodic movements of animals away from and back to their place of origin. It is done annually. Animals migrate to other places with more suitable conditions of temperature, food, more favourable living or breeding places and hibernation.

Example: African antelopes migrate seasonally to avoid drought. Fur seals and many whales make ocean voyages of thousands of miles to their breeding grounds, the former coming ashore on islands. Little brown bat live on trees in warm weather, but in cold weather they migrate to caves for warmer conditions.

14.7.1 Causes of Migration

- External pressures like temperature, drought, food shortage.

  For example, most of the mule deer of Yellow stone Park, migrate between summer and winter pastures, but those living near hot springs, where grazing is available all year, do not.
- Physiological and environmental changes.

  Example: Birds migrate due to cycle of enlargement of the reproductive organs in spring and their reduction in fall. Variation in day length is the chief external stimulus for this cycle: light received by the eye affects production of a hormone by the anterior pituitary gland, which stimulates growth of the reproductive organs.

14.7.2 Advantages of Migration

- Animals remain in favourable conditions e.g., avoid cold/extremes.
- Parents and offspring grow larger and therefore have a high survival rate, they leave more offspring.
- The population has a constant supply of food.
- Migration may lead to the colonization of a new area.
- Reduces diseases as the disease doesn't always have a host in the area.

- Reduces effect of predation habitats that have abundant food sources year-round also attract a greater number of predators that can threaten the nests.
- Birds that migrate to different habitats can avoid that onslaught of predators, giving their young-ones a better chance of reaching maturity.
- Because many different populations often meet at the "breeding grounds", migration increases genetic diversity as they often breed with individuals from a different population.

14.7.3 Effects of Migration

- Migration increases diversity in the gene pool of the population.
- Migration increases competition for resources, habitat and breeding places.
- Migratory animals acting as vectors for disease, nutrients and energy, and other materials such as seeds across habitat or ecosystem boundaries.

Migration and Dispersal are different from each other. Migration is the movement of large number of species from one place to another like bird migration. While dispersal is the spreading of individuals away from others, often parents or siblings, which are left behind in original areas, for example: mammals move away from their social groups.

SELF EVALUATION

Complete with appropriate terms

(i) Migration increases ..... in the gene pool.

(ii) ..... are self-sustaining oscillators.

(iii) ....., and ..... are examples of biological rhythms.

14.8 SUMMARY

Activities that facilitate survival and reproduction.

- Genetically programmed behaviours like physical traits such as body colour and wing venation.
- The most basic unit of innate behaviour is a simple reflex arc.
- Animal recognizes a stimulus and continues until all parts of the behaviour have been performed.
- **Courtship behaviour:** Males and females of a species carry out this behaviour before mating.
- **Territoriality:** Exclusive use of fixed space, which entails obtaining, defending, or advertising occupancy of the space. Mark territories using pheromones, visual and auditory signals.

- **Ritualized aggression:** To intimidate intruders and defend their territories, but without engaging in fights which are expensive in terms of energy and the risk of injury.
- **Dominance hierarchy:** Linear or nearly linear ranking exists, with each animal dominant over those below it and submissive to those above it in the hierarchy.
- Biological Rhythms are the repeating patterns of biochemical, physiological, and behavioural processes.
- Migration is movements of animals away from and back to their place of origin.
- Behaviour changes occur through practice or experience relates to learning.
- Habituation is a form of learning in which an organism decreases or ceases to respond to a stimulus after repeated presentations.
- Imprinting is a permanent attachment.
- Conditioning is a particular stimulus or a particular response linked to a reward or punishment.
- Latent learning is a form of learning that is not immediately expressed in an overt response.
- Social Behaviour is the action directed by an individual towards a member of its species. It includes competitive behaviour such as fighting, threat and submission and co-operative interactions like parental care and mating.
- **Group selection:** People who support and help one another may have an advantage over groups whose members are selfish.
- **Kin selection:** Favours the reproductive success of an organism's relatives, even at a cost to the organism's own survival and reproduction.

14.9 GLOSSARY

- **Behaviour** can be defined more precisely as an internally directed system of adaptive activities that facilitate survival and reproduction.
- **Biological** clocks are periodic biological fluctuation in an organism that corresponds to, and is in response to, periodic environmental change.
- **Conditioning** is a particular stimulus or a particular response is linked to a reward or punishment.
- **Habituation** is progressive decrease of the amplitude or frequency of a motor response to repeated sensory stimulation that is not caused by sensory receptor adaptation or motor fatigue.
- **Kinesis** is a change in the speed of movement (orthokinesis) or a change in the rate of turning (klinokinesis) which is directly proportional to the intensity of a stimulus.

- **Reciprocate** is a behaviour whereby an organism acts in a manner that temporarily reduces its fitness while increasing another organism's fitness, with the expectation that the other organism will act in a similar manner at a later time.
- **Reflex action** is different from fixed action pattern. Firstly, reflex action is a simple motor action, stereotype and repeatable but fixed action is complex motor act, involving a specific temporal sequence of component acts.
- **Taxis** is a movement directly toward (positive) or away from (negative) a stimulus.

14.10 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

I. State whether the following statements are True (T) or False (F)

1. Behaviour is precisely an external response directed internally.
2. Riding a bicycle is an innate behavioural activity.
3. In classical condition, animal learns to respond to the stimulus even in the absence of a reward or punishment.
4. Innate behaviour is also known as inherited behaviour.
5. Kinesis is no change in the speed of movement in presence of a stimulus.
6. Animals hibernate for food and breeding.
7. Touching something hot and pulling your hand back is a learned behaviour.
8. To mark their territories, animals use pheromones.
9. Latent learning is a form of learning which is immediately expressed.

II. Multiple Choice Questions

1. A trainer is teaching actions to dogs. It is
   (a) learning (b) imprinting
   (c) kinesis (d) courtship
2. What happens in a situation of fear?
   (a) heart rate decreases (b) blood pressure decreases
   (c) secretion of non-adrenaline (d) heart rate increases
3. Which behaviour activity is done before mating?
   (a) learning (b) habituation
   (c) courtship (d) imprinting
4. Territorial behaviour of animal provides:
   (a) shelter (b) food
   (c) breeding (d) all of the above

5. Periodic movement of animals from one place to another is called
   (a) migration (b) imprinting
   (c) conditioning (d) taxis
6. Which is an example of imprinting behaviour?
   (a) secretion of saliva (b) riding bicycle
   (c) newborn baby and mother (d) sacrificing life for others
7. In which behaviour are scent markings and visual signalling observed?
   (a) courtship (b) territorial
   (c) migration (d) habituation
8. Which of the following belongs to altruism?
   (a) Hamilton's rule (b) Pavlov's experiment
   (c) reflex arc (d) biological clock
9. Habituation behaviour is
   (a) period before mating
   (b) periodic movement from one place to other
   (c) structure in which a linear or nearly linear ranking exists
   (d) organism decreases or ceases to respond to a stimulus after repeated presentations

III. Long Answer Type Questions

1. Explain the different types of behaviour giving examples.
2. State the role of nervous system in coordinating behaviour.
3. Explain how the types of behaviour result from sequential responses.
4. Explain different reflex behaviours describing the components of a reflex arc.
5. Differentiate between simple reflex actions and a fixed action pattern.
6. Describe giving examples the forms of conditioning.
7. Explain the following stating their significance.
   (a) imprinting
   (b) conditioning
   (c) habituation
   (d) survival
   (e) courtship
   (f) behaviour
   (g) migration

8. Analyse and appreciate the importance of animal welfare. Also state behaviour of animals in society. Why do animals make territories?
9. Discuss the causes and effects of bird and other animal migration.
10. Differentiate the following:
    (a) classical and operant conditioning
    (b) migration and dispersion
11. Analyse the significance of latent learning. Relate learning and response to survival in the environment.
12. Explain the role of behavioural rhythms.
13. We all behave differently on different issues prevailing. What responses can effect a mental state of a diseased person? Surround your answer with logistics from AIDS patients. Also, advise on what treatment and behavioural response could generate pliable recovery for such patients.

Unit 15

Immune System, Vaccination and Antibiotics

Key Unit Competence

To be able to describe the immune system and apply the knowledge gained in familiar and unfamiliar contexts.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- state the origin and describe the mode of action of phagocytes.
- describe the modes of action of B-lymphocytes and T-lymphocytes.
- recognise phagocytes and lymphocytes under a light microscope.
- explain the meaning of the term immune response, making reference to the terms antigen, self and non-self.
- support and promote national immunisation days.
- explain the role of memory cells in long-term immunity.
- explain the role of antibodies in allergies.
- relate the molecular structure of antibodies to their functions.
- interpret the differences between cellular responses and humoral responses.
- distinguish between active and passive, natural and artificial immunity and explain how vaccination can control disease.
- distinguish between generalised and localised allergic reactions.
- discuss causes, symptoms and treatment of asthma and hay fever.
- support and have sympathy for asthmatic patients.
- discuss the reasons why vaccination programmes have eradicated smallpox but not measles, TB, malaria or cholera.
- define antibiotic as a substance produced by one microorganism that is capable of destroying or inhibiting the growth of another microorganism.
- explain how antibiotics work.
- explain the reasons for antibiotic resistance.
- carry out research and be able to present findings on the reasons for antibiotic resistance in the treatments of infections.

Introduction

For a very long time, people held the view that something in the thin air or foul air arising out of decomposing matter can cause illness. It was the pioneering work of scientists Louis Pasteur and Robert Koch who laid the foundation of germ theory of disease, showing for the first time that micro-organisms are responsible for causing various illnesses. Thus, in this unit, we study how our body fights with these micro-organisms to keep us healthy; how our immune systems are built; what is the role of vaccinations for building our immunity; and how in the event of extreme illness one resorts to the use of antibiotics to control infections.

For example the year 2020 will remain unforgettable because of the outbreak of the pandemic Covid-19.WHO declared covid-19 pandemic disease. Wearing mask, using hydro alcoholic sanitizer to wash hand and social distance were among the best preventive measures.Aged people and chronicle disease patients were warned to take care.

Who declared covid-19 pandemic disease?

Why aged people and chronicle disease patients were warned to take more care?

Why Covid-19 is considered as human threat?

15.1 IMMUNE SYSTEM

ACTIVITY 1

Observe the prepared slides of blood smear under microscope, first under 10 X and then under 40 X magnification. Draw what all you observe and try to answer the following:

(i) Do you see cells? (ii) Are they all similar? (iii) What are the differences between different types of cells? (iv) Which cells are most numerous? (v) What are they called? (vi) Which cells are less numerous? (vii) Are these cells all alike? (viii) What does the stain indicate?

We are exposed to micro-organisms all the time, as they are present in large numbers in the air we breathe, the food we eat and the water we drink. It is our defence system that keeps us free of disease and constitutes our immune system. Immune system has two main components: **Innate** and **Acquired.**

15.1.1 Innate Immunity

Innate immunity is present at birth and depends on:

(i) Anatomical and Physiological barriers,

(ii) White blood cells (mainly phagocytes)

(iii) Some soluble mediators

Anatomical and Physiological Barriers

Anatomical barriers consist of skin on the outside and mucous membranes lining gastro-intestinal tract, respiratory tract and genitourinary tract, while acidity in the stomach constitutes Physiological barriers.

Skin is the largest organ of our body and presents a physical barrier for pathogens to prevent their entry into the body. Some openings into the body are needed for the purpose of feeding, breathing and reproduction. They are also the potential sites of entry of pathogens from the environment. Therefore, the entire digestive tract, respiratory tract and genito-urinary tract are lined by mucous membrane which does not allow pathogens to gain entry into the tissues. High acidity within the stomach also helps to kill some pathogens ingested along with food.

White Blood Cells

White blood cells are the chief components giving us protection against infection.

When a blood smear is prepared, two types of cells can be identified: small, very numerous, without nucleus called red blood cells (RBC) because they contain red pigment, haemoglobin for oxygen transport and large, less numerous, with darkly staining nucleus called white blood cells (WBC), because they do not contain red pigment. Among the WBCs, different cell types can be distinguished:

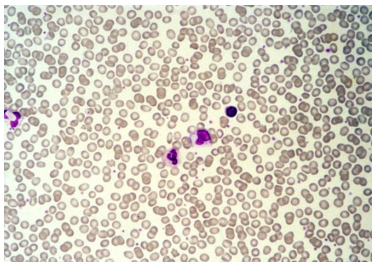


Figure 15.1: Shows two neutrophils, one monocyte and one lymphocyte among a large number of RBCs

(i) **Phagocytes**, which include neutrophils (having single, multi-lobed, nucleus) and monocytes (having kidney-shaped nucleus) with a moderate amount of cytoplasm, and

(ii) **Lymphocytes**, with a very large, darkly staining nucleus occupying the entire volume of the cell, with very little cytoplasm.

All blood cells arise within bone-marrow of long bones. RBCs and most WBCs complete their development within the bone-marrow, while T-lymphocytes migrate to thymus for further maturation and development. Monocytes circulate in blood for varying periods of time and then migrate to tissues and differentiate into macrophages. As the most important function of the immune system is to kill the pathogenic organisms to prevent the occurrence of disease, a very crucial attribute of immune system is to distinguish self from non-self.

In the absence of such a mechanism, the immune system might target one's own tissues. Identification of self from non-self is perfect by innate immune system, where-in receptors on

phagocytes recognize molecules present on microbial organisms as non-self. But lymphocytes, which constitute adaptive immunity, may sometimes, target one's own tissues, leading to the generation of auto-immune diseases, e.g., rheumatoid arthritis, multiple sclerosis, systemic lupus erythematosus.

Mode of Action of Phagocytes

Phagocytes, which include both neutrophils and macrophages, play an important role in innate immunity. They can identify foreign invading pathogens, discriminate them from cells of the body, and internalize them by throwing pseudopodia around them. Once within the phagocytes, pathogens are digested by a number of hydrolytic enzymes, thus freeing the body of disease-causing germs. Phagocytes also help in removing old, dead cells as well as cancerous cells (Figure 15.2).

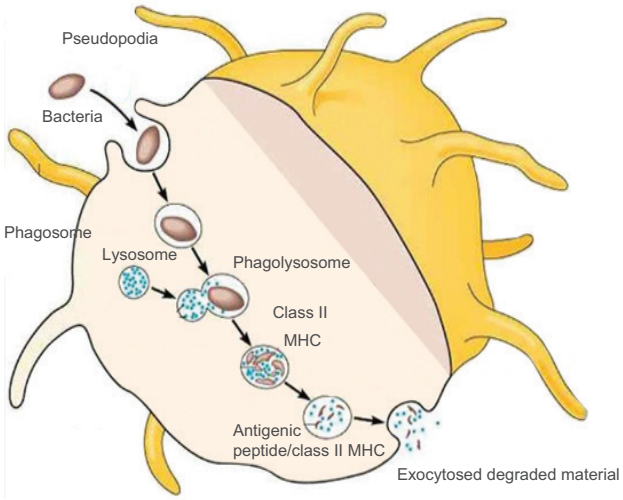


Figure 15.2: Showing process of phagocytosis by a macrophage

Soluble Mediators

Among soluble mediators of innate immunity are predominantly complement proteins which can identify foreign microbial organisms and punch holes in their membranes, thus, effectively killing them.

As soon as there is invasion of the body by any microbial organisms, innate branch of the immune system immediately comes into operation as it is present from the time of birth. However, if the infection persists, leading to the appearance of disease symptoms, it recruits elements of second line of defence, the ***Specific or Adaptive immune system***. Though both branches of immune system help in eliminating the infectious agents, there are important differences in the way these two systems work (see Table15.1).

Immune Response: Response produced by the body upon invasion of a foreign substance, especially infectious microbes and toxins produced by them and is protective in nature.

Antigen: Any substance, that is foreign to the body, upon entering the body, evokes the generation of immune response is called antigen. Infectious agents such as bacteria and viruses present a large number of antigens to which the body responds by mounting an immune response.

15.1.2 Adaptive or Acquired Immune System

Adaptive or acquired immune system is not present at the time of birth but acquired during one's life-time. However, once acquired, its memory persists in the body in the form of memory cells for a very long period of time. Generation of memory cells upon first exposure to infectious agent is seen in primary response. Primary response leads to the generation of activated lymphocytes of the B- or T- type as well as memory cells. This response is not only weak in intensity but also takes a long time to initiate.

However, upon second exposure to the same infectious agent, the immune response generated is faster and greater in intensity due to the already existing memory cells, and is called **secondary response** (Table 15.2). It is the genesis of heightened immune response upon second exposure that laid the foundation of all active vaccination programmes.

Table 15.1: Comparing Innate and Adaptive Immunity

Attribute	Innate	Adaptive
Recognition of self/ non-self	Perfect, response mounted against non-self only	Generally perfect, but sometimes response mounted against self as well, leading to auto-immune disease
Time of onset	Within minutes	Starts only after a few days
Specificity	Limited, mounts same response to a number of pathogens, due to limited number of receptors	Very high, mounts response only to the pathogen that activated it, due to very large number of receptors
Cells involved	Mainly macrophages, neutrophils and NK cells, though helper T lymphocytes stimulate phagocytic activity	Mainly B and T lymphocytes, though macrophages play a supportive role
Memory	None, thus same response generated with each infection	Present, thus second exposure to the same infective agent produces heightened response

Table 15.2: Comparing primary and secondary immune response

Feature	Immune Response	
	Primary	Secondary
Class of B lymphocytes	Naive, encountering antigen for the first time	Memory, having encountered the antigen in a previous exposure
Time of onset of response	4-7 days	1-3 days
Intensity of the peak response	Depends on the severity of infection	100-1000 times more than the primary response
Role of helper T lymphocytes	Not important	Very important, as cytokines secreted by them activate B lymphocytes
Type of antibody produced	Mainly IgM	Mainly IgG

Components of the Acquired or Adaptive Immunity

(i) **Humoral Immunity:** It is mediated by B-lymphocytes.

(ii) **Cell-mediated Immunity:** It is achieved by T-lymphocytes.

Humoral Immunity: B lymphocytes

Humoral immunity was discovered by Emil Behring and Shibasaburo Kitasato in 1890.

This proved to be a landmark experiment and it earned von Behring Nobel Prize in Medicine. This experiment showed two important things: one, that following infection or immunization, substances appeared in serum that have the capacity to protect against the infective agent; this laid the foundation of humoral branch of immunity; second, that immunity could be transferred from immunized to non-immunized organism; this laid the foundation of strategy of passive immunization. Generation of humoral response involves:

(a) Activation of B-lymphocytes

(b) Conversion of B-lymphocytes into plasma cells

(c) Secretion of antibodies

(d) Functions performed by antibodies

B-lymphocytes, 6 micrometre in size, having a darkly staining, large nucleus, and very little cytoplasm, bear receptors on their surface which recognize and bind antigens on microbial organisms. Binding of receptors leads to activation of B-lymphocytes, which undergo a number of mitotic divisions producing two kinds of cells, effecter cells called plasma cells and memory cells. Memory cells are long lived, retain the same receptors as the original B-lymphocyte and can get activated upon second exposure to the same infectious agent to give rise to a heightened response (Figure 15.3).

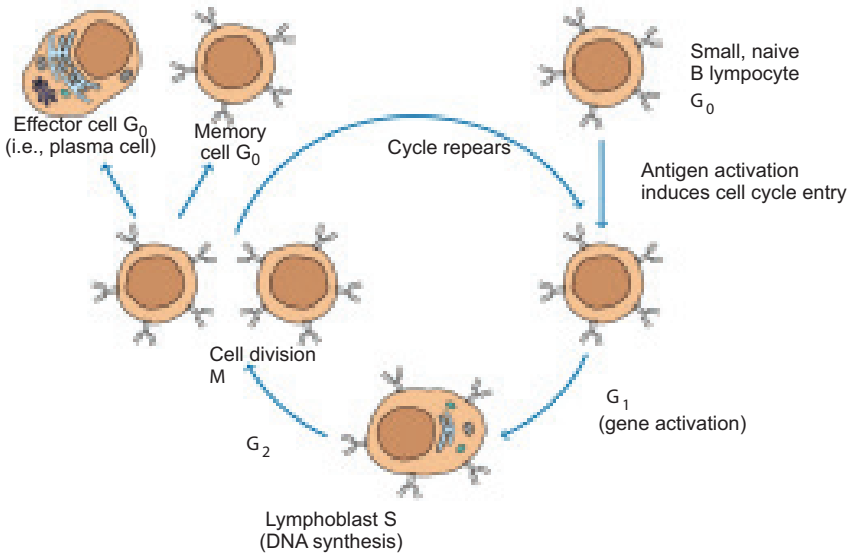


Figure 15.3: Activation of B-lymphocyte

Effecter cells or plasma cells, about 15 micrometre in size, with a large amount of cytoplasm having Golgi apparatus and endoplasmic reticulum, represent the end stage B-lymphocytes, which do not further divide but actively secrete antibody molecules at a high rate.
Antibodies are, proteins, called immunoglobulins, designated as Ig.

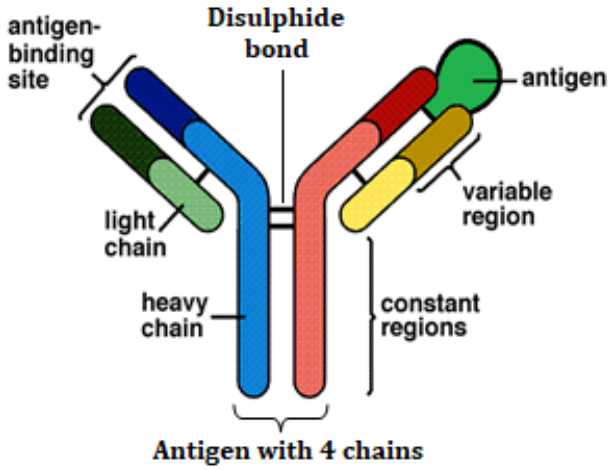


Fig15.4. Bonding between antibody and antigen

The diagram shows the basic structure of an antibody, which consists of four chains, two light and two heavy joined by disulphide bonds, light chain and heavy chain at one end, together constitute antigen binding site whereas constant region of two heavy chains performs the biological functions as described below. Different classes of antibodies differ in the number of such monomers and the numbers of disulphide bonds present in one molecule and hence are capable of performing different functions. Example: IgM is a pentamer composed of five monomers

The five primary classes of immunoglobulins are IgG, IgM, IgA, IgD and IgE. These are distinguished by the type of heavy chain found in the molecule. IgG molecules have heavy chains known as gamma-chains; IgMs have mu-chains; IgAs have alpha-chains; IgEs have epsilon-chains; and IgDs have delta-chains.. These antibodies are capable of recognising over a million different antigens and confer protection in a number of ways. Functions performed by antibodies are:

1. Antibodies bind to toxins produced by bacteria that cause infection like diphtheria or tetanus, effectively nullifying them.
2. By attaching to microbial pathogens, antibodies promote their clearance by phagocytes manifold.
3. Antibodies form a covering on bacteria and viruses, not allowing them to gain entry into tissues. Bacteria and viruses, thus having been coated, are eliminated by beating of cilia present on the epithelial cells in the respiratory tract or by peristalsis of the gastrointestinal tract.
4. Antibody, esp. of the IgG type, is highly mobile, capable of leaving circulation and reaching skin where it can neutralize surface bacteria. This antibody can also pass through the placenta reaching the developing foetus, providing it some protection against infections.
5. Antibody, esp. of the IgA type, is found in large amounts in mother's milk, and helps protect the new born against infections during the first months of life when infant's immune system is not fully functional.
6. Antibody of the IgE type, plays an important role against parasitic infections, though it is also responsible for the allergic reactions to various allergens in the environment and will be described later in detail.

Cell-Mediated Immune Response: T Lymphocyte

Though antibody molecules are highly specific and confer high degree of protection to the body against toxins and microbes present in blood and extra-cellular fluids, they are not able to neutralise those pathogens which live within the cells e.g., viruses, malarial parasite, some bacteria such as *Salmonella, Mycobaterium* etc. Therefore, in order to protect the body from intra-cellular infectious organisms as well as to eliminate cancerous cells, body mounts cell-mediated immune response.

Generation of cell-mediated immune response:

1. Recognition and binding of antigens by T-lymphocytes, macrophages, neutrophils, and natural killer cells (NK). These cells differ in the way they bind antigens. T-lymphocytes recognize and bind antigens only in association with another set of proteins called major histocompatibility complex (MHC). Macrophages, neutrophils and NK cells can bind to antibody-tagged cells.

2. T lymphocytes are of two types, helper T lymphocytes and Tc cells. Helper T lymphocytes play important role in both humoral and cell mediated immunity by secreting important cytokines.
3. Activation of the above mentioned cells (appearance of granules in T-lymphocytes and macrophages which are normally agranulocytes). T-lymphocytes get transformed into cytotoxic T lymphocytes, or CTL.
4. Secretion of cytotoxic chemicals/cytokines, perforins, granzymes, interferon gamma and tumour necrosis factor in the vicinity of cells carrying intracellular pathogens.
5. Cytotoxic chemicals/cytokines cause target cell destruction.

Table 15.3: Comparing Attributes of Humoral and Cellular Immunity

Humoral Immunity	Cellular Immunity
1. Targets extra cellular infectious agents in blood or tissue fluids	1. Targets Intra-cellular infectious agents and Cancer cells
2. Recognition of antigen by receptors on B-lymphocytes	2. Recognition of antigens-MHC by Tc lymphocytes and antibody-tagged cells by phagocytes and NK cells
3. Activation and proliferation of B-lymphocytes forming plasma cells and memory cells	3. Activation and proliferation of Tc lymphocytes forming CTL and memory cells Activation of Phagocytes and NK cells
4. Secretion of antibodies	4. Secretion of cyto-toxic chemicals
5. Clearance of infectious agent	5. Lysis of infected or cancerous cells

SELF EVALUATION

Complete with appropriate terms:

(i) ..... is the type of antibody produced by primary immune response.

(ii) Cell mediated immunity is achieved by .....

(iii) Antibody ..... is highly mobile and capable of reaching skin to neutralize bacteria.

(iv) ..... immunity leads to auto-immune disease.

ACTIVITY 2

Using different colours, learners can make flow diagram of immune response following infection by a toxin/bacteria in the extracellular fluid and also a flow chart of immune response following infection by bacteria such as Mycobacteria.

In these flow charts, draw different cell types participating in the immune response, and show all the steps which ultimately lead to clearence of the pathogen.

Discuss the following questions to clarify major immune mechanisms of the body.

(i) How does humoral branch of immunity recognize the pathogen?

(ii) How does cell mediated branch of immunity recognize the pathogen?

(iii) How are the two branches interconnected?

(iv) How are these two branches connected with innate immunity?

15.2 VACCINATION

ACTIVITY 3

Collect data of various diseases affecting a population such as smallpox, measles, malaria and tuberculosis. You can collect data from health centres, or hospitals. Make a point of collecting data before and after the vaccination provided in the same population.

Discuss the findings of different groups to assess whether vaccination programme has been equally successful for all the diseases or not.

Discuss why vaccination strategy has not worked against certain diseases.

While looking for answers for the above mentioned questions, you would have realized that in the past 40 years immunization against a number of diseases has saved millions of lives. World Polio Day is celebrated every year on 24th October, World Tuberculosis Day falls on 24th March every year, and World Immunization Week is observed by WHO from 24th to 30th April every year to have campaigns for awareness of the importance of vaccination in eradicating these debilitating diseases as well as to provide vaccinations worldwide.

Success of immunization programmes is evident by the facts such as: Small pox has been globally eradicated; Africa has not had a case of wild poliovirus since August 2014; India has been declared free of maternal and neonatal tatanus; during 2000–2014, measles vaccination prevented nearly 17.1 million deaths (decreaing deaths by 79%); deaths caused by tuberculosis have come down only marginally.

The pioneering work of Jenner and Pasteur laid the foundations of immunization programmes. They were able to confer protection to individuals against infectious diseases by exposing them to infectious agents. This initiated the process of active immunization in the medical field and saved millions of lives. However, the works of Kitasato showed that immunity can be transferred between two individuals, and this laid the foundation of passive immunization programmes. Though both these programmes confer protection against infectious agents, there are important differences between the two (as shown in Table 15.4).

Table 15.4: Comparing Active and Passive Immunization

Active Immunization	Passive Immunization
Generation of an immune response.	No generation of immune response.
Immune response is mounted to either natural infection (natural) or vaccination by weakened or mild form of pathogen (artificial).	Preformed antibodies (formed in other animals) (artificial) are either injected into the bloodstream or transferred from mother to foetus across placenta or in breast milk (natural).
Vaccination leads to the production of long lived memory cells, specific to the vaccination agent.	No memory cells are produced.
Effect lasts for a very long time, sometimes giving life-long immunity.	Effect lasts for a short time.
Can cause disease in immuno-deficient individuals.	Helps immuno-deficient individuals to survive.
Takes time to mount an immune response and thus not suitable in case of emergency.	Confers immediate protection and hence useful in emergency such as snake bite, dog bite.

ACTIVITY 4

Find out National Immunization Days for tuberculosis, measles, and cholera. Search medical journals to find out symptoms of these diseases and discuss in the class as to what role you can play to promote awareness campaigns.

Though **smallpox** has been successfully eradicated, eradication of others such as measles, tuberculosis, cholera and malaria has not been so successful. Success of smallpox vaccine was due mainly to the fact that pox virus did not mutate and the same vaccine could be used everywhere and the vaccine was highly effective.

On the other hand, though measles vaccination has decreased death rates drastically, its total eradication has not been achieved so far due to several reasons. The disease is highly infectious, and spreads very fast. As long as it is present in one area, unvaccinated children in any country are at risk. For measles, boosters are required, difficult to achieve in poor countries, Parents' decision not to vaccinate their children due to fear or other misconceived notions has also made the vaccination programme less effective.

Effective vaccine against cholera has not been available for **two major reasons:** (a) Immunity conferred by the vaccine is not long-lasting; (b) Cholera is a toxin-mediated disease while protective immune mechanism is antibacterial rather than antitoxic. Oral cholera vaccines have become available recently.

Tuberculosis is a major killer, causing 2 to 3 million deaths annually. According to WHO reports, nearly one-third of the world's population is currently infected with TB. Today, the only approved tuberculosis vaccine is Bacilli Calmette-Guerin (BCG) which was started in 1921. Though it is quite effective in infants and young children, in adults, its efficacy is variable. Many boosters are also being developed, MVA85A, being the most advanced boost available. BCG vaccine has not been modified since 1921 and that may also be one reason why it is not so effective. That bacteria may have changed through evolution is suggested by their evolution of resistance to a number of known antibiotics. A lot of effort is being devoted, but proving difficult as the bacterium lives within the cells and lack of suitable animal model for developing and testing human tuberculosis vaccine is posing a big challenge. In Africa, coinfections of human immunodeficiency virus and TB have led to increases in the incidence rate of TB.

Malarial parasite lives intracellularly and mutates very often to change surface antigens and thus proved very difficult organism for effective vaccine development.

15.3 ALLERGIES

ACTIVITY 5

Watch one video of a person with watery eyes, running nose, sneezing; another with an asthmatic person with breathing problems and using inhaler; another with a person stung by a bee, showing swelling and redness.

Collect labels on certain food items prepared from shellfish/peanuts/walnuts/showing warning to individuals.

See labels on penicillin vials, as a warning to be used only after initial testing.

After having seen these, try to answer the following:

(a) Why should some persons show watery eyes, running nose or asthmatic symptoms when there is nothing alarming in the environment?

(b) Why should common food items be a cause of worry?

(c) Why can't we use penicillin just as we use any other antibiotic?

Allergic reactions are seen when humoral or cell-mediated immune responses to non-parasitic, non-pathogenic substances lead to extensive damage of tissues in individuals prone to allergies or hypersensitive reactions. Hypersensitive responses are classified into four types (Figure 15.5).

1. IgE-mediated (Type I)
2. IgG or IgM-mediated (Type II)
3. Immune complexes (Type III)
4. Cell-mediated (Type IV)

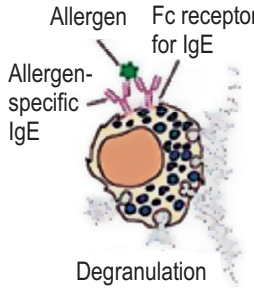
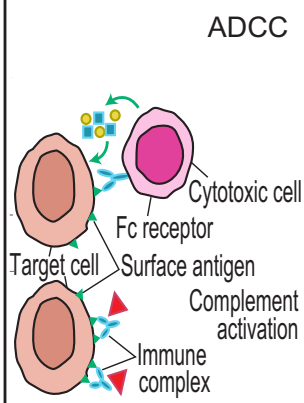
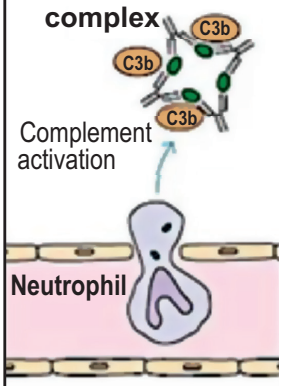
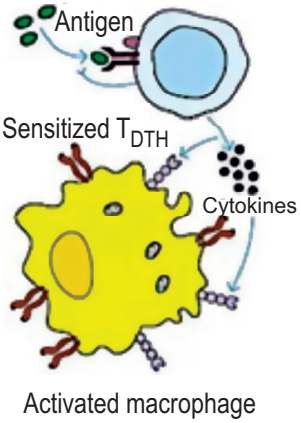
 **Type I**	 **Type II**	 **Type III**	 **Type IV**
IgE mediated Hypersensitivity	IgG mediated Cytotoxic Hypersensitivity	Immune Complex Mediated Hypersensitivity	Cell Mediated Hypersensitivity
Ag induces crosslinking of IgE bound to mass cells and basophils with release of vasoactive mediators	Ab directed against cell surface antigens meditates cell destruction via complement activation or ADCC	Ag-Ab complexes deposited in various tissues induce complement activation and an ensuing inflammatory response mediated by massive infilatration of neutrophils	Sensitized T_H1 cells release cytokines that activate macrophages or TC cells which mediate direct cellular damage
Typical manifestations include systemic anaphylaxis and localized anaphylaxis such as hay fever, asthma, hives, food allergies, and eczema	Typical manifestations include blood transfusion reactions, erythroblastosis fetalis, and autoimmune hemolytic anaemia	Typical manifestations include localized Arthus reaction and generalized reactions such as serum sickness, necrotizing vasculitis, glomerulnephritis, rheumatold arthritis, and systemic lumpus erthyematosus	Typical manifestations include contact dermatitis, tubercular lesions and graft rejection

Figure 15.5: Showing different types of hypersensitive responses

IgE-mediated (Type I) Hypersensitivity: First exposure to allergen leads to the formation of IgE type of antibodies which bind to mast cells present in large numbers throughout the body. Second exposure to the same allergen causes cross-linking of IgE molecules on the already sensitized mast cells, leading to their degranulation and release of substances stored in their granules such as histamine, heparin, proteases, etc. Principal effects seen are vasodilation and smooth muscle contraction (Figure 15.6). Vasodilation decreases blood pressure and contraction of smooth muscles of bronchioles affects respiration.

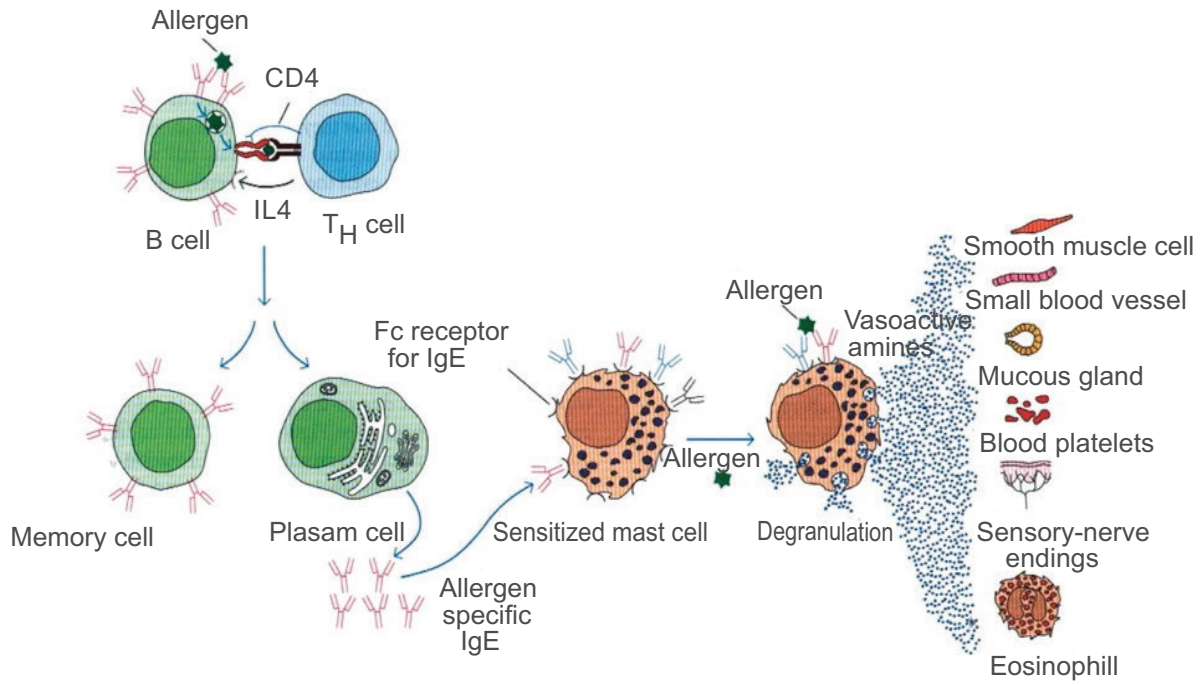


Figure 15.6: Showing type I hypersensitive reaction

Generalized allergic reaction, called anaphylaxis, starts when an allergen enters directly into the bloodstream or is absorbed from the gut or skin. It can be caused by venom from bee, wasp, ant stings; drugs such as penicillin, antitoxins. This should be treated quickly; otherwise it is shock-like and often fatal.

In localized allergic reaction, the damage is limited to a specific target tissue or organ. Examples include allergic rhinitis (hay fever), asthma, dermatitis, food allergies.

Hay fever occurs upon inhaling certain allergens in the air leading to watery eyes, running nose, sneezing and coughing, involving mainly upper respiratory tract.

Asthma involves lower respiratory tract when histamine released from mast cells causes contraction of bronchioles. Mucus accumulates in the air sacs, causing respiratory problems and the characteristic wheezing sound. It can prove fatal if left untreated for too long. Allergens, generally responsible for this reaction, are pollens, dust, fumes, insect products, or viral antigens.

Epinephrine helps in generalized reaction by relaxing the smooth muscles for respiration to restore and reducing vascular permeability so that blood pressure can normalize improving cardiac output. Antihistamines are used to relieve the symptoms of asthma and hay fever.

Table 15.5: Distinction between Generalized and Localized Allergic Reactions

Generalized Allergic Reaction	Localized Allergic Reaction
Very severe, multi-organ response, can be fatal, if not treated urgently.	Mild response, restricted to a target tissue or organ, generally not fatal.
Contraction of smooth muscles of bronchioles causing breathing problems.	Watery eyes, running nose, sneezing when allergen inhaled. Upper respiratory tract affected (Hay fever) or lower respiratory tract affected (Asthma).
Dilation of blood vessels decreasing blood pressure resulting in shock and collapse.	Small blood vessels begin to leak blood into tissues causing sudden and dramatic drop in blood pressure.
May be caused by penicillin, antitoxins, sting from bee, wasp, ant.	May be caused by pollen, dust, fumes, insect products.
Immediate administration of epinephrine can restore blood pressure and relax smooth muscles for normal breathing.	Use of anti-histamines relieves the symptoms.

IgG or IgM-mediated (Type II) Hypersensitivity occurs when antigen-antibody complex activates complement proteins which can cause rupture of cells. This is seen in blood transfusion reactions.

Immune complexes (Type III) deposited in tissues lead to complement activation and inflammation. This is seen after insect bites as swelling and reddening locally or in serum sickness as fever and shivering after receiving anti-tetanus anti-toxin.

Cell-mediated (Type IV) Hypersensitivity is mediated by helper T lymphocytes and macrophages as in contact dermatitis and graft rejection.

Important Message

Having read this section on hypersensitivity, can you visualize how you would go about helping one of your classmates showing such symptoms.

ACTIVITY 6

Collect data on diseases and their antibiotics. Make a table to present your research. Once you are done, discuss the following questions:

(i) How bacteria have acquired resistance against the antibiotic over the years.

(ii) Comment on the efficacy of antibiotics in treating a certain disease when the antibiotic for the disease was first discovered.

Note: Some of the diseases which can be investigated are: Dysentry, Tuberculosis, Pneumonia, Diphtheria, Cholera, Measles, Mumps, Smallpox.

The word 'antibiotics' is derived from the Greek word "anti" meaning against and "bios" life. Antibiotics are a class of chemicals produced by bacteria or fungi in order to inhibit the growth of other organisms in their vicinity so that competition for limited resources can be minimized. The first antibiotic, penicillin, was discovered by Alexander Fleming in 1928. Since then antibiotics have found great use in medicine. Though they are not effective against viruses, they are used to treat a number of bacterial infections.

A large number of antibiotics have been discovered from a variety of organisms, broadly belonging to two categories: bactericidal, which kill the bacteria and bacteriostatic, which slow down their growth and reproduction. Bactericidal antibiotics prevent the formation of cell wall while bacteriostatic antibiotics interfere with some aspect of bacterial metabolism, affecting either protein or RNA synthesis or DNA replication. They must work together with the immune system to remove microorganisms from the body. High concentrations may also be bactericidal.

Table 15.6 shows a few commonly used antibiotics, source organisms producing them and their activity. Figure 15.7 shows mode of **action of some antibiotics**.

Table 15.6: Types of Antibiotics

Antibiotic	Produced by	Activity
Amphotericin B	Streptomyces nodosus	Antifungal
Streptomycin	Streptomyces griseus	Gram+ and Gram – bacteria and mycobacteria
Tetracyclines	Streptomyces spp	Gram+ and Gram – bacteria
Kanamycin	Streptomyces kanamyceticus	Gram+ and Gram – bacteria & mycobacteria
Penicillin	Penicillium notatum	Gram+ bacteria

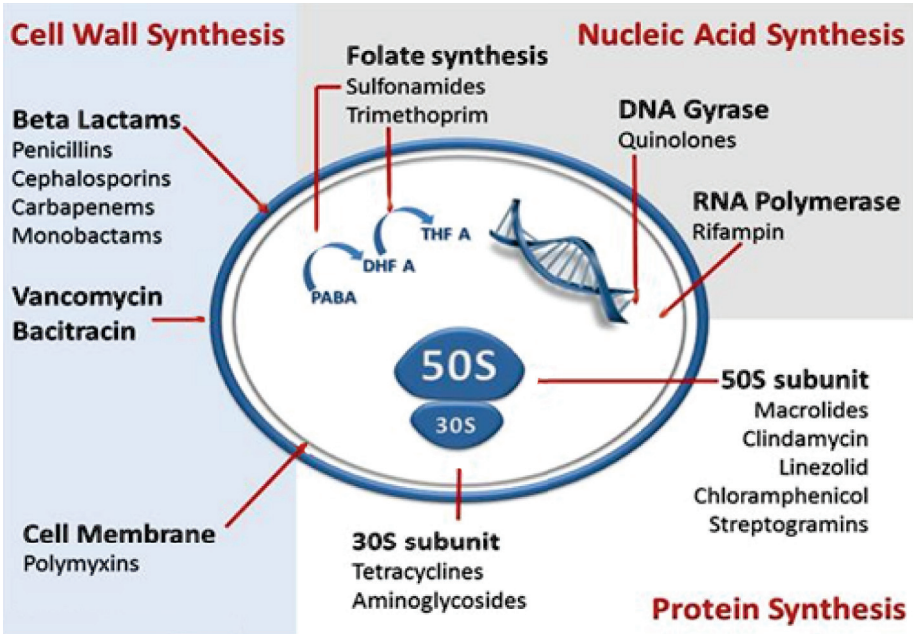


Figure 15.7: Mode of action of antibiotics

As the use of antibiotics has increased, it has also led to the evolution of resistance in a number of microbial pathogens with the result that earlier antibiotics are no longer effective in treating a disease. Resistance may have developed by a number of mechanisms e.g.,

1. Production of enzyme beta lactamase that breaks down beta- lactam ring of antibiotics such as penicillin and cephalosporin.
2. Mutation in a gene leading to the formation of an altered protein which does not bind penicillin.
3. Altered cell wall permeability confers resistance to tetracyclines, quinolones, penicillin.
4. Creating a barrier of biofilm, where bacteria are not attacked by the host's immune system as seen in *Salmonella*.
5. A gene can produce a product that can pump out the antibiotic as in Staphylococcus against *erythromycin*.
6. Some bacteria show alteration in ribosome structure so that protein synthesis is not affected.

SELF EVALUATION

Complete with appropriate terms:

(i) ..... leads to production of long lived memory cells.

(ii) Cholera is a ..... mediated disease.

(iii) ..... decreases blood pressure and contraction of muscles of bronchiols.

(iv) ..... occurs upon inhaling certain allergens in the air leading to sneezing and coughing.

(v) Penicillin is produced by .....

ACTIVITY 7

Using internet sources and medical journals, try to find out the following:

(i) Mortality caused by tuberculosis, measles, small pox and cholera.

(ii) How has medical science helped in reducing death rate caused by these diseases?

(iii) Has it been completely successful in this effort?

(iv) What role does nutrition play in fighting these diseases?

(v) Role of water and sanitation services in controlling spread of disease.

15.5 SUMMARY

- Immune system has the capacity to kill cells, it is very important for it to make a distinction between self and non-self.
- Whenever there is a failure in distinguishing self from non-self, auto-immune diseases develop such as multiple sclerosis, rheumatoid arthritis.
- Mounting of a successful immune response depends on a number of cells and chemical mediators, defect in any component can lead to immunodeficiency state such as absence of mature *T lymphocytes* in Di George syndrome.
- Immune system has two main parts, innate and adaptive.
- Two branches of the immune system collaborate with each other to make a highly effective immune response.
- Innate system is present at birth, comes into operation immediately upon infection, relies on barriers such as skin and mucous membranes, phagocytes and NK cells, and lacks memory.

- Adaptive system is acquired by 6 months after birth, takes time to mount an immune response, relies on B and T lymphocytes and has memory.
- Adaptive or acquired immunity is of two types, humoral and cell mediated.
- Humoral immunity generates specific antibodies against pathogens present in blood.
- Cell mediated immunity generates cyto-toxic chemicals to lyse infected cells.
- Antibodies neutralize toxins and help in eliminating microbial organisms.
- Antibodies are of five types IgM, IgG, IgA, IgE and IgD.
- There are two types of T lymphocytes: helper T lymphocytes and Tc lymphocytes.
- T lymphocytes recognize antigen of the pathogen in association with MHC.
- Helper T lymphocytes actively secrete a number of cytokines which affect the activity of macrophages, B lymphocytes and Tc cells converting the latter into CTL.
- CTLs, macrophages and NK cells secrete cytotoxic chemicals onto cells having intracellular pathogen causing cell death.
- Vaccinations can be Active or Passive.
- Active vaccination is achieved either by natural infection or by immunization with live attenuated or killed infectious organisms.
- Passive immunization is achieved by introduction of preformed antibodies.
- Generation of memory cells during first encounter with the infectious agent produces a secondary response with a high intensity.
- Vaccination programmes for a number of diseases have been very successful, though for some diseases, effective vaccines are not available yet.
- Although active vaccines have helped eradicate a number of diseases, they pose a serious threat in immuno deficient individuals.
- Passive immunization is chosen in cases of emergency or immunodeficiency.
- Allergies, also termed hypersensitive responses, which are potentially damaging to the tissues, are produced by the body to seemingly non-pathogenic substances in the environment.
- Allergies are broadly classified into four types: class I mediated by IgE; class II mediated by IgG or IgM; class III by activation of complement by immune complexes; class IV cell mediated (esp. macrophages) hypersensitivity.
- Type I allergies are seen in hay fever, asthma, food allergies; type II allergies are seen in blood transfusion reactions; type III allergies seen after insect bite or serum sickness after anti-tetanus injection; type IV allergies seen in contact dermatitis, graft rejection.
- When the hypersensitive reactions are limited to specific target tissue or organ, it is called localized reaction as seen in hay fever, asthma. However, when a large number of organs

become simultaneously affected upon entry of allergen directly into the bloodstream absorbed from the gut, it results in generalized reaction with fatal consequences.

Symptoms and treatment

- Type I hypersensitive reactions are mediated by heparin released by mast cells and epinephrine can reverse these effects in generalized reactions while antihistamines are used for localized reactions.
- In all other cases of allergies involving drug, food item, blood transfusion, anti-toxin antiserum, the best strategy is to immediately discontinue the use of such agents.
- Antibiotics are drugs used extensively by doctors to treat bacterial infections. Mortality rate due to bacterial infections has declined drastically since the use of antibiotics started.
- A number of soil microbes produce a large variety of chemicals to inhibit other organisms growing in their surroundings and provide a rich source of antibiotics.
- Antibiotics either kill bacteria by inhibiting their cell wall synthesis or slowing their growth by affecting DNA replication or RNA/ protein synthesis.
- Different antibiotics show different specificities, some antibiotics working against a number of bacteria, while others being more specific.
- Prolonged and overuse of antibiotics has led to evolution of different mechanisms by which bacteria have become resistant to commonly used antibiotics such as development of enzyme beta lactamase to break down beta lactam ring, actively move the drug out of the cell (efflux), change its cell wall permeability etc.

15.6 GLOSSARY

- **Acquired immunity:** It is the immunity that our body gains over time, similar to how an individual gains knowledge over time.
- **Antibiotics:** Substance that destroys or inhibits the growth of other microorganisms.
- **Antigen:** A substance that your immune system reacts against.
- **Cellular immunity:** It is an immune response that does not involve antibiotics but rather in values the activation of phagocytes, antigen specific T-lymphocytes.
- **Humoral immunity:** Immunity involving the transformation of B-lymphocytes into plasma cells that produce and antibiotics to a specific antigen.
- **Immune response:** The reaction of the cells and fluids of the body to the presence of a substance which is not recognised as a constituent of the body itself.
- **Immunity:** It is the defence mechanism of our body.
- **Innate immunity:** Immunity that is naturally present and is not due to prior mustization to an antigen form.
- **Vaccination:** Injection of a killed microbe in order to stimulate the immune system against the microbe, thereby preventing disease.

15.7 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. Innate immunity is present at birth.
2. Breast milk confers protection to newborn by providing IgE type of antibodies.
3. Antibodies can work by promoting phagocytosis of microbial agents.
4. Antibiotics help a patient in mounting an effective immune response.
5. Treating tuberculosis is becoming difficult because Mycobacterium tuberculosis has become resistant to a number of antibiotics.
6. Hay fever is a generalized allergic reaction caused by release of active mediators from mast cells.
7. Secondary immune response appears much faster because of the presence of memory cells persisting from previous infection.
8. Vaccination against snakebite is an example of passive immunization.
9. Allergies are of two types—innate and adaptive.
10. Beta-lactam antibiotics kill bacteria by blocking synthesis of their cell walls.

II. Multiple Choice Questions

1. Humoral immunity is carried out by the
   (a) B lymphocytes (b) T lymphocytes
   (c) Phagocytes (d) T lymphocytes, phagocytes and NK cells
2. Antibodies transferred across placenta to the developing embryo are
   (a) IgM (b) IgG
   (c) IgA (d) IgE
3. Plasma cells represent
   (a) B lymphocytes which are actively secreting antibodies.
   (b) T lymphocytes which are actively secreting cytokines
   (c) Monocytes which have entered tissues
   (d) CTL which are secreting perforins.
4. Mast cell degranulation leads to the release of
   (a) IgE, which causes vasodilatation and bronchoconstriction
   (b) IgE, which causes vasoconstriction and bronchodilation.
   (c) Histamine, which causes vasodilation and bronchoconstriction
   (d) Histamine, which causes vasoconstriction and bronchodilation

5. Tetracycline helps in treating respiratory tract infections by
   (a) preventing protein synthesis in influenza viruses
   (b) preventing protein synthesis in bacteria
   (c) preventing DNA repair in viruses
   (d) preventing cell wall synthesis in bacteria
6. Children born with Di George syndrome lack mature
   (a) B lymphocytes (b) T lymphocytes
   (c) Macrophages (d) NK cells
7. Faulty recognition of self-tissues as non-self leads to the development of
   (a) AIDS (b) Rheumatoid arthritis
   (c) Hay fever (d) Polio
8. Live attenuated vaccine types have the disadvantage over the inactivated vaccine types as
   (a) They require booster shots
   (b) They do not confer life-long immunity
   (c) They may mutate to virulent form
   (d) They do not stimulate the immune system strongly.
9. Immune response is
   (a) the defence mechanism of our body.
   (b) reaction of the cells and fluids of the body.
   (c) a substance that destroys or inhibits the growth of other microorganisms
   (d) None of the above
10. Nowadays, many antibiotics don't seem to work because
   (a) body starts degrading the antibiotics very rapidly
   (b) of increased levels of pollution
   (c) bacteria are rapidly evolving resistance to antibiotics already in use
   (d) pharmaceutical companies are not making good medicines now.

III. Long Answer Type Questions

1. With an illustrative diagram, state the origin and describe the mode of action of phagocytes.
2. Analyse and relate the molecular structure of antibodies to their functions. Also, state the role of antibodies in allergies.

3. Explain the following:
   (a) Phagocytes
   (b) Lymphocytes
   (c) Immune response
4. Compare giving diagrams the modes of action of B-lymphocyte and T-lymphocyte.
5. With examples, explain the role of memory cells in long-term immunity.
6. Differentiate between the following:
   (a) Active and passive immunity
   (b) Generalised and localised allergic reactions
7. Discuss causes, symptoms and treatment of asthma and hey fever. Also suggest the ways to encourage such patients.
8. State why vaccination programmes are able to eradicate smallpox but not measles, TB, malaria or cholera.
9. Define antibiotic. State how it works. Also, explain the reasons for antibiotic resistance.
10. Interpret the differences between cellular responses and humoral responses.
11. Carry out research and be able to present findings on the reasons for antibiotic resistance in the treatment of infections.
12. There is a lot of research for curing diseases around the globe. Discuss the plausible research going on for HIV AIDS. Also state the bodies immune response condition while tackling HIV.

Unit 16

Human Reproductive System and Gametogenesis

Key Unit Competence

To be able to relate the structures of the human reproductive system to their functions and describe gamete formation.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- describe the structure of human male and female reproductive systems.
- state where female and male gametes are produced.
- describe the histology of mammalian ovary and testis.
- relate the histology of the testis and ovary to their functions.
- outline gametogenesis in a male and a female human as a process involving mitosis, growth, meiosis and maturation.
- explain how spermatozoa are produced.
- explain how oocytes are produced.
- explain the significance of gametogenesis.
- analyse and interpret chart diagrams of spermatogenesis and oogenesis.
- prepare slides well to study the structure of gametes.
- research about gametes and their formation and deduce their findings.
- appreciate the significance of the process of gametogenesis at puberty as a key characteristic of sexual maturity.
- acknowledge the relevance of meiosis during gametogenesis as an essential tool in maintaining the diploid condition after fertilisation.

ACTIVITY 1

Have you ever wondered how is the generation transferred from one to another? Look into internet for matter related to the process of reproduction and reproductive organs. Make a report on it and present to the class.

ACTIVITY 2

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 ovary, 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. In the present unit, we will discuss the histological and anatomical details of organs involved in male and female reproductive systems, the process of formation of gametes i.e., spermatogenesis and oogenesis, structure of gametes i.e., spermatozoan and ovum in details.

16.2 MALE REPRODUCTIVE SYSTEM

The male reproductive system consists of the male sex organs, a system of various ducts and accessory sex glands.

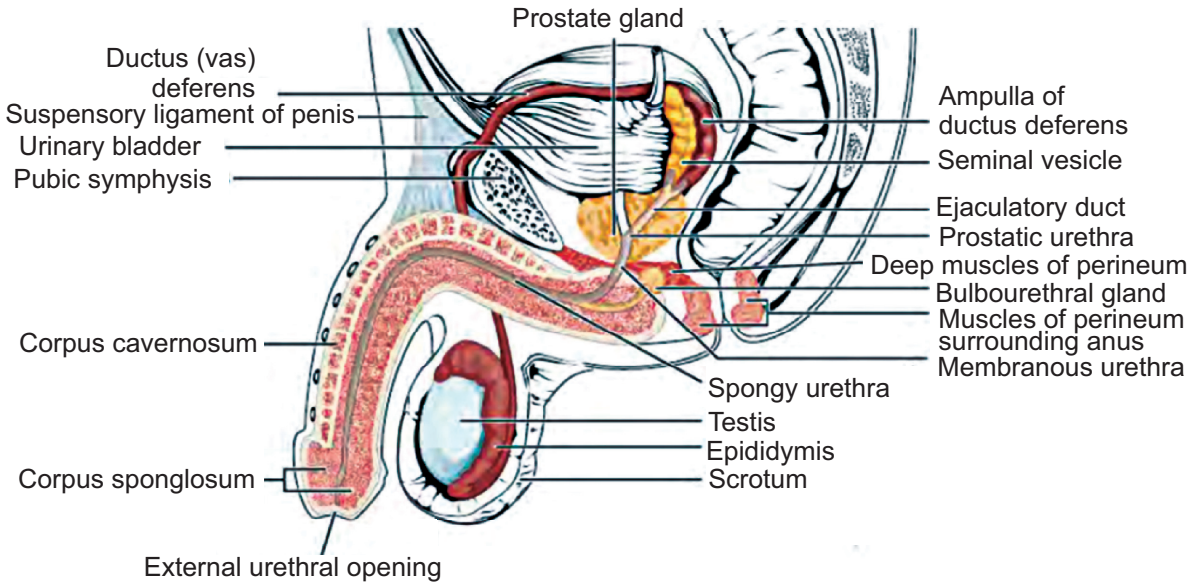


Figure 16.1: The overview of components of male reproductive system

16.2.1 Male Sex Organs

Scrotum: Scrotum is a bag like structure which is an out pouching of abdominal wall. Externally, it appears as a single pouch separated with a median ridge called raphe. Internally, it is divided into two sacs each of which contains a testis.

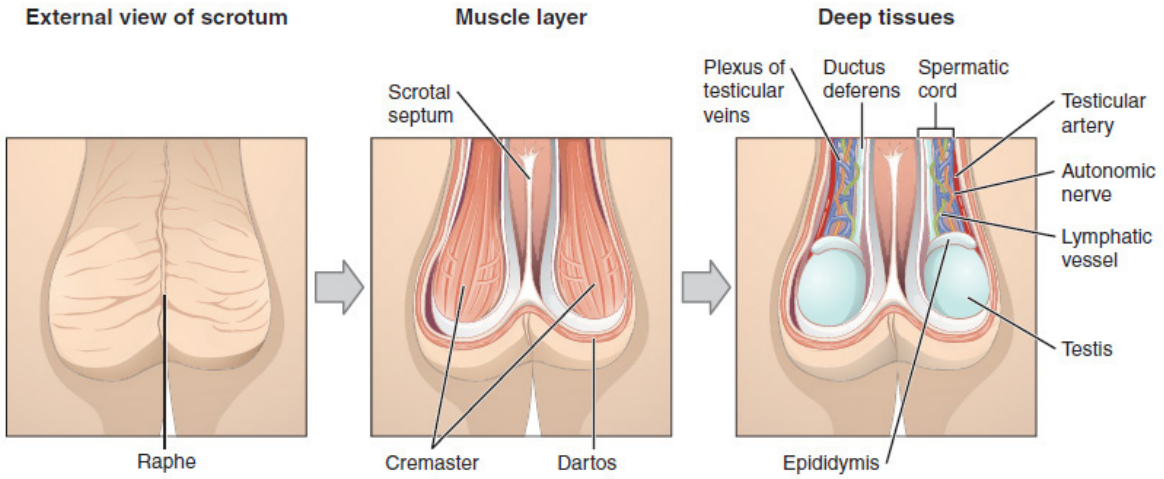


Figure 16.2: Scrotum from anterior view

The temperature of testes is maintained 2°C–3°C below the core body temperature which provides favourable environment for spermatogenesis. This lowering of temperature is regulated by scrotal muscle reflexes and venous pampiniform plexus present around the testicular artery.

Testes: Present inside the scrotal sacs are the oval shaped male sex organs, called testes. A human testis is about 4.5 cm long and 2.5 cm broad with 3 cm antero-posterior diameter, weighing approximately 10-15 grams. The testes are surrounded by serous sheath called **tunica vaginalis**, anteriorly and laterally. Behind tunica vaginalis is present a thick, white, fibrous capsule called **tunica albugenia**. Interior to it lies the tunica vasculosa, which is rich in vascular supply. Posteriorly, the tunica albuginea thickens greatly and is projected into the interior of the testis as the **Corpus Highmori or mediastinum testis**. The testes are held in position by mesenteries called **mesorchium**.

The ducts, blood & lymphatic vessels and nerves enter or leave the testis through the mediastinum. The connective tissue septa, called **septula testis** (singular- septum of testis) radiate from mediastinum into the testis. These septulae subdivide the interior of the testis into a number of pyramidal lobules called the **testicular lobules**. Each testicular lobule further contains several sperm producing convoluted tubules known as the **seminiferous tubules** (semin = seed; fer = to carry).

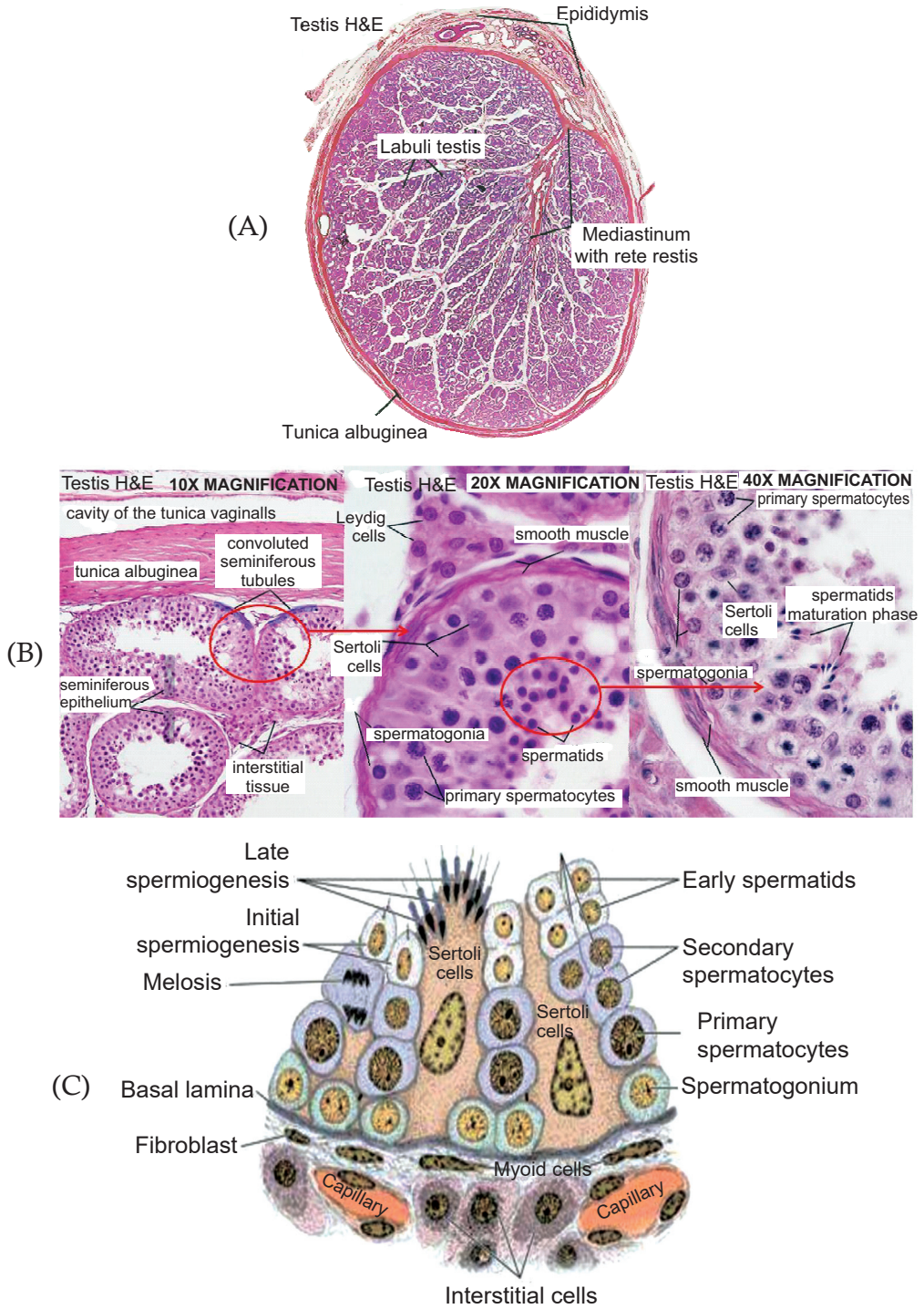


Figure 16.3: (A) Entire testis section at low magnification. (B) Histological sections of testis observed at different magnifications of objective lens. (C) Diagrammatic view of testis histology

The seminiferous tubules contain specialized epithelial cells, the spermatogenic cells and the supporting cells, also known as the sertoli cells. **Sertoli cells** provide support and nourishment, help in cell-to-cell communication, secrete inhibin and androgen binding protein etc. These are surrounded and supported by intertubular connective tissue which is rich in blood vessels and groups of epithelial cells, known as the **Leydig cells** (also called the interstitial cells or interstitial endocrinocytes). The leydig cells produce androgen and the male sex hormone, testosterone.

16.2.2 Male Reproductive Ducts

The ducts in male reproductive system help in storage and transportation of spermatozoa. The spermatozoa along with testicular fluid after their release into the lumen of seminiferous tubules (**spermiation process**) are propelled towards the **rete testis**. Rete testis is composed of various channels through which spermatozoa travel to **efferent ducts,** i.e., **vasa efferentia** (also called ductuli efferentes). Vasa efferentia further joins with epididymis. Epididymis is divided into three parts: head (caput), body (corpus) and tail (cauda) epididymis. The cauda epididymis is attached to scrotal sacs by a connective tissue called **gubernaculum**. Vasa efferentia joins epididymis from head region and vas deferens leaves the epididymis from tail region. The epididymis performs functions such as storage of spermatozoa, disposal of aged and abnormal spermatozoa and carries out maturational changes by secretion and absorption. Spermatozoa then pass through a single tube known as the **vas deferens**, also called **ductus deferens** or **ductus epididymis**. It joins with duct of seminal vesicle to form the **ejaculatory duct**. Both the ejaculatory ducts from either side further penetrate into prostate gland and empty into urethra. **Urethra** finally opens to the exterior through **penis**. Penis is both the excretory and reproductive functions as it passes both the urine and spermatozoa. Penis is divided into root, body i.e., shaft and glans penis. The shaft is composed of three columns of erectile tissues i.e. pair of corpora cavernosa on dorsal side and single corpus spongiosum on ventral side. Each column is surrounded by dense connective tissue called tunica albuginea. The root is the attached proximal portion and consists of bulb of penis. Glans penis is the distal, sensitive, cone shaped, hairless structure that contains sensory receptors for sexual stimulation. Prepuce or foreskin is the loose skin fold that covers the glans penis as sheath. Surgical removal of prepuce is called **circumcision.**

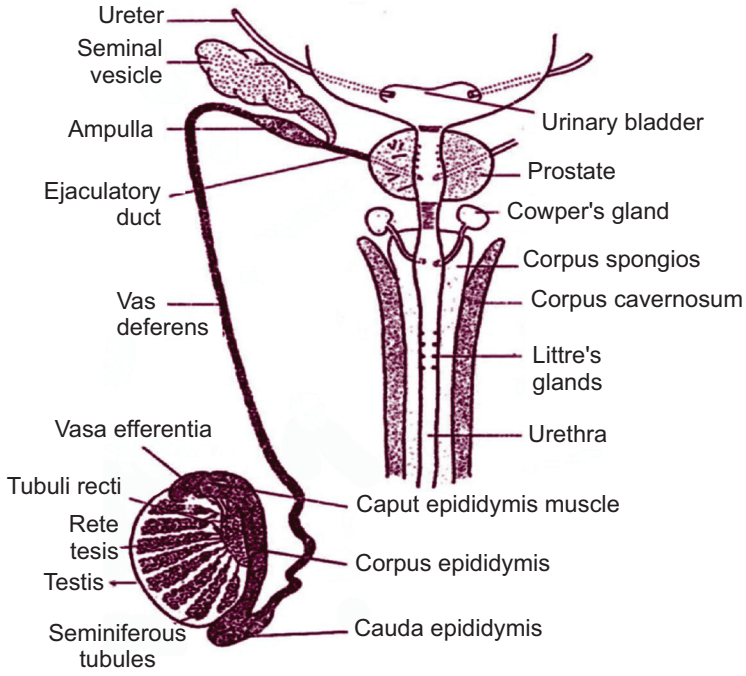


Figure 16.4: Diagrammatic view of Male Reproductive Ducts

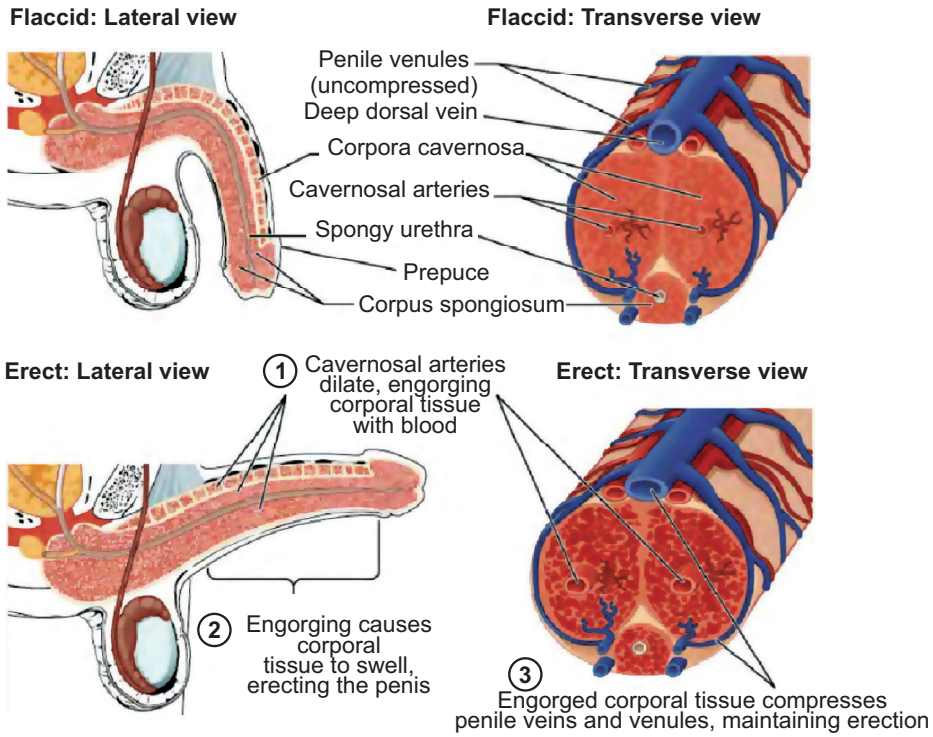


Figure 16.5: Anatomy of Penis, the Male Reproductive Organ

16.2.3 Accessory Male Reproductive Glands

These include a pair of **seminal vesicles**, a **prostate** and a pair of **bulbourethral glands**.

(i) ***The seminal vesicles*** are one pair of sac like structures near the base of the bladder. Their ducts join the vasa deferfintia to form the ejaculatory ducts. They produce an alkaline secretion which forms 70% of the volume of semen. The secretion of the seminal vesicle contains spermatozoa activating substances such as fructose, citrate, inositol, prostaglandins and several proteins. Fructose is a source of energy for the sperm. Prostaglandins stimulate uterine contractions and thus, may help the sperm to move towards the female's oviducts, where fertilization takes place. Some proteins of the secretion help coagulation of semen after ejaculation. Alkalinity of the seminal fluid helps to neutralize the acidic environment of the male urethra as well as that of female reproductive tract which would otherwise inactivate and kill sperms.

(ii) The ***prostate gland*** is of a size of a golf ball and surrounds the proximal portion of urethra. It produces a milky, slightly acidic secretion (pH = 6.5) which form 25% of the volume of semen. The secretion of the prostate gland nourishes the spermatozoa and aids in their motality.

(iii) ***The bulbourethral glands or cowper's glands*** are present on either side of the proximal portion of urethra. They secrete mucus that helps in the lubrication of penis and linning of urethra.

The secretions of the above glands constitute **seminal plasma** which is rich in fructose, calcium and certain enzymes. Fructose which is produced by the seminal vesicles, is not present anywhere else in the body, provides a forensic test, for rape. The presence of fructose in the female's genital tract confirms sexual intercourse.

Semen is the mixture of spermatozoa and seminal plasma (the secretions of the seminal vesicles, prostate gland and cowper's glands). It is ejected from the penis during ejaculation. A single ejaculate may contain 200 to 300 million spermatozoa (sperms). Semen is slightly alkaline (pH 7.35 to 7.50). Its alkalinity helps to neutralize the acidity of urethra left from the passage of urine and protects the sperms from the acidity of vagina.

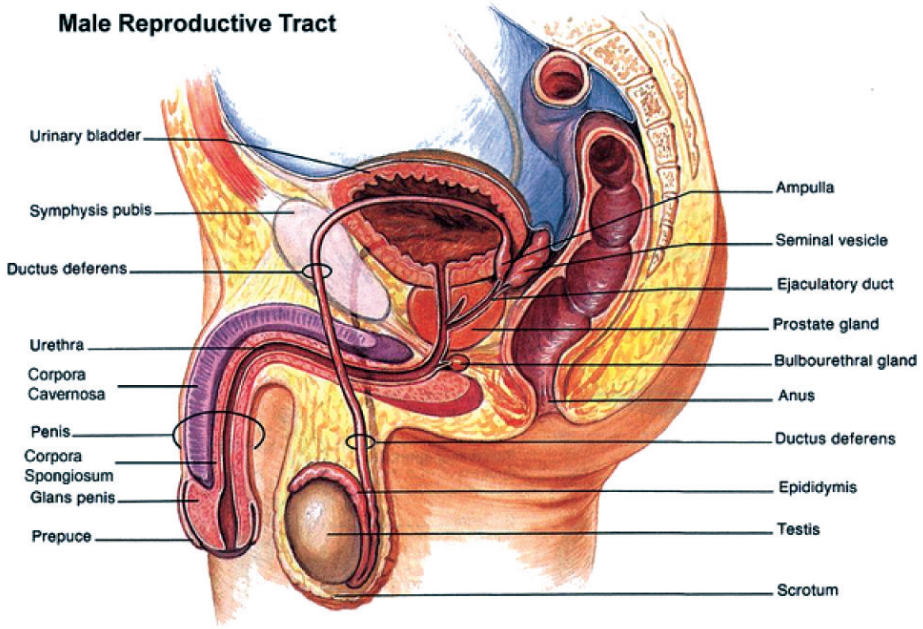


Figure 16.6: Sagittal view of human male reproductive system

Testosterone is the principal hormone of the testes which is synthesized in the Leydig cells from cholesterol and is also formed in the adrenal cortex. The major functions performed by testosterone in male reproductive system are:

- Gonadotropin regulation
- Spermatogenesis
- Sexual differentiation
- Wolffian stimulation
- Sexual maturation at puberty

Inhibin is another hormone of testicular origin that inhibits FSH secretion. Estradiol and estrone are also synthesized in testis in minor quantities.

SELF EVALUATION

Complete with appropriate terms:

(i) Male sex organs include ..... and ..... .

(ii) The seminiferous tubules contain specialized cells, the spermatogenic and supporting cells called ..... .

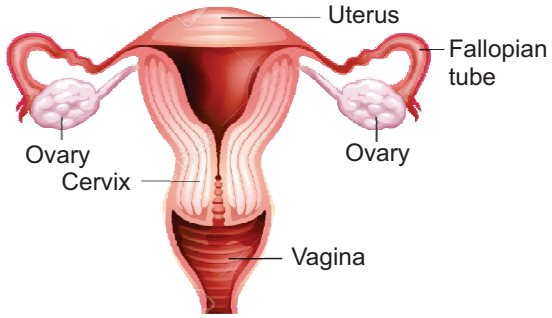
(iii) ..... joins epididymis from head region and ..... leaves the epididymis from tail region.

(iv) ..... provide alkaline environment that protects the passing spermatids.

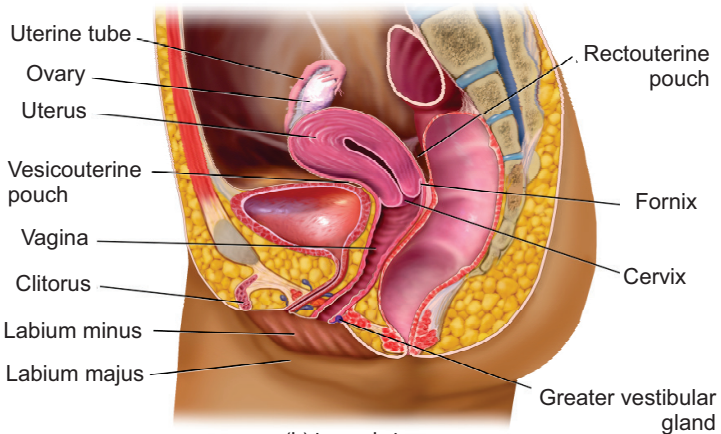
16.3 FEMALE REPRODUCTIVE SYSTEM

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.

Ovaries (singular: Ovary, Latin: Ovarium, literally meaning 'egg' or 'nut') — the primary sex organs in females are egg-shaped, paired structures, located in the upper pelvic cavity, one on



(a) Front view



(b) Lateral view

Figure 16.7: An overview of human female reproductive system

either side of the uterus in front of the ureter, embedded in the connective tissue matrix called **ovarian fossa**. A single ovary is about 2 to 4 cm long, 2 cm wide and 1.5 cm thick and weighs about 15 grams. Each ovary is held in place by three ligaments: **mesovarium** or the **broad ligament**, **suspensory ligament** and the **uteroovarian ligament**.

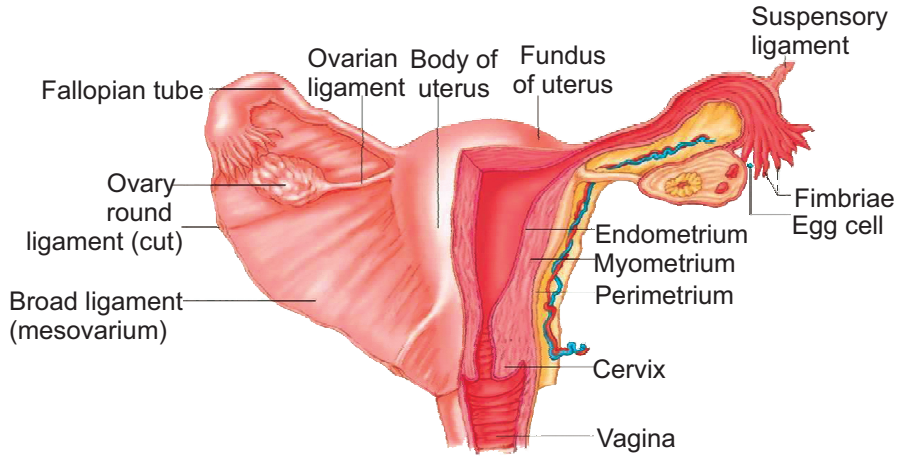


Figure 16.8: The relation between various structures of human female reproductive system. Ovarian ligaments can be seen clearly

Histology of the ovary: A typical human ovary is composed of connective tissue called **stroma**, wrapped by germinal **epithelium** which is further layered by **tunica albuginea**. The stroma is divided into two zones: an outer dense cortex and a less dense inner medulla. The medulla consists of loose connective tissue, blood vessels, lymphatics, smooth muscle fibres and nerves. The **cortex** consists of rounded structures called **ovarian** or the **Graafian** follicles, at various stages of development. Each follicle consists of a large ovum surrounded by several layers of follicular or granulosa cells.

A fully grown ovarian or the Graafian follicle typically consists of:

- an **oocyte** (15-30 µm wide) with a nucleus called the **germinal vesicle**, bounded by **vitelline membrane** which is further surrounded by **zona pellucida.**
- surrounding the **zona pellucida** is present **membrane granulosa**, consisting of **granulosa cells** or the **follicular cells**. The granulosa cells lying in close vicinity of the oocyte may become elongated to form the **corona radiata**.
- membrana granulosa is further covered on the outside by **theca interna** and **theca externa**.
- a cavity called **follicular antrum/cavity** filled with a fluid, the **liquor folliculi**.
- the oocyte anchors to the wall of the follicle by a thin layer of follicle cells called cumulus **oophorus**, which nourishes the oocyte.

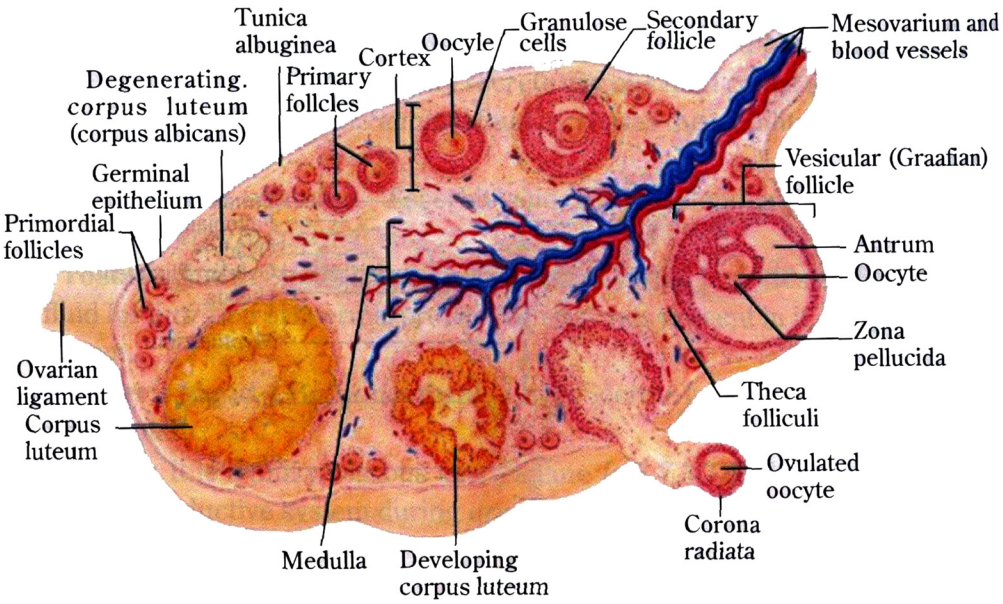


Figure 16.9: Diagrammatic view of the cross section of a human ovary. Ovarian follicles can be seen at various stages of development

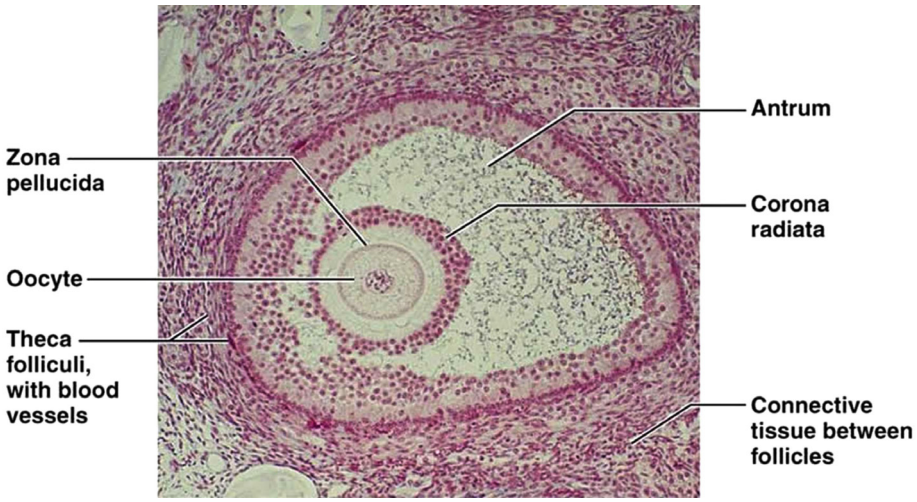


Figure 16.10: Structure of a mature Graafian follicle

Ovaries perform two important functions:

(a) **Oogenesis:** production of female gamete (ovum, pl. ova).

(b) **Production of hormones:** some of the follicular cells produce the hormone **estrogen**, while the follicle is developing and **progesterone** and **relaxin** while the follicle is degenerating as corpus luteum. Estrogen stimulates the growth and functions of female sex organs and development of secondary sexual characteristics. Progesterone prepares the uterine lining to receive embryo and maintains it during pregnancy. It also stimulates the growth of mammary glands. Relaxin helps in the relaxation of pelvic ligaments and softening and widening of the cervix during delivery of the baby (parturition).

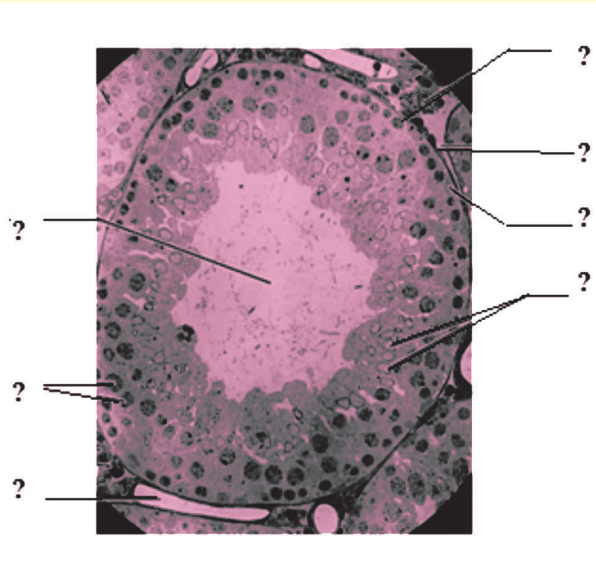
ACTIVITY 3

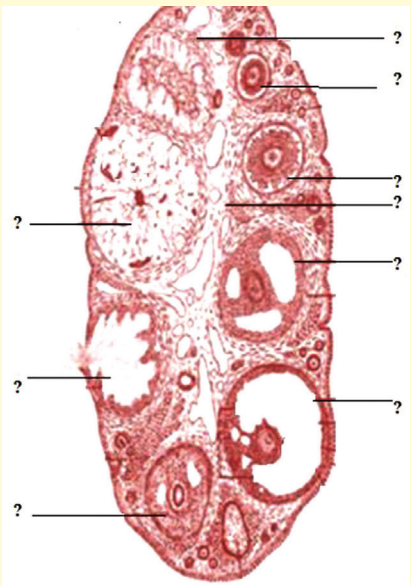
Aim: To study the histology of human testis and ovary using prepared slides and micrographs.

Theory: A typical testis is composed of various cell types i.e., sertoli cells, leydig cells, fibroblasts, primary and secondary spermatocytes, spermatids and basal lamina etc. A typical human ovary is composed of connective tissue consisting of rounded follicles, at various stages of development. Each follicle consists of a large ovum surrounded by several layers of follicular or granulosa cells. Germinal epithelium is the outermost boundary of the ovary.

Procedure:

Observe a permanent slide of transverse section (T.S.) of human ovary and testis under low power and then under high power microscope and locate various cell types.





On the basis of your observations;

1. Label the cell types in following micrograph of testis and ovary.
2. Complete the table given below based on histological analysis ofovary:

Stage of follicle development	Number of cells	Diameter	Known function(s)
Primary follicle			
Secondary follicle			
Graafian follicle			
Corpus luteum			

16.3.1 Female Reproductive Ducts

Oviducts: Also known as the uterine ducts or the fallopian ducts, lined with ciliated epithelia, they function to transfer the ovum from the ovary to the uterus and serve as the site of fertilization of the male and female gametes. Each oviduct, 10-12 cm long, extends from the margins of the ovary to the uterus and can be divided into four continuous regions as:

- **Infundibulum** — the part closest to ovary. It has finger-like projections called fimbriae that drape over the ovary and serve to receive the ovum released by the ovary during ovulation.
- **Ampulla —** the widest and major part of the tube, the site of fertlization.
- **Isthmus** — the narrower part, that links to the uterine wall.
- **Interstitial** or the **intramural** or the **uterine part**—that lies within the uterine wall.

Uterus: This is an 'inverted pear'-shaped, muscular, hollow (uterine cavity lies within), hormone-responsive organ that serves to house, nourish and protect the growing foetus till birth. Anatomically, the uterus consists of three parts:

- **Fundus**—the dome shaped part above the openings of the uterine parts of the fallopian tubes.
- **Corpus uteri or the 'body'**—the main centrally expanded portion.
- **Cervix**—the inferior narrow portion that opens into the vagina. A narrow, constricted region, about 1 cm long called **isthmus** joins the uterus with the cervix. The cervical canal or the cavity of the cervix communicates with the uterus internally by an aperture called internal os and with the vagina by **external os**.

Cervix and vagina together form the birth canal. During childbirth, it dilates widely to allow the baby to pass through. The wall of the uterus is composed of tissue layer called endometrium. The endometrium is shed during menstruation and is regenerated by the basal layer after each menstruation.

Vagina: It is a distensible, muscular tube, about 10 cm long, which extends from vulva (external genitalia) to the uterus. The vaginal opening on the vulva is termed the **vaginal orifice**. The orifice is partially covered by a membrane called **hymen** that ruptures during the first act of intercourse. However, it may get ripped off during some strenuous activities like sports or due to some disease. Vagina serves as a receptacle for the male copulatory organ during sexual intercourse, provides a passageway for the menstrual flow and forms part of the birth canal during childbirth.

16.3.2 External Genitalia (Vulva)

The female external genitalia include mons pubis, labia majora, labia minora, hymen and clitoris. **Mons pubis** is a cushion of fatty tissue covered by skin and pubic hair. The **labia majora** are fleshy folds of tissue which extend down from the mons pubis and surround the vaginal opening. The **labia minora** are smaller folds which lie under the labia majora. Anteriorly, labia minora merge together to form a small eractile organ called **clitoris**. It is Homologous to the male's glans penis. Posteriorly, the labia minora are fused together to form the **fourchette**. They also contain numerous sebaceous glands.

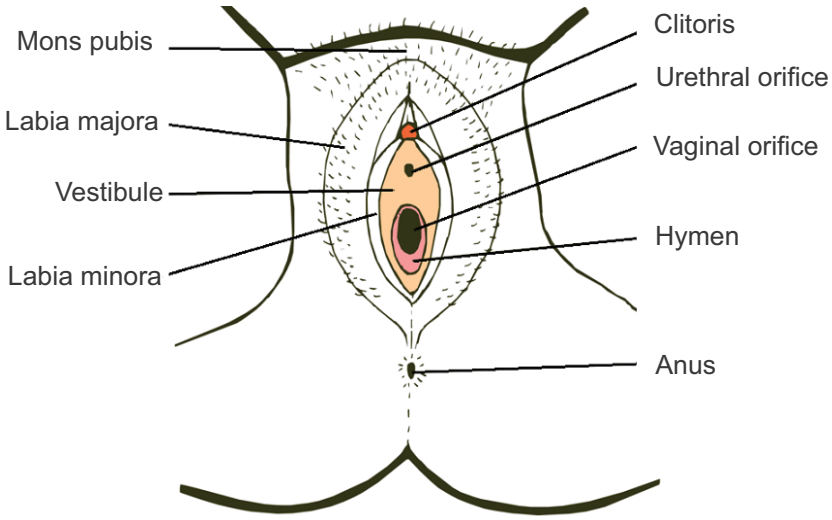


Figure 16.11: The external genitalia in human female

16.3.3 Female Reproductive Glands

The glands associated with vestibular region are broadly of two types:

- **Glands of Skene** or **Paraurethral glands (lesser vestibular glands):** Those are numerous minute glands present around the urethral orifice. They secrete mucus and are homologous to the male prostate glands.

- **Bartholin's glands (greater vestibular glands):** These are located on each side of vagina beside the vaginal opening and produce a mucus secretion to lubricate the vestibule that aids in sexual intercourse. They are considered homologous to the bulbourethral glands in males.
- **Mammary glands or Breasts:** These are modified sweat glands that produce milk. Though characteristic of all female mammals, they are also present in a rudimentary form in males. In females also, they remain underdeveloped until puberty. Each breast is covered with skin and bears a central protruding **nipple** surrounded by a pigmented area called areola. Internally, each breast consists of the glandular tissue, the fibrous connective tissue and the fatty or the adipose tissue:
    - The **glandular tissue** of each breast is divided into 15-20 mammary lobes. Each lobe is further divided into a number of **lobules** containing clusters of cells called alveoli. The cells of alveoli secrete **milk**, which is stored in the cavities (lumens) of alveoli. The alveoli open into mammary tubules. The tubules of each lobe join to form a **lactiferous or mammary duct**, which opens on the nipple. Just before their opening, the lactiferous duct swells to form the **mammary ampulla** or **lactiferous sinus**, which acts as a reservoir for milk during lactation. In non-pregnant and non-nursing women, the glandular structure of the breast is largely underdeveloped and the duct system is rudimentary.

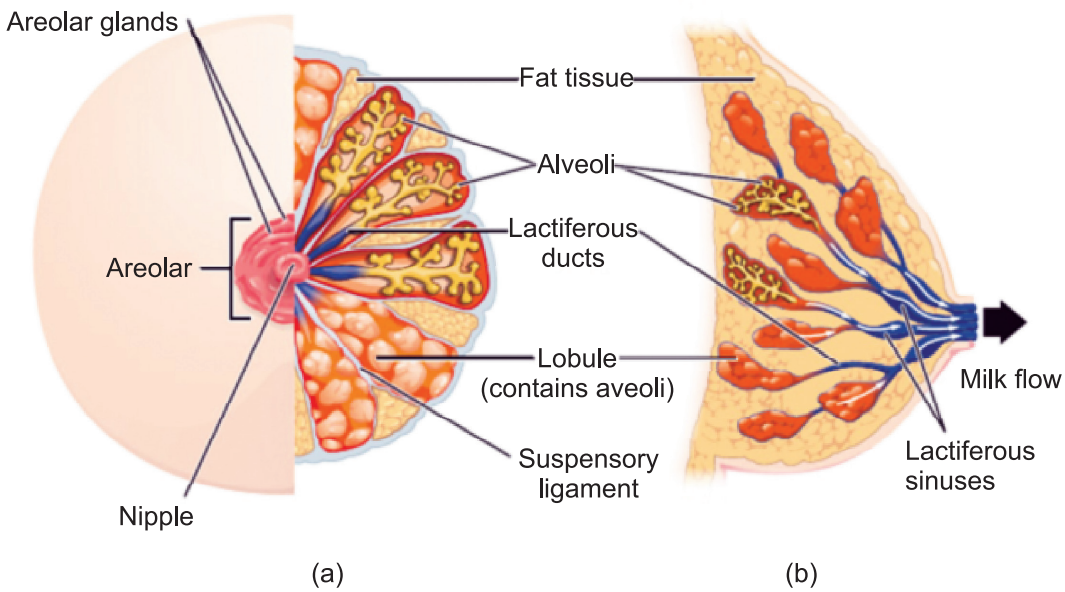


Figure 16.12: (a) Front view human breast with right half showing internal structure (b) Sagittal section of human breast

Human milk consists of water, organic and inorganic components. The main constituents include fat (droplets), casein (milk protein), lactose (milk sugar), mineral salts (sodium, calcium, potassium, phosphorus, etc.) and vitamins. Human milk is poor in iron and vitamin C content. With childbirth, the anterior lobe of pituitary secretes the hormone **prolactin**, which stimulates the production of milk. Another hormone **oxytosin** secreted by the posterior lobe of pituitary stimulates the release of milk, though the psychic state and nutrition of the mother also governs milk production.The first milk produced by each breast after childbirth is termed the **colostrum**. It is thick, yellowish fluid rich in proteins and antibodies, that provides passive immunity to the breastfed baby. Colostrum also helps the newborn's digestive system to grow and function properly.

16.3.4 Menstrual Cycle

Menstrual cycle is the reproductive cycle involving cyclic in the ovary and uterus that occurs in the female primates, e.g., humans, monkeys, apes, etc. This cycle is responsible for maturation of the ovum and its release from the ovary (**ovulation**) and preparation of the uterus for pregnancy. The menstrual cycle is regulated by hormones. A typical menstrual cycle in human female is about 28 days long with 3–5 days plus or minus variation. The onset of this cycle (known as **menarche)** generally starts at the age 12–15 (**puberty**) in girls and ends (known as **menopause**) by the age of 45–50 in humans.

One cycle is completed in three phases: the **uterine cycle** is divided into menstrual phase, proliferative phase, and secretory phase and correspondingly the **ovarian cycle** consists of the follicular phase, ovulation, and luteal phase.

1. **Menstrual phase or bleeding period** or the **menses** or **period (days 1–4):** Low levels of hormones progesterone and estrogen make the blood vessels of the endometrium constrict. This causes the endometrial lining to shed along with blood and unfertilized ovum.

   At the same time, under the influence of **Follicle stimulating hormone (FSH)** secreted by the anterior lobe of pituitary, ovaries are beginning **follicular phase** i.e., growth and proliferation of one of the follicles to become **Graafian follicle** or **tertiary follicle**.

2. **Proliferative phase (days 5-14): Gonadotrophic releasing factor** (GnRF) secreted by the hypothalamus stimulates the release of FSH and **Luteinizing hormone** (LH). High levels of FSH stimulate the ovarian follicle to secrete estrogens. The combination of FSH and LH, and estrogen, has a **positive feedback effect** on anterior pituitary, causing the release of more and more FSH and LH and thus, more estrogen.

Estrogens cause the endometrial lining of the uterus to proliferate, rapid cell multiplication occurs with development of uterine glands and blood vessels. Ovary is still undergoing follicular phase.

Towards the end of proliferative phase, high levels of estrogen trigger a sudden increase in the levels of **LH**. This **LH surge**, as it is called, lasts for 24-48 hours, causes the rupture of ovarian follicle and release of ovum from the ovary into the oviduct (= ovulation phase of the ovarian cycle).

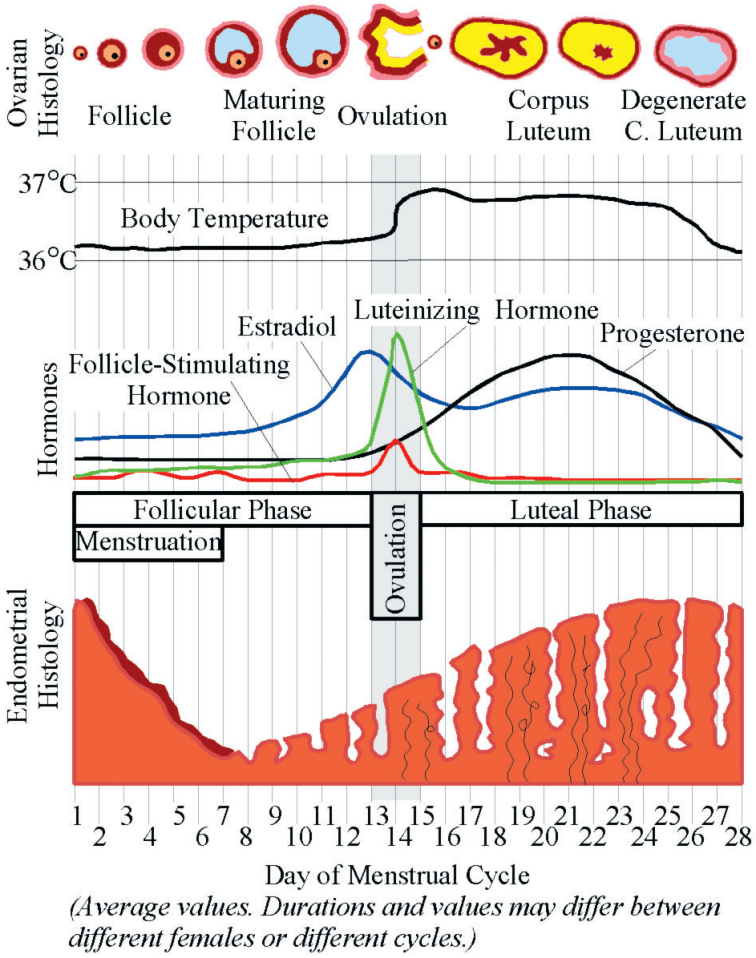


Figure 16.13: Diagrammatic presentation of various events during a menstrual cycle

3. **Secretory phase (days 14-28):** The final phase of the uterine cycle corresponds to the **luteal phase of the ovarian cycle** that lasts for about 10 days. The Luteinizing hormone (LH) secreted by the anterior lobe of pituitary stimulates the development of **corpus**

luteum from degenerating cells of the ovarian follicle after ovulation. Corpus luteum secretes large amounts of **progesterone** and some estrogen.

The combination of estrogen and progesterone inhibits the release of FSH and LH from pituitary (**negative feedback**). Progesterone prepares the uterus to receive, implant and nourish a fertilized egg during the second half of the menstrual cycle.

If implantation does not occur, the endometrium breaks down and menstruation occurs. Corpus luteum degresses and production of progesterone is lowered. This releases the inhibition of FSH and LH, thus initiating the next menstrual cycle.

Corpus Luteum

Corpus luteum (Latin means "yellow body"; plural: corpora lutea) is a temporary endocrine structure that develops from degenerating cells of the ovarian follicle after the release of ovum, under the influence of LH. It produces large amounts of progesterone.

If the oocyte is fertilized, the corpus luteum continues to proliferate and increases hormone production. By the end of the third month of pregnancy, luteal cells occupy a large part of the ovary and keep releasing progesterone. However, by the end of the fourth month, they regress slowly.

If the oocyte is not fertilized, the corpus luteum degenerates in 10–12 days after ovulation. It is visible only in the form of a white scar, the **corpus albicans**, on the outside of the ovary.

SELF EVALUATION

Complete with appropriate terms:

(i)..... stimulates the release of milk.

(ii) Ovary is held in place by three ligaments called ....., ..., and ..... .

(iii) Follicular cells produce ..... , ... and ..... .

(iv) ..... acts for reservs for milk during lactation.

16.4 GAMETOGENESIS

Gametogenesis is the process of formation of haploid gametes from undifferentiated, diploid germ cells in the gonads for sexual reproduction. Male and female sex cells or gametes i.e., sperms and ova are formed respectively in the male and female gonads (testes and ovaries).

Types and phases of gametogenesis: Formation of male gametes (sperms) is termed spermatogenesis and that of female gametes (ova, singular: ovum) is referred to as oogenesis. Both the processes undergo three basic phases, common to both:

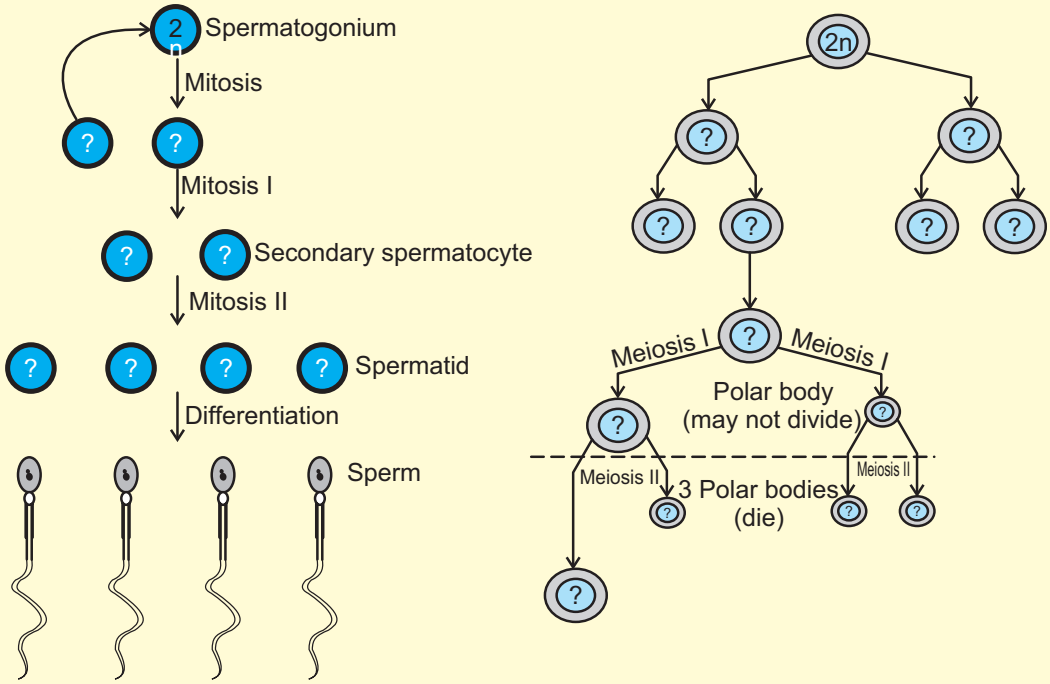
1. **Proliferative or the multiplication phase**
2. **Growth phase**
3. **Maturation or differentiation phase**

ACTIVITY 4

Aim: To understand the process of gametogenesis and haploid nature of gametes.

Theory: 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.

Procedure: Based on the chart diagrams of spermatogenesis and oogenesis shown below, compute the number of chromosomes at each stage, assuming 2n = 46.



16.4.1 Spermatogenesis

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: (i) Formation of spermatids and (ii) 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.

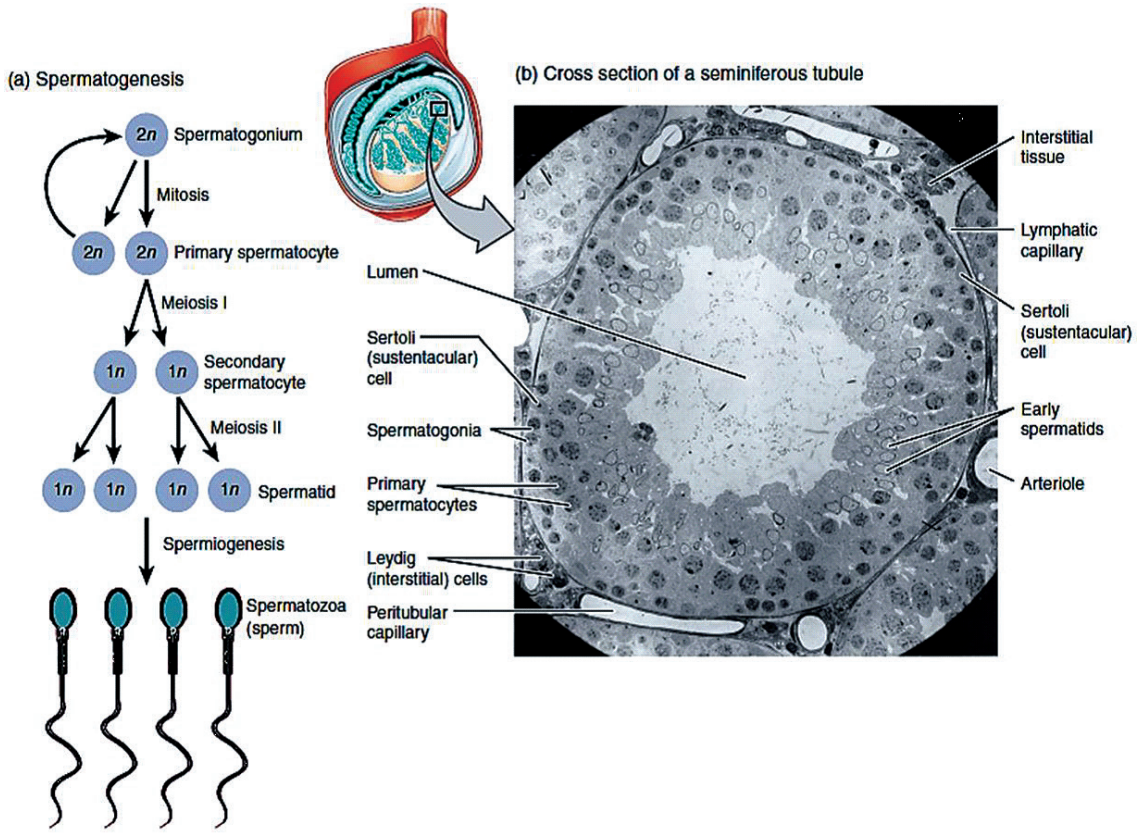


Figure 16.14: (a) Process of spermatogenesis showing chromosome numbers at various stages and the cross-section of a seminiferous tubule showing histological arrangement of various cell types (b) Stages in the formation of spermatozoan from spermatid and acrosome formation from golgi apparatus during 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.

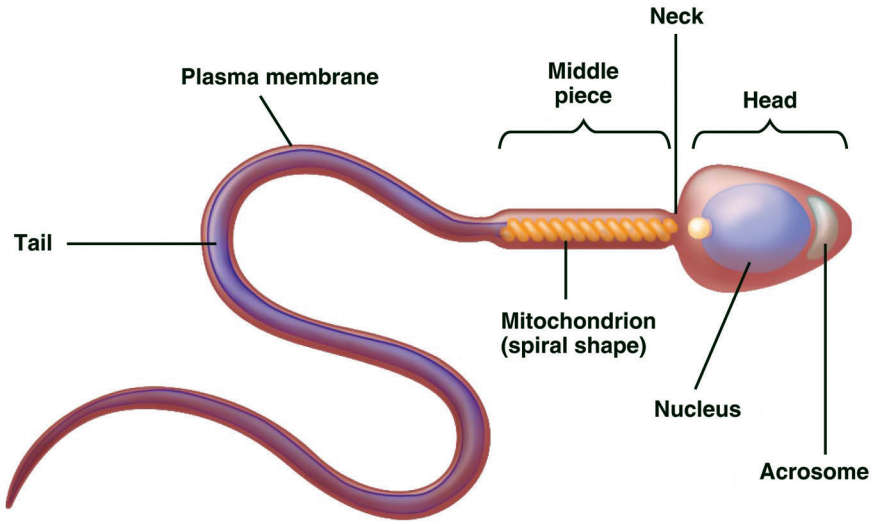


Figure 16.15: Structure of a sperm

(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 motality 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.

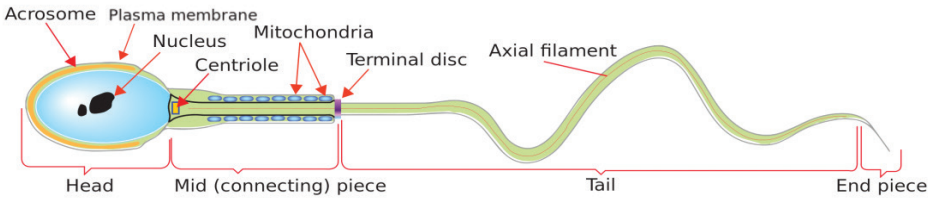


Figure 16.16: Structure of human sperm

16.4.2 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**.

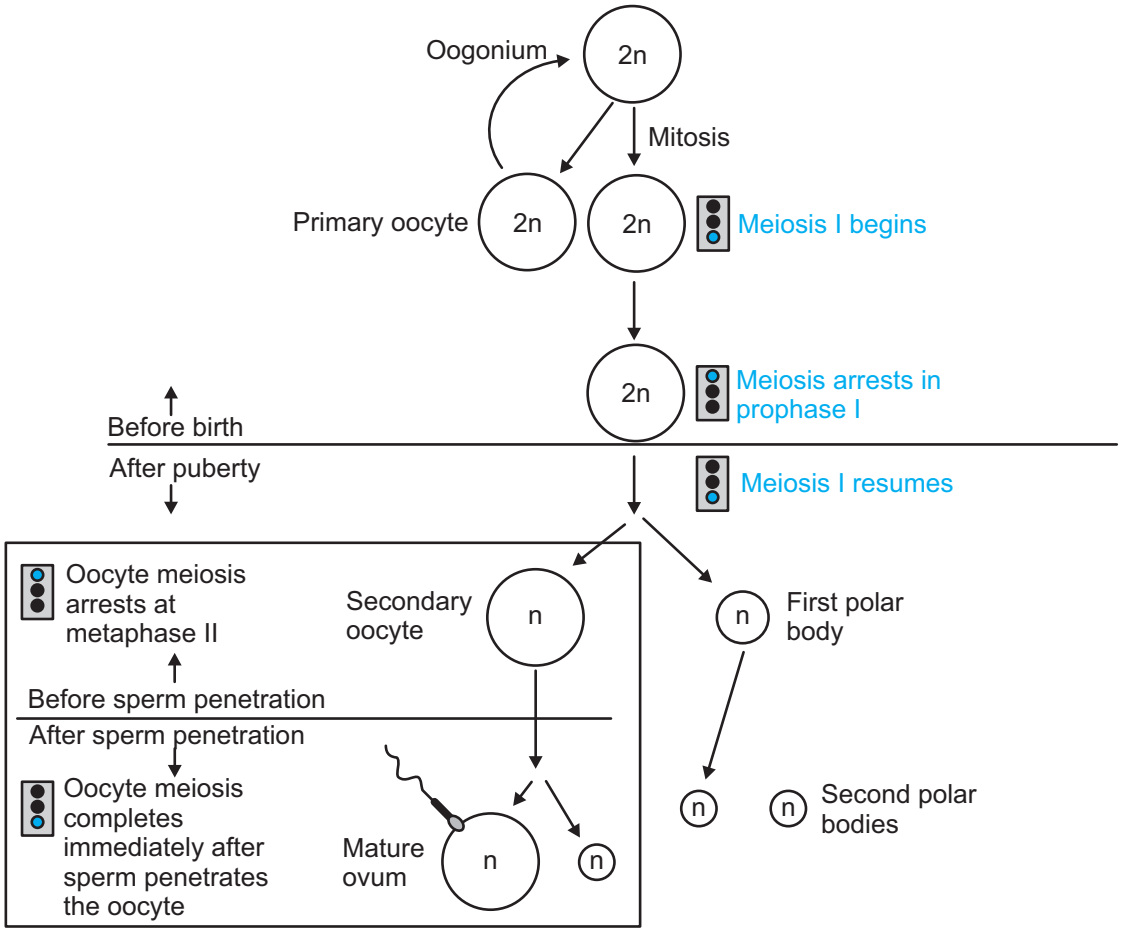


Figure 16.17: Schematic representation of oogenesis

(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 follicl**e.

(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.

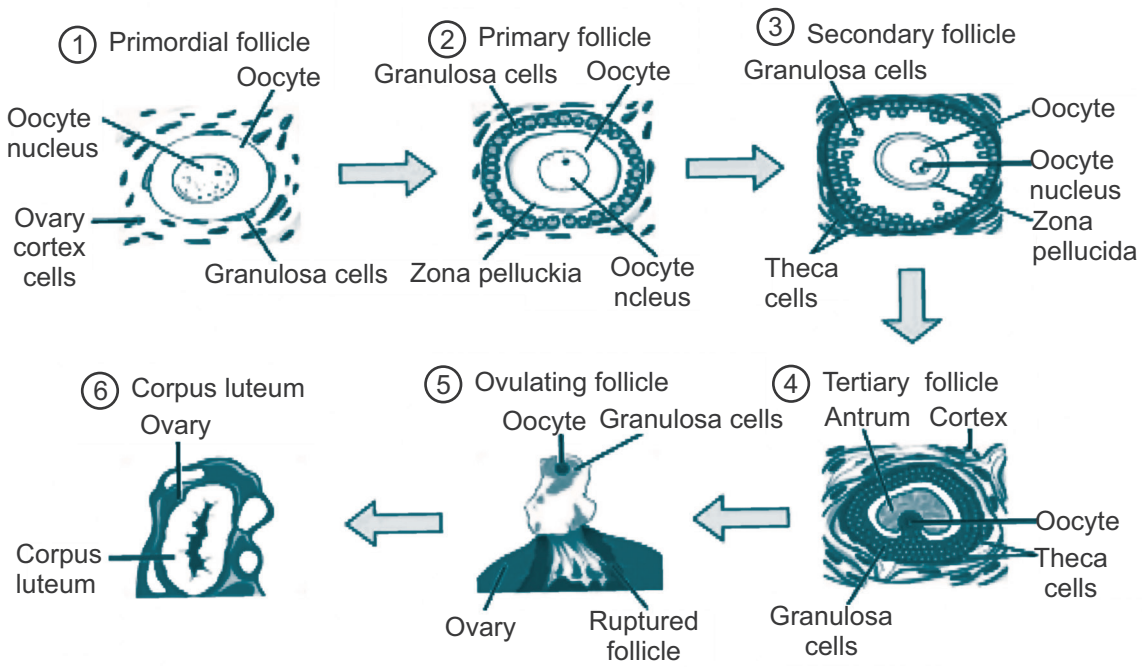


Figure 16.18: Maturation of a follicle shown in a clockwise direction proceeding from the primordial follicles. FSH stimulates the growth of a tertiary follicle, and LH stimulates the production of estrogen by granulosa and theca cells. Once the follicle is mature, it ruptures and releases the oocyte. Cells remaining in the follicle then develop into the corpus luteum.

Thus, from one oogonium (egg mother cell), one ovum and three polar bodies are formed. The ovum is the functional female gamete while the polar bodies take no part in reproduction and soon degenerate. The formation of polar bodies only helps the egg to get rid of one set of chromosomes and still enables the ovum to retain most of the cytoplasm and food for the future embryo. In case fertilization does not occur, the secondary oocyte undergoes degeneration and is driven out of the body.

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

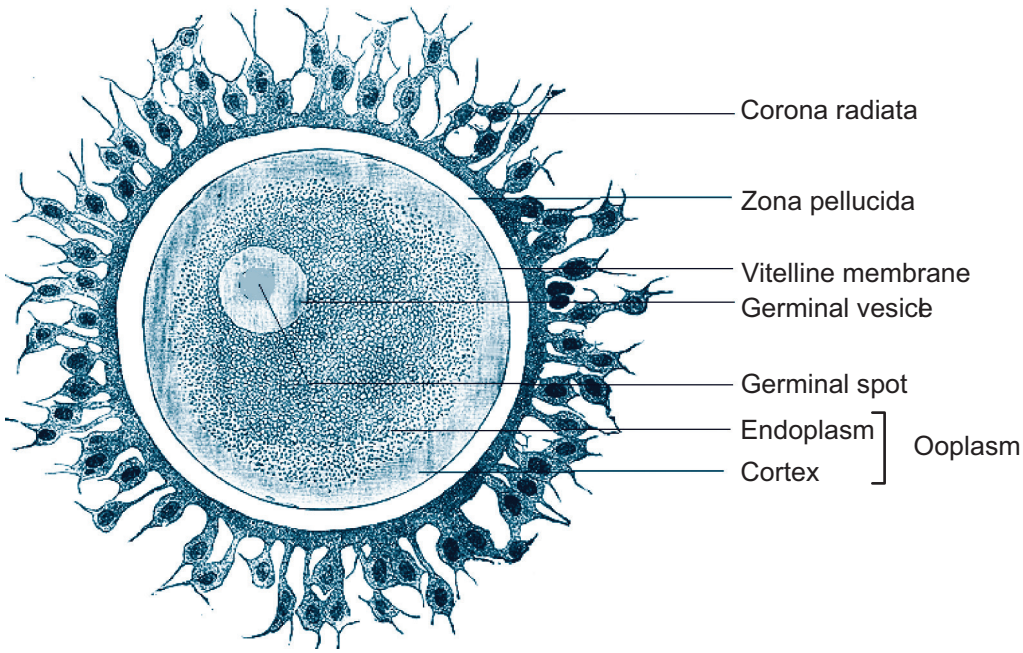


Figure 16.19: Structure of a mature human ovum with corona radiata surrounding it

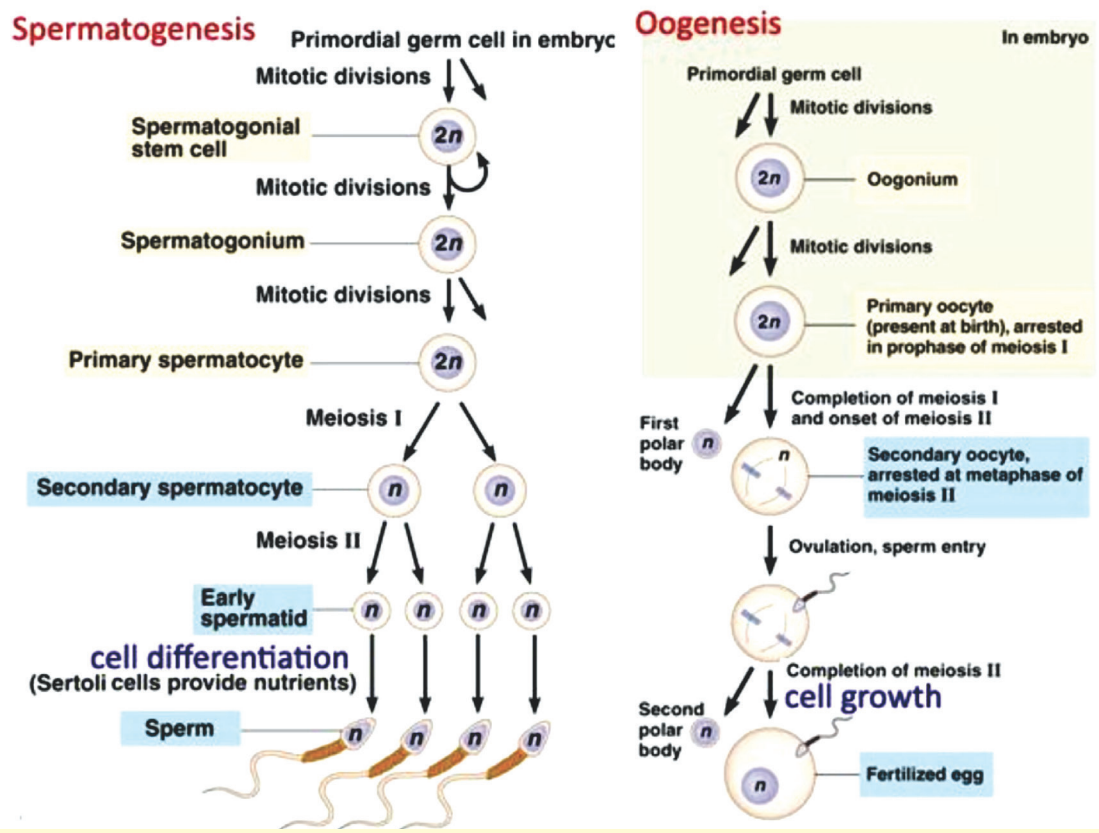
thin, transparent vitelline **membrane** which is further covered over by **zona pellucida**. There is a narrow space between these two membranes known as **perivitelline space**. During discharge of ovum from the Graafian follicle, several layers of follicular cells adhere to the outer surface of zonapellucida and are arranged radially forming **corona radiata**.

Differences between spermatogenesis and oogenesis

S. No.	Spermatogenesis	S. No.	Oogenesis
1.	It occurs in the testis.	1.	It occurs in the ovaries.
2.	The whole process is completed in the testes so that mature spermatozoa are released from the testes.	2.	The process gets completed in the oviduct i.e., oocytes at metaphase-II stage are released from the ovaries.
3.	Equal meiotic divisions occur.	3.	Unequal meiotic divisions occur.
4.	No polar body is formed.	4.	Polar bodies are formed at each meiotic division.
5.	One spermatogonium produces four functional spermatozoa.	5.	One oogonium produces only one functional ovum.
6.	A primary spermatocyte undergoes first meiotic division to produce two secondary spermatocytes.	6.	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.	7.	A secondary oocyte undergoes meiosis-II to produce one ootid and one polar body.

ACTIVITY 5

Study the chart diagrams of spermatogenesis and oogenesis. Identify various stages and write down the points of similarities and dissimilarities between the two processes.



Differences between sperm and ovum

S. No.	Sperm	S. No.	Ovum
1.	Sperms are produced in the testis.	1.	Ovum is produced in the ovaries.
2.	It is motile.	2.	It is non-motile
3.	It contains very small amount of cytoplasm.	3.	It contains large amount of cytoplasm.
4.	It is elongated in shape, externally differentiated into head, neck and tail.	4.	It is rounded in outline, not differentiated externally.
5.	Mitochondria forms a spiral in the neck region.	5.	Mitochondria are scattered in the ooplasm.
6.	Does not donate anything but the nucleus for the formation of the zygote.	6.	Donates entire self to the zygote after fertilization.

ACTIVITY 6

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:

Spermatozoan	Ovum
nucleus	germinal vesicle
proximal centriole	germinal spot
acrosome	ooplasm
axial filament	vitelline membrane
ring centriole	zonapellucida
mitochondria	corona radiata

SELF EVALUATION

Complete with appropriate terms:

(i) The three basic steps of gametogenesis includes ....., ... and ..... .

(ii) One spermatogonium produces ..... and one oogonium produces ..... .

(iii) ..... cells provide nutrition in spermatogenesis.

(iv) The tertiary follicle matures into ..... .

16.5 ONSET OF PUBERTY IN HUMANS

Males attain sexual maturity, or puberty as it is called, at the age of 11–13 years. At puberty, the primary sex organs (=gonads) mature and secondary (=external) sex organs mature and secondary sexual characters appear viz. development of pubic, chest and underarm hairs, growth of larynx resulting in deepening of voice, masculine pattern of fat distribution, thick secretion from skin oil glands, bone and muscle development, etc., are some of the prominent male secondary sexual characters. Testosterone controls the onset of puberty in males. Hypothalamus starts producing GnRH, which stimulates the anterior lobe of pituitary to secrete luteinizing hormone (LH) and follicle stimulating hormone (FSH).

Females attain puberty at the age of 12–15 years. At this age, pituitary gland starts producing **follicle-stimulating hormone (FSH)**. The FSH induces the development of ovaries, which produce the hormone estrogens, chiefly estradiol. Estrogen is responsible for the development of

secondary sex organs and **secondary sexual characters** in females, which include development of breasts and external genitalia, pigmentation of the areola, growth of pubic hair, axillary hair (in the armpits), widening of the pelvis and deposition of fat in thighs, buttocks and face. Puberty marks the onset of menstruation or **menarche** in females.

Differences between primary and secondary sex organs

S. No.	Primary sex organs	S. No.	Secondary sex organs
1.	They produce gametes.	1.	They do not produce gametes.
2.	They secrete sex hormones.	2.	They do not secrete sex hormones.
3.	Testis in male and ovaries in female are examples of primary sex organs.	3.	Epididymis, vas deferntia, penis, etc. are secondary sex organs in male and oviducts, uterus, etc. are examples of secondary sex organs in female.

16.6 SUMMARY

- Human male reproductive system carries out the functions of spermatogenesis i.e., formation of functionally active, motile sperms along with seminal plasma.
- The system comprises male sex organs i.e., testes (paired organ) and scrotum, a series of ducts that help in transportation and maturation of spermatozoa and the accessory glands which secrete the essential components of semen plasma.
- The temperature of testes is maintained 2°C –3°C below the core body temperature which provides favourable environment of spermatogenesis.
- The male reproductive ducts include vasa efferentia, vasa defrentia, epididymis, ejaculatory ducts and urethra primarily.
- The accessory glands of reproduction in human reproductive system are seminal vesicles, prostate gland, urethral (Littre's) glands and bulbourethral (Cowper's) glands.
- Human female reproductive system is designated to carry out the functions of ovulation, carry male and female gametes, fertilization, gestation and childbirth.
- Human female reproductive system consists of female sex organs- ovaries, duct system - oviducts or the uterine/fallopian tubes, uterus, cervix, vagina, the external genitalia – vulva and a pair of mammary glands.

- Ovaries produce female gametes- ova. They contain ovarian follicles at various stages of development. An ovarian follicle consists of ovum surrounded by granulosa cells and other layers for protection and nutrition.
- Oviducts transfer ovum from ovary to the uterus and serve as the site of fertilization. Each oviduct is divided into an infundibulum, ampulla, isthmus and uterine parts.
- Uterus is a hollow organ that serves as the site of implantation and nourishment of the embryo till birth. It consists of three parts – fundus, body and cervix. The inner lining is called endometrium.
- Cervix and vagina form the birth canal.
- External genitalia or vulva consists of mons pubis, clitoris, labia majora, labia minora and perineum.
- Glands include lesser vestibular and greater vestibular glands and a pair of mammary glands. Mammary glands function in the production of milk for the young one.
- Menstrual cycle consists of three phases: menstrual, proliferative and secretory in the uterus, corresponding to follicular, ovulation and luteal phases of ovarian cycle.
- The onset of menstrual cycle at puberty is termed menarche and end is called menopause.
- The menstrual cycle is governed by hormones.
- The process of formation of haploid male gametes or spermatozoa from diploid reproductive cells in males is called spermatogenesis.
- The complete process of spermatogenesis is broadly divided into two parts:
  (i) Formation of spermatids and (ii) Spermiogenesis or spermatoleosis.
- Spermatid formation is further divided into three phases as multiplication, growth and maturation phase.
- Spermiogenesis is the process of series of changes to transform a non-motile spermatid into motile, functional spermatozoa.
- Oogenesis is the formation of haploid ovum from diploid undifferentiated germ cells in the ovary.
- Oogenesis is completed in three phases of discontinuous steps.
- Proliferative or multiplication phase involves proliferation of oogonial cells by mitosis.
- Growth phase is all about growth and differentiation of primary oocyte and development of mature ovarian follicle.
- Maturation phase provides time for the oocyte to undergo two meiotic divisions to produce functional haploid ovum.

16.7 GLOSSARY

- **Castration:** The surgical removal of testis is called castration.
- **Coitus:** The sexual act of transferring sperms of male to vagina of female.
- **Cryptorchidism:** Abnormality wherein the testes do not descend down from the abdomen to scrotum is called cryptorchidism (crypt = hidden; orchid = testis).
- **Ectopic pregnancy:** A pregnancy occurring in the fallopian tube or outside of the uterine lining.
- **Ejaculation:** The process of propulsion of semen out of the urethra at the time of orgasm.
- **Emission:** Emission is the phenomenon of movement of sperms from the testes into the urethra along with secretions from the various accessory glands of reproduction, where they mix to form semen.
- **Erection:** The accumulation of blood in penile erectile tissue leading to temporary swelling and elongation of penis is called erection. This accumulation of blood is because of dilation of arteries and compression of veins of penis.
- **Gynecomastia:** The condition when mammary glands become functional in males.
- **Hypermastia:** Presence of more than the normal number of breasts.
- **Hysterectomy:** Surgical removal of the uterus is known as hysterectomy.
- **Impotence or erectile dysfunction:** Impotence is the failure to achieve and/or maintain the erection for coitus.
- **Orgasm:** Orgasm is a pleasurable feeling of physiological and psychological release associated with the culmination of sexual stimulation. Emission and ejaculation of semen accompany orgasm in males.
- **Tubectomy:** Surgical procedure for sterilization in which a woman's fallopian tubes are clamped and blocked, or severed and sealed.
- **Vasectomy:** Bilateral ligation of vas deferens as a contraceptive measure in males is called vasectomy.

16.8 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. Germinal vesicle is the mitochondria of the ovum.
2. Urethral gland in human males is also called gland of Littre.

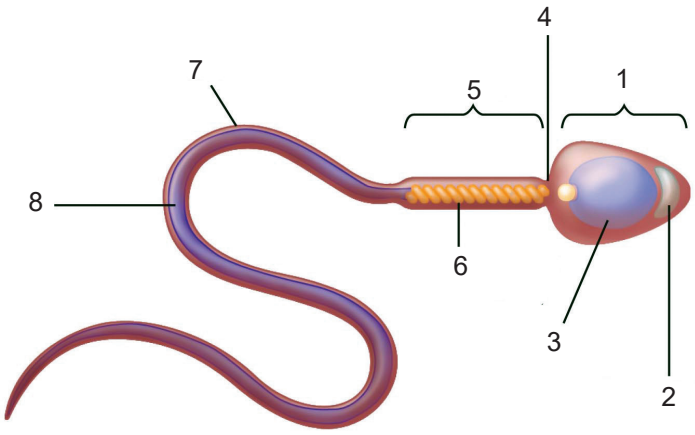
3. The proliferative phase involves two meiotic divisions of the oocyte.
4. Clitoris is considered homologous to penis of males.
5. Testosterone is synthesized in sertoli cells.

II. Fill in the blanks

1. Cowper's gland in human male is also called ..... .
2. Testes are present in the sac called .....
3. ..... hormone helps in the relaxation of pelvic ligaments during childbirth.
4. The site of fertilization in human female is ..... .
5. Corpus luteum secretes large amounts of hormone ..... .
6. The onset of menstrual cycle at puberty is termed ..... .
7. The caudaepididymis is attached to scrotal sacs by a connective tissue called ..... .
8. The hormone responsible for most of the secondary sex characters in human male is ..... .

III. Long Answer Type Questions

1. Give an account of various processes involved in oogenesis in human females.
2. Draw a well labelled diagram of human spermatozoan.
3. Give a detailed account of male reproductive accessory glands and discuss their role in male reproductive system.
4. Describe the histological structure of human testis.
5. With the help of suitable diagrams, explain the structure of human female reproductive system in detail.
6. Describe the internal anatomy of a typical human ovary.
7. Explain the steps leading to the formation of corpus luteus? What is its significance?
8. State where male and female gametes are produced.
9. Explain the significance of gametogenesis.
10. (i) Identify the structure shown in figure.
    (ii) Name the parts marked 1–8 in the figure.
    (iii) Write the functions of the parts marked 7 and 8.
    (iv) Name the chemical substance present in the part marked 2.
    (v) What is the importance of the chemical substance present in the part marked 2?



11. Genetic disparity has since ages disturbed the masses on Earth. Reproduction is a natural process but still the work for male and females is defined in the society. Assess your understanding to support gender equality. Also, list the names of organizations supporting the cause in Rwanda.

Unit 17

Genetics

Key Unit Competence

To be able to explain the role of genes in inheritance and how genetic disorders occur.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- explain the terms gene, locus, allele, dominant, recessive, co-dominant, linkage, test cross, F1 and F2, phenotype, genotype, homozygous and heterozygous.
- explain how to conduct a test cross.
- explain why monohybrid ratios of 1:2:1 occur.
- describe an example of inheritance involving multiple alleles.
- explain the effect of lethal genes on phenotype ratios.
- analyse various patterns of inheritance.
- appreciate the roles of genes in determining the phenotype and patterns of inheritance.
- use genetic diagrams to solve problems involving monohybrid and dihybrid crosses, including those involving autosomal linkage, sex linkage, and codominance, multiple alleles and gene interactions. (The term epistasis does not need to be used: knowledge of the expected ratio for various types of epistasis is not required. The focus is on problem-solving).
- use the complete and accurate format to show a genetic cross and the results of a simple monohybrid cross.
- use genetic diagrams to solve problems involving test crosses.
- use the chi-squared test to test the significance of the differences between observed and expected results (the formula for the chi-squared test will be provided.).
- demonstrate monohybrid and dihybrid inheritance.
- give a genetic explanation of Mendelian dihybrid inheritance.
- explain the use of test crosses to determine unknown genotypes in studies of dihybrid inheritance.
- explain the significance of recombination.

- explain how sex is determined in humans and the role of sex related Y genes in determining sex.
- describe how non-disjunction can affect the distribution of sex chromosomes in gametes and offspring.
- explain why linked genes do not show independent assortment.
- explain how crossover values can be used to make a chromosome map.
- interpret Pedigree charts.

17.1 CONCEPTS OF INHERITANCE

ACTIVITY 1

You must be familiar with the statements such as:
"You look similar to your mum but your skin colour is like that of your dad." Or
"Your eye colour is same as that of your grandfather".
Discuss such example for traits where you resemble to your family in traits such as hair colour, eye colour, skin colour etc.

We all are aware of the fact that we resemble to our parents (grand-parents) and siblings in our appearance such as eye colour, hair texture, skin colour etc. We are also aware of the fact that certain diseases run in the family such as diabetes, hemophilia etc. which indicates that certain characters or traits are passed on from parents to their offspring. This phenomenon is known as **Heredity** or **Inheritance**.

An organism produced by sexual reproduction has 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**.

17.2 MENDEL'S LAWS OF INHERITANCE

ACTIVITY 2

A farmer came to complain to the seed seller in this way: " I always buy the red bean seeds from your shop but this time, look, they produce red and some few yellow colored been. What did you put in the seed you gave me?"

How can you help to solve such a conflict?

Is there any pattern by which traits pass on from one generation to another?

17.2.1 Mendel's Experiments

In 1856, Gregor Mendel conducted experiments in garden pea (Pistum 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 (Figure 17.1), 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.

Gregor Mendel: Father of Genetics (*Source:* http://www.biography.com/people/gregor-mendel-39282)

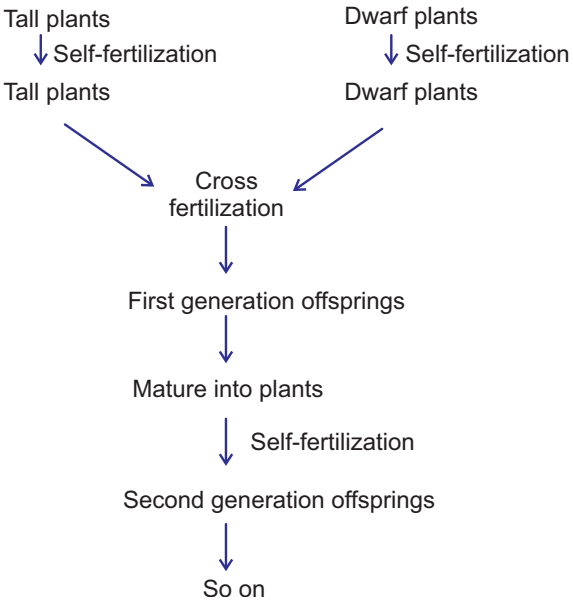


Figure 17.1: A hypothetical experimental plan by Mendel to follow the inheritance of particular trait or monohybrid inheritance (for example – stem height)

17.2.2 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 17.2).

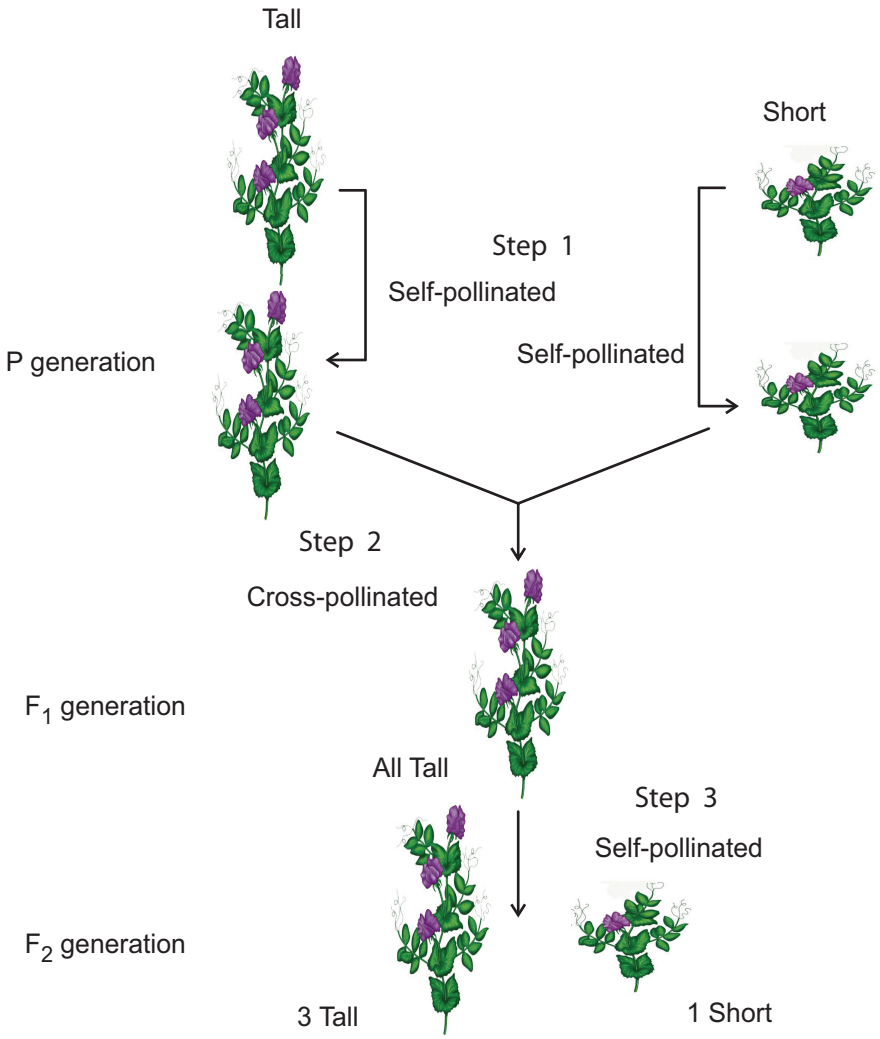


Figure 17.2: The experimental observation from a cross between tall and dwarf plants

- 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 17.3), 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.

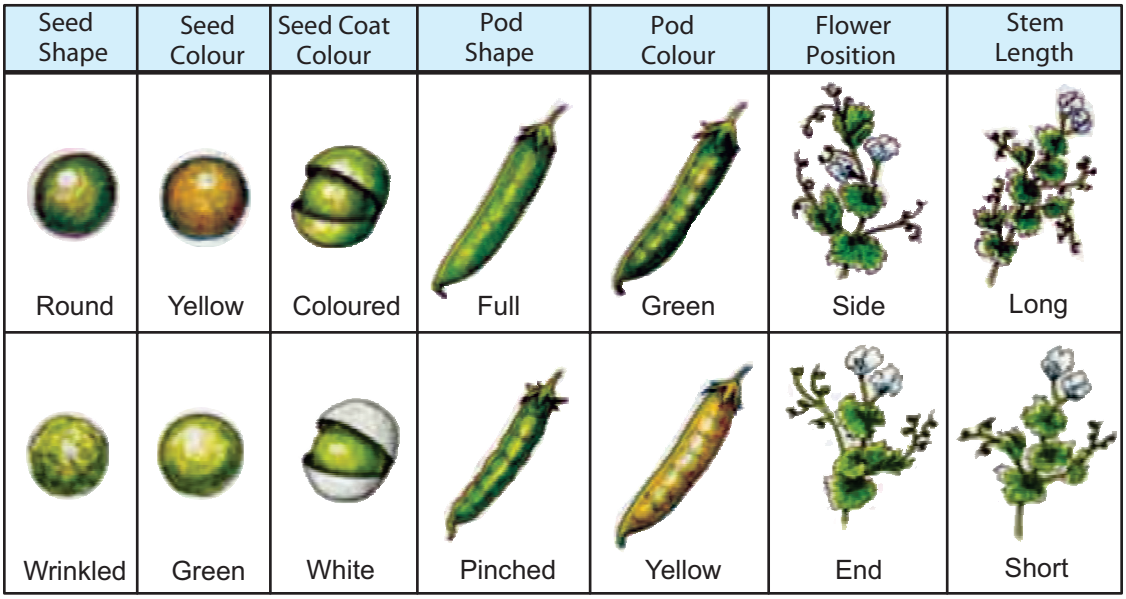


Figure 17.3: A seven pairs of contrasting traits in garden pea, the inheritance pattern was followed

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.*

17.2.3 Mendel's Postulates: Principles of Inheritance

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 17.4).
- 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.

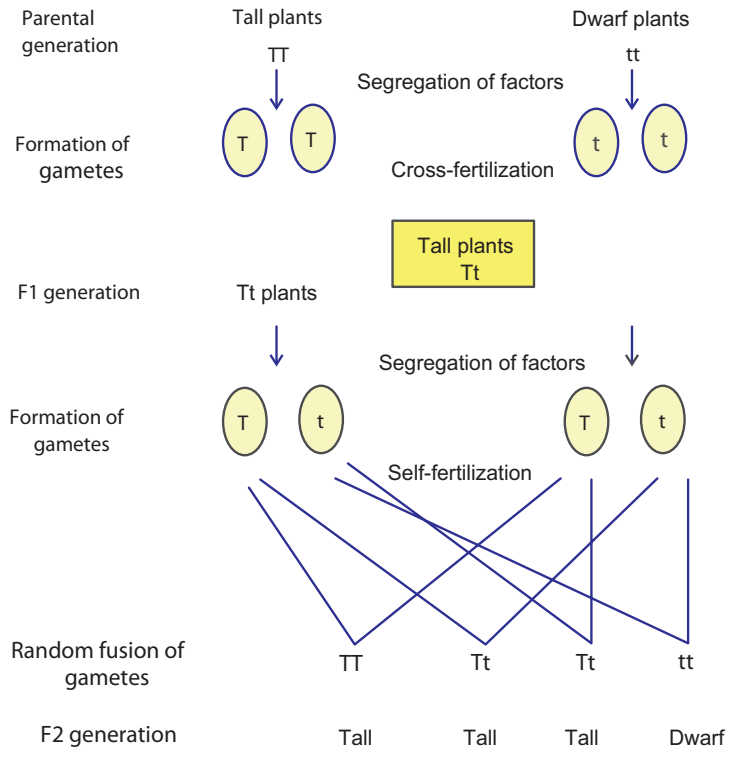


Figure 17.4: Mendel's conclusion from hybridization experiments (shown for trait : stem height)

- In F1 generation, only one of the parental traits is expressed, it indicates that out of two forms of factors for the single trait, one factor is dominant. For example: Tt organisms are tall, so the factor for tallness "T" is dominant over the factor "t" for dwarfness. The factor which remains under-expressed in presence of dominant factor is known as recessive factor.
- In the F1 populations, the factors again randomly segregate in the gametes. So a 'Tt' organism will produce two type of gametes either having 'T' or't' form for particular trait. During self-fertilization, there is random fusion of gamete and formation of TT, Tt, Tt or tt. Hence, three out of four F2 progeny becomes tall whereas one out of four progeny are small (figure 4). The tall and dwarf varieties are obtained in the ratio of 3 : 1. The F2 ratio (3 : 1) obtained is known as monohybrid ratio.
- Mendel concluded that the F2 ratio (3 : 1) indicates the morphological pattern of trait (for example in case of stem height, it indicates tall verse short), so it is also known as phenotypic ratio (Phenotype: morphological appearance). Genetically, it is further divided into 1 : 2 : 1 (Genotypic ratio) as Pure dominant: hybrid: pure recessive.

17.2.4 Reasons Behind Mendel's Success

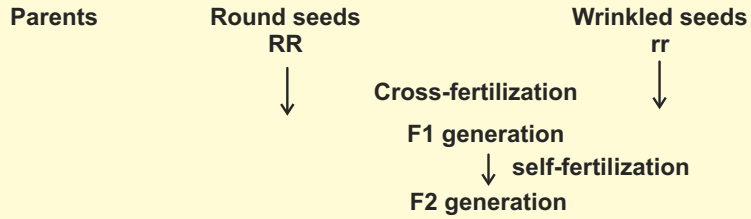
His experiments were highly successful and he was able to discover the pattern of inheritance. The reasons for his success are as follows:

- His choice of experimental organism i.e. garden pea, was extremely good as it generates a large number of generations in a very short duration.
- Pollination of garden pea leads to large number of offsprings due to which the inheritance pattern could be followed in the progeny.
- Furthermore, Mendel studied one trait at a time thereby allowing him to deduce useful interpretations.
- Lastly, his mathematical background played an important role in deducing the results.

ACTIVITY 3

Problem A

Aim: A plant with round seeds along with wrinkled seeds is crossed. What will be the genotype and phenotype of F1 generation and F2 generation if trait follows Mendelian pattern of Inheritance?



Procedure:

- Observe the given diagram carefully.
- Draw the punnett square showing the gametes from both the parents on each side.
- Note down the genotype and phenotype of F1 generation.
- Again draw the punnett square showing the gametes of F1 parents.
- Note down the genotype and phenotype of F2 generation.

Problem B

Aim: Demonstrate monohybrid inheritance using beads of two different colours.

Materials Required:

Class notebook

Two colour beads (red and yellow)

Procedure for monohybrid inheritance:

- Open pouch containing beads of two different colours.
- Count total number of beads.
- Divide total number of beads with 4 (T/4 = z)
- Differentiate beads according to their colour and count them respectively.
- Divide each number obtained in the previous step with value "z" and make a ratio.
- Discuss whether the observed ratio is in accordance with the Mendelian monohybrid ratios.

17.3 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" constitute 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 (Figure 17.5).

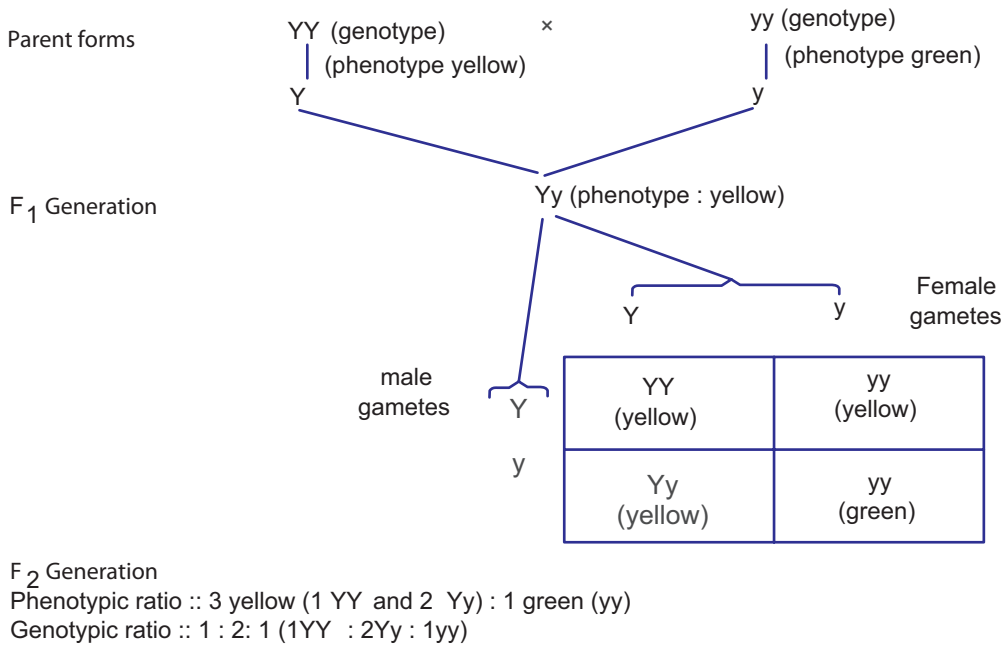
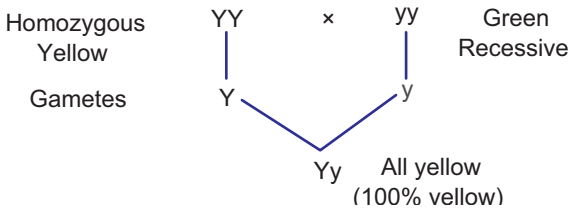


Figure 17.5: Mendel's monohybrid experiment on garden pea (*Pisum sativum*)

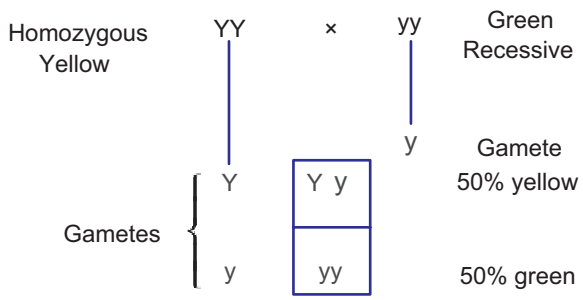
Test Cross: It is cross between hybrid forms (dominant phenotype) with other parent with recessive form of particular trait (homozygous recessive). It is generally used to identify the genotype of hybrid form. The progenies are observed. If all progeny demonstrates only dominant form of trait thereby 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:



In case of a double heterozygous, *i.e*, heterozygous yellow and round (*Yy Rr*) crossed with double recessive, *i.e*, recessive green and wrinkled (*yy rr*) the ratio will be 1 : 1 : 1 : 1.

Back Cross: The mating of the hybrid form with one of its parent or with individual genetically similar to parent is known as back cross. When the back cross is carried out for several generations, the hybrid becomes genetically closer to that parent. The back cross is commonly used in horticulture and animal breeding.

Chi-Square Test: The statistical test used to analysis genetic data especially obtained from breeding experiments. When breeding experiments are carried out, the progeny number is counted and based on their phenotype, the ratio is calculated. But there is always a difference in observed value from expected value. However, this might happen by chance or there can be a real difference behind this deviation. Hence, chi-square analysis test is used to find out whether deviations are by chance or there is indeed difference in observed value.

Probability of Deviation

Using chi-square analysis, the probability or p value is calculated. Probability of deviation indicates whether differences in observed value from expected value are by chance or not. If probability is very high (equal to or more than 0.05 or 5%) then probability of deviation by chance is high and there is no significant difference in observed and expected value. However, if probability of deviation by chance is less (less than 0.05 or 5%) then observed value is significantly different from expected value.

Calculation of p Value

For its calculation, chi-square and degree of freedom is needed.

How to Use Chi-square Analysis by Example

Just consider a monohybrid cross for a trait pod colour in garden pea was carried out. In F2 generation, out of 582 plants, 428 green and 152 yellow were observed. We want to know whether this cross is following Mendelian monohybrid ratio 3:1. According to expected ratio, plant with green phenotype should be 437 (3/4 of total number) and yellow phenotype should be 145 (1/4 of total number). Now we can see there is difference in observed value from expected value, whether this deviation is by chance or significantly different, and chi-square analysis can be used according to formula in Table 17.1.

Table 17.1: Calculation of chi-square value from the given data

Number of classes/ phenotype	Observed number (o)	Expected number (e)	Deviation (d) = (o – e)	d^2	$d^2 = d^2/e$
Green	428	437	–9	81	0.185
yellow	152	145	7	49	0.338
Total					0.523

Degree of freedom is always one number less than total number of classes. Degree of freedom represents the quantum of independency that is there with the given classes. If there are two classes, then only one class has freedom to fall in any criteria other class has no choice. (for example : provided there are pairs of socks, there are two classes but freedom is there with one socks which can be part of left or right foot, there is no option for second socks). Hence, degree of freedom (D) can be represented as:

$$D = n - 1$$

(Where n is total number of classes)

Probability of deviation calculation can be calculated by using probability table (Table 17.2) wherein left column degree of class (D) is written and on right row (top most) Probabilities are mentioned. At degree of freedom 1 (black arrow), summation of chi-square 0.523 value (red box) shows p value as 0.30–0.50 (blue oval) or 30 to 50%. It indicates that deviation is by chance. There is no significant difference between observed and expected value. Hence, the given cross follows Mendelian ratio (3 : 1).

Table 17.2: Probability table for chi-square analysis

Degrees of freedom	Probability										
	0.95	0.90	0.80	0.79	0.50	0.30	0.20	0.10	0.03	0.01	0.001
→ 1	0.04	0.02	0.06	0.15	0.45	1.07	1.64	2.71	3.54	6.64	10.83
2	0.10	0.21	0.45	0.71	1.39	2.41	3.22	4.66	5.99	9.21	13.81
3	0.35	0.55	1.01	1.42	2.37	3.64	4.64	6.21	7.82	11.34	14.27
4	0.71	1.05	1.65	2.20	3.39	4.38	5.99	7.78	9.49	13.28	18.47
5	1.14	1.61	2.34	3.00	4.35	6.06	7.29	9.24	11.07	15.09	20.52
6	1.63	2.20	3.07	3.81	5.35	7.21	8.56	10.61	12.59	16.81	22.44
7	2.17	2.81	3.82	4.07	6.35	8.38	9.30	12.01	14.07	18.48	24.32
8	2.73	3.49	4.59	5.52	7.34	9.50	11.00	13.34	15.51	20.09	24.12
9	1.32	4.17	5.38	6.30	8.34	10.04	12.24	14.65	16.52	21.67	27.88
10	3.94	4.80	6.18	7.27	9.31	11.78	13.44	15.91	18.31	23.21	29.50
	Nonsignificant								Significant		

ACTIVITY 4

Aim: Use genetic diagram below to solve problems involving test crosses

Parents — Blue flower (Bb) × Test Cross — Red flower (bb)

Formation of gametes — Bb → B, b; bb → b

Progeny

	b	b
B	Bb (Blue |flower)	Bb (Blue |flower)
b	bb (Red |flower)	bb (Red |flower)

Phenotype

Expected Ratio — 1 (blue) : 1 (red)

On test cross, out of 500 progeny 245 plants are observed with blue flowers and 255 plants are observed with red flowers. But according to test cross ratio, total 500 progeny should be expected as 250 blue flowers and 250 red flowers.

With the help of a chi-squared analysis test the significance of differences between observed and expected results.

- Using Chi-square formula, calculate the value for chi-square followed by its summation.
- Find the degree of freedom.
- Find the value of probability of deviation using probability table.
- Discuss your results in group.

17.4 INDEPENDENT ASSORTMENT AND SEGREGATION

What do you think would have happened if Mendel would have tried inheritance pattern of two traits? Do inheritance of one trait is dependent on the inheritance pattern of another trait?

17.4.1 Dihybrid Cross: Experiment and Observation

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.

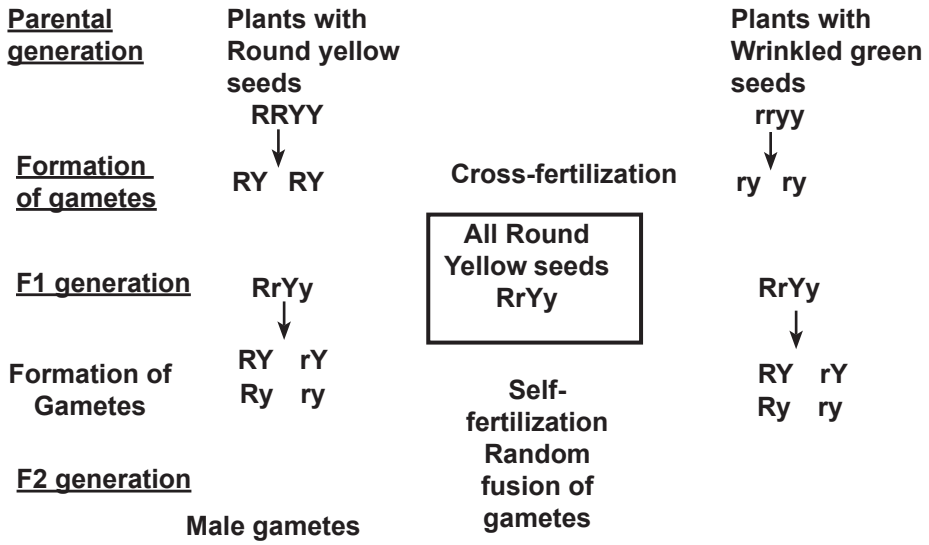
  In addition to parental phenotype combination, two new phenotype combinations/ recombinants (wrinkled and yellow and round and green seeds) were observed. Mendel hypothesized that the factors for different traits separate and assort independently in the gametes (factor for seed shape can assort with 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*** (Figure 17.6).

  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 of genotype 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 17.6: A dihybrid cross between plants with dominant round yellow seeds with plants with recessive traits wrinkled and green seeds through two generations

Random fusion of F1 gametes is represented with the help of **Punnett's square**. The four phenotypes—two parental (written in black) and two recombinants (written in purple and red) are obtained in the ratio of 9:3:3:1.)

17.4.2 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.

17.4.3 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 colour 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 (Figure 17.7).

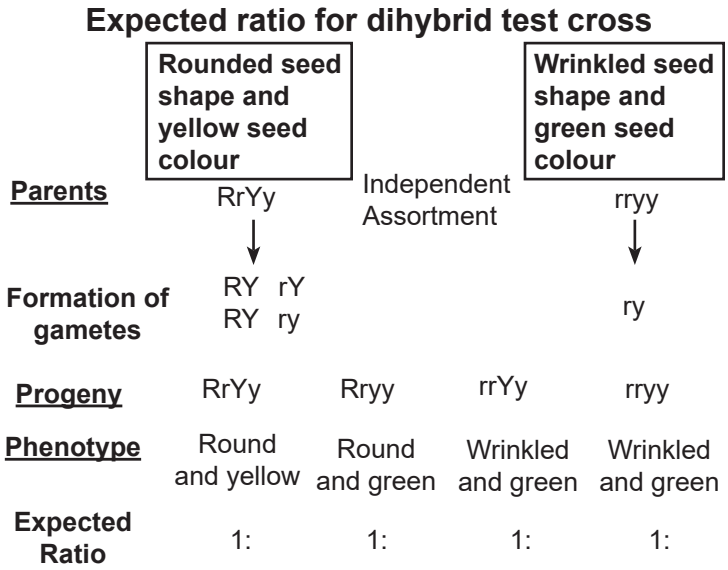


Figure 17.7: Dihybrid test cross ratio when plant has dominant heterozygous genotype for two traits

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.

ACTIVITY 5

Aim: To demonstrate dihybrid inheritance using beads of two different colour and two different sizes.

Materials Required:

Class notebook

Two colour beads (red and yellow)

Two size beads (Large and small)

Procedure for dihybrid inheritance:

- Open pouch containing beads of two different colours and different sizes.
- Count total number of beads.
- Divide total number of beads with 16 (T/16 = h)
- Differentiate beads according to their colour and size and count them respectively.
- Divide each number obtained in the previous step with value "h" and make a ratio.

Discuss whether the observed ratio is in accordance with the Mendelian dihybrid ratios.

17.4.4 The Chromosome Theory of Inheritance

According to Mendel's law of inheritance, there are two factors for each character, each factor segregates and assorts independently in the gametes without getting influenced by presence of other factors for different traits. Similarly, same rules are followed for chromosomes during cell division and cell biologists have confirmed that similar to Mendel's factors.

- Chromosomes are also found in pairs,
- Segregate and assort independently in the gametes at the time of meiotic cell division.

This indicates that Mendel's factors or genes are located on the chromosomes and it is chromosomes which segregate and independently assort in the gametes. This is most popularly known as **chromosome theory of inheritance** which was independently given by Sutton and Boveri in 1902.

SELF EVALUATION

Complete with appropriate terms:

(i)A cross of F_1 with the recessive parent is ..... .

(ii) ..... is the father of genetics.

(iii) Mendel selected ..... varieties of garden pea.

(iv) F_2 generation shows 9 : 3 : 3 : 1 ratio in ..... .

17.5 INHERITANCE: VARIATIONS FROM MENDEL'S PATTERN

Do you find all traits in accordance with Mendalian pattern?

Is there always two alleles for a trait in a population, if no discuss some examples.

Is one allele is always dominant to another?

Do product of all alleles are equally beneficial?

Are all our traits independent of inheritance of other traits? Think of metabolic pathways where product of one reaction is substrate for next event and so on. Here the enzymes of reaction will not be dependent on another enzyme of reaction of same metabolic pathways.

17.5.1 Co-dominance

When in heterozygote, both alleles of gene for particular trait are expressed, the phenomenon is known as co-dominance. The best example of co-dominance is the MN blood group antigens which are found in Red Blood Cells in Human. In Homozygous MM and NN individuals, antigen M and Antigen N are expressed but in heterozygous MN individuals both antigen M and N are co-expressed on the surface of RBC. When two heterozygous individuals are mated, Progeny are obtained in phenotypic ratio of 1 (MM) : 2 (MN) : 1(NN) instead of 3 : 1 monohybrid Mendalian ratio (Figure 17.8).

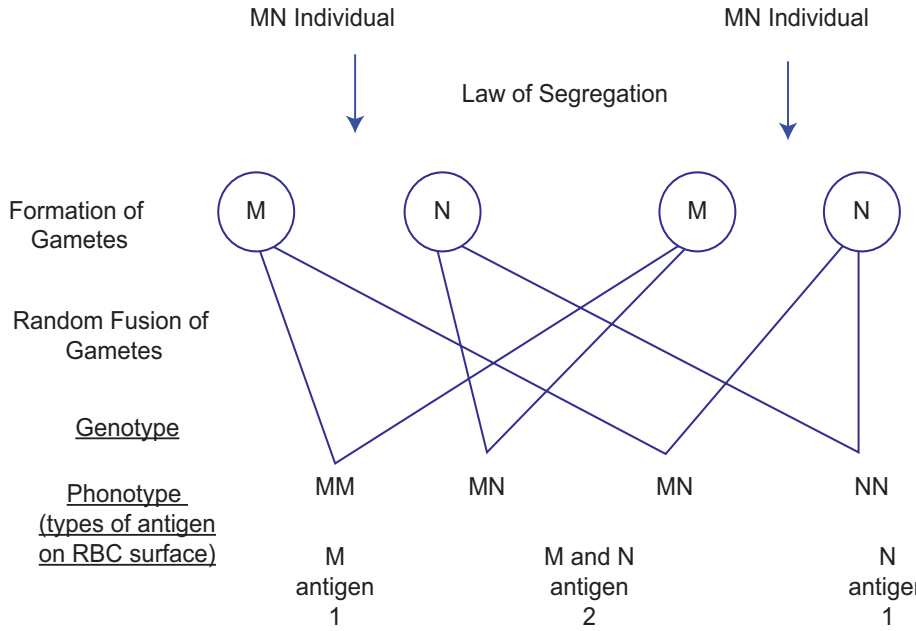


Figure 17.8: Cross between heterozygous MN individual – demonstrating co-dominance and characteristic phenotypic ratio 1 : 2 : 1

17.5.2 Multiple Alleles

It is well established that there are two alleles for a single gene. However, sometimes in a population there can be more than two alleles for a certain gene which can be illustrated by the ABO blood group system. In ABO blood group system, there are three alleles I^A, I^B and I^O in the population. The alleles decide the type of glycoprotein found on the surface of erythrocytes (red blood cells). There are four blood types phenotype as depicted in table 17.3. The Individual with blood group A express A type of glycoprotein while the individual with blood group B express B type of glycoprotein. The individual with blood group AB expresses both types of glycoprotein while O type individual contains neither A or B.

Alleles I^A and I^B are dominant to I^O so A type individuals can have I^A I^A or I^A I^O genotype. Similarly, B type can have I^B I^B or I^B I^O genotype. Alleles I^A and I^B are co-dominant so when present together in AB individuals are expressed together. Alleles I^O is recessive so O type individuals are recessive homozygous I^O I^O. ABO Blood type example demonstrates unique combination of multiple alleles as well as co-dominance.

Table 17.3: The ABO blood type in human population

Individual blood type	Phenotype (type of glycoprotein)	Allele present (Genotype)
A	A	I^A I^A/ I^A I^O
B	B	I^B I^B/I^B I^O
AB	A and B both	I^A I^B
O	None	I^O I^O

ACTIVITY 6

Aim: Consider two co-dominant alleles P and R. Draw a genetic diagram showing a cross between two heterozygous individual (PR)? Discuss genotypic and phenotypic ratio in progeny.

Procedure:

- Make a genetic diagram showing two heterozygous parents.
- Draw their gametes and with the help of Punnett square, make their progeny and give their genotype and phenotypic ration.
- Discuss it among yourselves and with class teacher.

17.5.3 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 C in chicken has serious effect on development of the organism and results in following phenotype:

- Aberrant form "creepers" in Heterozygous individual (Cc)
- Completely "lethal" in homozygous dominant (CC).

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 17.9).

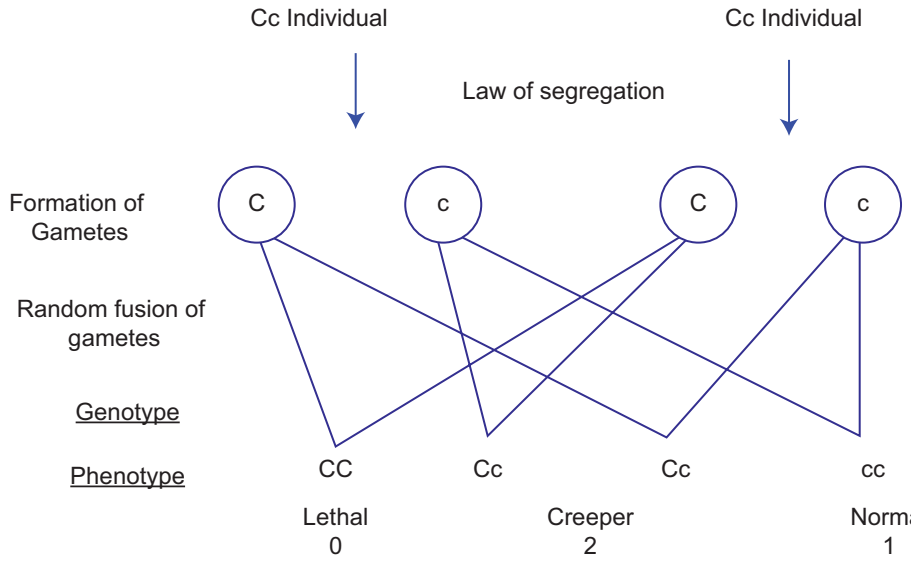


Figure 17.9: Cross between two creepers chickens — demonstrating lethality and characteristic ratio 2 : 1

ACTIVITY 7

Aim: In mice, dominant allele Y is for yellow coat colour while recessive allele y is for agouti coat colour.

(a) The yellow coat colour mice were self-bred. The yellow and agouti mice are produced in the ratio of 2 : 1. What could be the reason for change in Mendelian monohybrid ratio?

(b) What is the genotype of mice having yellow coat colour?

Materials Required:

Notebook

Lethal allele information

Procedure:

- Read about lethal allele.
- Try to solve the genetic problem.
- Discuss it among yourself.

17.5.4 Incomplete Dominance

Sometimes the allele is not completely dominant or completely recessive. In such heterozygotes individuals, intermediate phenotype is observed. Such phenomenon is known as incomplete dominance or semi-dominance or intermediate inheritance. For example: in Snapdragon (Antirrhinum majus) a cross between plants with red and white flower variety produces all plants with pink flower or intermediate phenotype. When two heterozygous plants with pink flowers are mated, Progeny are obtained in phenotypic ratio of 1 (red) : 2 (pink) : 1 (white) instead of 3 : 1 monohybrid Mendelian ratio (Figure 17.10).

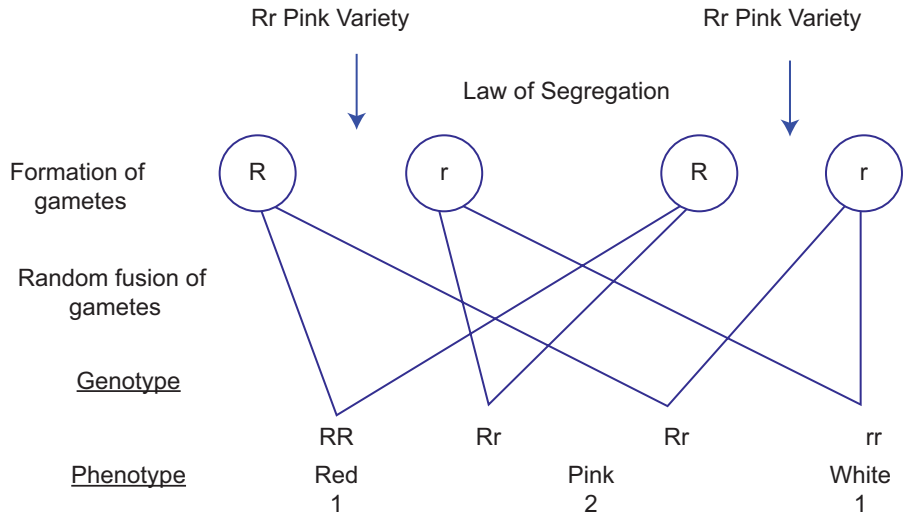
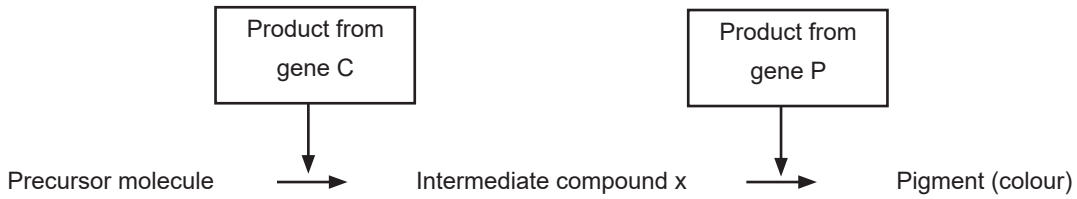


Figure 17.10: Cross between two heterozygous plants (pink variety) in snapdragon — demonstrating incomplete dominance and characteristic phenotypic ratio 1 : 2 : 1

17.5.5 Gene Interaction

There are cases when product of one gene influences the product/phenotypic expression of another gene and this phenomenon is known as gene interaction (meaning: standing on/to mask).

One of the examples illustrating this is flower colour in sweet pea (*Lathyrus odoratus*), where P dominant allele determines formation of the pigment anthocyanin (responsible for purple flower colour). However, plants with PP and Pp will have purple flower only when another allele of different gene C is present in dominant form. So product of gene C influences phenotypic expression of gene P. The reason for this phenomenon can be explained as follows. It is observed that gene C encodes for enzyme that synthesizes intermediate compound x from precursor molecule. The intermediate compound is converted to coloured pigment via product/enzyme of gene P.



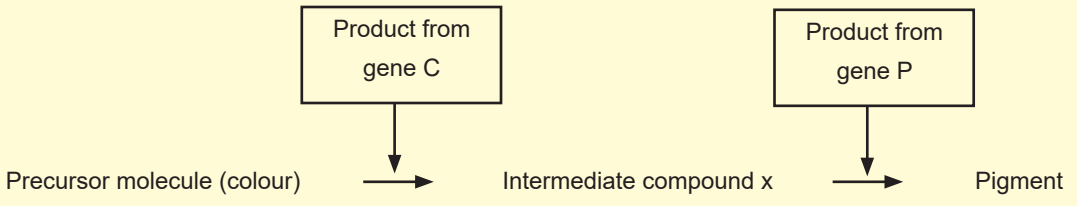
Therefore, at least one allele of both gene C and P should be dominant to have colour flower. Such interaction where allele for one gene complements expression of allele of another gene is known as complementary gene interaction. The respective genes are known as complementary gene.

ACTIVITY 8

Aim: In a given reaction, can you find gene interaction? If yes, what are the genes? If gene "H" is present in homozygous recessive form and "A" gene is present in homozygous dominant form, would you expect product A?

Procedure:

- Observe the reaction carefully.
- Note the number of gene that is required for the formation of product A.
- Considering the given condition in the question, try to answer to the best of your knowledge.
- Discuss among yourself and with your class teacher.



17.6 LINKAGE AND CROSSING OVER

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?

17.6.1 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 (figure 17.6). 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.

Table 17.4: Observed dihybrid test cross frequency exception to law of independent assortment

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%

17.6.2 Linkage 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 (Figure 17.12). The cross-over event between two gene loci in non-sister chromatids is responsible for formation of recombinant chromatids and their separation (Figure 17.11).

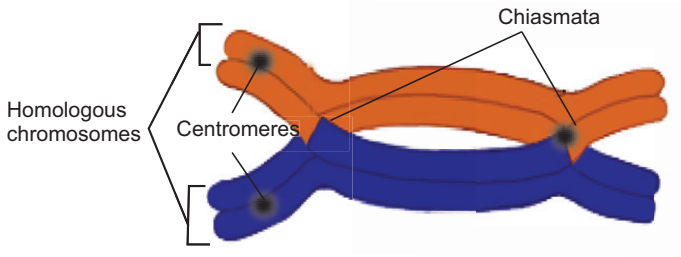


Figure 17.11: Micrograph demonstrating chiasmata formation in homologous chromosomes.

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 (Figure 17.12). 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.

17.6.3 Chromosome Map

A chromosome map is the linear arrangement of genes in the chromosome with their relative distance. It is based on fact that the frequency of crossing over between two genes is directly proportional to the physical distance between the two. Therefore, the distance between genes is indicated by percentage of crossing over (recombinant frequency). The distance unit is map unit or 1cM (centi-Morgan, in honour of T. H. Morgan), so when 1% recombinant frequency is observed between two genes, the genes are said to be 1 map unit apart.

T. H. Morgan and Sturtevant carried out extensive work in drosophila in finding recombination frequency between different genes and based on recombination data, they generated chromosome map.

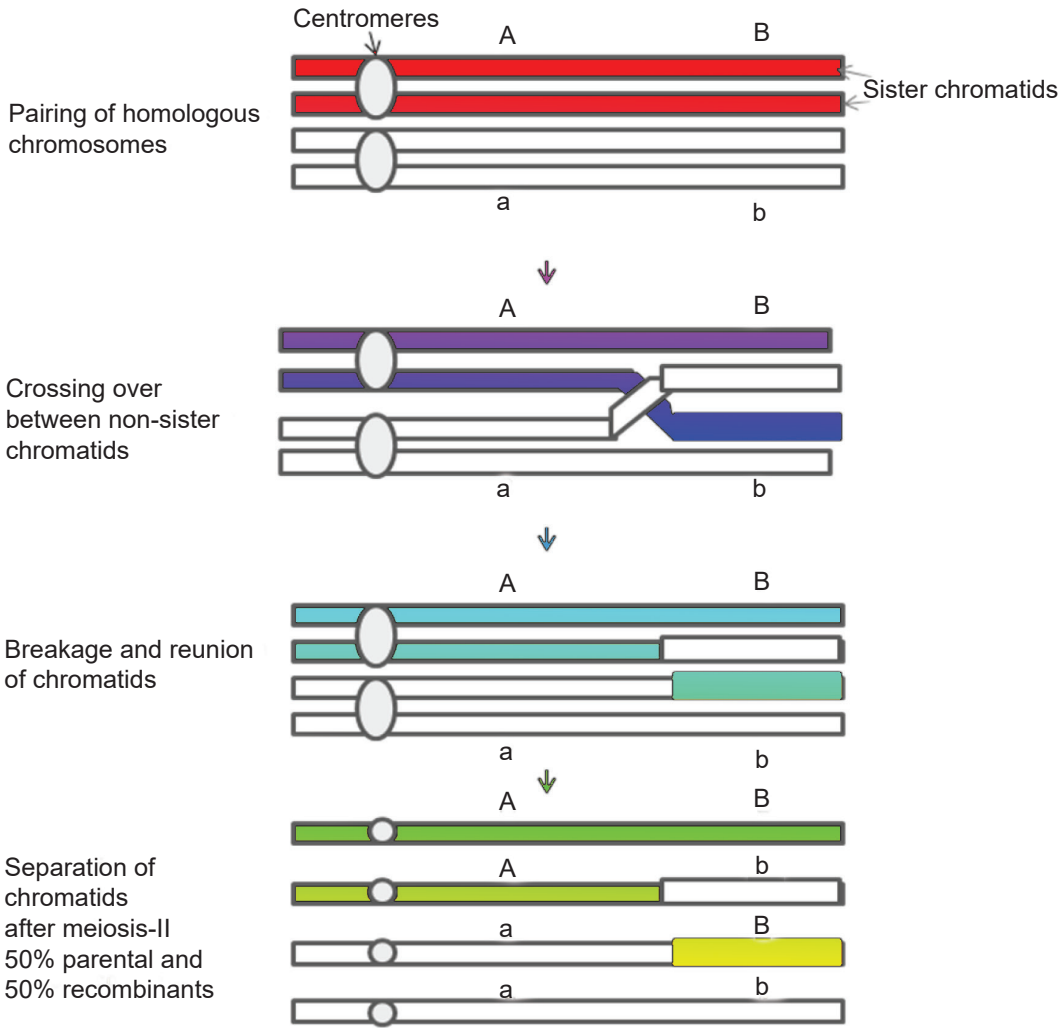
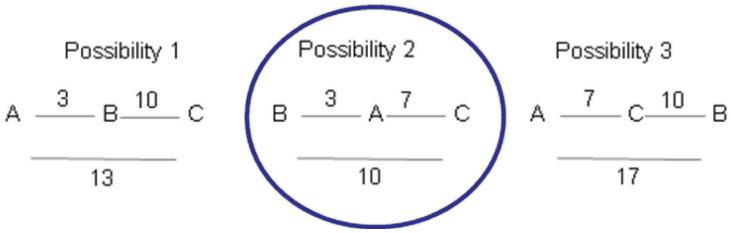


Figure 17.12: Separation of genes A and B located on the same chromosome via crossing over—two chromatids retain parental arrangement of the alleles while two are recombinant

A and a alleles of gene A while B and b are alleles of gene B. In recombinant chromatids allele "A" combine with "b" allele while "a" combine with "b".

For example: if recombination frequency between two genes A and B is 3% or 3 map unit. If distance between B and C is 10 map unit and distance between A and C is 7 map unit, then we can make chromosome map based on the information of recombination frequency. There are three possibilities:



But based on the information, possibility B represents the actual order of genes.

At the same time, we should remember even when genes are very far, there are 100% chances of crossing over but recombinant frequency will not exceed more than 50% only because with increased distance, double or multiple cross events happens which cancels the effect of single cross over.

SELF EVALUATION

Complete with appropriate terms:

(i)..... is the phenomenon in which genes for different traits do not show independent assortment.

(ii) Complete the table. Identify a, b and c.

S. No.	Pattern of inheritance	Monohybrid f1 Phenotypic expression
1.	Co-dominance	a
2.	b	The progeny resemble only one of the parents
3.	Incomplete dominance	c

(iii) A plant with genotype AABbcC is selfed F_2 phenotypic ratio would be .....

(iv) How many types of gametes are found in F1 progeny of cross AABBCC and aabbcc.

17.7 SEX DETERMINATION

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.

17.7.1 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

17.7.2 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.

17.7.3 Evidence for Role of Y Chromosomes in Sex Determination in Humans

The early evidence for the role of Y chromosome in sex determination is provided by certain individuals with chromosome number abnormality i.e. turner syndrome and Klinefelter syndrome which are caused by non-disjunction of sex chromosomes in meiosis.

- **Turner syndrome:** Here individuals have 45 chromosomes in contrast to normal complement of 46 chromosomes. The turner individuals have chromosome complement 45 (XO) and are sterile females. They tend to have short height; fail to develop secondary sexual characters and immature internal sex organs.

It indicates that the presence of two X chromosomes is not important at least in female sex determination; obviously, it is essential for proper development of female.

- **Klinefelter syndrome:** Here individuals have 47 chromosomes in contrast to normal complement of 46 chromosomes. The Klinefelter individuals have chromosome complement 47 (XXY) and sterile male. They tend to have underdeveloped testis, taller than the average male, breast development.

It indicates that despite the presence of two XX chromosomes, the sex of the individual is male. So presence of Y chromosome determines maleness.

17.7.4 Non-disjunction of Sex Chromosomes

Chromosome non-disjunction: it is the failure of the homologous chromosomes to separate at anaphase at the time of cell division. The phenomenon was first observed by C. Bridges in drosophila.

It involves autosomes or sex chromosomes.

Generally, two sex chromosome synapse at the time of meiosis and segregate equally in the gametes, so gametes have single sex chromosomes.

If synapsed sex chromosomes fail to separate, then one type of gamete receives both sex chromosomes while other receives none.

For example: If non-disjunction of sex chromosomes happens in egg formation, then one egg will receive both X chromosomes while other receives none in contrast to equal distribution of sex chromosomes. The fusion of the egg with normal sperm with single chromosome X or Y leads to individuals with XXX (super-female), XXY (Klinefelter syndrome), XO (Turner syndrome) and YO (lethal phenotype) (Figure 17.13).

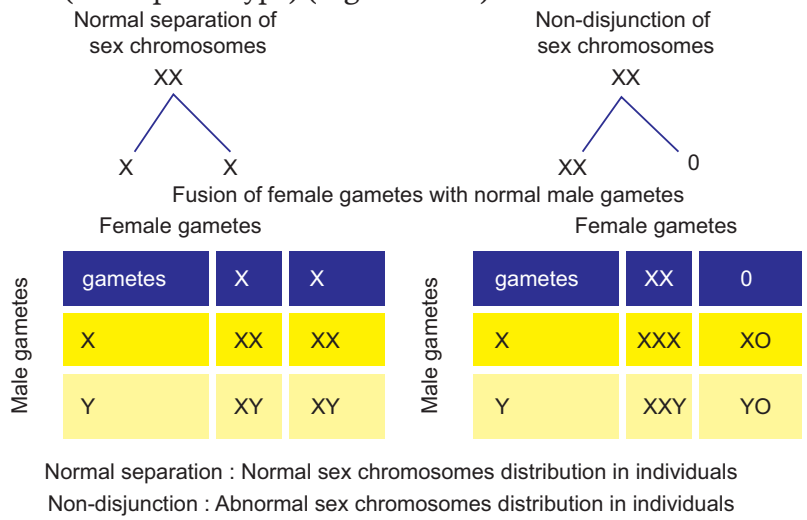


Figure 17.13: Non-disjunction of sex chromosomes at meiosis—leads to abnormal gametes and abnormal phenotype in humans.

17.8 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. Strangely, he observed that all F2 white-eye flies were male just like their grandfather (Table 17.5).

Table 17.5: Summary of Morgan breeding experiment of cross between white eye male and red eye female

Parents	F1 (Expected Phenotype)	F2 (Observed Phenotype)
Red-eye female flies and white-eye male flies	F1 all red-eye flies	F1 all red-eye flies
F1 male and female	F2 75% red-eye flies (male and female) 25% white-eye flies (male and female)	F2 50% red-eye flies (all female) 25% red-eye male flies 25% white-eye male flies

Morgan explained that the recessive allele must have been associated with X chromosome. Males have one X chromosome only unlike female which carries two X chromosome so they are hemizygous (only one allele for a gene) for X-linked genes.

In this experiment, white-eye male parent must have transferred its X chromosome to all F1 females and Y chromosome to all sons. F1 females are heterozygous carrying one normal X chromosome with normal eye colour i.e., red and other X chromosome with white eye gene while F1 males had one normal X chromosome from their mother, thus had red-eyed and Y chromosome from father.

The F2 males obtained their X chromosomes from heterozygous F1 mothers. The half of the F2 males received normal X chromosome while other half received X chromosome with recessive allele hence developed white-eyes (Figure 17.14).

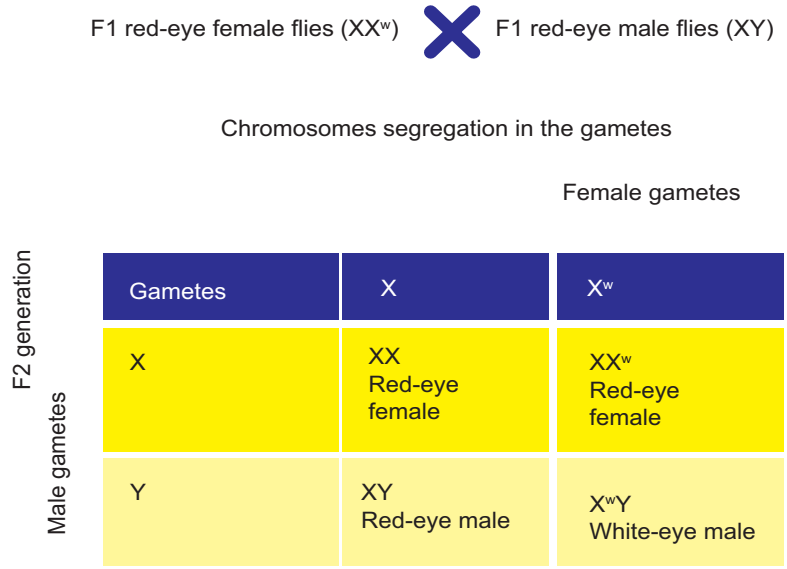


Figure 17.14: A cross between F1 red-eye male and female representing sex-linked inheritance of trait to F2 generation

Here, the characters are transmitted from male parent to grandson through carriers (heterozygous) F1 daughter. Trait is recessive and X-chromosome linked. For this work, Mendel was awarded Nobel Prize in 1933.

17.8.1 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.

It never appears in female. Y chromosome has very few genes. A few traits are Y-linked.

For example:

- Hairy ears trait in human in which bristly hairs grow from ear.

ACTIVITY 9

Aim: If a colourblind man (X^cY) marries a normal homozygous female (XX), what are the chances of their progeny being affected with the disease?

Procedure:

- Make gametes from male and female.
- Draw Punnett square showing the random fusion of gametes to get F1 generation.
- Observe the results and discuss among yourselves and class teacher.

17.9 GENETIC DISORDER

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.

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.

Polygenic genetic disorder: caused by abnormalities in more than one gene. For example: cancer, diabetes etc.

Chromosomal genetic disorder: caused by change in the structure (deletion, duplication) or number of chromosomes (chromosomes becomes high or less 47, 45 etc). For example: Turner's syndrome, klinefelter's syndrome.

17.9.1 Single-gene Genetic Disorder

There are two types:

1. **Autosomal-linked disorder:** 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.

   In X-chromosome dominant, the affected gene is dominant and present on the X-chromosomes. The female with X-linked disease (XX*) when marries a normal man (XY), has 50% chance of having an affected offspring.

   The male with X-linked disease (X*Y) when marries a normal woman (XX), has all affected daughters (XX*) but sons will be unaffected.

   For example: X-linked hypophosphatemia which causes bone deformity.

   In X-chromosome recessive, the affected is recessive and is present on the X-chromosome. It is more common in males. The male with X-chromosome linked genetic disease will have normal sons and daughter but pass trait to half of their grandson.

The female with one mutant allele and one normal allele (XX*) will have 50% chance of having affected sons but 100% chance of unaffected daughters.

For example: Haemophilia

Y-linked genetic disease: It is caused by mutation in the gene located on the Y chromosome. It only appears in male. The disease is always transferred from father to son.

For example: hairy pinna

17.9.2 Pedigree Analysis: Studies of Inheritance of Genetic Diseases in Humans

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).

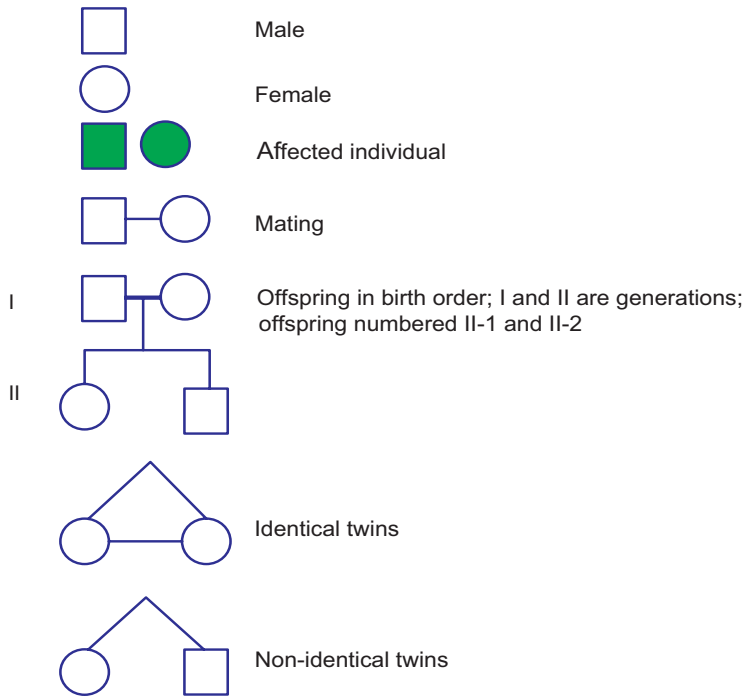


Figure 17.15: The symbols used in human pedigree analysis

In the tree, there are different symbols (Figure 17.15). The females are represented by circles and males by squares. A horizontal line between circle and squares represent marriage. The vertical line in middle of horizontal line represents their offsprings. The offsprings are written from left to right in the order of birth. The solid symbols represent the particular genetic disease studies while open symbols represent unaffected individuals.

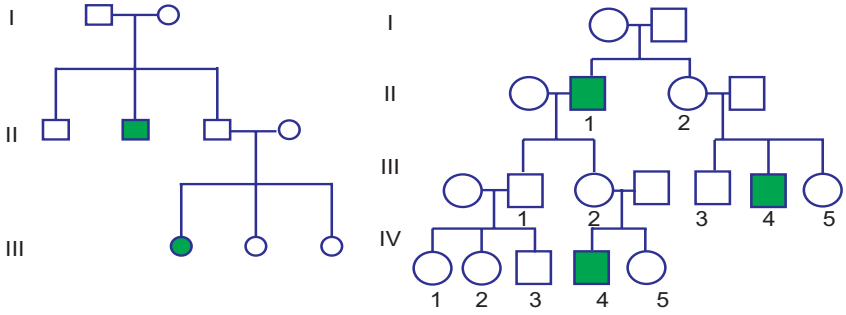
Hypothetical Pedigree for Different Genetic Traits

Based on the transmission of genetic trait, the different pedigree can be made.

(a) **Recessive pedigree:** if an affected person has unaffected parents, it indicates that nature of affected gene is recessive. It can be autosomal or sex-linked.

If it appears randomly in male and female, then it is autosomal (Figure 17.16 (a)).

If affected person is mostly males, then it might be sex-linked recessive genetic trait (Figure 17.16 (b))



(a) Autosomal recessive pedigree (b) X-linked recessive pedigree

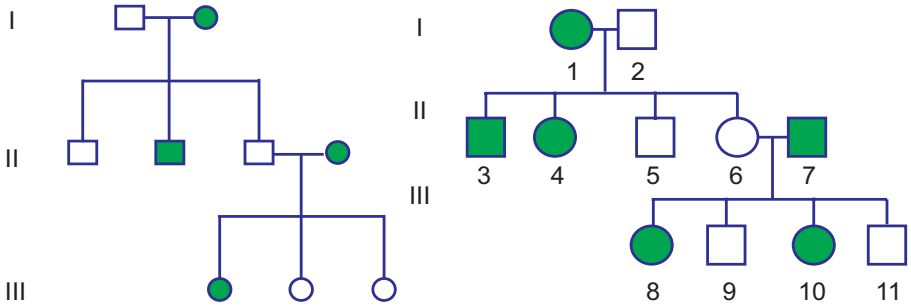
Figure 17.16: Recessive pedigree

(b) **Dominant pedigree:** if an affected person has affected parents and traits appears almost in every generation, it indicates that nature of affected gene is dominant. It can be autosomal or sex-linked.

If it appears randomly in male and female, then it is autosomal (Figure 17.17 (a)).

If trait is passed on every generation but differentially transmitted based on sex of the affected person, then trait is X-linked dominant (Figure 17.17 (b)).

An affected father will pass the disease to all of his daughters. An affected mother will pass the trait equally to her sons and daughters.



(a) Autosomal dominant pedigree (b) X-linked dominant pedigree

Figure 17.17: Dominant pedigree

17.9.3 Significance of Pedigree Analysis

(a) Pedigree analysis is very useful to find out nature of genetic trait in family.

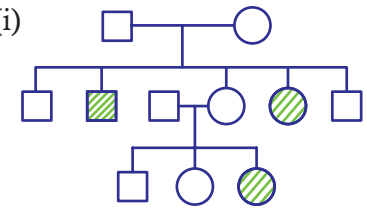
(b) It is useful to study the inheritance pattern of traits in organisms in which there is long generation time, especially in humans.

(c) Pedigree analysis is used by genetic counsellors to advise couples about the possibility of having genetically defective children when a defect runs in their family.

SELF EVALUATION

Choose the correct statement or complete with appropriate terms:

(i)



The following pedigree shows:

(a) Inheritance of a recessive sex-linked disease like haemophilia.

(b) Inheritance of a sex-linked inborn error of metabolism like phenylketonuria.

(c) Inheritance of a condition like phenylketonuria and autosomal recessive trait.

(d) The pedigree chart is wrong.

(ii) ..... disease affects muscle coordination. It is a neurogenetic digenerative disease.

(iii) In turner's syndrome ..... .

(iv) ..... is the failure of homologous chromosomes to seggregate at anaphase.

ACTIVITY 10

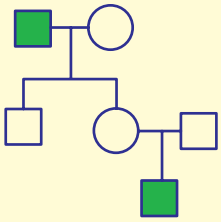
Aim: Use the following pedigree information and answer the following:

(a) Indicate transmission of particular trait (shown in solid box).

(b) Identify any genetic disorder following same pattern.

(c) Based on information, make a presentation representing pedigree tree with the genotype and phenotype of particular trait.

(d) If an affected male marries a carrier woman, what will be the ratios of their progeny being affected and unaffected?



Procedure:

- Revise the inheritance pattern of genetic traits (refer to section 17.9).
- Identify the type of inheritance and example for the same.
- Re-draw pedigree tree, representing genotype and phenotype for the particular trait.
- Solve the genetic problem.

17.10 SUMMARY

- Inheritance/heredity is the phenomenon of transmission of traits from parents to offspring.
- Mendel conducted breeding experiments in garden pea to study inheritance pattern of several traits. He found that the first generation progeny always exhibited one of the parental trait (dominant) while the second generation progeny exhibited both the forms of trait dominant and recessive in 3 : 1 ratio, popularly known as phenotypic monohybrid ratio. He postulated that there are two factors for each trait, the factors segregate (principle of segregation) at the time of gamete formation and reunite in zygote.
- Mendel's factors are now known as gene, two alternate forms are known as alleles. Mendel also devised a test cross which helps us to differentiate pure dominant form from the hybrid dominant form. Chi-square test is used to analysis genetic data when observed data has deviation from the expected value. We can find out whether there is significant deviation from the expected value or not.
- Mendel carried out dihybrid cross where parent plants differ in contrasting form of two traits. He found that F1 plants exhibited dominant form of both traits and F2 plants exhibited four types of phenotypes (two parental types and two new recombinants) in the dihybrid ratio of 9 : 3 : 3 : 1. He concluded that factors of different traits segregate and assort independently in the gametes (principle of independent assortment). Mendel's factors or genes are found to be located on chromosomes.
- In population there can be more than two alleles (multiple allele), although a particular individual will have two alleles. Sometimes both the alleles are equally expressed (co-dominance) as in ABO blood type. There can be incomplete dominance where one form is not completely dominant. Also, sometimes allele is lethal which leads to the death of the individual. Also, one gene may influence the expression of another gene. It leads to variation in Mendelian ratio.

- The genes located on the same chromosomes, inherit together the phenomenon is called as linkage. The genes located on the same chromosome occasionally assort independently via the physical phenomenon known as crossing over. The frequency of crossing over increases as distance between gene loci on the chromosome increases, so the frequency of recombinant will vary. It also helps in finding the distance between gene loci (chromosome map).
- Sex determination in humans is determined by the presence of Y chromosome. The "Y" chromosome plays an important role in determining maleness. It has gene testis determining factor (TDF) which initiates the sequence of events required to differentiate primordial gonadial tissue into testis.
- The genes located on sex chromosome (X and Y chromosome), demonstrate sex linkage. The inheritance of such traits depends on the sex of the individual.
- The genetic diseases may happen due to changes in genes or chromosomes on which genes are located. The inheritance of genetic disease caused by genes can be traced by pedigree analysis which involves collection of information about the expression of particular genetic trait in the family's history.

17.11 GLOSSARY

- **Alleles:** There are two genes which occur on the same locus in homologous chromosomes and centrails due expression of a trait or character in an individual.
- **Character:** It is a feature of an individual for example, stem height, flower colour, seed shape etc.
- **Dominant gene:** Gene which always expresses itself in presence of its contrasting allele.
- **F_1 generation:** It is generation of hybrids produced from a cross between two true breeding potental forms.
- **F_2 generation:** It is a generation of individuals, which arises as a result of inbreeding of individuals of F_1 generation.
- **Gene:** A unit of heredity.
- **Genotype:** It is the genetic constitution of an organism.
- **Recessive gene:** A gene which fails to express itself in presence of its contrasting dominant allele.
- **Phenotype:** It is expressed on observable characteristics of an organisms.
- **Trait:** It is an inherited character and its detectable variant. For example, tall and dwarf variant of stem height.

17.12 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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

1. Heredity is the transfer of traits from one parent to offsprings.
2. In the monohybrid cross between tall and dwarf plants, second generation plants were all tall.
3. In codominance, both the alleles of gene are equally expressed.
4. The genes located on same chromosomes are always linked and never assort independently.
5. In humans, XXY individual will be male.
6. In recessive genetic diseases, affected person can have one affected and another unaffected homozygous parent.
7. The frequency of crossing over increases as distance between the linked genes decreases.
8. The sex linkage phenomenon was first observed in Drosophila.
9. In pedigree analysis, the dominant traits are observed every generation.
10. Non-disjunction of chromosomes can happen at meiosis and mitosis.

II. Multiple Choice Questions

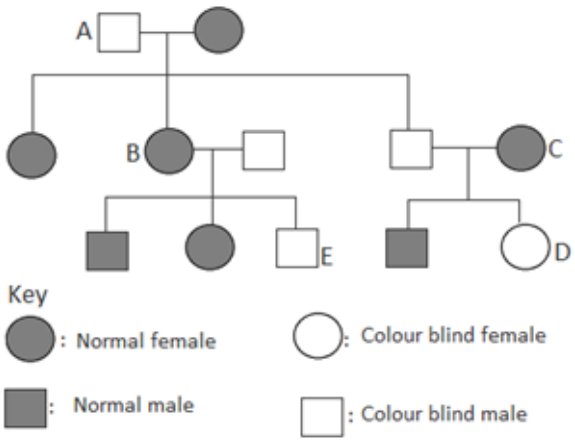
1. Which of the following reasons are true for Mendel's success?
   (a) He studied many traits at one time
   (b) He worked with pure lines
   (c) His model organisms were Homo sapiens
   (d) He was a chemist
2. Offsprings produced during first progeny are also known as:
   (a) F1 generation (b) F_2 generation
   (c) F3 generation (d) P generation
3. Mendel was successful in his experiments because garden pea:
   (a) Produces large number of offsprings
   (b) Has long reproduction cycle
   (c) Does not show self-pollination
   (d) Has difficulty to grow

4. A gamete has ..... number of alleles for a particular gene:
   (a) 0 (b) 1
   (c) 2 (d) 3
5. The Phenotypic Mendelian monohybrid ratio can be described as:
   (a) 3 : 1 (b) 1 : 2 : 1
   (c) 2 : 1 (d) 2 : 2
6. What is Semi-dominance
   (a) When both the traits are expressed
   (b) When both traits are partially expressed
   (c) When both traits are not expressed
   (d) When only one trait is expressed
7. A cross between two plants with two pair of contrasting traits is commonly known as:
   (a) Monohybrid cross (b) Dihybrid cross
   (c) Trihybrid cross (d) Tetra-hybrid cross
8. Test cross is a cross between
   (a) F1 hybrid with any of the parent
   (b) F1 hybrid with recessive parent
   (c) F1 hybrid with other individual similar to parent
   (d) None of the above
9. Genetic makeup of Klinefelter syndrome is
   (a) 44 autosomes + XXY (b) 44 autosomes + XXX
   (c) 44 autosomes + XXXX (d) 44 autosomes + XY
10. Huntington's disease in humans is the example of:
   (a) Autosomal dominant genetic disease
   (b) Autosomal recessive genetic disease
   (c) X-linked dominant genetic disease
   (d) X-linked recessive genetic disease

III. Long Answers Type Questions

1. Explain the terms gene, locus, allele, dominant, recessive, co-dominant, linkage, test cross, F1 and F2, phenotype, genotype, homozygous and heterozygous.
2. Explain how to conduct a test cross.
3. Explain why monohybrid ratios of 1:2:1 occur.

4. Describe an example of inheritance involving multiple alleles.
5. Explain the effect of lethal genes on phenotype ratios.
6. Give a genetic explanation of Mendelian dihybrid inheritance.
7. Explain the use of test crosses to determine unknown genotypes in studies of dihybrid inheritance.
8. Explain the significance of recombination.
9. Explain how the sex is determined in humans and the role of sex related Y genes in determining sex.
10. Describe how the non-disjunction can affect the distribution of sex chromosomes in gametes and offspring.
11. Explain why the linked genes do not show independent assortment.
12. Explain how crossover values can be used to make a chromosome map.
13. How can genetic studies by supportive for environment protection? State the role of different genetic aspects to list and cure diseases since ages. What relevance can be cited to support genetics as an important branch of biology?
14. A man claims to be the father of a child who is blood group AB. The man is blood group O and the mother of the child is blood group A. State with reasons whether the man could be the father of the child.
15. Red-green colour blindness is sex-linked recessive condition. The gene of colour blindness is carried on the X-chromosome. The figure below shows a family tree. Workout the genotypes of the individuals labelled A – E.



Unit 18

Mutations

Key Unit Competence

To be able to describe the types, causes and effects of mutation in organisms.

LEARNING OBJECTIVES

At the end of this unit, the learner will be able to:

- define mutation.
- describe types of mutation and causes of mutations.
- explain the significance of mutations.
- make a chart illustrating and summarising different kinds of gene and chromosomal mutations.
- distinguish between gene and chromosomal mutation.
- use a thin clay log composed of different colours to represent different chromosomes.
- manipulate the clay to show how an inversion can occur.
- explain that gene mutation occurs by substitution, deletion, inversion and insertion of base pairs in DNA. Outline how such mutations may affect the phenotype.
- outline the effects of mutant alleles on the phenotype in the following human conditions: albinism, sickle cell anaemia, haemophilia and Huntington's disease.
- explain the relationship between genes, enzymes and phenotypes with respect to the gene for tyrosinase involved in the production of melanin.
- explain how a change in the base sequence of the gene for haemoglobin results in abnormal haemoglobin and sickle-shaped red blood cells.
- explain that the environment may affect the phenotype.
- use internet to search simulations of mutations and deduce the findings.

18.1 MUTATIONS: INTRODUCTION

ACTIVITY 1

After the 1945 Hiroshima and Nagasak atomic bomb, the survivors and their offspring developed many health problems such as blood cancer (Leukemia), thyroid cancer, polydactyly etc.

How the atomic is related to health problem?

Why these health problems of 1945 have effects on children borne many years later?

Nothing was known about mutations before 19th century. Darwin first noticed some sudden changes in the organisms which he called as "sports". De Vries (1901) observed several, sudden changes in *Oenothera lamarckiana*, and called them mutations. Several sudden mutations were observed, for example, Ancon sheep (Figure 18.1) is a short legged variety which appeared suddenly in 1791 and hornless cattle developed from horned cattle in 1889.

Normal Ewe (Female Sheep) | Ancon Sheep (Short Legged Sheep) | Normal Ram (Male Sheep)

Figure 18.1: Ancon sheep with its normal parents

With the work of G. Mendel, inheritance of characters was established and subsequent work by several researchers firmly established that DNA constitutes the genetic material of any individual and it is very faithfully replicated and passed on to the offspring to conserve the parental characters in all subsequent generations. However, once in a while, the process becomes erratic for various reasons and alterations are seen in the DNA. Mutation is the sudden change in the genetic material of an individual.

In this unit, you will study the different types of mutations, how are they produced, their effect on phenotype and what role environment plays in the production of a phenotype. Finally, we will discuss as to why a detailed study of mutations is helping us not only to understand evolutionary process better, but also find the ways of treating cancer.

18.2 TYPES OF MUTATIONS

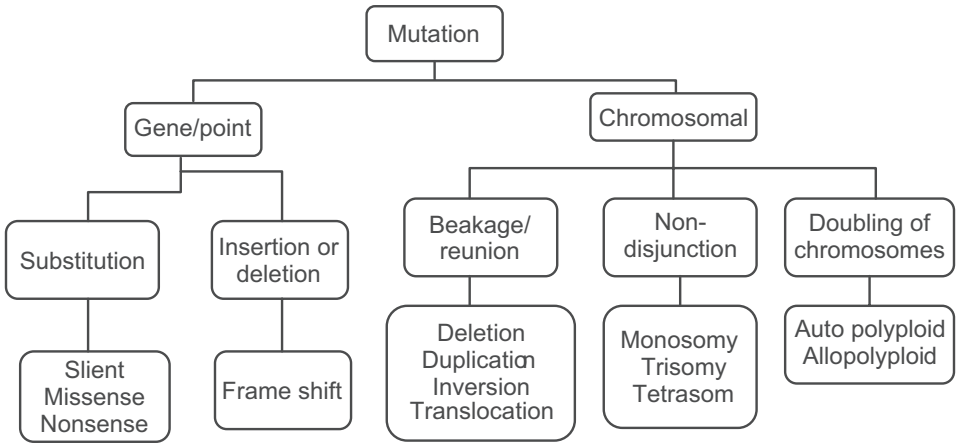
ACTIVITY 2

Have you noticed the variations which run in the families? It means it can pass from one generation to another generation.

Discuss more such examples.

Mutations can broadly be categorized as somatic and germ-line, depending on whether mutation occurs in a somatic cell or gamete. If mutation occurs in a somatic cell in a particular tissue, it may not affect the functioning of the tissue as the tissue may be composed of hundreds of normal cells. However, if a mutation occurs in a gamete, upon fertilization the zygote and hence all cells of offspring will carry the mutation.

Mutations can also be classified as shown in the following chart.



Although all mutations occur in genetic material altering the structure of DNA, consequences of different types of mutations are very different. Table 18.1 compares the attributes of gene mutations and chromosomal mutations.

ACTIVITY 3

Aim: To discuss the types and significance of mutations with the help of computer simulations.

Materials Required:

DNA sequences of different human proteins

Genetic code table

Genetic code table

Types of amino acid table

Notebook

Tetrahedron dice with names of each nucleotide (A, C, G and T).

Procedure:

1. First transcribe the given DNA sequence into mRNA sequence.
2. Translate mRNA sequence into amino acids with the help of genetic code table.
3. Note down the sequence of amino acid for protein.
4. Now randomly decide any nucleotide to change of given DNA sequence. (Choose by your favourite number, your birthday date..... completely random). Now roll the tetrahedron dice and look for the nucleotide. Replace it with new nucleotide. Consider it mutation 1.
5. Note down nucleotide and replace the original nucleotide with new nucleotide. There can be different possibility. Make a table as given below and record your observation.

Mutation	DNA sequence	mRNA sequence	Change in protein	Type of mutation
No Mutation	No change	No change	Same protein	No mutation
Mutation at site ——	Change in triplet code of original sequence	Change in triplet code of original sequence	Same protein Silent mutation	
Mutation at site ——	Change in triplet code of original sequence	Change in triplet code of original sequence	Different amino acid but chemically similar to original amino acid	Conservative mutation
Mutation at site ——	Change in triplet code of original sequence	Change in triplet code of original sequence	Different amino acid	Non-conservative mutation
Mutation at site ——	Change in triplet code of original sequence, stop codon	Change in triplet code of original sequence, stop codon	No amino acid and termination of protein synthesis	Non-sense mutation

6. Record your observation for mutation 1.

7. Repeat it thrice (for three mutation) from step 4 to 6, randomly choose any nucleotide to mutate and record your observation.
8. Discuss the types of mutations in the class.

For deletion mutation

9. Now randomly decide any nucleotide to delete in given DNA sequence. Suppose we mutate nucleotide number 10.

   Note down DNA sequence. Consider it **deletion mutation**.
10. Transcribe the new sequence into mRNA sequence.
11. Translate the mRNA sequence into protein.
12. Note down its effect.

For Insertion mutation

13. Now randomly decide any new nucleotide to insert at random site in given DNA sequence. Note down DNA sequence. Consider it **deletion mutation**.
14. Transcribe the new sequence into mRNA sequence.
15. Translate the mRNA sequence into protein.
16. Note down its effect.

18.2.1 Gene or Point Mutations

Gene or point mutations involve single nucleotides and can occur by one of the following mechanisms (Figure 18.2):

Substitution is the replacement of one base by another. 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**.

Silent mutation, when the triplet codon continues to code for the same amino acid because genetic code is degenerated, or the amino acid substituted has similar chemical property causing no change in the function of the protein or the change has occurred in non-coding region of DNA.

Missense mutation, when substitution of a base produces a codon that causes incorporation of a different amino acid. If the amino acid added is chemically similar to the original amino acid, it is called conservative missense mutation but if the amino acid added is chemically dissimilar, it is called non-conservative missense mutation.

Nonsense mutation, when substitution of a base leads to the formation of a stop codon, terminating protein synthesises at that point. Polypeptide, thus formed, is incomplete and hence non-functional.

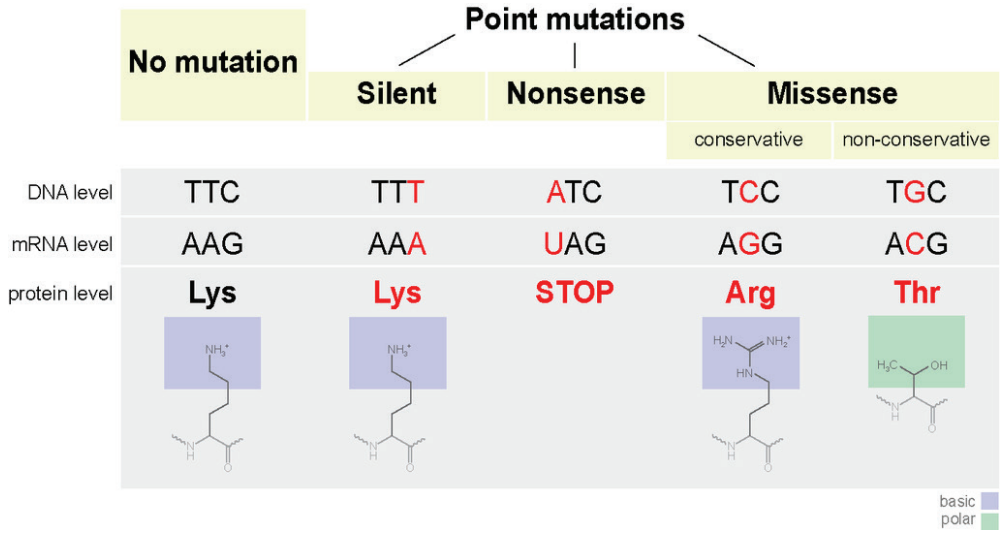


Figure 18.2: Consequences of point mutation

Frame-shift mutation here insertion or deletion of bases alters the reading frame of the genetic code which is comma-less, causing the different sequences of amino acids being coded from the point of mutation onwards. This type of mutation is called frame-shift mutation and this has far reaching consequences on protein function. Effect of this mutation in not confined to just one amino acid replacing another but the entire sequence of amino acids in the protein gets altered (Figure 18.3) and the protein becomes totally non-functional.

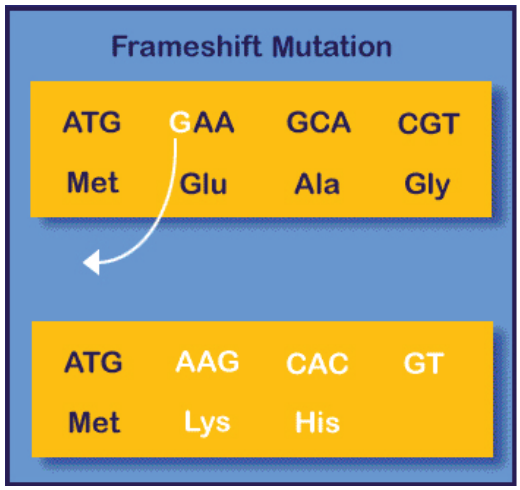


Figure 18.3: Frame-shift mutation

18.2.2 Chromosomal Mutations

ACTIVITY 4

Aim: To manipulate a thin clay log composed of different colours to represent different genes in order to show how an inversion can occur.

Materials Required:

Thin clay log composed of different colours

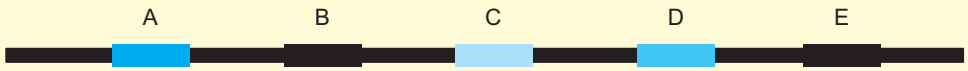
Notebook

Colour markers

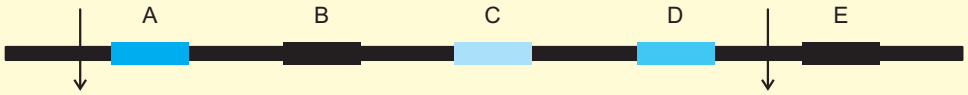
Scale

Procedure:

1. Just consider the thin log as single chromosomes, assemble five different colours to represent as gene such as A, B, C, D and E.



2. Break the thin log at two sites



3. Reunion the broken parts in inverse manner.
4. Observe the order of genes after reunion of fragments in inverse manner.
5. Compare it with original order of genes.
6. Discuss your observation in the class.
7. Enumerate the effect of inversion in phenotype of organism.

Whenever breaks occur in chromosomes, their structures change. If a chromosome or set of chromosomes shows more than one break followed by reunion, chromosomal rearrangements are formed. If a break occurs in a chromosome followed by loss of the fragment, it is called deletion, resulting in loss of genetic information. On the other hand, if a segment occurs more than once, it results in gain of genetic information and is called **duplication**. If a chromosome breaks at two points and fuses again but in reverse order, there is no loss or gain of genetic information but it alters the sequence of genes in the chromosome and is called **inversion**. If breaks occur in non-homologous chromosomes, and the broken fragment from one joins another non-homologous chromosome, it results in translocation, altering linkage relationships (Figure 18.4).

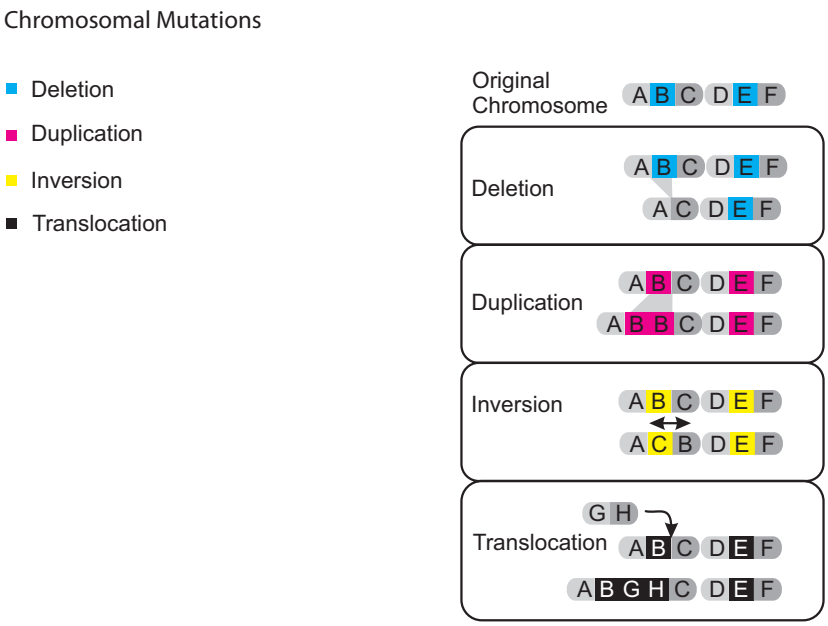


Figure 18.4: Structural changes in chromosome

Whenever the number of chromosomes gets changed, it results in Numerical changes in chromosomes. It happens due to non-disjunction, failure of homologous chromosomes to segregate at anaphase, leads to monosomy (2n – 1) and trisomy (2n + 1). Sometimes fertilization of ovum by two sperms can produce triploidy and fertilization of diploid gametes or doubling of chromosomes can produce tetraploidy.

18.2.3 Differences between Gene and Chromosomal Mutations

ACTIVITY 5

Aim: To discuss the differences between gene and chromosomal mutation and one possible effect on an organism.

Materials Required:

Red colour clay Beads, log made up of clay, notebook

Procedure:

1. In log, make 5 beads of red colour clay and number it 1 to 5.

2. Now consider the beads as gene and log as chromosome.
3. First in the log, try to change any bead. Either break it by deleting some part of clay material from it or paste some extra clay to it or replace the clay with same and different colour clay.
4. Note down your observation according to the following table:

	Effect on beads (Gene)	Effect on chromosome (log)
Replacement with same colour clay		
Replacement with different colour clay		
Insertion		
Deletion		

5. Now take the log, do the following changes:
   (a) cut the log.
   (b) cut the log at two sites and paste it in opposite orientation.
   (c) Add the clay beads of same colour.
   (d) Add the clay beads of different colours.
   (e) Note down your observation according to the following table:

	Effect on beads (Gene): number	Effect on chromosome (log) : size
Cut the log (Deletion)		
Cut the log at two sites and paste in opposite manner (Inversion)		
Add the beads of same colour (duplication)		
Add the beads of different colours (translocation)		

6. Discuss the effect of gene and chromosome mutation on the phenotype of the organism with the help of example.

Table 18.1: Gene mutation vs chromosome mutation

Gene mutation	Chromosome mutation
Change in nucleotide sequence in a single gene thus affecting functioning of a single gene	Change in either structure, gene arrangement or number of chromosomes thus affecting functioning of a number of genes at the same time
Leads to creation of new alleles	Leads to creation of altered karyotype

Can sometimes be corrected	Cannot be corrected
Can be either substitution or frame shift mutation	Can be either deletion, duplication, inversion or translocation, or numerical changes
Example includes sickle cell anaemia, albinism	Example includes Turner's and Down syndrome

18.3 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 among 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.
- Removal of amino group from a base is called deamination. Deamination of cytosine produces uracil. As uracil is not a normal base for DNA, repair system can correct the change. However, if not corrected, adenine will pair up with uracil, ultimately, causing a change from C-G to T-A, a transition mutation.

DNA also contains small amounts of 5-methylcytosine ($5^{m}C$) in place of normal base cytosine. Deamination of $5^{m}C$ produces thymine, a normal base in DNA and hence not corrected. Therefore, $5^{m}C$ results in C-G to T-A transitions.

(ii) Induced mutation happens due to mutagens (agents that induce mutations). It can be physical mutagens or chemical mutagens (Figure 18.5).

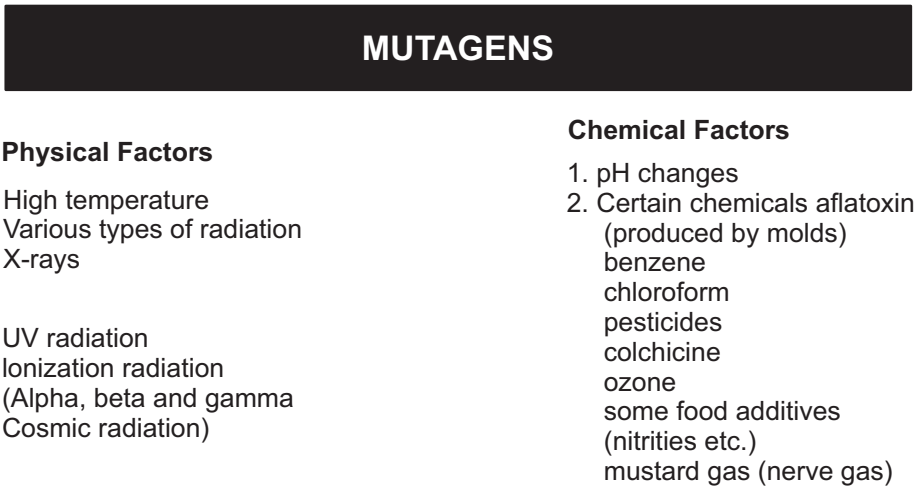


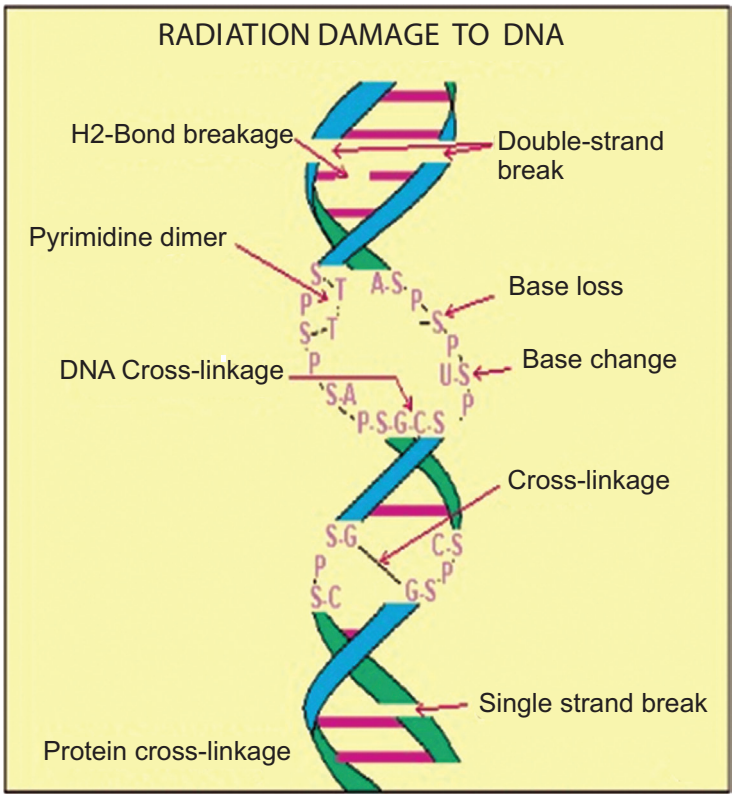
Figure 18.5: Physical and chemical mutagens

(a) **Radiation:** H. J. Muller was the first to show, in 1927, that mutation can be induced by X ray treatment. High energy rays collide with atoms and cause the release of electrons, leaving positively charged-free radicals or ions. These ions, in turn, collide with other molecules, causing release of further electrons. Thus, as the rays pass through the tissue, they leave a core of ions along its entire track. This process of ionization can occur by background radiation or be induced by machine-produced X rays, protons, and neutrons, as well as by alpha, beta, and gamma rays released by radioactive isotopes of the elements. Ultraviolet rays, though have less energy, can raise electrons in the outer orbitals to higher energy level called excitation. When molecules contain atoms either in ionic state or excited state, they become chemically less stable and thus, more prone to change, making radiation as powerful mutagens. Energy of X rays can also cause physical breaks in chromosomes, thus resulting in the loss of chromosome segments or changes in chromosome structure (deletion, duplication, inversion, translocation).

Mutational effect of ultraviolet (UV) radiation was demonstrated by Edgar Altenburg in 1928. UV rays are strongly absorbed by pyrimidines, especially thymine, leading to the formation of thymine dimmers. Thymine dimers interfere with DNA replication and DNA repair mechanism, causing mutation in DNA.

The damage by radiation has been shown in Figure 18.6.

Since radiation affects large segments of chromosome at the same time, a number of characters get altered simultaneously, but molecular details cannot be studied.



Physical Mutagens

Radiation was the first mutagenic agent known; its effects on genes were first reported in the 1920's.

Radiations are of two types.

i. EM radiations
ii. Ionizing radiations

Figure 18.6: Damage to DNA by physical mutagens – radiations

(b) **Chemical:** C. Auerbach first discovered the mutagenic effects of mustard gas and related compounds during World War II. Bhopal gas tragedy in India in December 1984 resulted in the death of 2500–6000 individuals, affecting adversely 200,000 people. Tragedy occurred with the release of methyl iso cyanate (MIC) in the form of gas and more than 21 chemicals in the MIC storage tank. A number of tests provided evidence that MIC is capable of inducing chromosomal damage.

People working in nickel and asbestos refineries, rubber industry, leather industry, coal tars, wood dust are routinely exposed to a number of mutagenic and potentially carcinogenic agents.

Chemical mutagens are of two types:

(a) That are mutagenic to both replicating and non-replicating DNA, e.g., alkylating agents (Figure 18.7) and nitrous acid (Figure 18.8).

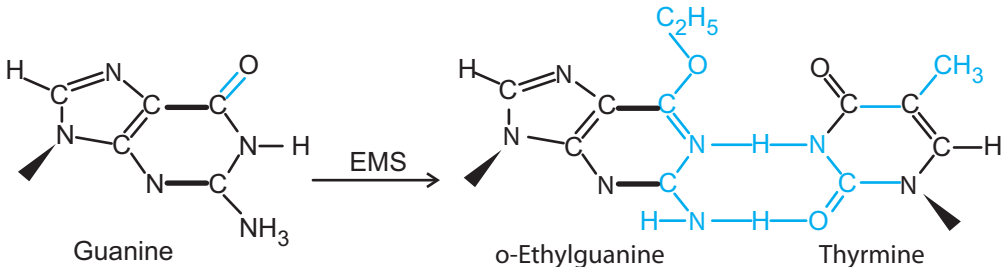


Figure 18.7: Alkylating agents (EMS) change bases such that their Hydrogen bonding pattern alters. For example, guanine gets changed to ethylguanine and pairs with thymine instead of cytosine.

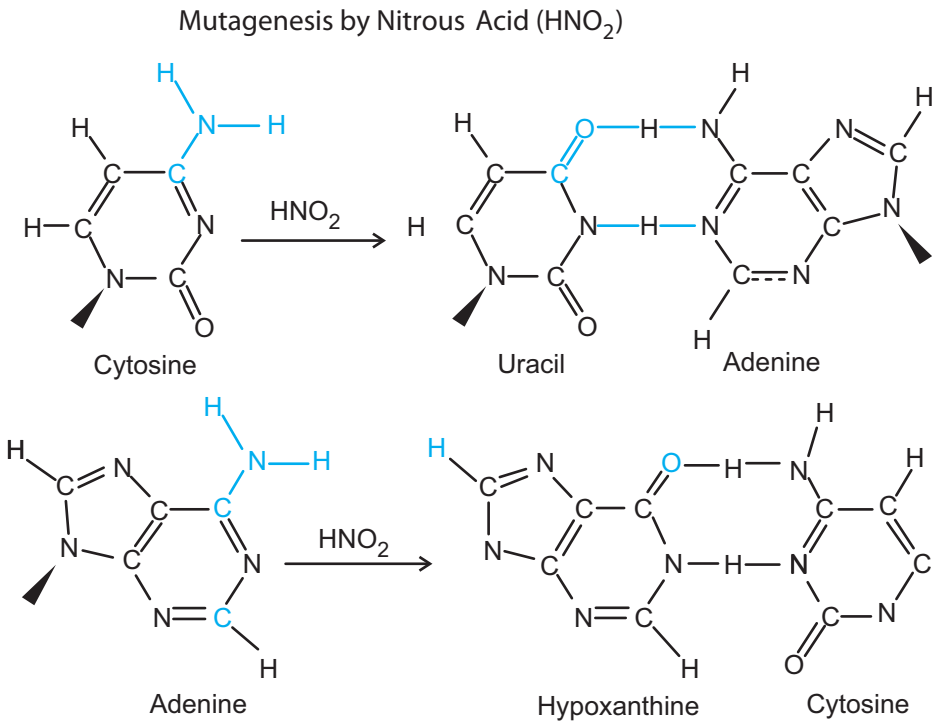


Figure 18.8: Nitrous acid leads to deamination of cytosine and adenine which get change into uracil and hypoxanthine.

(b) That's mutagenic only to replicating DNA, base analogs and acridine dyes.

Base analogs are structurally very similar to normal bases of nucleic acids and thus, can be incorporated mistakenly in place of the normal ones. However, once incorporated, they alter base pairing affinities, e.g., 5-bromouracil (Figure 18.9), a thymine analog, undergoes a tautomeric shift and pairs with guanine. During DNA replication, if 5-bromouracil is present in its enol form, it will be added opposite guanine in the template strand causing AT to GC transition (Figure 18.10).

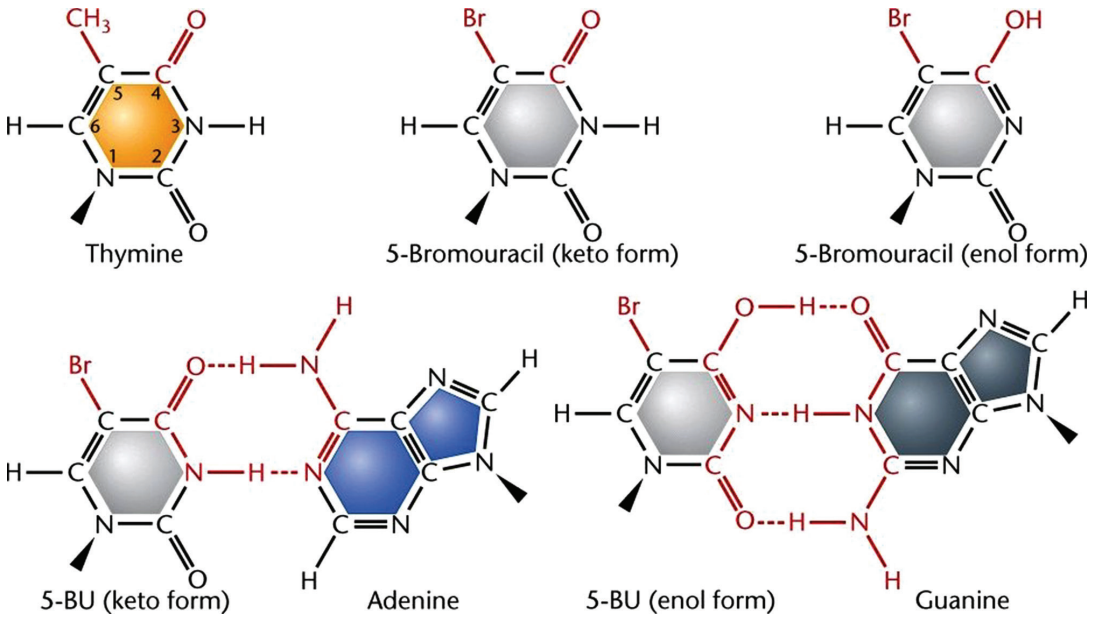


Figure 18.9: 5-bromouracil–Base analog of thymine and its tautomeric forms (keto and enol)

In this way, 5-bromouracil can promote a change of an AT base pair into a GC base pair

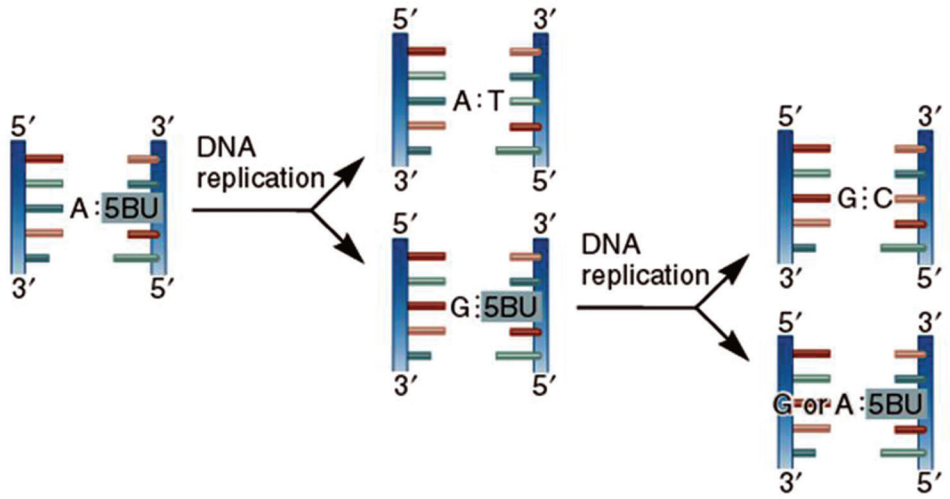


Figure 18.10: 5-bromouracil causes mutation while DNA replication

Acridine dyes intercalate DNA sequences (Figure 18.11) and stabilize DNA looping which might be missed by DNA polymerase resulting in deletion or addition of genetic material causing frame shift mutation.

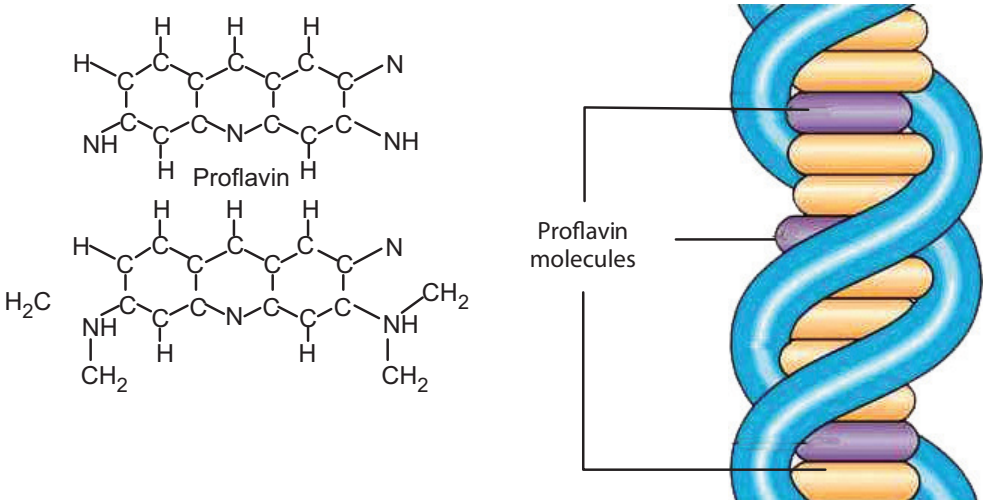


Figure 18.11: Acridine dyes – intercalating agent causing frameshift mutation.

SELF EVALUATION

Complete the sentence with appropriate terms:

(i) Substitution of one base by another may lead to ..... or ..... mutation.

(ii) Now disjunction of chromosomes can lead to ..... or ..... .

(iii) Induced mutation happens due to ..... and ..... .

(iv) If a chromosomes breaks and fuses again in reverse order, it is called ..... .

18.4 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 (Figure 18.12) and DOPA is converted to melanin, the pigment which gives colour to the skin.

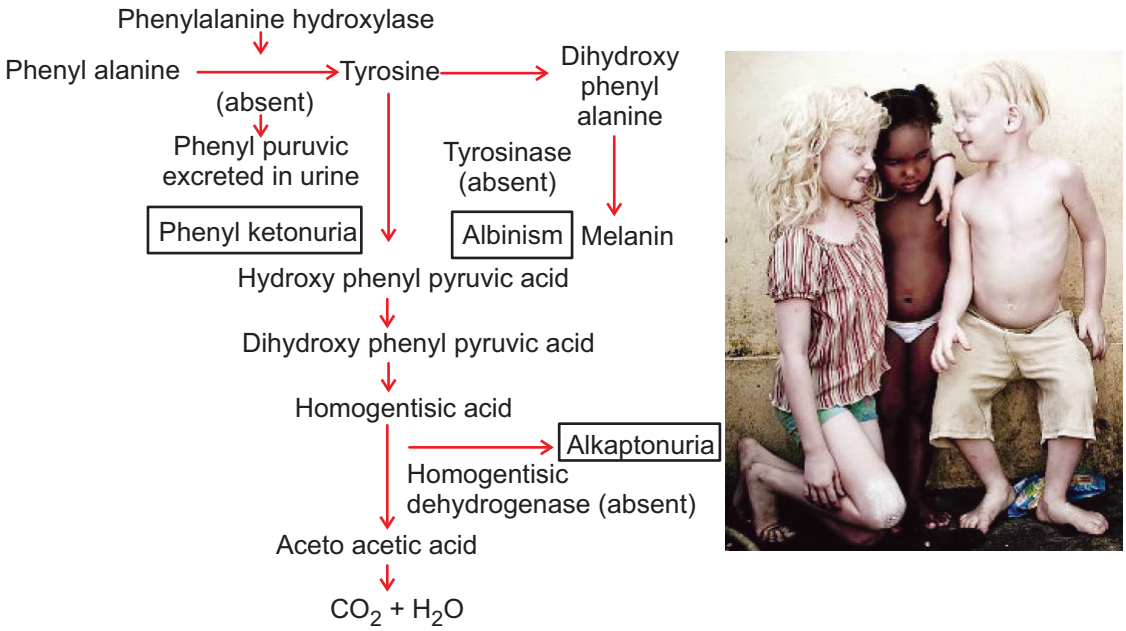


Figure 18.12: A biochemical reaction for the production of skin pigment melanin (left). The mutation in gene responsible for the formation of tyrosinase leads to change in phenotype resulting in albinism (right) where affected person have white skin, white hairs and red eyes.

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.

ACTIVITY 6

Aim: Use charts and illustrations to show how sickle cell anaemia is inherited and outline the features of the offspring with or without sickle cell anaemia.

Materials Required:

Charts (pedigree tree) and literature about sickle cell anaemia

Notebook

Procedure:

1. Read charts and literature about sickle cell anaemia.
2. For inheritance, try to look for sickle cell anaemic patients' family history (pedigree tree).

3. Observe the following points:
   - Whether trait is seen in every generation or it skips generation
   - Whether the affected person has unaffected parents or affected parents
   - Whether the trait is limited to particular sex or randomly happens in both the sexes.
4. Note down the inheritance pattern (recessive/dominant and autosomal/X-chromosome/ Y-chromosome linked).
5. Discuss your observations in the class.
6. Based on effect of mutation on phenotype, tabulate effect of sickle cell anaemia on the affected offspring in comparison with offspring without disease.

S. No.	Offspring with Sickle cell anaemia	Normal offspring
1.	Shape of RBC	
2.	Hb level	
3.	Flow in blood vessels	
4.	Effect on different organs	
5.	Overall physiology	

7. Discuss your observations in the class.

Sickle-cell anaemia is a disease which is caused due to synthesis of abnormal haemoglobin, the protein present in red blood cells for transporting oxygen. This disease was first studied by J. Herrick, who found that red blood cells in patients suffering from the disease have the following characteristics:

- Lose their characteristic disc shape, become sickle-shaped whenever oxygen tension becomes low (Figure 18.13),
- Rupture very easily thus causing anaemia.

It has also been found that sickle cells don't easily squeeze through the capillaries (Figure 18.14) as they are not flexible. This leads to blockage of capillaries, not letting blood flow into tissues depriving them of oxygen and ultimately causing tissue damage.

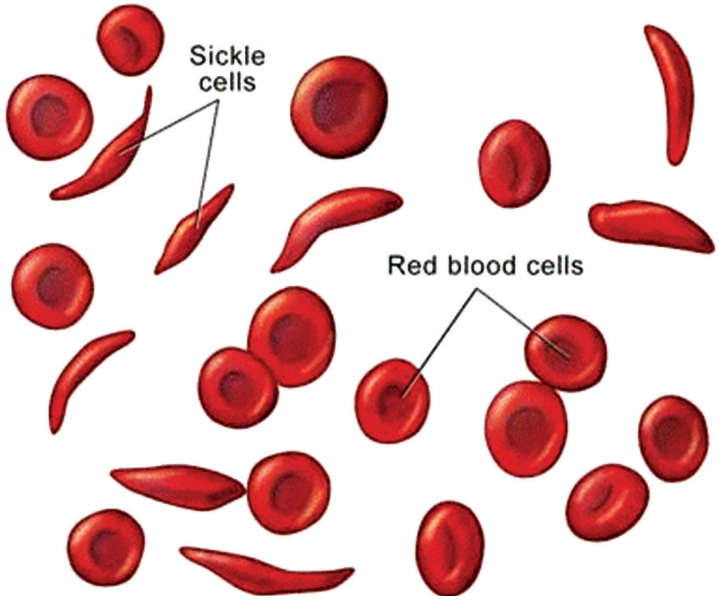


Figure 18.13: Red blood cells become sickle shaped in sickle cell anaemia

Thus, people suffering from sickle cell anaemia can have a number of health problems like heart failure, pneumonia, paralysis, kidney failure, abdominal pain, etc. Survival rate of such patients is very low. Disease occurs in a milder form and is known as sickle cell trait wherein patients show some symptoms in areas of low oxygen tension but do survive.

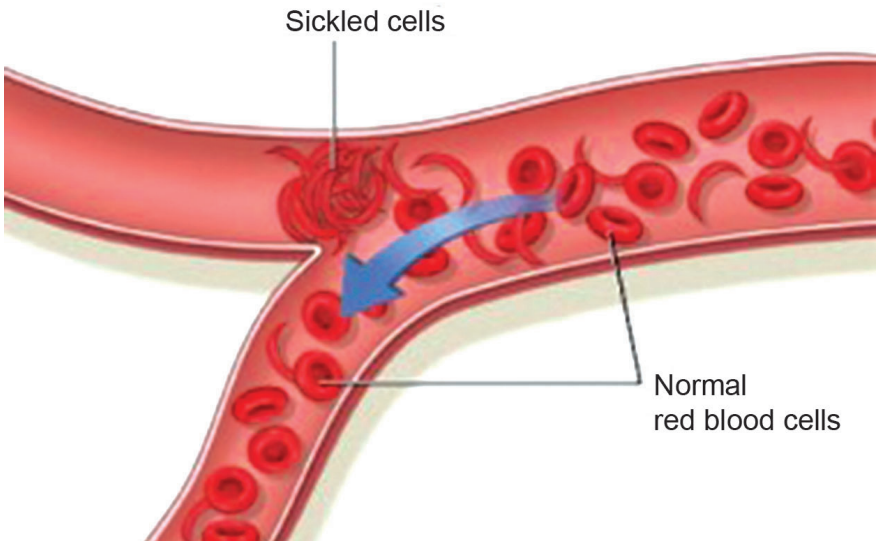


Figure 18.14: Sickle shaped red blood cells are not able to squeeze through the capillaries leading to blockage in capillaries

Work of L. Pauling showed that normal people made one type of protein haemoglobin, while people suffering from sickle cell anaemia had another type of haemoglobin and people with sickle cell trait had 1:1 mixture of two types of haemoglobins. Thus, it was hypothesized that people with sickle cell trait were heterozygous, carrying two different alleles and making two types of haemoglobins, Hb-A and Hb-S; normal people were homozygous and making one type of haemoglobin, Hb-A and people with sickle cell anaemia were homozygous, making one type of haemoglobin, Hb-S.

Haemoglobin consists of four polypeptide chains, two alpha and two beta, each of which is associated with a heme group to bind oxygen. V. M. Ingram, on comparing the amino acid sequence of Hb-A and Hb-S, found that while beta polypeptide of Hb-A had glutamic acid (with a negative electric charge) at the sixth position, beta polypeptide of Hb-S had valine (with no electric charge) at the same position. This substitution of amino acids (Figure 18.15) causes the beta polypeptides to fold up in a different way causing sickling of red blood cells.

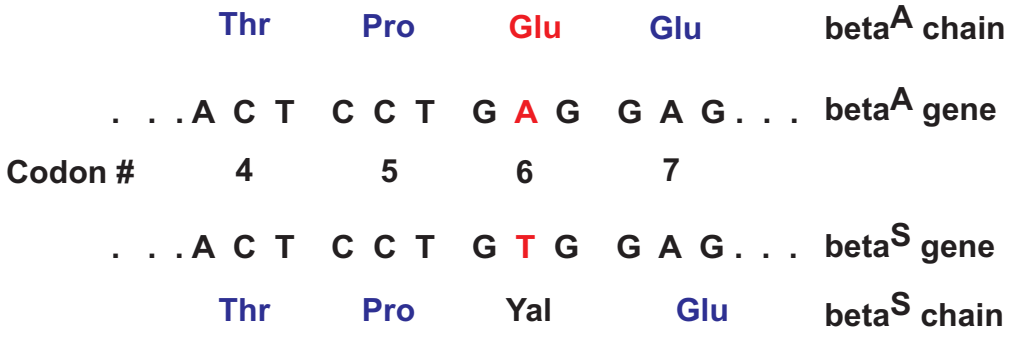


Figure 18.15: Substitution of single nucleotide in beta S chain (shown in red) resulting in change in 6th amino acid and different type of hemoglobin Hb-S

Haemophilia normally, we find that after minor injury or prick, bleeding automatically stops after a brief period. Excessive bleeding is prevented by the presence of clotting factors which work in a cascade-like fashion. However, there are individuals who continue to bleed for long periods of time even with minor bruises and may also show spontaneous bleeding. This bleeding disorder is called haemophilia. Haemophilia is of two types: haemophilia A and haemophilia B. Though both types occur due to a defect in blood clotting process, the two are a result of mutations in different genes. Haemophilia A (also called classical haemophilia) is more common, occurring with a frequency of 1 in 4000 males, and is due to deficiency of blood clotting factor VIII. Haemophilia B (also known as Christmas disease) is less common, occurring with a frequency of 1 in 20,000 males, and is due to deficiency of blood clotting factor IX. As the gene F8, coding for factor VIII and gene F9, coding for factor IX are present on X chromosome, a

single copy of either of the mutant genes can cause this disorder in males whereas females will show the disorder only when homozygous for the mutant alleles. This accounts for the higher frequency of the disorder seen in males in the population.

Huntington disease: All individuals have Huntington gene which codes for huntingtin protein. Although it is synthesized by all cells, its critical function is seen in the brain where it interacts with other proteins in the nerve cells. Addition of CAG repeats in Huntington gene in excess of the normal number increases the number of glutamines in the protein, causing misfolding of the protein and a mutant phenotype. This protein accumulates in nerve cells, causing extensive damage. Symptoms include involuntary movements and progressive central nervous system degeneration. Although Huntington disease is found to be due to autosomal, dominant allele, expression of this allele begins only by the age of thirty years by which time the parents have already passed on the gene to their offspring.

18.5 EFFECT OF ENVIRONMENT ON THE EXPRESSION OF PHENOTYPE

Have you ever thought if identical twins get separated at the time of birth and reared separately in different regions of earth with varied environment, will they be phenotypically identical? Discuss among your friends and teachers.

It is not always true that phenotype is completely reflected by genotype. Although our phenotype is governed by our genotype, environment also plays a very important role. It is the close interaction between genotype and environment that determines the phenotype shown by any individual. This can be appreciated by the following examples.

(a) A person who has normal genes for making haemoglobin but lacks sufficient iron in the diet develops anaemia. Phenotype of this individual can be reversed by including sufficient iron in the diet.

(b) Individual with normal genes can make adequate amounts of thyroid hormone, thyroxine; yet, in the absence of sufficient dietary iodine, he may develop hypothyroidism.

(c) Surrounding temperature can have an important influence on phenotype of individuals by affecting kinetic energy of reacting substances. Plant evening primrose shows red flowers when grown at 23°C and white flowers when grown at 18°C. Siamese cats and Himalayan rabbits (Figure 18.16) show white fur on all parts except nose, ears and paws, as the wild type enzyme responsible for pigment production is functional at the lower temperature present in extremities, but it loses its catalytic activity at the slightly higher temperature found in the rest of the body.

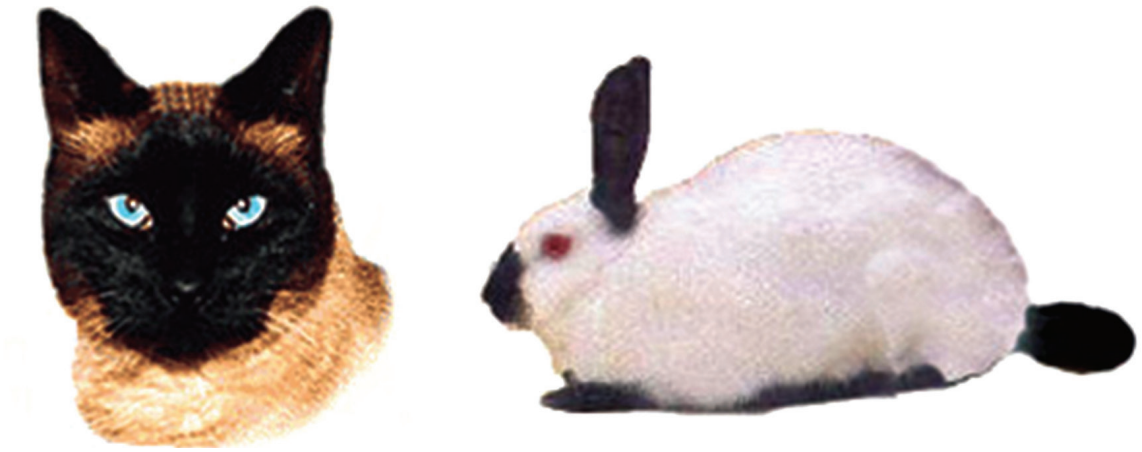


Figure 18.16: Siamese cats and Himalayan rabbits

(d) Individuals who are born with a deficiency of phenylalanine hydroxylase enzyme needed to convert phenylalanine to tyrosine, concentration of phenylalanine builds up in the body, especially in the brain causing neurological damage. Phenylalanine free diet allows them to lead a near normal life, without showing the effects of mutation.

(e) Every day, we are exposed to a large number of chemicals in our environment such as food additives, colouring agents in food items, textile dyes, cosmetics, pesticides, industrial compounds and so on. Some of these chemicals have mutagenic effects, and can cause genetic diseases.

18.6 SIGNIFICANCE OF MUTATIONS

Although the term 'mutation' was not used by Mendel, he was able to deduce that genetic characters are controlled by unit factors that exist in pairs in individual organisms and if two unlike unit factors exist in the same individual, one unit factor is dominant to the other, which is called **recessive**. Later studies revealed the true nature of these unit factors which are now called genes. As seen in the sections above, mutations have played very important roles as discussed below.

(i) **Role in disease:** As studied in earlier sections, mutations have been responsible for a number of diseases such as sickle cell anaemia, haemophilia, Huntington disease, and albinism. Each individual has tumour suppressor genes and mutation in any of these genes can lead to the development of tumours.

(ii) **Role in evolution:**

(a) Mutations play the most important role of creating new alleles. If there were no different alleles, all individuals would be homozygous at all loci. Presence of different alleles in individuals of a population is responsible for the diversity seen in any population. For example, blood group alleles IA, IB and IO. So mutation can bring about change in genetic constitution of an organism. So mutations bring genetic polymorphism in population which may or may not lead to evolution.

(b) Furthermore, it has been observed that certain African countries show higher incidence of sickle cell allele as compared to other regions. Sickle cell allele somehow confers protection against malaria and hence occurs with higher frequency in those regions where malaria is prevalent. Individuals homozygous for sickle cell allele do not survive as oxygen transport to tissues is affected and individuals homozygous for the normal allele may suffer from malaria. Hence, mutant allele in this case happens to confer an advantage in the heterozygous condition.

(c) Mutations have another very important consequence. Rapid rate of mutation in bacteria and viruses has helped them evolve resistance not only to our immune system but also to various antibiotics. Thus, treatment against diseases caused by these microbial organisms is becoming increasingly difficult.

(iii) Role in genetic research: Humans have around 20,000 genes. Although, scientists know the functions of a number of genes, vast majority of the genes have still not been assigned function. To study the function of a gene, researchers induce mutations in specific genes and look for possible effects. Thus, induced mutagenesis is helping us gain insight into genetics of cell cycle control points and hence the cells becoming cancerous. Cytogenetic studies have revealed a high degree of correlation between chromosomal rearrangements and leukaemias.

(iv) Mutations play an important role in agriculture as well by providing diversity of alleles which may confer stress resistance, yield and regional adaptability.

SELF EVALUATION

Complete with appropriate terms:

(i) Tell the cause of the following diseases

(a) Sickle cell anaemia

(b) Huntington disease

(c) Dawn's syndrome

(d) Albinism

(ii) ..... have helped develop resistance in virus and bacteria.

18.7 SUMMARY

I. Mutation, types and their effects on phenotype

- Mutation is any permanent change in the genetic material of an organism. Somatic mutations are not passed to offspring whereas germinal mutations are heritable.
- Point mutations refer to changes occurring in single nucleotides.
- Substitution of one base by another may lead to silent (no change), missense (altered codon) or nonsense (stop codon). Change is confined to single codon.
- Altered codons lead to the incorporation of a different amino acid altering the function of the protein. Examples are seen in diseases like sickle cell anaemia, haemophilia, and albinism.
- Insertion or deletion of a base changes the frame of reading the genetic code, resulting in frame shift mutations. Genetic code being comma-less, addition or deletion of one base alters all subsequent codons, coding for a sequence of amino acids which are totally different from the original sequence.
- Chromosomal mutations refer to changes in structure or number of chromosomes.
- Chromosome breakages can cause deletion (loss of genetic material), duplication (gain of genetic material), inversion (fusion of broken segments in opposite orientation) or translocation (fusion of a part of one chromosome to another, non-homologous chromosome).
- Non-disjunction of chromosomes can lead to monosomy (2n – 1) or trisomy (2n + 1). Example of monosomy is Turner's syndrome and example of trisomy is Down's syndrome.
- Addition of haploid sets to the chromosome complement of a cell can change the ploidy level creating triploid, tetraploid individuals. This can occur whenever two sperms happen to fertilise a single ovum, creating a triploid situation or a diploid egg is fertilised by a diploid sperm (all chromosomes fail to disjoin). This has given rise to newer varieties of plants such as seedless bananas.

II. Causes of mutations

- Chance effects like mistakes during DNA replication, hydrolysis.
- Ionizing radiation for example X rays, protons, neutrons and alpha, beta and gamma rays emitted by radioactive elements have high energy and can penetrate the tissues causing damage to DNA in a number of ways depending on the dose.
- Non-ionizing radiation for example UV rays don't penetrate tissues because of low energy but are strongly absorbed by nitrogenous bases, esp. thymine, causing the formation of thymine dimers. This makes them highly mutagenic and excessive exposure to solar radiation can lead to development of skin cancers.

- Chemical mutagens belong to two classes: one which produces mutations in replicating and non-replicating DNA for example alkylating agents, nitrous acid and the other produces mutations only in replicating DNA for example acridine dyes, base analogs.
- These chemicals generally produce mutations by altering base pair affinities.
- A number of common chemicals routinely encountered in environment such as bromine, pesticides, food additives, etc., may work the same way and thus potentially carcinogenic.
- A number of these chemicals have found in treating cancers.

III. Effects of environment on the phenotype

- Phenotype of any organism is the result of interaction of genotype and environment.
- Interaction may be due to the effect of temperature on enzyme activity.
- Effect of mutant allele can be minimized by modifying the environment for example, children born with phenylketonuria may lead a near normal life if fed on diet free of phenylalanine.

IV. Significance of mutation

- Majority of new mutations are generally deleterious, resulting in disease; some mutations are adaptive for example, sickle cell allele conferring protection against malaria.

18.8 GLOSSARY

- **Chromosome mutation:** In values charge in chromosome structure due to leakage of chromosome.
- **Mutagens:** Any chemical or physical agent that came mutations.
- **Mutations:** It is a permanent alteration of the nucleotide sequence gene mutation. Involves of geneme of an organism single nucleotide change.

18.9 END UNIT ASSESSMENT

Do all these exercises in your exercise book.

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
   (c) substitution mutation (d) chromosomal mutation
3. In mutational event, when adenine is replaced by guanine, it is a case of
   (a) transition (b) transcription
   (c) transversion (d) frame shift mutation
4. Which of the following is not ionising radiation
   (a) X rays (c) UV rays
   (b) cosmic rays (d) alpha rays
5. Which of the following chemicals can affect non-replicating DNA?
   (a) nitrous acid (b) Acridine dyes
   (c) bromouracil (d) None of the above
6. Phenotype of individual depends upon
   (a) environment only (b) genotype only
   (c) environment and genotype (d) mutagens
7. Which is the type of chromosome structure mutation?
   (a) Aneuploidy (b) Polyploidy
   (c) Trisomy (d) duplication
8. Which is the example for gene mutation?
   (a) Turner syndrome (b) Klinefelter syndrome
   (c) Haemophilia (d) Down syndrome
9. Thymine dimers are caused by
   (a) X-Rays (b) Gamma rays
   (c) alpha or beta particles (d) UV rays

10. A mutation that causes the change in one aminoacid with chemically similar amino acid is known as
    (a) Non-conservative mutation (b) Conservative mutation
    (c) Non-sense mutation (d) Silent mutation

III. Long Answer Type Questions

1. In your own words, explain what is mutation.
2. Describe the types of mutation and causes of mutations.
3. Explain the significance of mutations.
4. Explain that gene mutation occurs by substitution, deletion, inversion and insertion of base pairs in DNA. Outline how such mutations may affect the phenotype.
5. Explain that the environment may affect the phenotype.
6. Outline the effects of mutant alleles on the phenotype in the following human conditions: albinism, sickle cell anaemia, haemophilia and Huntington's disease.
7. Explain the relationship between genes, enzymes and phenotypes with respect to the gene for tyrosinase involved in the production of melanin.
8. Explain how a change in the base sequence of the gene for haemoglobin results in abnormal haemoglobin and sickle-shaped red blood cells.
9. Distinguish between gene and chromosomal mutation.
10. Mutation plays a significant role in evolution. State the role. Also, evolution is the biggest theory supporting environment sustenance. Guide the role of mutation in developing a sustained environment and continue the diversity in organisms.

REFERENCES

- Dr. B. S. Chauhan, *Environmental Studies*, University Science Press, New Delhi.
- Wilfred D. Stein, W. R. Lieb, *Transport and Diffusion Across Cell Membranes*, Academic Press Inc. (London) Ltd.
- Daniel L. Kaplan, *The Initiation of DNA Replication in Eukaryotes*, Springer International Publishing.
- Michael Robert, Michael Jonathan Reiss, Grace Monger; *Advanced Biology*, Nelson Publishers, UK.
- C. Ladd Prosser, *Environmental and Metabolic Animal Physiology*, Wiley-Liss Inc.
- Daniel D. Chiras, *Human Biology*, Jones and Bartlett Publisher, Sudbury.
- Beckett B. S. (1986). *Biology A Modern Introduction*. Oxford University Press, GCSE Edition.
- Kent, M (2000). *Advanced Biology. A New Mainstreamtext for the New Specifications*. Oxford University Press, New York.
- McKean DG (1984). *Introduction to Biology*. Third tropical edition.
- MINEDUC, *Advanced Level Biology Curriculum*. Kigali: NCDC.
- https://en.wikibooks.org/wiki/A-level_Biology/Biology_Foundation/nuclear_division
- http://www.biology-pages.info/D/Diffusion.html
- http://www.biology-pages.info/D/DNAReplication.html
- http://www.biotopics.co.uk/genes/dna.html
- http://www.biology-pages.info/C/Codons.html
- http://byjus.com/biology/photosynthesis-autotrophic-nutrition/
- http://www.livescience.com/26579-immune-system.html
- http://www.mcwdn.org/body/reproductive.html
- http://www.youtube.com/watch? v=8mvkcH 15220

INDEX