COURSE GUIDE

BIO 306
GENERAL PHYSIOLOGY II

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INTRODUCTION

General Physiology II is a second semester course. It is a two-credit unit compulsory course which all students offering Bachelor of Science (B.Sc.) in Biology must take.

General physiology is an important area of study for scientists. Physiology is the science of the function of living systems. This includes how organisms, organ systems, organs, cells and bio-molecules carry out the chemical or physical functions that exist in a living system.
Since this course entails the study function of living systems, we will focus on the osmotic regulation in animals, excretory mechanism and transport systems. Also, homeostatic mechanism, coordination in animals and plant-water relations will be treated.

WHAT YOU WILL LEARN IN THIS COURSE

In this course, you have the course units and a course guide. The course guide will tell you briefly what the course is all about. It is a general overview of the course materials you will be using and how to use those materials. It also helps you to allocate the appropriate time to each unit so that you can successfully complete the course within the stipulated time limit.

The course guide also helps you to know how to go about your Tutor-Marked Assignments which will form part of your overall assessment at the end of the course. Also, there will be tutorial classes that are related to this course, where you can interact with your facilitators and other students. Please you are encouraged to attend these tutorial classes.
This course exposes you to general physiology, a sub-discipline and very interesting field of biology.

COURSE AIMS

This course aims to enable you to explain the functions of living systems and how organisms, organ systems, organs and cells carry out the chemical or physical functions that exist in them.

COURSE OBJECTIVES

To achieve the aims set above, there are objectives. Each unit has a set of objectives presented at the beginning of the unit. These objectives

will give you what to concentrate and focus on while studying the unit and during your study to check your progress.
The comprehensive objectives of the course are given below. At the end of the course you should be able to:

- define the term osmoregulation
- explain the need for osmoregulation in animals
- define the terms osmosis, osmotic concentration, osmoconformers, osmoregulators, euryhaline and stenohaline animals
- highlight the factors affecting evaporative water loss in terrestrial animals
- describe how terrestrial animals overcome the problems of water loss and water gains
- explain low-level autoimmunity
- define the term excretion
- enumerate important excretory products in animals
- describe the process of excretion in plants
- define the term excretory organ
- explain why contractile vacuole is not considered as an excretory organ
- describe how the Malpighian tubules perform excretory functions in insects
- describe the mechanism of absorption of mineral salt
- explain the process of ascent of sap
- enumerate the factors that affect the rate of transpiration
- differentiate between solute and water potential
- define turgor pressure, wall pressure, diffusion pressure deficit (DPD) and suction pressure
- highlight the significance of turgor pressure and imbibition in plants.

WORKING THROUGH THE COURSE

To successfully complete this course, you are required to read each study unit, textbooks and other materials provided by the National Open University of Nigeria.

Reading the reference materials can also be of great assistance.
Each unit has self–assessment exercises which you are advised to do. At certain periods during the course, you will be required to submit your assignments for the purpose of assessment.

There will be a final examination at the end of the course. The course should take you about 17 weeks to complete.

This course guide provides you with all the components of the course, how to go about studying and how you should allocate your time to each unit so as to finish on time and successfully.

THE COURSE MATERIALS

The main components of the course are:

1 The Study Guide
2 Study Units
3 References/Further Reading
4 Assignments
5 Presentation Schedule

STUDY UNITS

The study units in this course are given below:

Module 1 Osmoregulation in Animals

Unit 1 Osmoregulation and Osmotic Response in the Marine Environment
Unit 2 Osmotic Response in the Freshwater Environment
Unit 3 Osmotic Response in the Terrestrial Environment

Module 2 Excretory Mechanism

Unit 1 Excretion and Excretory Products in Plants and Animals
Unit 2 Excretion in Invertebrates
Unit 3 The Vertebrate Kidney

Module 3 Transport Systems

Unit 1 Transport System in Plants
Unit 2 Transport System in Animals
Unit 3 The Cardiovascular System

Module 4 Coordination in Animals

Unit 1 Nervous Coordination in Animals
Unit 2 Endocrine Coordination In Animals
Unit 3 Homeostasis

Module 5 Plant-Water Relations

Unit 1 Diffusion and Osmosis
Unit 2 Osmotic and Water Potential
Unit 3 Absorption of Water and Minerals

ASSESSMENT

There are three aspects to the assessment of this course.
The first one is the self-assessment exercises. The second is the tutor-marked assignments and the third is the written examination to be taken at the end of the course.

Do the exercises in the units, applying the information and knowledge you acquired during the course. The tutor-marked assignments must be submitted to your facilitator for formal assessment in accordance with the deadlines stated in the presentation schedule and the assignment file. The work submitted to your tutor for assessment will account for 30% of your total work.

At the end of this course you have to sit for a final or end-of-course examination of about three hours which will account for 70% of your total course mark.

TUTOR-MARKED ASSIGNMENT

This is the continuous assessment component of the course and it accounts for 30% of the total score. You will be given four TMAs by your facilitator to answer. Three of which must be answered before you are allowed to sit for the end of the course examination.

These answered assignments must be returned to your facilitator.
You are expected to complete the assignments by using the information and material in your reading references and study units.
Reading and researching into the references will give you wider view point and deeper understanding of the subject.

Make sure that each assignment reaches your facilitator on or before the deadline given in the presentation schedule and assignment file. If for any reason you are not able to complete your assignment, make sure you contact your facilitator before the assignment is due to discuss the possibility of an extension. Request for extension will not be granted after the due date unless under an exceptional circumstance.

Make sure you revise the whole course content before sitting for the examination. The self-assessment exercises and TMAs will be useful for this purpose; and if you have any comments, please do contact your tutor before the examination. The end-of-course examination covers information from all parts of the course.

COURSE MARKING SCHEME

Assignment	Marks
Assignment 1-4	Four assignments, best three marks of the four count at 10% each = 30% of course marks.
End of course examination	70% of overall course marks
Total	100%

FACILITATORS/TUTORS AND TUTORIALS

Sixteen hours are provided for tutorials in this course. You will be notified of the dates, times and location for these tutorial classes.
As soon as you are allocated a tutorial group, the name and phone number of your facilitator will be given to you.

These are the duties of your facilitator:

- he or she will mark and comment on your assignment
- he will monitor your progress and provide any necessary assistance you need
- he or she will mark your TMAs and return to you as soon as possible.

(You are expected to mail your tutor-marked assignments to your facilitators at least two days before the schedule date).

Do not delay to contact your facilitator by telephone or e-mail for necessary assistance if:

- you do not understand any part of the study in the course material
- you have difficulty with the self assessment activities
- you have a problem or question with an assignment or with the grading of the assignment.

It is important and necessary that you attend the tutorial classes because this is your only chance to have face to face contact with your facilitator and ask questions which will be answered instantly. It is also a period where you can point out any problem encountered in the course of your study.

SUMMARY

General Physiology II is the science of the function of living systems which includes how organisms, organ systems, organs, cells and bio-molecules carry out the chemical or physical functions that exist in a living system. You will learn that coordination and regulation of living cells in the living systems is controlled by enzymes in the body.
Also, this course explains the functions of different systems of the body involved in physiology. For example, transport system, excretory system, osmoregulation, homeostasis and coordination.

On the completion of this course, you will understand the basic knowledge of different systems of the body involved in physiology and their functions for proper coordination among the organs - systems in the body. In addition, you will be able to answer the following questions:

- Why are marine invertebrates osmoconformers?
- Why are the osmotic responses in freshwater animals opposite that of the marine animals?
- Describe osmotic responses of freshwater invertebrates and vertebrates
- Highlight the factors affecting evaporative water loss in terrestrial animals.
- Describe how terrestrial animals overcome the problems of water loss and water gains.
- Why is excretion indispensable in animals?
- Enumerate the important excretory products in animals.
- Account for the differences in excretion in plants and animals.
- Describe the patterns of excretion in animals.
- Outline the major functions of the mammalian kidney.
- Describe the structure of the mammalian kidney.
- Explain osmoregulatory organs in invertebrates.
- Explain the process of waste formation and list e different group of animals and the form of waste excrete out.
- Explain the two major division of nervous system.
- Explain the types of central nervous system with diagrams and examples.
- Explain the structural and functional unit of a neuron.

The list of questions you are expected to answer is not limited to the above.

General physiology is a very interesting field of biology. I wish you success in this course.

MAIN COURSE

MODULE 1 OSMOREGULATION IN ANIMALS

UNIT 1 OSMOREGULATION AND OSMOTIC RESPONSE IN THE MARINE ENVIRONMENT

CONTENTS

1.0 INTRODUCTION

The term osmoregulation is the process of regulation of osmotic (dissolved solute) concentration and water in animals. This unit describes the need for osmoregulation, the physiological mechanisms involved and the organs used for osmoregulatory responses among marine animals.

2.0 OBJECTIVES

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

- define the term osmoregulation
- define the terms osmosis, osmotic concentration, osmoconformers, osmoregulators, euryhaline and stenohaline

animals
- explain osmoregulation in marine invertebrates
- describe the relationship between osmotic equilibrium and ionic composition of marine animals
- explain the differences between osmotic responses in marine teleost and marine elasmobranch.

3.0 MAIN CONTENT

3.1 The Need for Osmoregulation in Animals

Water is a vital component of an animal’s body; it is required for the maintenance of life and other metabolic processes. It forms the primary medium as well as the most essential nutrients in all animals. Water accounts for between 60% and 95% of an animal’s body weight. The water within animals may be inside cells as ***intracellular fluid (ICF)*** or it may be outside cells in the form of ***extracellular fluid (ECF)***. The ECF itself may be distributed between several smaller compartments, such as blood plasma and cerebrospinal fluid. A variety of solutes in form of ions and nutrients are dissolved in these fluids. Animals need to maintain appropriate and correct amounts of water and solutes in their various body fluids. The ability to regulate water and solute concentrations in animals is referred to as osmoregulation. Osmoregulation and excretion are intimately linked together in animals as most animals utilise their excretory organs for osmoregulatory functions. Animals in general require osmoregulation in order to ensure the:

- protection of the animal's internal environment from harmful fluctuations
- maintenance of balance in water loss and uptake in the animal’s body
- proper control of the animal’s internal environment.

3.2 The Principle of Osmosis

The term osmosis is best described as the movement of water across a selectively permeable membrane which separates two solutions, from a region of water high concentration (i.e. a dilute solution) to a region of lower water concentration (i.e. a concentrated solution). When two aqueous solutions of different solute concentrations are separated by a membrane permeable to water but impermeable to solute molecules, you will notice that water diffuses through the membrane from the dilute solution to the more concentrated solution. What happens here is termed osmosis. This process will continue until equilibrium is established, at which point there is no further net movement of water and the concentrations of solution on either side of the selectively permeable membrane are equal. A selectively permeable membrane is one which allows only water to pass through it and no other substances.

3.3 Osmotic Responses of Animals

Animals may be classified into two broad categories on the basis of their osmotic responses; they are either **osmoconformers** or **osmoregulators**.

3.3.1 Osmoconformers

Osmoconformers are animals whose body fluid concentration is exactly the same as that of the immediate environment in which they live. Typical osmoconformers include marine invertebrates, whose body fluid concentration is the same as that of salt water. This implies that the two solutions (body fluid /sea water) are isosmotic (that is, with the same osmotic pressure). Although these animals may be in osmotic equilibrium, they do not necessarily have to possess the same composition or be in ionic equilibrium. In this regard, a great deal of energy is required for ionic regulation. Hence, for osmoconformers, there is need for a corresponding change in the osmotic concentration of their body as soon as the external environment changes in its osmotic concentration. Some osmoconformers are capable of tolerating broad changes in the osmotic concentration of their immediate environment. These are referred to as euryhaline animals. On the other hand, some osmoconformers can only tolerate much smaller changes in the osmotic concentration of their immediate environment. They are known as stenohaline animals.

3.3.2 Osmoregulators

Osmoregulators on the other hand are animals which maintain a body fluid concentration that is different from that of their immediate environment. If the osmotic concentration of body fluids is maintained at a concentration greater than that of the immediate environment they are said to be hyperosmotic regulators (e.g. crabs); if they maintain their body fluid concentration below that of the immediate environment they are said to be hypoosmotic regulators (e.g. some crustaceans). Terrestrial animals including humans, by virtue of the fact that they live on land, are usually in hyperosmotic condition to their environment, hence they are osmoregulators.

3.4 Marine Invertebrates

The marine environment is essentially characterised by high salinity, mineral concentration, temperature, density, acidity and tidal action. These physical and chemical characteristics remain fairly constant through the year except in some seasons where there are slight fluctuations. The animals found in this environment have body fluid concentration similar to the salt water where they live. They differ from the seawater they inhabit on the basis of their ionic composition. These organisms overcome their osmotic challenges either as osmoconformers or osmoregulators.

Most marine invertebrates are osmoconformers, that is, the osmotic concentration of their body fluids is the same as that of the seawater they live in. This means that they are in osmotic equilibrium (i.e. there is no net gain or loss of water). However, this osmotic equilibrium does not necessarily imply that they are in ionic equilibrium. Differences (even slight differences) in ionic composition between seawater and body fluids will result in the formation of concentration gradients. The resultant loss or gain of ions may challenge the physiology of the animal concerned and may also challenge the osmotic equilibrium. For example, an animal may gain ions from the seawater if a particular ion is at a greater concentration in seawater than it is inside the animal. This will result in the body fluids becoming hyperosmotic in relation to seawater and this in turn will result in the osmotic gain of water. Table 1 below presents the ionic composition of some marine invertebrates and their ambient sea water.

Table 1: **The Ionic Composition of Marine Invertebrates and Seawater**

	Ion (mmol l^{-1})					
Species	Na^+	K^+	Mg^{2+}	Ca^{2+}	SO_4^{2-}	Cl^-
Seawater	479.0	10.2	55.0	10.3	29.9	540.0
Jellyfish	464.0	10.6	54.0	9.8	15.5	567.0
Shore crab	500.0	12.0	30.0	24.0	16.6	550.0
Mussel	490.0	12.8	54.0	12.5	29.5	563.0

Source: Rastogi, S.C. (2007)

Generally, osmotic concentrations of ions are not significantly different from the corresponding concentration in seawater. However, there are some exceptions, such as SO_4^{2-} and Ca^{2+}which in some species may be present in concentrations markedly different from that found in seawater. This means that the concentrations of such ions need to be physiologically regulated, thus, ions must be actively secreted or absorbed. In certain marine invertebrates such as jellyfish, SO_4^{2-} ions are excreted to reduce the density of the animal, so that its buoyancy can increase. SO_4^{2-} ion is relatively heavy and eliminating it from the animal will amount to reducing the animal's weight and increasing its buoyancy. The animal may also lose or gain ions via the general body surface through the ingestion of food as well as the production of waste substances in form of urine. However, there are few exceptions in which some other invertebrates like octopus maintain body fluid concentrations that are more concentrated (hyperosmotic) to salt water; while others such as brine shrimp and a few crustaceans possess less concentrated (hypoosmotic) to salt water.

3.5 Marine Vertebrates

Marine vertebrates show some remarkable differences in their osmotic responses when compared with the saltwater invertebrates. Marine vertebrates are either osmotic conformers or osmotic regulators. A typical example of osmoconformers who are in osmotic and ionic equilibrium with seawater is the hagfish. Hagfish (cysclostomes) are the most primitive vertebrates. They show some resemblance with the marine invertebrates in their osmotic response. Hagfish utilises a kind of osmotic and ionic conformation that has been used as physiological evidence that vertebrates evolved in the marine environment. The majority of other marine fish, however, show varying degree of osmotic and ionic regulation. The osmotic concentration of their plasma is approximately one-third that of seawater, therefore they are hypoosmotic regulators.

3.5.1 Marine Elasmobranchs

The elasmobranchs (the cartilaginous fishes) are very successful osmoregulators because they have evolved a novel way of achieving this regulation. Given that their plasma is only one-third as concentrated as the seawater in which they live, they face two problems - the loss of water and the gain of ions. The loss of water is minimised by the animals achieving osmotic equilibrium by the addition of solutes to their plasma. The solutes added are urea and trimethylamine oxide (TMAO). Urea is produced as an end product of protein metabolism, whilst the biosynthesis of TMAO is less clear. In many cases, more urea and TMAO is added to the plasma than is necessary to produce osmotic equilibrium, thus, making the plasma hyperosmotic to seawater. The result of this is that the animal gains water across the surface of the gills. Gills are usually made up of large surface area, thin walled and highly vascularised. They serve as sites for the gain and loss of water and ions in aquatic animals. This gain and loss of water and ions is advantageous to elasmobranchs because excess water can be used for the production of urine and the removal of waste products, such as excess ions that diffuse into the animal which occurs across the gills. Water gain also means that the animals do not need to drink seawater as a means to overcome potential water loss, and in avoiding this they avoid ingesting large amounts of salt that is dissolved in seawater, which would serve to further exacerbate the problems of ionic regulation.

Potentially, the biggest problem with the addition of large amounts of urea to the plasma is that urea tends to denature and inactivate other plasma proteins. However, these animals have overcome this problem to such an extent that proteins and enzymes are unable to function correctly without urea. Similarly, another problem faced by the elasmobranchs is the gain of ions. This is because their plasma has a different solute composition to salt water; a concentration gradient therefore exists that favours the movement of ions into the animals. For instance, there is a massive influx of Na^+ ions across the gills. Elasmobranchs overcome this kind of problem with a special gland known as rectal gland. The rectal gland helps in the excretion of excess Na^+ ions. It is a specialised gland which opens out into the rectum and secretes a fluid which is rich in NaCl. The small osmotic influx of water into these animals allow for the production of urine, which is another route by which excess NaCl may be excreted.

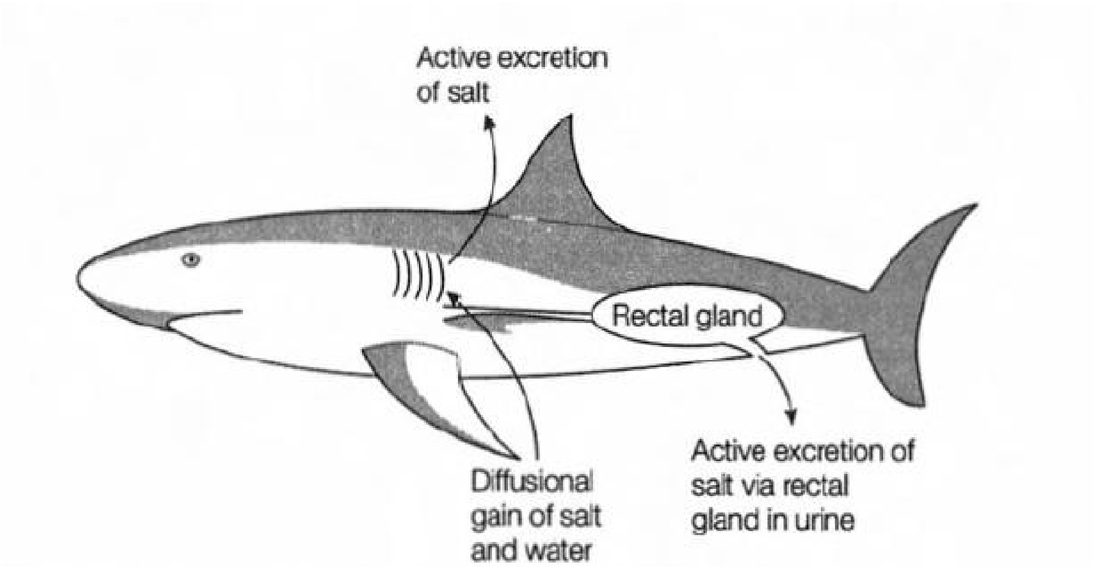

Fig. 1: Sites of Loss and Gain of Water and Salt in the Shark
Source: Rastogi, S.C. (2007)

3.5.2 Marine Teleosts

Marine teleosts (bony fishes) face similar problems as elasmobranchs as their plasma is less concentrated than seawater. Loss of water, particularly across the gills, is compensated for by drinking large volumes of seawater. This solves one problem, but exacerbates another by adding a further salt load to the animal. This means that the animal must somehow excrete large amounts of NaCl. Since the kidney of teleost fishes is unable to produce concentrated urine, there be some other organ that is able to excrete large amounts of NaCl. This organ is the gill, which has a dual function in gas exchange and osmoregulation.

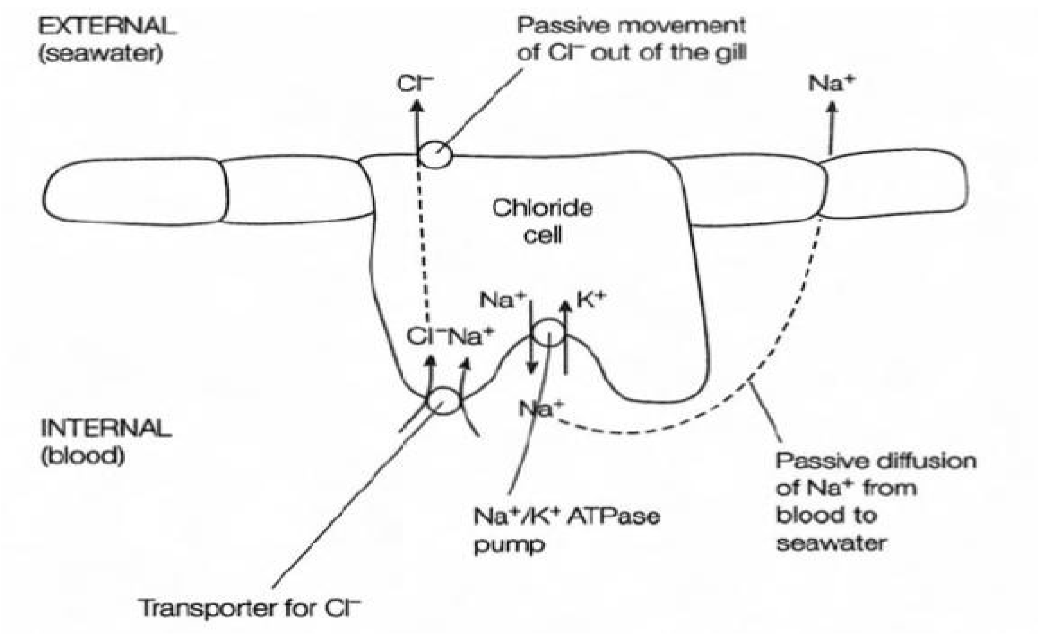

Fig. 2:The Mechanism by which NaCl is Extruded from Chloride Cells in the Fish Gill
Source: Rastogi, S.C. (2007)

The gills of marine teleosts contain special cells known as *chloridecells* which are responsible for active transport of NaCl from plasma to seawater. Cl^- ions are actively extruded form the blood into the chloride cells, accompanied by the passive diffusion of Na^+. Hence, Cl^- moves passively out from the gill into the surrounding seawater.

4.0 CONCLUSION

In this unit, you have learnt about osmoregulation in animals, the different kind of osmotic responses in animals and how each animal responds to the prevailing osmotic fluctuations in the environment.

5.0 SUMMARY

Just like you have seen in this unit, an animal's environment changes constantly in term of its ionic composition, this results in varying degree of fluctuations which the animal must always overcome. An animal may be either an osmoregulator or osmoconformer. Osmoconformers are animals whose body fluid concentration is exactly the same as that of the immediate environment in which they live, while osmoregulators are animals which maintain a body fluid concentration that is different from that of their immediate environment.

You have seen in this unit that, the presence of unique physical and chemical properties in the marine environment confers unique physiological characteristics on the inhabiting animals. This environment is remarkably rich in dissolved oxygen, salinity and light penetration. The density of the salt water is dependent on both temperature and salinity. The marine animals maintain body fluid concentration similar to the salt water where they live. They differ from the seawater they inhabit on the basis of their ionic composition. These organisms overcome their osmotic challenges either as osmoconformers or osmoregulators.

6.0 TUTOR-MARKED ASSIGNMENT

1. Differentiate between the terms osmoconformers and osmoregulators.
2. Why are marine invertebrates osmoconformers?
3. Osmoregulation is important in the life of an animal. Discuss.

7.0 REFERENCES/FURTHER READING

Cote, C. J. (1994). *Principles of Renal Physiology*. (3rd ed.). London: Chapman and Hall.

Prosser, C. L. (1991). *Comparative Animal Physiology*. (4th ed.). New York: Wiley-Liss.

Rankin, J. C. & Davenport, J. (1981). *Animal Osmoregulation*. Glasgow: Blackie.

UNIT 2 OSMOTIC RESPONSE IN THE FRESHWATER ENVIRONMENT

CONTENTS

1.0 INTRODUCTION

In this unit, you will discover that the freshwater environment is another interesting environment where organisms exhibit notable physiological adjustment in terms of osmotic regulation. To begin with, the organisms in the freshwater environment are unique. This is simply because their osmoregulatory problems are the opposite of those faced by marine animals. Freshwater animals, by definition, must be hyperosmotic to the water in which they live. It would be impossible for any animal living in freshwater to be in osmotic and ionic equilibrium with it, unless the body fluids were made of distilled water. This means they face two problems – they tend to gain water from their immediate environment by osmosis and lose ions by diffusion due to the presence of large concentration gradients as only a minimal amount of solutes are dissolved in freshwater. Animals living in such an environment must be capable of significant osmotic and ionic regulation.

2.0 OBJECTIVES

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

- describe the osmotic challenges animals in the freshwater environment face
- describe osmotic responses of freshwater invertebrates and vertebrates.

3.0 MAIN CONTENT

3.1 Freshwater Invertebrates

For both invertebrates and vertebrates, one way of limiting the gain of water (and loss of ions) would be to have an impermeable body surface. However, even if this were the case, water and ion movement across gills could still occur relatively unhindered. The water that is gained by invertebrates is excreted as urine - the urine flow rate in freshwater is much higher than that of corresponding marine species. However, the excretion of urine also results in the loss of ions and so exacerbates the diffusive ion losses which occur in these animals. In order to compensate for the loss of ions, active uptake mechanisms transport ions from the freshwater back into the animal. In many freshwater invertebrates, the site of ion uptake is not known and it is thought to occur across the general body surface area. However, in some invertebrates the site of uptake is known with some degree of certainty. In freshwater crustaceans, for example, it is known that active transport of ions occurs across the gills; in aquatic insect larvae, active transport of ions has been shown to occur in the anal gills.

3.2 Freshwater Vertebrates

Freshwater vertebrates face the same osmotic and ionic problems as freshwater invertebrates. When considering freshwater vertebrates, it is only necessary to consider the osmotic and ionic relations of the teleosts - there are very few elasmobranchs that are true freshwater species. Like invertebrates, the major site of osmotic water gain in teleosts is the gills. The excess water is removed by the production of large quantities of very dilute urine. Although the urine is dilute, it does contain some dissolved solutes, and because large volumes of urine are produced, urine excretion may result in a relatively large loss of ions. This in turn compromises the ion loss which is already occurring by diffusion from plasma to water. Some loss of ions can be compensated for by the gain of ions from food. However, the main source of ion gain is by the active transport of ions in the gills. It is thought that the transport of ions across the general body surface is insignificant.

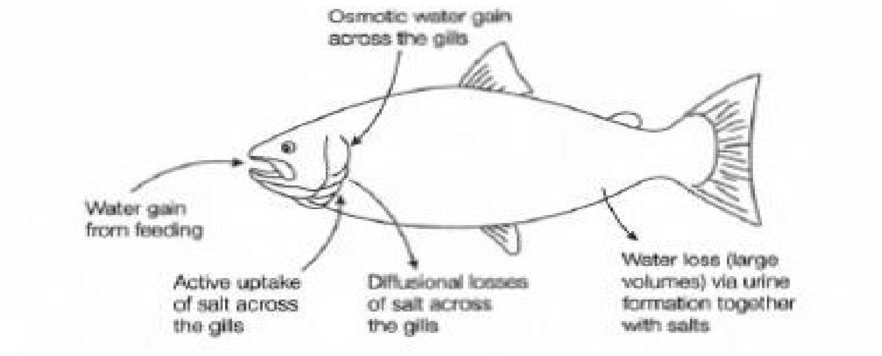

Fig. 1: The Osmotic and Ionic Relationships of Freshwater Teleost
Source: Rastogi, S.C. (2007)

4.0 CONCLUSION

In this unit, you have learnt about the osmotic responses in freshwater animals, the differences in the way freshwater invertebrates and vertebrates overcome the challenges imposed on them in their environment.

5.0 SUMMARY

As you have seen earlier in this unit, freshwater animals face osmoregulatory problems that are almost opposite to those faced by their marine counterparts. In particular, freshwater animals have body fluids hyperosmotic to their medium. They gain water from their immediate environment by osmosis and lose ions by diffusion due to the presence of large concentration gradients as only a minimal amount of solutes are dissolved in freshwater. Freshwater animals are capable of both ionic and osmotic regulation as no animal in the freshwater environment is truly in ionic and osmotic equilibrium with the environment. They conserve salts by producing urine which is generally less concentrated than blood.

6.0 TUTOR-MARKED ASSIGNMENT

1. Why are the osmotic responses in freshwater animals opposite that of the marine animals?
2. Describe osmotic responses of freshwater invertebrates and vertebrates

7.0 REFERENCES/FURTHER READING

Ian, K. (1998). *Introduction to Animal Physiology*. (1st ed.). Oxford, UK: BIOS Scientific Publishers Ltd.

Rastogi, S.C. (2007). *Essentials of Animal Physiology*. (4th ed.). New Delhi: New Age International Publishers.

UNIT 3 OSMOTIC RESPONSE IN THE TERRESTRIAL ENVIRONMENT

CONTENTS

1.0 INTRODUCTION

The arthropods and the vertebrates are the earliest groups of animals that colonised the terrestrial environment, except in some cases. The ability to live on land has provided these organisms with access to increased amounts of oxygen, but poses a great threat to their water and ionic balance. This is primarily because on land there is limited availability of water, so a major threat facing these animals is dehydration. Thus, life on land could be considered to be a compromise between gas exchange and dehydration. The cause of the greatest amount of water loss for terrestrial animals is evaporation and such losses must be compensated for.

2.0 OBJECTIVES

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

- highlight the factors affecting evaporative water loss in terrestrial animals
- describe how terrestrial animals overcome the problems of water loss and water gains
- describe osmotic responses in terrestrial mammals.

3.0 MAIN CONTENT

3.1 Factors Affecting Evaporative Water Loss in Animals

A number of factors influence evaporative water loss from an animal. These include:

- water content of the atmosphere - evaporation will be reduced as the water content (i.e. the relative humidity) of the atmosphere increases
- temperature - evaporation will increase as temperature increases
- movement of air over the evaporating surface - as air movement increases, so will the rate of evaporation
- barometric pressure - as barometric pressure decreases the rate of evaporation increases
- surface area - the larger the surface area exposed to the environment increases, the greater the water loss.

For any animal, it is essential that in the long term, it maintains a balance between water loss and water gain. Table 1 below presents the possible routes for water loss and gain in terrestrial animals. These have attempted to solve the osmotic problems of their way of life in a number of ways.

Table 1: Possible Routes of Water Loss and Again Among Terrestrial Animals

Water loss	Water gain
Evaporative loss (from the body surface and respiratory structures)	Drinking
Losses from urine	Water content of food
Losses from feces	Metabolic water
Loss from other secretions, e.g. saliva	Uptake across the general body surface

Source: Rastogi, S.C. (2007)

3.2 Terrestrial Invertebrates

Arthropods are the largest proportion of terrestrial invertebrates. They include insects and spiders, of which the former are the most numerous. Other members of this phyla, the crustaceans are predominantly aquatic' animals. One of the defining characteristic features of insects is the presence of an exoskeleton. The exoskeleton is covered by wax which forms the **cuticle** of the insect. The presence of the cuticle is one means by which evaporative water loss from the general body surface area can be reduced. However, it is important to note that the cuticle is not totally impermeable to water, as there is still some element of water loss across it. Even so, the cuticle still represents a formidable barrier to evaporation. Disruption to the arrangement of the waxes covering the exoskeleton, by physical or thermal damage, for example, results in increased water loss by evaporation.

A second site of evaporative water loss from insects is the respiratory system, via the spiracles. Although many of the trachea which originate from the spiracles are covered with chitin, water loss from here may still represent a significant burden to the animal; in order to limit such loss, many insects utilise cyclic respiration. The loss of water via feces and urine production in insects is minimal as water from urine and faeces are reabsorbed before released into the environment as waste products. This situation is aided further by the fact that insects excrete nitrogenous waste as uric acid which is extremely insoluble in water, so it can be excreted with the loss of little water. A further adaptation to water conservation is seen in some insects (e.g. cockroaches), which, rather than excrete uric acid, deposit it in stores around the body, such as in the cuticle. This reduces even further the necessity to lose water when waste products are excreted.

The most obvious means of gaining water for insects is by drinking, for example, from rainfall, pools, and so on. However, this is a source not available to all insects, such as those that live in hot arid environments and desert regions. Other potential sources of water include food, and the production of water during metabolism of food stuffs (metabolic water). In terms of water in food, perhaps the richest source of water is from plants. Finally, some insects, such as cockroaches, balance their water budget by absorbing water vapour from the air in the environment around them.

3.3 Terrestrial Vertebrates

Terrestrial vertebrates comprise the reptiles, birds, and mammals. Amphibians are often ignored because they are not truly terrestrial animals by their nature. Reptiles, which include snakes, lizards, crocodilians and tortoises, have dry, scaly skin which is well adapted to terrestrial life in that it represents a significant barrier to evaporative water loss. In addition, they excrete their nitrogenous waste as uric acid, which requires the loss of very little water. They are also able to produce very dry faeces which further limit water loss.

In terms of water gain, the drinking of water may present a problem because of the hot, arid environments where many of these animals are found. This means that water in food, together with water obtained during the metabolism of food, represents the most significant gain of water. Some lizards and tortoises produce dilute urine which is stored in the bladder. This may be reabsorbed when the animals are dehydrated.

3.3.1 Birds

Birds too, exhibit similar adaptations to maintaining a suitable water balance as seen in reptiles. However, the water balance of birds may be further compromised by the fact that they must maintain a more or less constant body temperature. One way in which a heat-stressed bird may lose heat is to lose water by evaporation, which causes cooling. This may be achieved by the phenomenon of *gular fluttering*. It is the rapid oscillatory movement of the mouth and throat which promotes water loss. It is analogous to panting in mammals. Gular fluttering represents a potential disruption to the animal's water balance, but, because birds are able to satisfy their water requirements by drinking for the simple reason that they are able to fly to find sources of water, this is not a significant problem. However, one potential problem with drinking water, particularly for marine birds, is that the water has a very high salt content. Together with the ingestion of large amounts of salt in their food, this means that these birds need to excrete large amounts of salt. To achieve this, marine birds have paired nasal salt glands. When the birds are facing a salt overload they begin to secrete a solution which is essentially a concentrated solution of NaCl. The glands are rendered inactive until the bird becomes salt stressed. Similar glands are also found in reptiles, which, although primarily terrestrial animals, may spend part of their life in a marine environment.

Water loss by birds is further reduced by the fact that they excrete very dry urine (uric acid) like the reptiles. This method of limiting water loss is so efficient that the water content of feces may be as a low as 25%. This has undoubtedly contributed to the success of birds and reptiles living in hot, arid environments.

3.3.2 Terrestrial Mammals

Terrestrial mammals like reptiles and birds have the same potential routes for the loss and gain of water. The evaporative loss of water from the general body surface area is minimised by the presence of relatively impermeable skin and of fur and hair. Of greater importance, in terms of water loss, is evaporative loss from the respiratory tract - this may account for a large proportion of the water lost from an animal.

However, mechanisms have evolved which serve to limit this loss. One such mechanism is breathing out air that is at a lower temperature than normal body temperature. This phenomenon is seen in all mammals. During inspiration, the walls of the nasal passages transfer heat to the air entering the respiratory system. When the animal breathes out, warm air from the respiratory system passes over this cooled surface and condensation of water occurs. Water and salt loss also occur in those animals capable of sweating. In this situation, though, such losses are a means of regulating body temperature and not a true osmotic response.

Water gain for many mammals is simply achieved by drinking. However, this is not possible for desert dwelling mammals. The kangaroo rat *(Dipodomys specfabilis)*, for example, does not drink, but survives on metabolic water - the oxidation of glucose, for instance, produces ATP, carbon dioxide, and water. Some mammals, for example, whales and dolphins, are exclusively marine-living mammals. It might be thought that such animals would face severe osmotic problems due to the gain of large amounts of salt from food. This may well be the case, but these animals have very efficient kidneys which can produce highly concentrated urine; thus, ensuring that the excess salt they consume is excreted. However, it is not possible to produce urine of infinite concentration. Generally, it is only possible to produce urine which is three to four times more concentrated than the plasma from which it has been formed.

4.0 CONCLUSION

In this unit, you have learnt about life on land, the challenge of dehydration and water loss in terrestrial animals and how these challenges are overcome.

5.0 SUMMARY

The adaptation of animals to the terrestrial life has provided these organisms with access to increased amounts of oxygen, as well as a great threat to their water and ionic balance. This is due to the fact that there is limited availability of water on land; hence, animals are prone to the problem of dehydration. The life of animals in the terrestrial environment is always seen as a compromise between gas exchange and dehydration. The primary cause of the greatest amount of water loss for terrestrial animals is evaporation; and water loss due to evaporation must be physiologically compensated for.

6.0 TUTOR-MARKED ASSIGNMENT

i. Highlight the factors affecting evaporative water loss in terrestrial animals.
ii. Describe how terrestrial animals overcome the problems of water loss and water gains.
iii. Describe osmotic responses in terrestrial mammals.

7.0 REFERENCES/FURTHER READING

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MODULE 2 EXCRETORY MECHANISMS

UNIT 1 EXCRETION AND EXCRETORY PRODUCTS IN PLANTS AND ANIMALS

CONTENTS

1.0 INTRODUCTION

You are familiar with the fact that all living organisms carry out several metabolic activities which are essential for their sustenance and well being. As a consequence, these metabolic activities are usually accompanied by the production of waste products. The major waste products are carbon dioxide (CO_2) water and nitrogenous compounds (ammonia, urea and uric acid). For example, waste products produced during the break down of carbohydrates and fats are water and CO_2 while nitrogenous compounds are produced as waste products when protein is metabolised. These waste materials if allowed to accumulate in the body may become harmful to the cells of the body. Hence, their removal is necessary. The removal and elimination of toxic waste products from the cells and tissues of the body is known as **excretion**. Excretion is the removal from the body of waste products of metabolism which if allowed to accumulate, would prevent the maintenance of a steady state. The tissues or organs responsible for the elimination of the waste products are called **excretory organs.**

2.0 OBJECTIVES

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

- define the term excretion
- enumerate important excretory products in animals
- describe the process of excretion in plants
- explain the patterns of excretion in animals.

3.0 MAIN CONTENT

3.1 Excretion in Plants

Plants, unlike animals do not have notable problems regarding excretion. This is largely because of the fundamental differences that exist in the physiology and mode of life between plants and animals. Plants are producers and they synthesise all their organic requirements according to their metabolic demands. Plants manufacture only the amount of protein necessary to satisfy immediate demand. There is never an excess of protein and therefore very little excretion of nitrogenous waste substances. If proteins are broken down into amino acids, the latter can be recycled into new proteins. Three of the waste substances produced by certain metabolic activities in plants (oxygen, CO_2 and water) are raw materials for other reactions in plants. Excess CO_2 and water are used up while excess oxygen is given off to the atmosphere as excretory products by diffusion.

However, most organic waste products of plants are stored within dead permanent tissues in plants. The bulk of most perennial plants is composed of dead tissues into which excretory materials are passed. In this state they have no adverse effects upon the activities of the living tissues. Apart from this, many mineral salts, taken up in form of ions may accumulate organic acids, which might prove harmful to plants, often combine with excess cations and precipitate out as insoluble crystals which can be safely stored in plant cells. For example, calcium ion and sulphate ions are taken up together but sulphate ions is used up immediately in amino acid synthesis leaving an excess of calcium ions. These combine with oxalic and pectic acids to form harmless insoluble products such as calcium oxalate and calcium pectate. Substances are not only eliminated through leaf loss but also through petals, fruits and seeds, although excretory function is not the primary function of their dispersal. However, in aquatic plants, most of their metabolic wastes are lost into their surrounding water via diffusion.

3.2 Excretory Products in Animals

Excretory substances are produced during metabolism of nitrogenous substances like amino acids and nucleic acids. Metabolism of carbohydrates and fats produces CO_2 and H_2O which are easy to remove. Protein metabolism produces nitrogenous waste material such as ammonia, uric acid and urea.

3.2.1 Nitrogenous Waste Products

In living organisms, proteins serve as important dietary constituents needed for building, growth and repair of the body cells. Proteins are nitrogen containing compounds which are metabolised to form end products such as ammonia, urea and uric acid. These end products are derived from the degradation of proteins, amino acids, pyrimidines and purines in the body.

Ammonia

Nitrogenous excretory products are produced by the breakdown of proteins, nucleic acids and excess amino acids. The first product of the breakdown of excess amino acid is ammonia. Ammonia is produced by the removal of the amino group from amino acid through a process called **deamination**. Ammonia may be excreted immediately or converted or converted to urea or uric acid. Deamination of amino acid occurs in the liver. Ammonia is a toxic substance and is constantly being produced in the tissue by deamination of amino acids. It is removed rapidly from the body. Mammals cannot withstand ammonia in their blood, while amphibians, reptiles, and fishes can withstand a higher concentration of ammonia. Also, many invertebrates have demonstrated high tolerance of ammonia in their blood.

Urea

This is derived the metabolism of amino acids and purines in the liver. It is highly soluble in water and less toxic than ammonia. The human blood usually has high tolerance of urea concentration. Urea is produced in the body by the metabolism of three amino acids, ornithine, citrulline, and arginine in most vertebrates and mammals.

Uric acid

Uric acid is the most important nitrogenous waste product in uterine of birds, reptiles, snails, and insects. It is formed from ammonia. It is less toxic, insoluble in water and may be stored or excreted in crystalline form. Its formation is an adaptation for the conservation of water since its elimination requires very little water.

Other nitrogenous constituents Guanine

Spiders excrete almost exclusively a chemical called guanine. It is even less soluble as compared to uric acid and hence requires no water for elimination. It is a metabolic waste of nucleotide metabolism. It is also found in penguins.

Xanthine and hypoxanthine

These are excreted by a number of insects.

Trimethylamine oxide

Marine teleost fishes excrete a large proportion of their nitrogen as trimethylamine oxide (TMAO). A large amount of this compound is also stored in their body for osmoregulation, i.e. to minimise loss of water and entry of salts.

Hippuric acid and ornithuric acid

Hippuric acid is formed in mammals. The diets of mammals contain traces of benzoic acid which is a toxic substance. This benzoic acid combines with amino acid glycine to form a less toxic substance hippuric acid. In birds, dietary benzoic acid combines with ornithine and is excreted in the form ornithuric acid.

Creatine and creatinine

These are excreted from the muscle, brain, blood, and urine in animals.

Pterydines

Pterydine are regarded as excretory product which are important pigments in insects. In some insects, traces of pterydine are excreted in the faeces, wings, fat body and urine.

3.3 Patterns of Excretion

On the basis of the kind of nitrogenous waste products excreted from the body, animals can be categorised into different patterns of excretion

Ammonotelism

Animals excreting their nitrogenous waste in the form of ammonia are known as ammonotelic. This phenomenon is known as ammonotelism.

Ammonia, the first metabolic waste product of protein metabolism is the most toxic form and requires large amount of water for its elimination. It is highly soluble in water with which it forms ammonium hydroxide (NH_4OH) which injures cells directly by alkaline caustic action. It is most suitable for aquatic organisms which have a constant access to water. No energy is required to produce ammonia. Kidneys do not play any significant role in its removal. Many bony fishes, aquatic amphibians, and aquatic insects are ammonotelic in nature. In anurans (amphibians) the larval tadpoles excrete ammonia, while the adults produce urea.

Uricotelism

Animals which excrete their nitrogenous waste mainly in the form of uric acid and urates are known as **uricotelic**. The phenomenon is known as **uricotelism**. All terrestrial animals like insects, reptiles, and birds excrete uric acid. Uric acid (which requires more energy) is produced by degradation of purines (e.g. guanine) in liver and kidneys to some extent. In uricotelic animals, excess nitrogen is first used in synthesis of purines. A purine is changed to xanthine (from hypoxanthine or guanine) which is then oxidised to **uric acid**. Part of uric acid is oxidised further to form allantoin and **allantoic acid**. Teleost fish excrete allantoate or hydration product of allantoin. In most fishes and amphibians, allantoate is hydrolysed to urea and glyoxylate. Some marine invertebrates have gone a step further by hydrolysing urea to ammonia and carbon dioxide.

Ureotelism

Animals that excrete their nitrogenous waste mainly in the form of urea are known as ureotelic and the phenomenon is known as ureotelism. Terrestrial adaptation necessitated the production of lesser toxic nitrogenous wastes like urea and uric acid for conservation of water. Mammals, many terrestrial amphibians and marine fishes mainly excrete urea. Ammonia produced by metabolism is converted into urea in the liver of these animals and released into the blood which is filtered an excreted out by the kidneys. Urea can be stored in body for considerable periods of time, and is least toxic. It is eliminated in the form of urine. Ureotelism is exhibited by semi-terrestrial animals, e.g. some earthworms, adult amphibians, elasmobranch (cartilagineous fishes) and mammals.

Guanotelism

In some arthropods such as spiders, guanine is a predominant excretory products elaborated by the Malpighibian tubules and cloacal sacs. This pattern of excretion is known as Guanotelism and such animals are said to be guanotelic.

Trimethylamine oxide

Marine teleost excrete trimethylamine oxide as the major nitrogenous product which is soluble in water and nontoxic in nature. It is absent in marine elasmobranch. Marine teloests are faced with the problem of maintaining osmotic balance by retaining water in the body which is aided by trimethylamine oxide. This compound is present in small quantities in the muscle, and blood of the marine fish which diffuses out through the membrane. This compound has a foul smell and is probably derived from the breakdown products of lipoproteins. Considerable amounts of trimethylamine oxides are formed in octopus, squids, crabs and barnacles. It is found in the urine of certain animals like echinoderm, oysters, gastropods and tunicates.

4.0 CONCLUSION

In this unit, you have learnt that excretion is vital to maintenance of steady internal environment. Excretion in plants is different from that of the animals because of differences in physiology and mode of life. Nitrogen is never and cannot be excreted as free nitrogen, rather as break down of nitrogenous compounds. Ammonotelic animals excrete nitrogenous compounds as ammonia. Those that excrete them as urea are called ureotelic animals. Uricotelic animals excrete them as uric acid.

5.0 SUMMARY

Excretion is vital to maintenance of steady internal environment, if waste products are allowed to stay in the body; they could be harmful to the tissues of the body.

Plants show differences in their excretion in comparison with that of animals because of the differences in physiology and mode of life.
In animals, nitrogen cannot be excreted as free nitrogen; rather it has to be metabolised as break down of nitrogenous compounds.
Ammonia is the first metabolic waste product of protein metabolism. It is the most toxic form, it requires large amount of water for its elimination. It is most suitable for aquatic organisms which have a constant access to water.

Terrestrial animals such as insects, lizards, snakes and birds are uricotelic. Uric acid production in these animals is related to the problem of water conservation.

6.0 TUTOR-MARKED ASSIGNMENT

1. Why is excretion indispensable in animals?
2. Enumerate the important excretory products in animals.
3. Account for the differences in excretion in plants and that of animals.
4. Describe the patterns of excretion in animals.

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UNIT 2 EXCRETION IN INVERTEBRATES

CONTENTS

1.0 INTRODUCTION

The tissues or organs responsible for the elimination of the waste products are called **excretory organs**. These organs are involved in the removal of waste products of metabolism, such as the breakdown products of nitrogen metabolism and the removal of exogenous substances. Excretory organs also participate in the osmoregulatory mechanism; ensuring equilibrium between the gains and loss of substances. If a particular substance is in excess in body fluids, its excretion is increased through the excretory organs and vice versa. In this unit, the physiology of the different excretory organs in invertebrate animals will be our focus.

2.0 OBJECTIVES

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

- define the term excretory organ
- explain why contractile vacuole is not considered as an excretory organ
- describe how the Malpighian tubules perform excretory functions in insects.

3.0 MAIN CONTENT

3.1 Excretion in Lower Animals

3.1.1 Protozoans

These are the most primitive invertebrate animals. Although they do not have specialised excretory organs, the waste are discharged through cellular membrane. Several mechanisms like osmosis, diffusion, etc. are responsible for waste elimination through the membrane. However, in a number of species, contractile vacuole serves as excretory organelles. The contractile vacuole is most suitable for the protozoans because they are present in freshwater environment where there is a constant osmotic gain of water. They are less present in marine species. Contractile vacuoles are spherical shaped organelles which water enters. The vacuole then fuses with the membrane of the protozoan and the water is expelled to the environment. The rate of water extrusion is related to the external osmotic concentration of the environment, and, therefore, the water influx. As the osmotic concentration of the external fluid surrounding the protozoan decreases (i.e. becomes more dilute), the rate of water entering the protozoan and, therefore, the amount of water that needs to be expelled increases.

3.1.2 Ceolenterates

Colenterates also do not possess specialised excretory organs and processes like diffusion osmosis and active transport to regulate the fluids in the body. The need for organs of excretion is greatly restricted. However, contractile vacuoles, or structures serving similar functions, are also found in coelenterates but much less is known about the physiology of these structures compared to the contractile vacuoles in protozoans.

3.1.3 Platyheliminthes

Animals that belong to the group possess characteristic specialised excretory structure known as flame cell system. The flame cell is a large cell blinded at one end and bearing many cytoplasmic processes. There are series of such cells which open in an excretory duct. The nucleus is displaced generally towards the blind end side and the cytoplasm bears many secretory droplets. A bunch of cilia arises in the hollowed out cytoplasmic region which keeps on moving to produce a directed flow of fluids. The excretory products enter the flame cells in a fluid state from the parenchymatous cell by diffusion. Excess of water along with metabolic waste are thus discharged by the flame cells. True excretory organs are found in all animals above the levels of coelenterates. The simplest of these excretory organs are found in platyhelminthes and are called **protonephridia.** Protonephridia are excretory structure which exist as closed or blind-ended, tubules and which do not connect with the coelomic cavity. The cell which forms the tips of the blind-ended tube is ciliated. If it contains a single cilia it is called a **solenocyte.** In Platyhelminthes, where the cell which froms the tips of the blind-ended tube is made up of several cilia, the protonephridia is known as a **flame cell**.

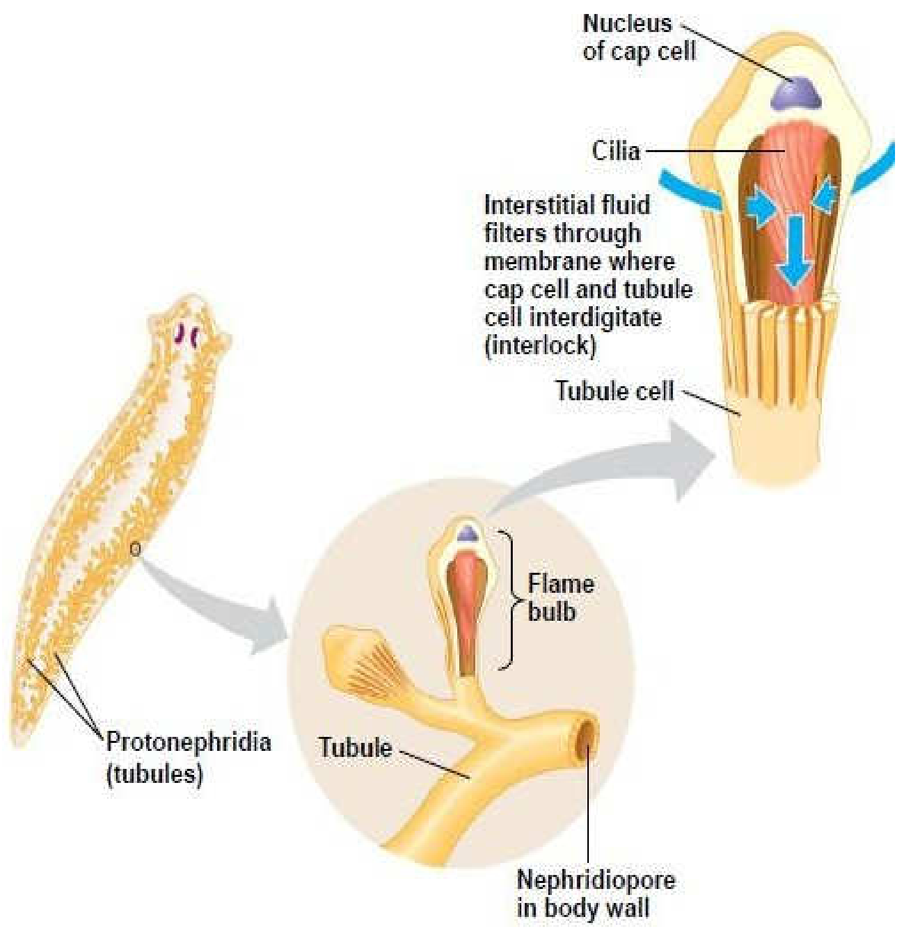

Fig. 1: The Arrangement of Protonephridia in Platyhelminthes
Source: Rastogi, S.C. (2007)

3.1.4 Annelida

The excretory organs are in the form of tubular and coiled structures called **nephridia or metanephridia**. These are excretory organs with ciliated opening to the coelom called the **nephridiostome** and which end in pores which open to the external environment, called **nephridiophores**. Blood is filtered across the membranes of capillaries and the fluid produced enters the coelomic space. This is a good example of ultrafiltration, since only water and molecules of small molecular weight enter the coelomic fluid, whilst larger molecules, such as proteins, remain in the vascular system. The fluid in the coelom then enters the metanephridia through the nephridiostome. The initial urine which is formed passes along the metanephridia where its composition is altered by the processes of reabsorption and secretion. The result is the production of urine which is hypoosmotic (i.e. less concentrated) to the body fluids from which it was formed. These metanephridia eventually eliminate urine rich in urea and ammonia.

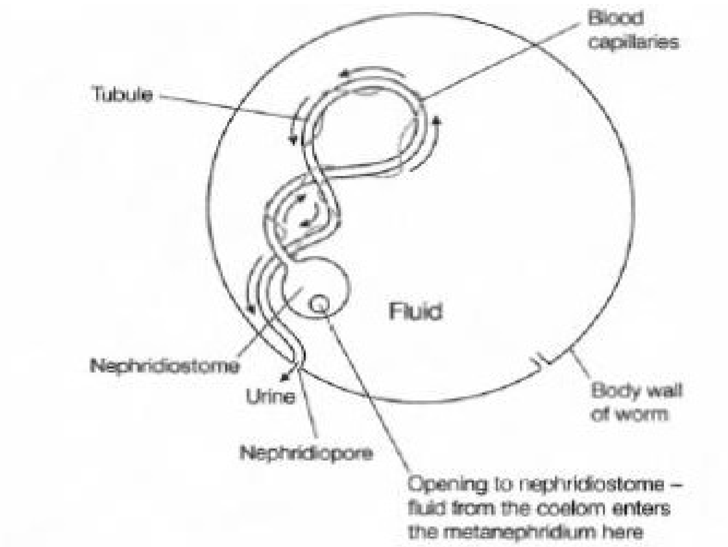

Fig. 2: The Arrangement of Metanephridia in Annelids
Source: Rastogi, S.C. (2007)

3.1.5 Mollusca

In molluscs, the excretory organs are in the form of kidneys and pericardial glands. The kidneys are mesodermal organs which communicate with the coelom, whereas the epithelial lining of the pericardium containing glandular tissues serve as pericardial gland. In cephalopods, the nitrogenous wastes are eliminated in the form of guanine, while uric acid and urea in opisthobranchs and bivalves respectively.

3.1.6 Arthropoda

The excretory organs in arthropods are of several types and include nephridia, coxal gland, green gland, shell gland and Malpighian tubules.

Of all these organs, the Malpighian tubules have proved to the most efficient organs of excretion in terrestrial arthropods. **Malpighian tubules** are the excretory organs of the insects. The precise number of these structures present in an insect will vary from just a few to many hundreds. Malpighian tubules have a closed end which lies in the fluid-filled cavity known as the **haemocoel**, and an open end which opens into the gut between the midgut and the rectum. Because insects have an open circulatory system that operates at low pressure, there is no driving force for the ultrafiltration of body fluids. In this sense, the Malpighian tubule operates a little differently to all other excretory organs. In order to form urine, potassium ion is actively transported from the haemocoel into the lumen of the Malpighian tubules. As a result of this, chloride ions follow, via diffusion and, ultimately, water due to osmotic potential differences. Other substances enter the tubule, including sodium ions, urates and nutrients, such as amino acids. The urine then flows down the tubule and enters the midgut. It is possible that there is some modification of the composition of the urine as it passes down the tubule, but the vast majority of alteration occurs in the rectum prior to its discharge to the environment. In the rectum, both the nature and composition of the urine changes markedly. The concentrations of ions, such as K+, are drastically reduced **-** in some cases by as much as 75%. More importantly, there is a tremendous amount of water reabsorption and the urates precipitate out as uric acid

However, in crustaceans such as crabs and lobsters the excretory organs are the **green**, **or antennal glands** which is located in the head region. The green gland consists of a blind-ending sac called the end sac connected to a tubule, the **nephridial canal**, which terminates in a region called the bladder. The bladder exits to the external environment via an excretory p ore which is situated near to the base of the antenna. The end sac is surrounded by coelomic fluid which is filtered to produce the initial urine which lies within the gland.

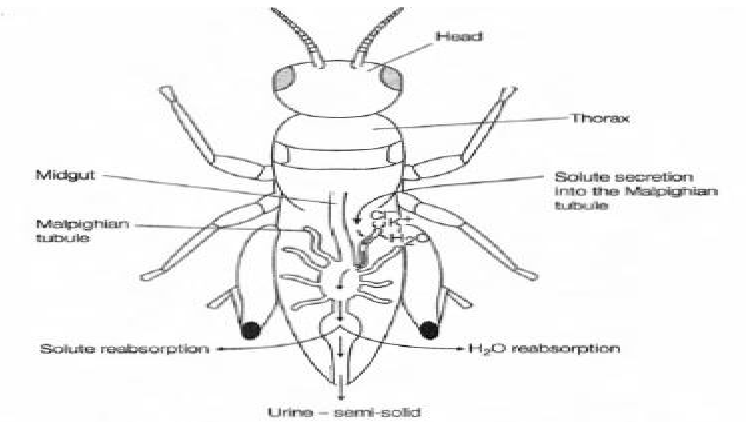

Fig. 3: The Arrangement of Malpighian Tubules in a Typical Insect
Source: Rastogi, S.C. (2007)

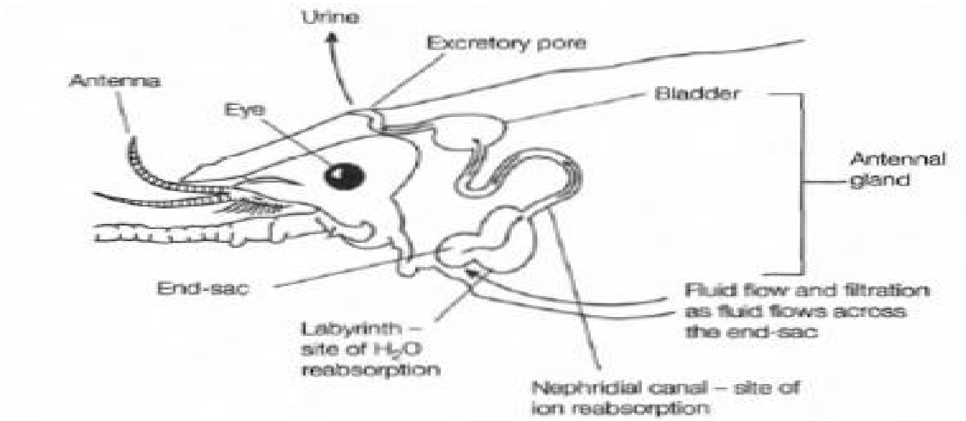

Fig. 4: The Arrangement of Green Gland (Antennal Gland) in Crustacean

Source: Rastogi, S.C. (2007)

As with all excretory structures, the composition of the urine at this stage is similar to that of the body fluid (hemolymph) from which it was formed, with the exception that it contains no substances of high molecular weight, such asproteins. As this fluid passes along the nephridial canal, water and other solutes are reabsorbed. Unlike the bladder in mammals, for example, the bladder associated with the antennal gland is also capable of reabsorbing substances.

Table 1 Different Excretory Organs in Lower Animals

No.	Animals	Excretory organ	Examples
1.	Protozoans	Plasmalemma	Amoeba
2.	Porifera	General body surface	Sycon
3.	Coelenterates	General body surface	Hydra
	In the above three, contractile vacuole is also there which is not really an excretory organ. It is specially for water balance & helps to get rid of extra water that diffuse into the cell.		
4.	Platyhelminthes	Flame cells (Solenocytes) Protonephridium	Taenia, Planaria Larva of platyhelminth miracidium, redia larva,
6.	Aschelminthes	Renette cell (excretory cell)	Ascaris
7.	Annelida	Nephridia Chloragogen cells	Earthworm Earthworm megascolex
8.	Arthropoda	Malpighian tubules, uricose gland, Urate cells Coxal gland Green gland	Cockroach Spider, Scorpion (arachnida) Prawn (crustacea)
	Special glands called rectal glands reabsorb water and ions and urine which are mixed with faeces. This is an adaptation of dry habitat.		
9.	Echinoderm	Tubefeet (podia) & dermal branchea (thin walls of gills)	Starfish
10.	Protochordates	Solenocytes Neural gland Glomerulus	Amphioxus Herdmania Balanoglossus

Source: Rastogi, S.C. (2007)

4.0 CONCLUSION

In this unit, you have learnt about the process of excretion in invertebrates, the different excretory organs and their physiology. Protozoans because they are present in freshwater environment where there is a constant osmotic gain of water make use of contractile vacuoles as the most suitable excretory structure. Colenterates do not possess specialised excretory organs. Platyhelminthes have flamecell, annelids possess metanephridia while arthropods possess Malpighian tubule, coxal gland and green glands as their excretory organs.

5.0 SUMMARY

Excretory organs are the tissues or organs responsible for the elimination of the waste products in animals. The contractile vacuole is most suitable for the protozoans because they are present in freshwater environment where there is a constant osmotic gain of water. True excretory organs are found in all animals above the levels of coelenterates. The simplest of these excretory organs are found in platyhelminthes and are called protonephridia. Crustaceans such as crabs and lobsters posses green or antennal glands as the excretory organs which is located in the head region.

6.0 TUTOR-MARKED ASSIGNMENT

1. Define the term excretory organ.
2. Explain why contractile vacuole is not considered as an excretory organ.
3. Describe how the Malpighian tubules perform excretory functions in insects.

7.0 REFERENCES/FURTHER READING

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UNIT 3 THE VERTEBRATE KIDNEY

CONTENTS

1.0 INTRODUCTION

The kidney is the vertebrate excretory organ evolved for adaptation on land. It performs the function of excretion and osmoregulation. Kidneys function in a significant manner in the maintenance of internal environment of the body. The mammalian kidney is usually considered a typical example of the structure and function of a typical vertebrate kidney.

2.0 OBJECTIVES

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

- explain the term nephrogenesis
- draw and label the mammalian kidney
- highlight the parts of the mammalian kidney
- enumerate the functions of the kidney.

3.0 MAIN CONTENT

3.1 Development of Kidney

The process by which the kidney develops is described as nephrogenesis. The mammalian kidney develops from intermediate mesoderm. Kidney development proceeds through a series of three successive phases, each marked by the development of a more advanced pair of kidneys: the pronephros, mesonephros, and metanephros.

Pronephros

During approximately 22 days of gestation period in humans, the paired pronephroi appear towards the cranial end of the intermediate mesoderm. In this region, epithelial cells arrange themselves in a series of tubules called nephrostomes and join laterally with the pronephric duct, which does not reach the outside of the embryo. Thus, the pronephros is considered nonfunctional in mammals because it cannot excrete waste from the embryo.

Mesonephros

Each pronephric duct grows towards the tail of the embryo, and in doing so induces intermediate mesoderm in the thoracolumbar area to become epithelial tubules called **mesonephric tubules**. Each mesonephric tubule receives a blood supply from a branch of the aorta, ending in a capillary tuft analogous to the glomerulus of the definitive nephron. The mesonephric tubule forms a capsule around the capillary tuft, for the filtration of blood. This filtrate flows through the mesonephric tubule and is poured into the continuation of the pronephric duct, now called the **mesonephric duct** or **Wolffian duct**. The nephrotomes of the pronephros degenerate while the mesonephric duct extends towards the most caudal end of the embryo, ultimately attaching to the cloaca. The mammalian mesonephros is similar to the kidneys of aquatic amphibians and fishes.

Metanephros

During the fifth week of gestation, the mesonephric duct develops an outpouching known as **ureteric bud**, near its attachment to the cloaca. This bud, also called the **metanephrogenic diverticulum**, grows posteriorly and towards the head of the embryo. The elongated stalk of the ureteric bud, the **metanephric duct**, later forms the ureter. As the cranial end of the bud extends into the intermediate mesoderm, it undergoes a series of branchings to form the collecting duct system of the kidney. It also forms the major and minor **calyces** and the **renal pelvis**. The portion of the intermediate mesoderm in contact with the tips of the branching ureteric bud is known as the **metanephrogenic blastema**. Signals released from the ureteric bud induce the differentiation of the metanephrogenic blastema into the **renal tubules**. As the renal tubules grow, they come into contact and join with connecting tubules of the collecting duct system, forming a continuous passage for flow from the renal tubule to the collecting duct. Simultaneously, precursors of vascular endothelial cells begin to take their position at the tips of the renal tubules. These cells differentiate into the cells of the definitive glomerulus.

3.2 Parts of Mammalian Excretory System

Kidneys

These are paired structures present in the abdominal cavity, protected by the last two pairs of ribs (floating ribs). In humans, the kidneys are metanephric, mesodermal in origin, developed from the nephrostome of early embryo. These are dark red, bean shaped with a concavity on the inner side known as **hilus**, from where the blood vessels, lymphatic vessels and nerves enter or leave the kidneys. The right kidney is slightly lower than the left kidney to accommodate the liver. Each kidney is covered by a thin fibrous capsule of connective tissue, known as **renal capsule**. Around this capsule, there is another layer of fat, the **adipose capsule**, which is again surrounded by an outer layer of fibrous connective tissue, the **renal fascia**. All these layers protect the kidneys from infections and injuries.

Internally, the kidney is divided into two parts - outer dark **cortex** and inner light **medulla**. The cortex contains Malpighian body, proximal convoluted tubule, distal convoluted tubule and a relatively small part of loop of Henle. The medulla is divided into a number of conical regions called as **renal pyramids** or **medullary pyramids**, which are composed of **nephrons** and blood vessels. Each renal pyramid terminates into a pointed structure, the **renal papillae** towards the pelvis side. In between the two renal pyramids, the cortex invaginates into the medulla forming the **renal columns of Bertini**. The renal pyramids are connected with the **minor calyces**, which join together to form **major calyces**. Normally, there are 7-13 minor calyces and four major calyces in a human kidney. The major calyces open in the **renal pelvis**, which is connected with the **ureter**, present outside the kidney.

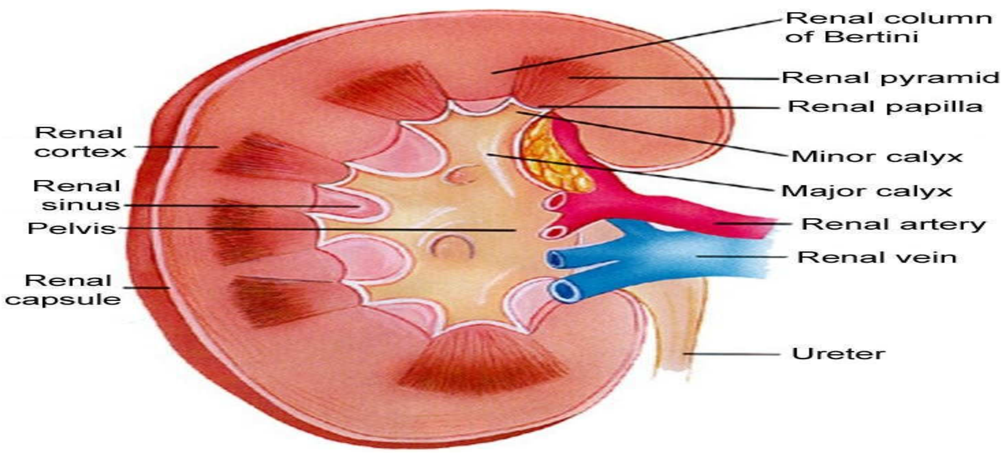

Fig. 1. The Mammalian Kidney
Source: Rankin and Davenport (1981)

Ureters

These are thick, muscular, narrow tubes leaving the kidney from the renal pelvis, run behind through the hilus and opens in the urinary bladder. Each ureter is about 25-30cm long and carries urine from the kidneys to the urinary bladder through peristalsis.

Urinary Bladder

Ureters open in the urinary bladder, which is a muscular sac lying in the pelvic cavity. Urinary bladder stores the urine temporarily and opens into the urethra whose opening is guarded by two pairs of circular sphincters - **internal sphincter**, made up of smooth muscles and **external sphincter**, made up of skeletal muscles. The internal sphincter is under involuntary control and the external sphincter is under voluntary control of the nervous system.

Urethra

It is a muscular tube, which extends from the neck of urinary bladder and leads to the external opening of the urinary tract. In males, urethra is long (20 cm approx.) and opens at the tip of penis by **urinogenital aperture** and carries both semen and urine. The urethra of females is short (4 cm approx.) and opens by urethral opening, in front of the vaginal aperture. It carries only urine.

3.3 Functions of Kidney

Excretory function Excretion of waste products

The kidneys excrete a variety of waste products produced by metabolism, including the nitrogenous wastes: urea (from protein catabolism) and uric acid (from nucleic acid metabolism).

Homeostatic function Acid-base balance

The kidneys regulate the pH, by eliminating H ions concentration called augmentation mineral ion concentration, and water composition of the blood. By exchanging hydronium ions and hydroxyl ions, the blood plasma is maintained by the kidney at a neutral pH 7.4. Urine, on the other hand, is acidic at pH 5 or alkaline at pH 8. The pH is maintained through four main protein transporters: NHE3 (a sodium-hydrogen exchanger), V-type H-ATPase (an isoform of the hydrogen ATPase), NBC1 (a sodium-bicarbonate cotransporter) and AE1 (an anion exchanger which exchanges chloride for bicarbonate).

Blood pressure

Sodium ions are controlled in a homeostatic process involving aldosterone which increases sodium ion absorption in the distal convoluted tubules. When blood pressure becomes low, a proteolytic enzyme called Renin is secreted by cells of the juxtaglomerular apparatus (part of the distal convoluted tubule) which are sensitive to pressure. Renin acts on a blood protein, angiotensinogen, converting it to angiotensin I (10 amino acids). Angiotensin I is then converted by the Angiotensin-converting enzyme (ACE) in the lung capillaries to Angiotensin II (8 amino acids), which stimulates the secretion of Aldosterone by the adrenal cortex, which then affects the kidney tubules. Aldosterone stimulates an increase in the reabsorption of sodium ions from the kidney tubules which causes an increase in the volume of water that is reabsorbed from the tubule. This increase in water reabsorption increases the volume of blood which ultimately raises the blood pressure.

Plasma volume

Any rise or drop in blood osmotic pressure due to a lack or excess of water is detected by the hypothalamus, which notifies the pituitary gland via negative feedback. A lack of water causes the posterior pituitary gland to secrete antidiuretic hormone, which results in water reabsorption and an increase in urine concentration. Tissue fluid concentration thus returns to a mean of 98%.

Secretory function Hormone secretion

The kidneys secrete a variety of hormones, including erythropoietin, urodilatin and vitamin D. When an individual is bled or becomes hypoxic, haemoglobin synthesis is enhanced, and production and release of RBCs from the bone marrow (erythropoesis) are increased, brought about by increased level of erythropoetin. In adults, about 85% of erythropoetin comes from kidneys and 15% from the liver. During foetal and neonatal life, the major site of erythropoetin production and erythropoesis is the liver but in a child, erythropoetin production is taken over by the kidney and erythropoesis is taken over by the bone marrow.

3.4 The Structure and Function of the Nephron

The **nephron** forms the basic structural and functional unit of the kidney. Primarily, the nephron is responsible for regulation of water and soluble substances by filtering the blood, reabsorbing what is needed and excreting the rest as urine. Each human kidney possesses about one million nephrons. Nephrons eliminate wastes from the body, regulate blood volume and pressure, control levels of electrolytes and metabolites, and regulate blood pH. Its functions are vital to life and are regulated by the endocrine system by hormones such as antidiuretic hormone, aldosterone, and parathyroid hormone. Each nephron is composed of an initial filtering component, the **renal corpuscle** and a tubule specialised for reabsorption and secretion, the **renal tubule**. The renal corpuscle filters out large solutes from the blood, delivering water and small solutes to the renal tubule for modification.

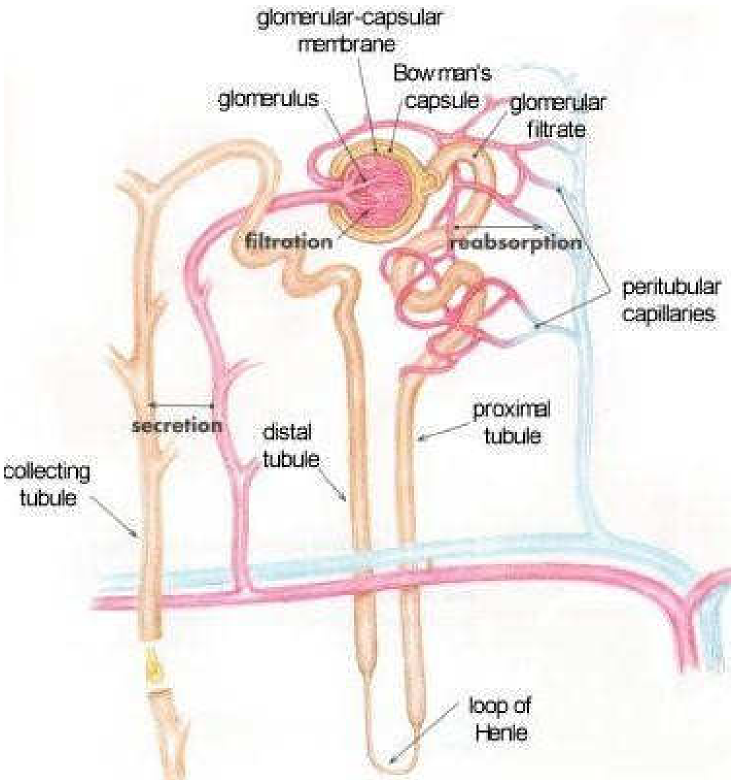

Fig. 2: The Structure the Nephron and Tubular Secretion
Source: Rankin and Davenport (1981)

A. Malphigian body

Composed of a glomerulus and Bowman's capsule, the renal corpuscle or the Malphigian body is the beginning of the nephron. It is the initial filtering component of a nephron.

- **Glomerulus**

The glomerulus is a capillary tuft that receives its blood supply from an **afferent arteriole** of the renal artery. The glomerular blood pressure provides the driving force for water and solutes to be filtered out of the blood and into the space made by Bowman's capsule. The remainder of the blood, basically the blood plasma, not filtered into the glomerulus passes into the narrower **efferent arteriole**. It then moves into the **vasa**

recta, which are collecting capillaries intertwined with the convolutedntubules through the interstitial space, and through which the reabsorbed substances also enter. This then combines with efferent venules from other nephrons into the renal vein, and rejoins the main bloodstream.

- **Bowman's Capsule**

It is also called the glomerular capsule; it surrounds the glomerulus and is composed of a visceral inner layer and a parietal outer layer, both formed by simple squamous epithelial cells. Fluids from blood in the glomerulus are collected in the Bowman's capsule (i.e., glomerular filtrate) and further processed along the nephron to form urine.

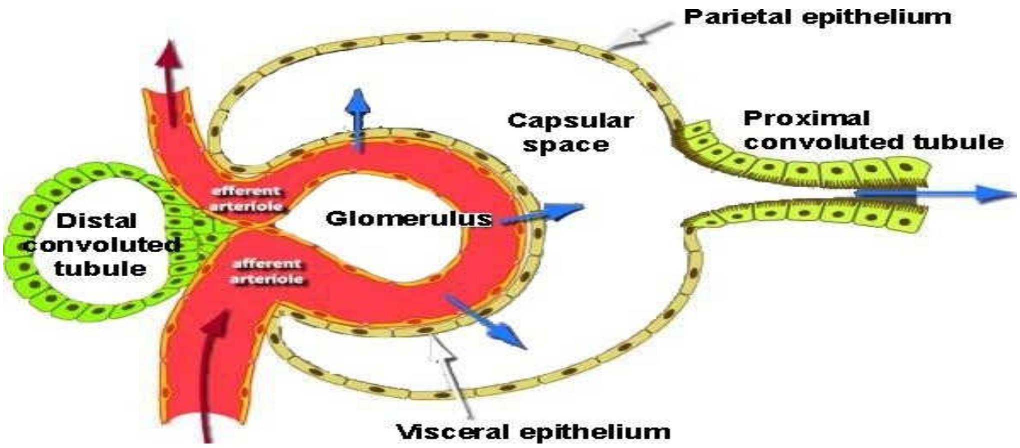

Fig. 3: The Bowman's Capsule
Source: Rankin and Davenport (1981)

B. Renal tubule

The flow of the renal tubule is as follows:

Proximal Convoluted Tubule (PCT)

The proximal convoluted tubule as a part of the nephron can be divided into an initial convoluted portion and a following straight, descending portion. Fluid in the filtrate entering the proximal convoluted tubule is reabsorbed into the peritubular capillaries, including approximately two-thirds of the filtered salt and water and all filtered organic solutes (primarily glucose and amino acids).

Loop of Henle

The loop of Henle (also known as the nephron loop) is a U-shaped tube that consists of a descending limb and ascending limb. It begins in the cortex, receiving filtrate from the proximal convoluted tubule, extends into the medulla, and then returns to the cortex to empty into the distal convoluted tubule. Its primary role is to concentrate the salt in the interstitium, the tissue surrounding the loop. It is divided into descending and ascending limbs:

Descending limb

Its descending limb is **permeable to water but completely impermeable to salt**, and thus only indirectly contributes to the concentration of the interstitium. As the filtrate descends deeper into the hypertonic interstitium of the renal medulla, water flows freely out of the descending limb by osmosis until the tonicity of the filtrate and interstitium equilibrate. Longer descending limbs allow more time for water to flow out of the filtrate; so longer limbs make the filtrate more hypertonic than shorter limbs.

Ascending limb

Unlike the descending limb, the ascending limb of Henle's loop is **impermeable to water**, a critical feature of the countercurrent exchange mechanism employed by the loop. The ascending limb actively pumps sodium out of the filtrate, generating the hypertonic interstitium that drives countercurrent exchange. In passing through the ascending limb, the filtrate grows hypotonic since it has lost much of its sodium content. This hypotonic filtrate is passed to the distal convoluted tubule in the renal cortex.

Distal convoluted tubule (DCT)

The distal convoluted tubule is not similar to the proximal convoluted tubule in structure and function. Cells lining the tubule have numerous mitochondria to produce enough energy (ATP) for active transport to take place. Much of the ion transport taking place in the distal convoluted tubule is regulated by the endocrine system. In the presence of parathyroid hormone, the distal convoluted tubule reabsorbs more calcium and excretes more phosphate. When aldosterone is present, more sodium is reabsorbed and more potassium excreted. Atrial natriuretic peptide causes the distal convoluted tubule to excrete more sodium. In addition, the tubule also secretes hydrogen and ammonium to regulate pH. After traveling the length of the distal convoluted tubule, only 3% of water remains, and the remaining salt content is negligible.

C. Collecting tubule

Each distal convoluted tubule delivers its filtrate to a system of collecting ducts, the first segment of which is the collecting tubule. The collecting duct system begins in the renal cortex and extends deep into the medulla. As the urine travels down the collecting duct system, it passes by the medullary interstitium which has a high sodium concentration as a result of the loop of Henle's countercurrent multiplier system.

Though the collecting duct is normally impermeable to water, it becomes permeable in the presence of antidiuretic hormone (ADH). As much as three-fourths of the water from urine can be reabsorbed as it leaves the collecting duct by osmosis. Thus, the levels of ADH determine whether urine will be concentrated or diluted. Dehydration results in an increase in ADH, while water sufficiency results in low ADH allowing for diluted urine.

Lower portions of the collecting duct are also permeable to urea, allowing some of it to enter the medulla of the kidney, thus maintaining its high ion concentration (which is very important for the nephron). Urine leaves the medullary collecting ducts through the renal papilla, emptying into the renal calyces, the renal pelvis, and finally into the bladder via the ureter. Because it has a different embryonic origin than the rest of the nephron, the collecting duct is sometimes not considered a part of the nephron.

The collecting tubules from the nephrons unite together to form a larger **collecting duct**, which unite to form still larger dicts called **ducts of Bellini**. The latter runs through the renal pyramids and opens in the renal pelvis.

D. Juxtaglomerular apparatus

The juxtaglomerular apparatus occurs near the site of contact between the thick ascending limb and the afferent arteriole. It contains three components:

1. **Macula densa.** A tightly packed area of cells, including the **renin granular cells**; the macula densa checks the chemical composition of fluid in the distal convoluted tubule.
2. **Juxtaglomerular cells.** These are specialised smooth muscle cells in the wall of the afferent arteriole and are the site of renin synthesis and secretion and thus play a critical role in the renin-angiotensin system.
3. **Extraglomerular mesangial cells.** These couple to arteriole and have no specific function.

4.0 CONCLUSION

In this unit, you have been introduced to the mammalian kidney vis-à-vis its development, structure and functions. The different parts of the kidney as well as the nephron were also covered. Kidneys function in a significant manner in the maintenance of internal environment of the body.

5.0 SUMMARY

The possession of kidneys among vertebrates especially mammals is a strategy for terrestrial adaptation and water conservation. Kidneys function in a significant manner in the maintenance of internal environment of the body. It performs a dual function of osmoregulation and excretion. The process of development of kidney is called nephrogenesis

6.0 TUTOR-MARKED ASSIGNMENT

1. Describe the phases of nephrogenesis in vertebrates.
2. Outline the major functions of the mammalian kidney.
3. Describe the structure of the mammalian kidney.

7.0 REFERENCES/FURTHER READING

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MODULE 3 TRANSPORT MECHANISMS

UNIT 1 TRANSPORT SYSTEM IN PLANTS

CONTENTS

1.0 INTRODUCTION

Plants need water, wilted leaves recover when water is conducted upward into the leaves. Leaves require water and carbon dioxide for photosynthesis to take place, the food produced in the leaves has to be transported to other parts of the plant such as the stem, the roots flowers and fruits. All these processes of transport in plants are carried out via conducting tissues. The movement of water and minerals within and out of the cells of plants via conducting tissue is termed transport system. Transport systems in plants and animals refer to the movement of materials from various parts of the organisms where they are produced or obtained to the parts where they are used, stored or removed from the body.

2.0 OBJECTIVES

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

- highlight the reason why plants and animals need transport system
- list and explain mechanism for movement of molecules such as diffusion, osmosis and active transport
- explain the structure and function of xylem and phloem in plants.

3.0 MAIN CONTENT

3.1 Need for Transport System in Plants and Animals

Transport system is necessary in plants and animals because every cell of the organism needs to obtain all the essential materials for its metabolism such as nutrients, oxygen, and water. It is also necessary to remove and dispose metabolic waste such as carbon dioxide, water and urea. In plants, transport is necessary to move mineral salts and water from the roots to the stems and leaves. Transport is also required to move hormones in plants and animals from where they are produced to the area of need. Glucose from the leaves and storage organs are some of the substance being regularly transported in plants.

3.2 Mechanisms for Movement of Molecules

Molecules move in and out of a cell through the cell membrane, which forms the boundary of each cell. The cell membrane is selectively permeable to substances, which means that it permits entry and exit of certain molecules only. The movement of molecules takes place by diffusion, osmosis, and active transport.

3.2.1 Diffusion

Molecules move out from their region of higher concentration to the region of lower concentration. For example, during respiration, oxygen-laden air in lungs being at a higher concentration moves into blood capillaries having lower concentration of oxygen in them. Such movement of particles or molecules from a region of their higher concentration to a region of their lower concentration is termed diffusion.

3.2.2 Osmosis

Osmosis is the movement of water molecules from a region having more water molecules to a region having less water molecules when separated by a semi-permeable membrane. Semi-permeable membrane means a membrane which allows some molecules (e.g. water molecules) to pass through it but not some other larger molecules. No energy is spent during diffusion or osmosis.

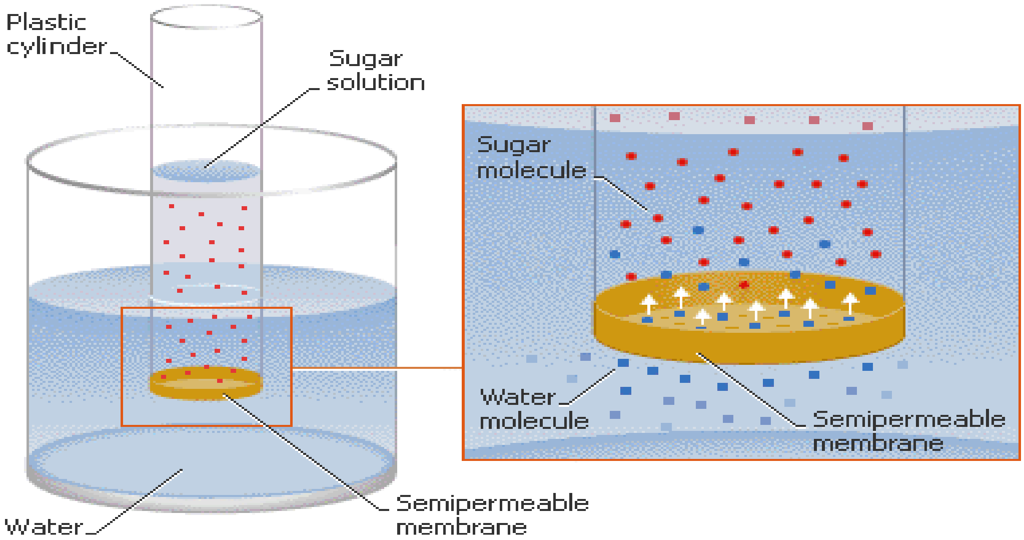


Fig. 1: The Process of Osmosis

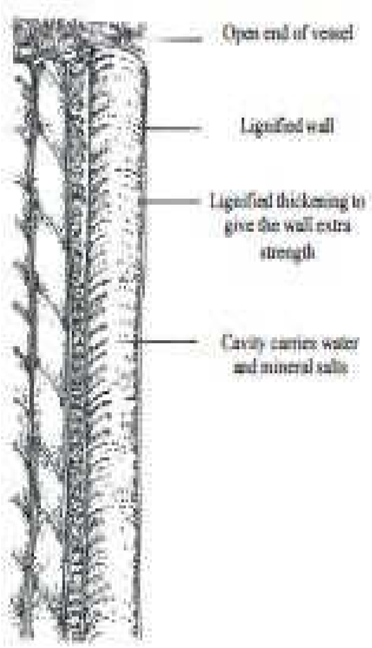
3.2.3 Active Transport

In active transport, molecules have to move (against concentration gradient) i.e., from a region of their lower concentration to a region of their higher concentration. Energy is required in active transport.

3.3 Transport of Materials in Plants

3.3.1 Transport of Water

Transport system in plants occurs in xylem and phloem called the vascular bundles. Roots of plants take up water and minerals from the soil. How does this water move up from roots to leaves for needs like photosynthesis? Once inside roots, these materials are transported upward to the stems, leaves, flowers, fruits and seeds. Tracheids and vessels (Fig. 2), which are non-living cells of xylem, transport water picked up by root hairs (Fig. 3) from soil to the leaves. The upward movement of water and minerals termed 'ascent of sap' is against gravity and is due to transpiration pull. Transpiration is the process in which a lot of water evaporates (as water vapour) from pores on the surface of leaf called **stomata** (Fig. 4). This evaporation creates a vacuum and pulls up waterthrough the xylem.



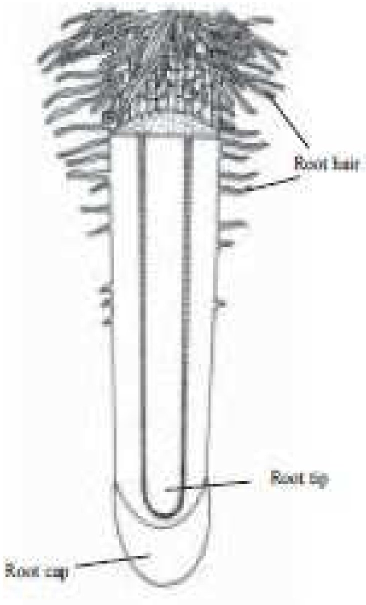


Fig. 2: Vessels in Xylem **Fig. 3: Root Hairs**

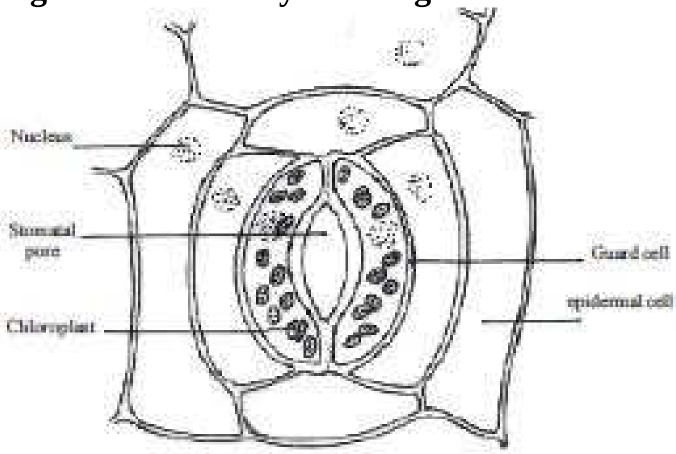


Fig. 4: Structure of Stomata

3.3.2 2 Transport of Food Material

Sugars and other food molecules synthesised in the leaves are transported to other parts of the plant through phloem. Sieve tubes are living cells of the phloem, which transport food (Fig. 5). Transport of food material from leaves to other parts of the plant is called translocation. This food may be stored in fruits, stem or roots.

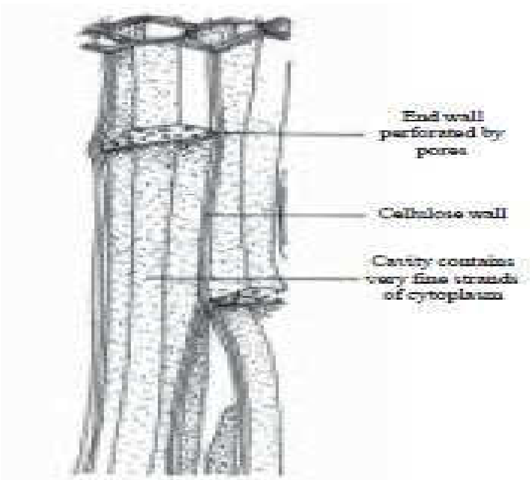


Fig. 5: Sieve Tubes in Phloem for Translocation

4.0 CONCLUSION

In this unit, you have been introduced to the mechanisms involved in transport of water and materials in plants. Sugar and other vital food substances produced during photosynthesis are conveyed from the leaf to their site of storage via the phloem through a process known as translocation in plants.

5.0 SUMMARY

In this unit, we learned that water and nutrients are essential for plant healthy life. Transport system in plants occurs in xylem and phloem called the vascular bundles. The upward movement of water and minerals termed 'ascent of sap' is against gravity and is due to transpiration pull.

6.0 TUTOR-MARKED ASSIGNMENT

1. Highlight the reasons plants and animals need transport system.
2. Describe the process of osmosis in plants.
3. Explain the structure and function of xylem and phloem in plants.

7.0 REFERENCE/FURTHER READING

Taylor, D.J. *et al.* (1999). *Biological Science.* (3rd ed.). Cambridge: Cambridge University Press.

UNIT 2 TRANSPORT SYSTEM IN ANIMALS

CONTENTS

1.0 INTRODUCTION

In unicellular organisms such as an *amoeba*, nutrients and respiratory gases enter the cell and waste materials leave the cell by diffusion and other cellular processes. Thus, these organisms are capable of exchanging matter directly with the outside environment. In multicellular organisms, the process of matter exchange is more complex. The trillions of specialised cells in a multicellular organism are organised into functional, structural units, such as tissues and organs. The individual cells that make up these structural units require nutrients and oxygen, and they must rid themselves of wastes, just as unicellular organisms do. Thus, an efficient system for transporting materials within the body is necessary. This system of transport in animals is described as the **circulatory system.** In this unit, you will learn how different groups of animals exchange nutrients, oxygen and waste between them and their environment.

2.0 OBJECTIVES

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

- highlight the main functions of the circulatory system
- itemise the major components of blood
- describe open and closed circulation in animals
- enumerate the primary functions of blood.

3.0 MAIN CONTENT

3.1 Main Functions of the Circulatory System

The circulatory system has the following 3 main functions:

1. It transports gases (from the respiratory system), nutrient molecules, and waste materials (from the digestive system).
2. It regulates internal temperature and transports chemical substances that are vital to health from one part of the body to the other.
3. It protects against blood loss from injury and against disease-causing microbes or toxic substances introduced into the body.

3.2 Major Components of the Circulatory System

The circulatory system has three major components: the heart, the blood vessels, and the blood. The **heart** is a muscular organ that continuously pumps the blood through the body and generates blood flow. The **blood vessels** are a system of hollow tubes through which the blood moves. Together, the heart and blood vessels comprise the *cardiovascular system* (*cardio* comes from a Greek word meaning “heart,” and *vascular* comes from a Latin word meaning “vessel”). **Blood** is the fluid that transports nutrients, oxygen, carbon dioxide, and many other materials throughout the body

3.3 Transport System in Lower Animals

Among the unicellular protists, oxygen and nutrients are obtained directly from the aqueous external environment by simple diffusion. The body wall is only two cell layers thick in cnidarians, such as *Hydra*, and flatworms, such as *Planaria*. Each cell layer is in direct contact with either the external environment or the gastrovascular cavity. The gastrovascular cavity of *Hydra* extends from the body cavity into the tentacles, and that of *Planaria* branches extensively to supply every cell with oxygen and nutrients.

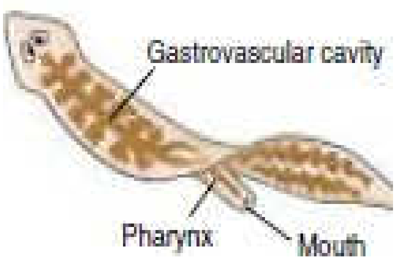


Fig. 1: Gastrointestinal Cavity in *Planaria*

3.4 Open and Closed Circulatory Systems

Larger animals, however, have tissues that are several cell layers thick, so that many cells are too far away from the body surface or digestive cavity to exchange materials directly with the environment. Instead, oxygen and nutrients are transported from the environment and digestive cavity to the body cells by an internal fluid within a *circulatory system.*

Open circulatory system

Many invertebrates have an open circulatory system. It is common in molluscs and arthropods. The system is called "open" because blood flows freely within the body cavity and makes direct contact with organs and tissues. In other words, there is no distinction between the blood and the interstitial fluid. Open circulatory systems, which evolved in crustaceans, insects, molluscs and other invertebrates, pump blood into a hemocoel (a blood-filled, open body cavity) with the blood diffusing back into the circulatory system between cells. Blood is pumped by the heart into the body cavities, where tissues are surrounded by the blood. In invertebrates, such as insects and molluscs, the mixture of blood and fluids that surrounds the cells is called *hemolymph*. In insects such as the grasshopper, hemolymph is pumped through a single vessel that runs from the head to the abdomen. In the abdomen, the vessel divides into chambers that function as the insect's heart. Tiny holes in the heart wall, known as ostia, allow hemolymph to enter the heart chambers from the body cavity. The hemolymph is pushed from one chamber to the next by muscle contractions. Nutrients and wastes are exchanged between the hemolymph and cells in the heart chambers before the hemolymph passes back into the transporting vessel to be eliminated from the insect's body.

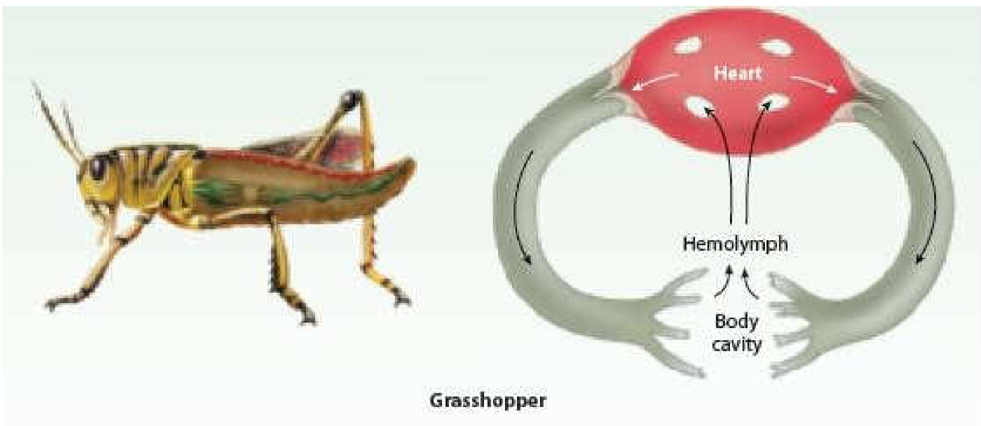


Fig. 2:Open Circulatory System in Grasshopper Closed circulatory system

In a closed circulatory system, the circulating fluid, or blood', is always enclosed within blood vessels that transport blood away from and back to a pump, the heart. Annelids and all vertebrates have a closed circulatory system. In annelids such as an earthworm, a dorsal vessel contracts rhythmically to function as a pump. Blood is pumped through five small connecting arteries which also function as pumps, to a ventral vessel, which transports the blood posteriorly until it eventually reenters the dorsal vessel. Smaller vessels branch from each artery to supply the tissues of the earthworm with oxygen and nutrients and to transport waste products.

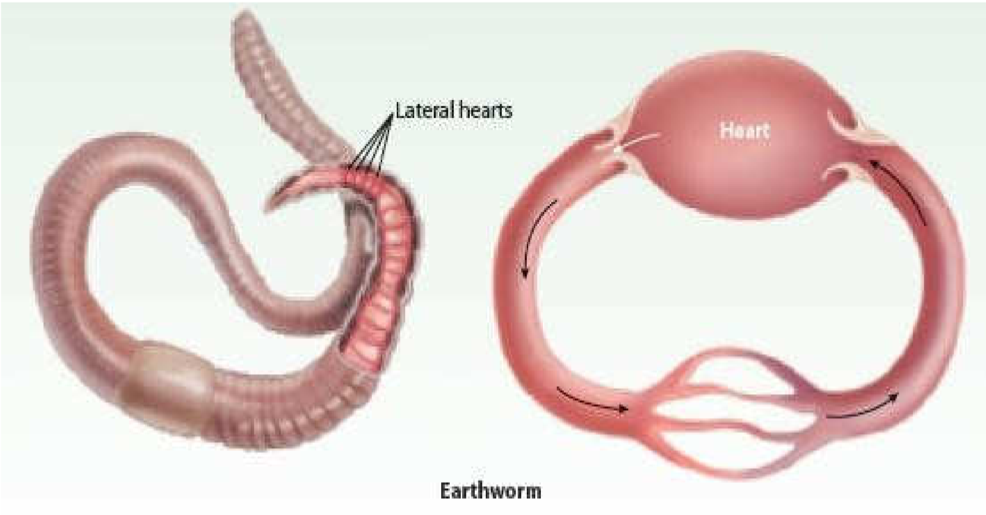


Fig. 3: Closed Circulatory System in Earthworm

3.5 The Composition of Blood

The vertebrate blood is a specialised connective tissue comprising of a fluid matrix, **plasma** and **formed elements**.

The **plasma** is the straw-coloured liquid part of blood. In mammals, plasma is about 90% of water and provides the solvent for dissolving and transporting nutrients. A group of proteins (albumins, fibrinogen, and globulins) comprise another 7% of the plasma. It is the concentration of these plasma proteins that influences the distribution of water between the blood and extracellular fluid. Because *albumin* represents about 60% of the total plasma proteins, it plays important roles with respect to water movement. *Fibrinogen* is necessary for blood coagulation (clotting), and the globulins transport lipids and fat-soluble vitamins. *Serum* is plasma from which the proteins involved in blood clotting have been removed. The *gamma globulin* portion functions in the immune response because it consists mostly of antibodies. The remaining 3% of plasma is composed of electrolytes, amino acids, glucose and other nutrients, various enzymes, hormones, metabolic wastes, and traces of many inorganic and organic molecules.

The **formed elements** fraction is the cellular component of the vertebrate blood. It consists of ***erythrocytes*** (red blood cells RBCs), ***leukocytes*** (White blood cells); WBCs), and platelets (thrombocytes). White blood cells are fewer in number than red blood cells, generally being 1-2% of the blood volume. White blood cells are divided into ***agranulocytes*** (without granules in the cytoplasm) and ***granulocytes*****.** There are two types of agranulocytes: *lymphocytes* and *monocytes*. The granulocytes have granules in the cytoplasm. There are three types of granulocytes; *eosinophils*, *basophils*, and *neutrophils*.

3.5.1 Red Blood Cells (RBCs)

Red blood cells, also called *erythrocytes*, make up approximately 44 percent of the total volume of blood. ("Erythrocyte" comes from two Greek words, *erythros* for red, and *kytos* for hollow). Red blood cells are specialised for oxygen transport. The oxygen carrying capacity of the blood is dependent on the number of erythrocytes that are present and the amount of hemoglobin that each red blood cell contains. A mature mammalian erythrocyte is a disk-shaped cell with no nucleus. Each cell is packed with about 280 million iron-containing molecules of the respiratory protein hemoglobin. Large quantities of oxygen can be transported in the blood because hemoglobin has special properties that allow it to pick up, or chemically bind with oxygen. Hemoglobin releases oxygen in the presence of cells that need it. Hemoglobin also transports some of the carbon dioxide waste from cells. After carbon dioxide diffuses into the blood, it enters the red blood cells, where a small amount binds to hemoglobin.

3.5.2 White Blood Cells (WBCs)

These serves as scavengers that destroy microorganisms at infection sites, remove foreign chemicals and remove debris that results from dead or injured cells. All WBCs are derived from immature cells (called stem cells) in bone marrow by a process called *hematopoiesis*. Granulocytes are made up of three types:

Eosinophils are phagocytic; they ingest foreign proteins and immune complexes rather than bacteria. In mammals, eosinophils also release chemical that counteract the effects of certain inflammatory chemicals released during allergic reactions.

Basophils are the least numerous white blood cells. When they react with a foreign substance, their granules release histamine and heparin. Histamine causes blood vessels to dilate and leak fluid at a site of inflammation, and heparin prevents blood clotting.

Neutrophils are the most numerous of the white blood cells. They are chemically attracted to sites of inflammation and are active phagocytes.

Agranulocytes are of two types; monocytes and lymphocytes. Lymphocytes exist in two forms B cells and T cells.
B cells originate in the bone marrow and colonise the lymphoid tissue, where they mature.
T cells are associated with and influenced by the thymus gland before they colonise lymphoid tissue and play their role in the immune response.

3.5.3 Platelets (thrombocytes)

Platelets are disc-like shaped cell fragments that function to initiate blood clotting. When a blood vessel is injured, platelets immediately move to the site and begin to clump together, attaching themselves to the damaged area, and begin the process of blood coagulation.

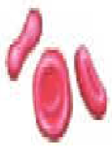
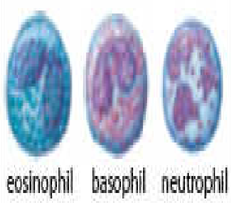
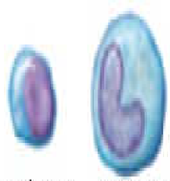
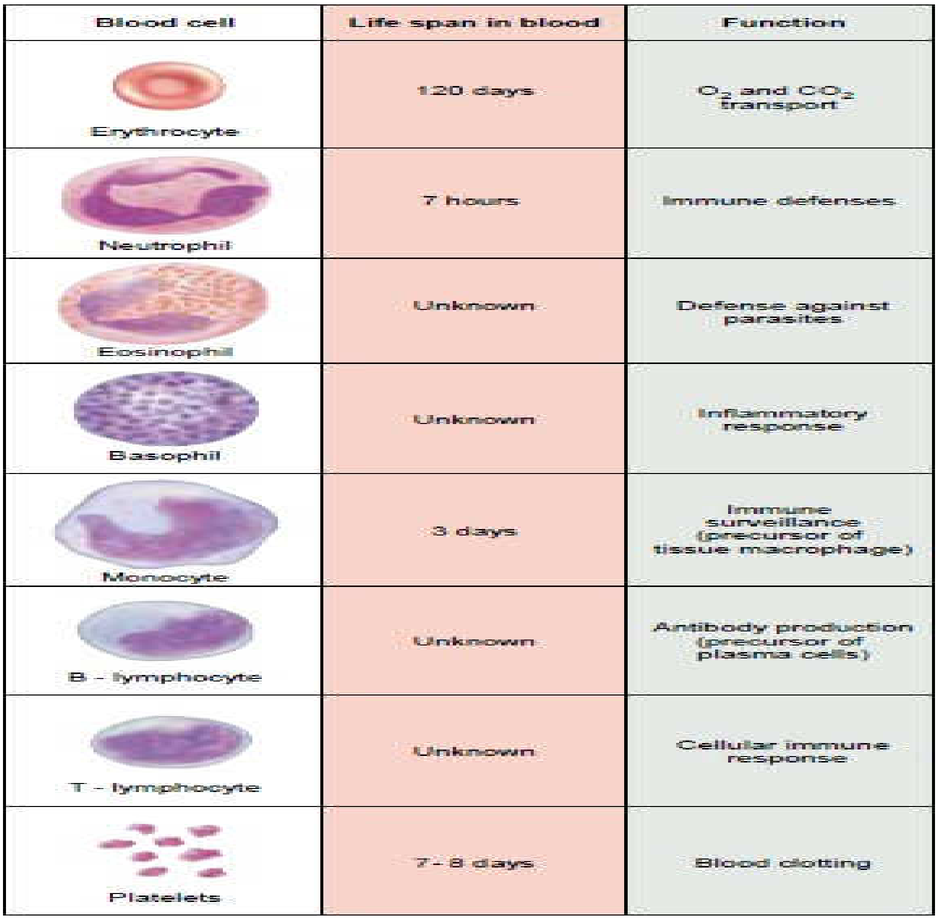
Point of Comparison	Red blood cells	White blood cells		Platelets
		Granulocytes	Agranulocytes	
Origin	red bone marrow	red bone marrow	thymus, red bone marrow	red bone marrow, lungs
Cells present per mm^3 of blood (approximate)	5 500 000 (male) 4 500 000 (female)	6000	2000	250 000
Relative size	small (8 μm diameter)	largest (up to 25 μm)	large (10 μm)	smallest (2 μm)
Function	to carry oxygen and carbon dioxide to and from cells	to engulf foreign particles	to play a role in the formation of antibodies (defence function)	to play a role in the clotting of blood (defence function)
Life span	120 days	a few hours to a few days	unknown	2–8 days
Appearance				

Fig. 4: The Constituents of Blood



Blood cell	Life span in blood	Function
Erythrocyte	120 days	O_2 and CO_2 transport
Neutrophil	7 hours	Immune defenses
Eosinophil	Unknown	Defense against parasites
Basophil	Unknown	Inflammatory response
Monocyte	3 days	Immune surveillance (precursor of tissue macrophage)
B - lymphocyte	Unknown	Antibody production (precursor of plasma cells)
T - lymphocyte	Unknown	Cellular immune response
Platelets	7- 8 days	Blood clotting

Fig. 5: The Functions of Blood Cells

3.6 The Functions of Blood

Respiration
Transportation of oxygen and carbon dioxide is the fundamental function of the blood. Transport of oxygen from the lungs to different tissues, and the transport of carbon dioxide from the tissues to lungs are mainly carried out by the blood.

Transport of food materials
Blood is the only medium by means of which the absorbed food materials are transported to various parts of the body

Excretion
Metabolic wastes such as urea, uric acid, creatine, water, carbon dioxide, etc., are transported by blood, to kidney, lungs, skin and intestine for removal.

Regulation of blood temperature

The blood has an important role in the regulation of body temperature by distributing heat throughout the body. This heat is generated in the muscles by the oxidation of carbohydrates and fats.

Maintenance of acid-base balance
The blood has buffering capacity and maintains normal acid-base balance in the body.

Regulation of water balance
Blood serves to maintain water balance in the body by exchanging water between the blood and the tissue fluid.

Defense
Blood affords protection to the body against infections and the antibodies.

Transport of hormones
Blood is the only medium which serves to distribute hormones to different parts of the body.

Clotting
Loss of blood from the body through injury is prevented by the action of thrombocytes of the blood.

Transport of metabolites
Blood is responsible for the supply of chemicals and essential metabolites.

4.0 CONCLUSION

In this unit, you have learnt about transport system in animals, the types of circulation in lower animals and vertebrates. You have also seen the main constituents of blood and their various functions.

5.0 SUMMARY

Lower animals such as amoeba maintain a close contact with their immediate environment; thus, diffusion is sufficient for the exchange of materials between them and their environment. Multicellular organisms require specialised organs for the transport of food and waste products. Arthropods and mollusks have open circulatory system, while vertebrates have closed circulation. Blood is a vital circulating fluid in animals with a variety of constituents. These constituents perform different functions in organisms.

6.0 TUTOR-MARKED ASSIGNMENT

1. Highlight the main functions of the circulatory system.
2. Itemise the major components of blood.
3. Describe open and closed circulation in animals.
4. Enumerate the primary functions of blood.

7.0 REFERENCES/FURTHER READING

Miller, S. A. & Harley, J. P. (1994). *Zoology*. England.

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UNIT 3 THE CARDIOVASCULAR SYSTEM

CONTENTS

1.0 INTRODUCTION

The cardiovascular system comprises of the heart, the blood vessels (arteries, arterioles, capillaries, venules and veins) and the blood. In vertebrates, the system of blood circulation is closed, through which the transport of oxygen and nutrients to tissues is carried out. Blood vessels form a tubular network that permits blood to flow from the heart to all the cells of the body and then back to the heart. *Arteries* carry blood away from the heart, whereas *veins* return blood to the heart. Blood passes from the arterial to the venous system in *capillaries*, which are the thinnest and most numerous of the blood vessels.

2.0 OBJECTIVES

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

- highlight and describe the types , and functions of blood vessels in vertebrates
- describe the structure of the heart and blood circulation in fish, amphibian and mammal
- explain the term cardiac cycle
- draw and label the structure of the mammalian heart.

3.0 MAIN CONTENT

3.1 Blood Vessels

3.1.1 Arteries

An **artery** is a blood vessel that sends blood from the heart to any part of the body. The heart pumps blood the through the main artery called the dorsal aorta. The main artery then divides and branches out into many smaller arteries so that each region of the body has its own system of arteries supplying it with fresh, oxygen-rich blood. Arteries are tough on the outside and smooth on the inside. An artery wall actually has three layers: an outer layer of tissue, a muscular middle layer, and an inner layer of epithelial cells. The muscle in the middle is elastic and very strong. The inner layer is very smooth so that the blood can flow easily with no obstacles in its path. The muscular wall of the artery helps the heart pump the blood. When the heart beats, the artery expands as it fills with blood. When the heart relaxes, the arteries contract and exert force that is strong enough to push the blood along through the body. This rhythm between the heart and the arteries results in an efficient circulation system.

3.1.2 Veins

Veins are similar to arteries but, because they transport blood at a lower pressure, they are not as strong as arteries. Like arteries, veins have three layers: an outer layer of tissue, muscle in the middle layer, and a smooth inner layer of epithelial cells. However, the layers are thinner, containing less tissue. Veins receive blood from the capillaries after an exchange of oxygen and carbon dioxide has taken place, and the veins transport deoxygenated blood back to the lungs and heart. It is important that the deoxygenated blood keeps moving in the proper direction and not be allowed to flow backward. This is occurrence is made possible by valves that are located inside the veins. The valves are like gates that only allow this particular type of blood to move in one direction.

3.1.3 Capillaries

Arteries branch through the body like the branches of a tree, becoming smaller in diameter as they grow farther away from the main vessel. The smallest branches are capillaries. Capillaries are microscopic blood vessels where the exchange of important substances and wastes occurs. Capillary walls are only one cell thick. This permits easy exchange of materials between the blood and body cells, through the process of diffusion. These tubes are so small that red blood cells move single-file through these vessels. The diameter of blood vessels changes in response to the needs of the body. For example, when you are exercising, muscle capillaries will expand, or dilate. This increases blood flow to working muscles, which brings more oxygen to cells and removes extra wastes from cells.

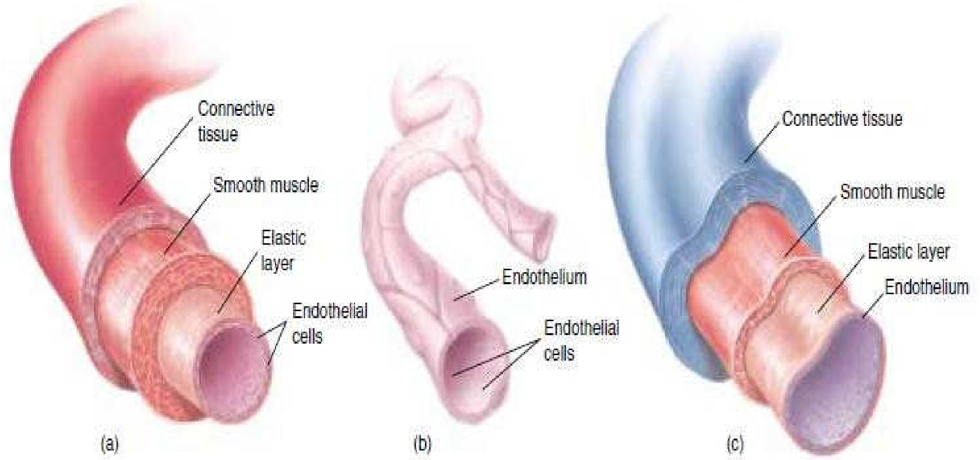

Fig. 1: The Structure of (a) Artery (b) Veins (c) Capillaries

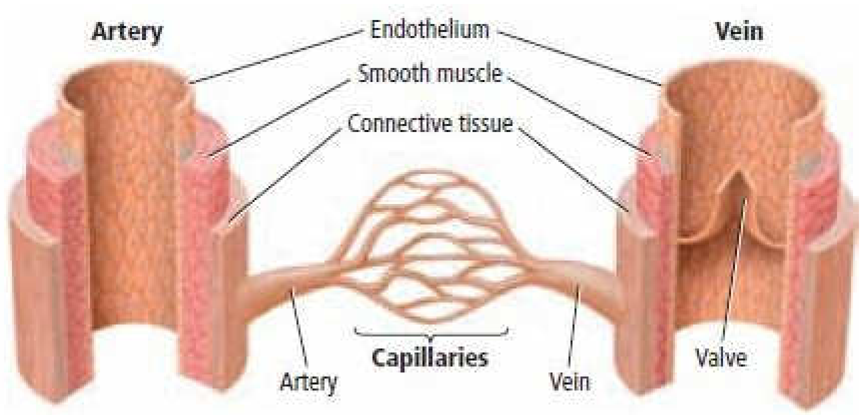

Fig. 2: Blood Circulation in the Body

3.2 The Vertebrate Hearts

3.2.1 The Fish Heart

The development of gills by fishes required a more efficient pump, and in fishes we see the evolution of a true chamber - pump heart. The fish heart is, in essence, a tube with four chambers arrayed one after the other. The first two chambers - the **sinus venosus** and **atrium** - are collection chambers, while the second two, the **ventricle** and **conus arteriosus,** are pumping chambers. As might be expected, the sequence of the heartbeat in fishes is a peristaltic sequence, starting at the rear and moving to the front, similar to the early chordate heart. The first of the four chambers to contract is the sinus venosus, followed by the atrium, the ventricle, and finally the conus arteriosus. In fish, the electrical impulse that produces the contraction is initiated in the sinus venosus; in other vertebrates, the electrical impulse is initiated by their equivalent of the sinus venosus.

The fish heart is remarkably well suited to the gill respiratory apparatus and represents one of the major evolutionary innovations in the vertebrates. Perhaps its greatest advantage is that the blood that moves through the gills is fully oxygenated when it moves into the tissues. After blood leaves the conus arteriosus, it moves through the gills, where it becomes oxygenated; from the gills, it flows through a network of arteries to the rest of the body; then it returns to the heart through the veins. This arrangement has one great limitation, however. In passing through the capillaries in the gills, the blood loses much of the pressure developed by the contraction of the heart, so the circulation from the gills through the rest of the body is sluggish. This feature limits the rate of oxygen delivery to the rest of the body.

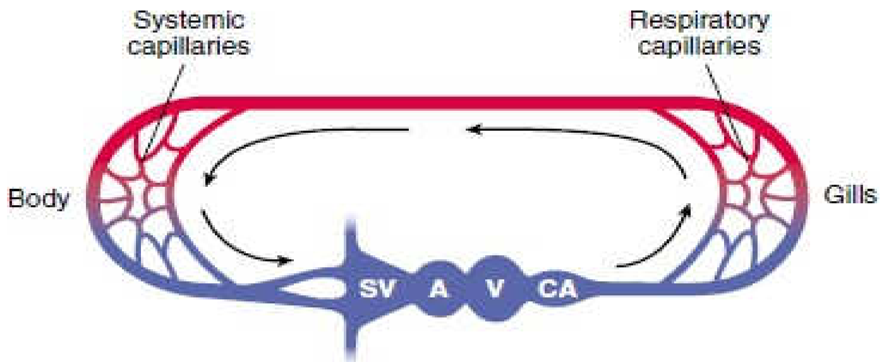

Fig. 3: Heart and Blood Circulation in Fish

3.2.2 Amphibian Heart

The development of lungs by amphibians necessitated a significant change in the pattern of circulation. After blood is pumped by the heart through the *pulmonary arteries* to the lungs, it does not go directly to the tissues of the body but is instead returned via the *pulmonary veins* to the heart. This brings about two circulations: one between heart and lungs, called the **pulmonary circulation,** and one between the heart and the rest of the body, called the **systemic circulation.** If no changes had occurred in the structure of the heart, the oxygenated blood from the lungs would be mixed in the heart with the deoxygenated blood returning from the rest of the body.

The amphibian heart has two structural features that help reduce this mixing. First, the atrium is divided into two chambers: the right atrium receives deoxygenated blood from the systemic circulation, and the left atrium receives oxygenated blood from the lungs. The conus arteriosus is partially separated by a dividing wall which directs deoxygenated blood into the pulmonary arteries to the lungs and oxygenated blood into the *aorta*, the major artery of the systemic circulation to the body. Because there is only one ventricle in an amphibian heart, the separation of the pulmonary and systemic circulations is incomplete.

Amphibians in water, however, can obtain additional oxygen by diffusion through their skin. This process, called **cutaneous respiration,** helps to supplement the oxygenation of the blood in these vertebrates.

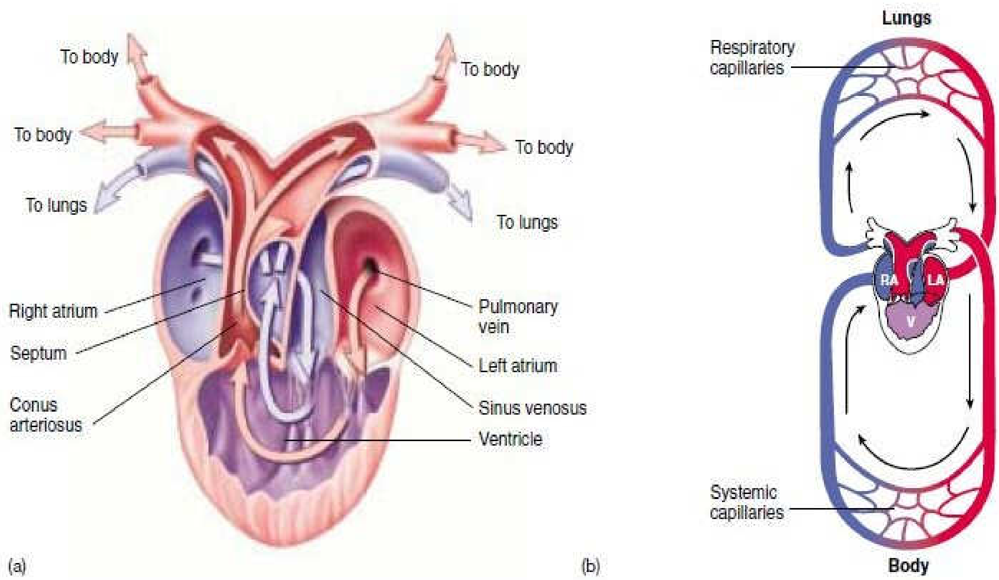

Fig. 4: Amphibian Heart and Blood Circulation

3.2.3 The Mammalian Heart

Mammalian heart is a four-chambered muscular organ pumping through the body via blood vessels. It is made up of two separate atria and two separate ventricles. The right atrium receives deoxygenated blood from the body and delivers it to the right ventricle, which pumps the blood to the lungs. The left atrium receives oxygenated blood from the lungs and delivers it to the left ventricle, which pumps the oxygenated blood to the rest of the body. This completely double circulation is powered by a two-cycle pump. Both atria fill with blood and simultaneously contract, emptying their blood into the ventricles. Both ventricles contract at the same time, pushing blood simultaneously into the pulmonary and systemic circulations.

The increased efficiency of the double circulatory system in mammals and birds is thought to have been important in the evolution of endothermy (warm-bloodedness), because a more efficient circulation is necessary to support the high metabolic rate required. Because the overall circulatory system is closed, the same volume of blood must move through the pulmonary circulation as through the much larger systemic circulation with each heartbeat. The left ventricle, which pumps blood through the higher-resistance systemic pathway, is more muscular and generates more pressure than does the right ventricle. Throughout the evolutionary history of the vertebrate heart, the sinus venosus has served as a pacemaker, the site where the impulses that initiate the heartbeat originate. The *sinoatrial (SA) node,* is still the site where each heartbeat originates.

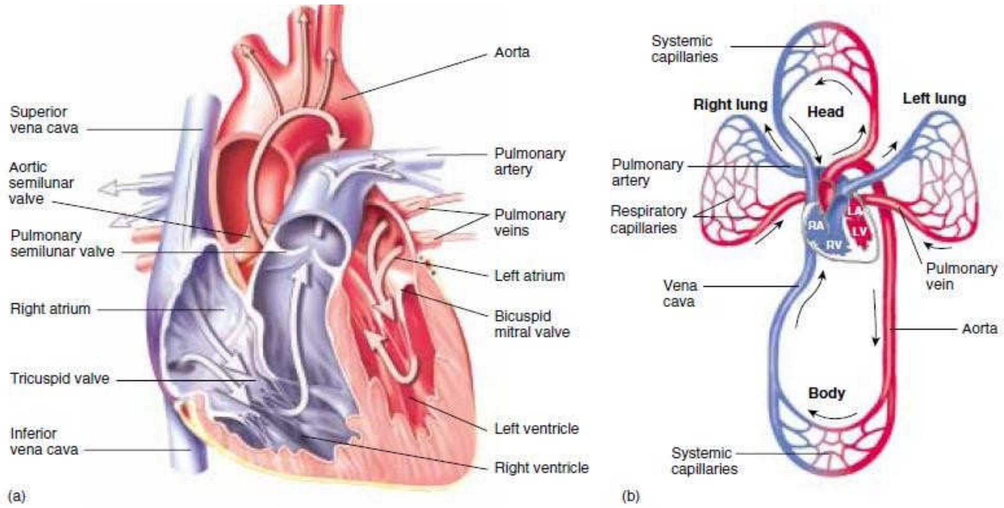

Fig. 5: Mammalian Heart and Blood Circulation

3.3 The Cardiac Cycle

The cardiac cycle is the sequence of events in one heartbeat. It is the simultaneous contraction of both atria, followed a fraction of a second later by the simultaneous contraction of both ventricles. The heart consists of cardiac muscle cells that connect with each other when one contracts the other relaxes. It gets its rest between beats. A heartbeat has two phases:

Phase 1
Systole is the term for contraction. This occurs when the ventricles contract, closing the A-V valves and opening the Semi-Lunar valves to pump blood into the two major vessels leaving the heart.

Phase 2
Diastole is the term for relaxation. This occurs when the ventricles relax, allowing the back pressure of the blood to close the semi-lunar valves and opening the A-V valves.

The cardiac muscles of the heart contracts repeatedly. The contraction spreads over the heart like a wave, beginning in a small region of specialised cells in the right atrium called the Sino-Atrial Node (SAN). This is the hearts natural pacemaker, and it initiates each beat. The impulse spreads from the SAN through the cardiac muscle of the right and left atrium, causing both atria to contract almost simultaneously. When the impulse reaches another special area of the heart, right in the centre of the septum, known as the Atrio- Ventricular (or AV) Node, the impulse is delayed for approximately 0.2 s. This allows time for the ventricles to fill completely. The AV Node relays the electrical impulse down the septum, along the Bundle of His, to the base of the ventricles. The ventricles then contract simultaneously, from the bottom upwards, thus allowing them to empty completely with each beat. The heartbeat is initiated by the Sino-Atrial Node and passes through the Atrio-Ventricular Node, remaining at the same rhythm until nerve impulses cause it to speed up or to slow down.

4.0 CONCLUSION

In this unit, you have learnt about the cardiovascular system, comprising of the heart, the blood vessels and the blood. You have also been introduced to the evolution of hearts as an adaptive strategy as animals move from water to land.

5.0 SUMMARY

The cardiovascular system comprises of the heart, the blood vessels (arteries, arterioles, capillaries, venules and veins) and the blood. Blood vessels form a tubular network that permits blood to flow from the heart to all the cells of the body and then back to the heart. *Arteries* carry blood away from the heart, whereas *veins* return blood to the heart. Blood passes from the arterial to the venous system in *capillaries*, which are the thinnest and most numerous of the blood vessels. The cardiac cycle is the sequence of events in one heartbeat. It is the simultaneous contraction of both atria, followed a fraction of a second later by the simultaneous contraction of both ventricles.

6.0 TUTOR-MARKED ASSIGNMENT

1. Highlight and describe the types and functions of blood vessels in vertebrates.
2. Describe the structure of the heart and blood circulation in fish, amphibian and mammal.
3. Explain the term cardiac cycle.
4. Draw and label the structure of the mammalian heart.

7.0 REFERENCES/FURTHER READING

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MODULE 4 COORDINATION IN ANIMALS

UNIT 1 NERVOUS COORDINATION IN ANIMALS

CONTENTS

1.0 INTRODUCTION

The behaviour of an animal in its environment to maintain itself depends on the coordination of its organs systems. Without coordination of various organ systems, various physiological processes would work in a haphazard way, without linking together activities. The linking together in time and space of various activities of an animal is called **coordination**. Coordination is brought about by the nervous system and sense organs, and by means of chemical substances (hormones) secreted by the endocrine glands.

During the course of evolution, nervous systems have become more complex. This is largely because animals have become larger and more mobile, requiring more neurons than a sedentary animal. The most fundamental function of a nervous system is (1) to receive a stimulus (2) transmission of a stimulus to a central "brain", (3) interpretation and analysis of the stimulus and (4) proper response by an effector. With the evolution of a complex nervous system and bilateral symmetry, cephalisation (formation of a head) has taken place, and the ganglia in the head became large enough to be called a brain, which is the main nervous control centre of the body.

2.0 OBJECTIVES

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

- describe the functions of the nervous system and list its subdivisions
- list, draw and label the major parts of the brain and spinal cord and explain their functions
- explain the structure of a neuron, a nerve and describe the conduction of
- impulse through a nerve fibre and across the synapse
- define reflex action and draw the components of the reflex arc
- list various sensory receptors in human body and describe the structure and functioning of the sense organs - eye, ear, nose, tongue and skin.

3.0 MAIN CONTENT

3.1 Major Divisions of Nervous System

There are two major divisions of nervous system:

Central Nervous System (CNS)
The CNS consists of brain and spinal cord. It is the site of information processing (receiving information and responding to it).

Peripheral Nervous System (PNS)
This consists of all the nerves entering and leaving the brain and the spinal cord.

The brain
The brain is a very delicate organ lodged inside the cranium of the skull. It is protected by three coverings, the meninges (meninx: membrane): an outer tough duramater (dura: tough; mater: mother), a thin delicate web-like middle arachnoid (arachne: spider), and the innermost highly vascular piamater (pia: tender) richly supplied with blood vessels. The space between the membranes is filled with a fluid called cerebrospinal fluid. There are cavities inside the brain, which are also filled with the same fluid.

The brain consists of three main regions:

(i) **forebrain** consisting of cerebrum and diencephalon
(ii) **midbrain** a small tubular part between the fore and the hindbrain
(iii) **hindbrain** consists of cerebellum, pons, and medulla oblongata.

The individual parts of the brain are described below:

(a) Cerebrum

This is the largest part of the brain, divided into two (the right and the left) parts called cerebral hemispheres. Their outer surface is highly convoluted with ridges and grooves. Each hemisphere is hollow internally and the walls have two (an inner and an outer) regions. The outer region (cerebral cortex) contains cell bodies of the nerve cells and being grayish in colour it is called *gray matter*. The inner region is composed of whitish axon fibres and is called the *white matte*r. Corpus callosum is a sheet of criss-cross nerve fibres connecting the two cerebral hemispheres. Left side of the cerebrum controls the right side of the body and vice-versa.

The **cerebral cortex** has three main functions:

(i) It controls and initiates voluntary muscle contractions.
(ii) It receives and processes information from the sense organs, like the eyes, ear, nose, etc.
(iii) It carries out mental activities of thinking, reasoning, planning, memorising, etc.

(b) Diencephalon

This is the part of the forebrain lying below the cerebrum. It consists of the following two parts:

1. Thalamus

This is an egg shaped mass of gray matter, located in the centre below the cerebrum. It is the relay centre for sensory impulses (e.g. pain and pleasure) going to the cerebrum.

2. Hypothalamus

This is a region of the brain located below thalamus. It controls motivated behavior such as eating, drinking and sex. It controls the secretions of pituitary gland hanging below it. It also serves as the regulation centre of body temperature and body fluids.

(c) Cerebellum

The cerebellum is a smaller region of the brain located at the base and under the cerebrum. It has numerous furrows instead of convolutions. It also has a cortex of gray matter. Its two main functions are:

- to maintain the balance of the body, and
- to coordinate muscular activities.

(d) Medulla oblongata

This is the last part of the brain, which is connected to the spinal cord. Its functions are as follows:

(i) It is the centre for breathing, coughing, swallowing, etc.
(ii) It controls heartbeat, the movement of alimentary canal and many other involuntary actions.

In all, **12 pairs of nerves** (cranial nerves) come out of the brain, some of these are sensory, some motor and some are of mixed type.

The spinal cord

The spinal cord extends from the medulla of the brain downward almost the whole length of the backbone. It is also wrapped in the same three meninges as the brain and the space between them contains the same cerebrospinal fluid. The arrangement of the white and gray matter is reversed in it i.e. white matter is outside and the gray matter inside.

Functions of the spinal cord

(i) Carries out reflexes below the neck.
(ii) Conducts sensory impulses from the skin and muscles to the brain.
(iii) Conducts motor responses from the brain to the trunk and limbs.

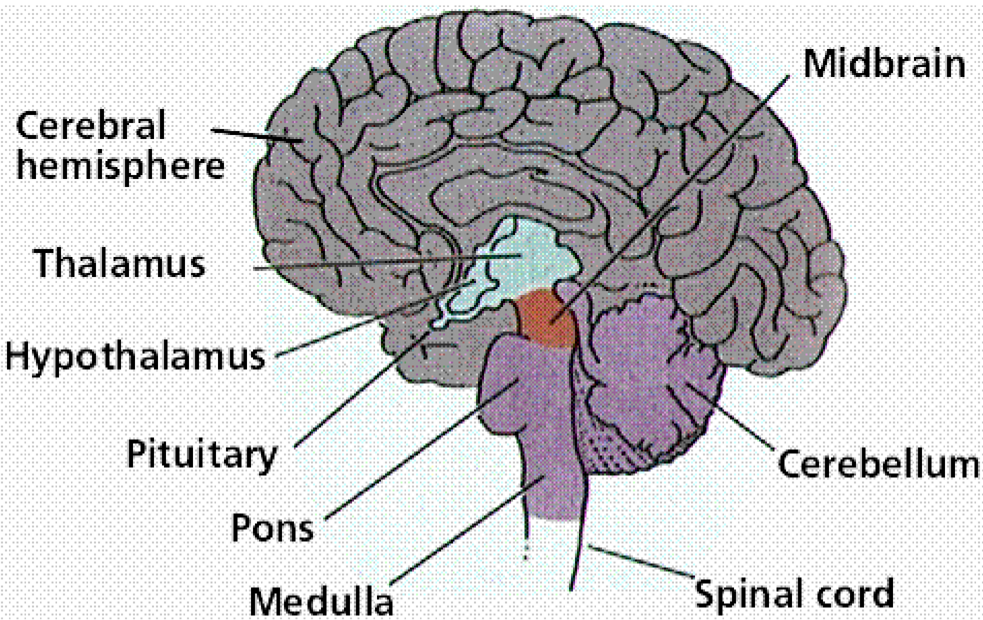

Fig. 1: Parts of the Brain as Seen from the Middle of the Brain

3.2 Peripheral Nervous System

The peripheral nervous system consists of all nerves arising from the brain and the spinal cord. Overall, it consists of two kinds of pathways: the afferent (receiving) sensory pathways and efferent (carrying away) motor pathways.

The **afferent (receiving/sensory) pathways** are included in two kinds of nerves:

(1) Purely sensory nerves, for example the cranial nerves received from the eyes, ears, nose, etc.
(2) Mixed cranial nerves like the fifth (facial nerve) which contains sensory fibres bringing sensations from the face but it also contains motor fibres which carry impulses away to the jaw muscles.

The **efferent (sending) pathway** may be subdivided into somatic and autonomic nervous systems.

The somatic nervous system controls the voluntary muscles. It includes most **cranial nerves** as well as the motor nerve fibres of the **spinal nerves**. Both these convey message from the CNS to the **voluntary muscles**.

Autonomic nervous system (ANS) innervates the involuntary muscles and the glands. It consists of a pair of chains of ganglia and nerves on either sides of the backbone. This system is essentially a motor system, which regulates the involuntary actions of the internal organs. It consists of two parts: (a) sympathetic nervous system and (b) parasympathetic nervous system.

Sympathetic nervous system prepares the body for facing emergency situations while **parasympathetic nervous system** reestablishes the normal conditions once the emergency is over.
The opposite effects of the two subdivisions of the autonomic nervous system on the different organs are listed below in the table 1.

Table 1: Effects of Autonomic Nervous System

S/N	**Organ**	**Effect of Sympa-activity**	**Effect of Parasympathetic Activity**
1	Eye pupil	Dilated	Constricted
2	Heart beat	Speeded up	Slowed down
3	3. Blood vessels a. on skin	Constricted	Dilated

	b. on muscles	Dilated	No effect
4	Bronchioles	Dilated	Constricted
5	Urinary bladder	Muscles relaxed	Muscles contract (feeling of urination)
		Sphincter contracted	Sphincter relaxed
6	Sweat	secretion Increased	No effect
7	Blood sugar	Increased	No effect
8	Salivary secretion	Stops	Increased
9	Tear glands	Activated	Slowed down
10	Erector muscles of skin hair	Stimulated hair raised	Relaxed hair flattened
11	Adrenal glands	Increased secretion of adrenalin	No effect
12	Intestine	Peristalsis decreased	Peristalsis increased
13	Stomach glands	Decreased secretion	Increased secretion

The autonomic nervous system is strongly influenced by emotions such as grief, anger, fear, sexual stimulation, etc.

3.3 Neuron – The Structural and Functional Unit of Nervous System

Nervous tissue is composed of two main cell types: neurons and glial cells. Neurons transmit nerve messages. Glial cells are in direct contact with neurons and often surround them. Three types of neurons occur. Sensory neurons typically have a long dendrite and short axon, and carry messages from sensory receptors to the central nervous system. Motor neurons have a long axon and short dendrites and transmit messages from the central nervous system to the muscles (or to glands). Interneurons are found only in the central nervous system where they connect neuron to neuron.

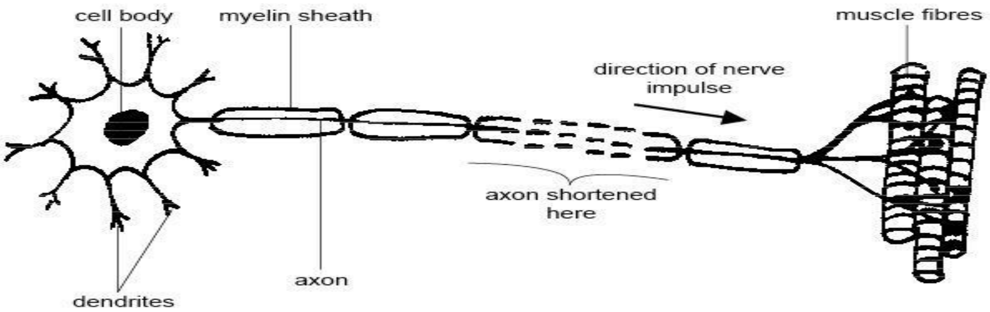

Fig. 2: A Motor Neuron

The **cell body** (perikaryon) contains nucleus and cell organelles in the cytoplasm. **Dendrites** (short branching processes) extend out from the cell body. They bring signals (impulses) from the receptor or from the axon endings of another neuron. There may be as many as 200 dendrites in a single neuron allowing as many connections with the axon endings of other neurons. A long **nerve fibre or axon** carries the impulse from the cell body towards its terminal branches which may either pass on the impulse to another neuron, or into a muscle or gland to bring about the required action. Synapse is the point of communication between one nerve cell and another or between nerve cell and a muscle. A sheath of fatty material (myelin) often covers the axon, and such nerve fibres are called medullated or myelinated fibres.

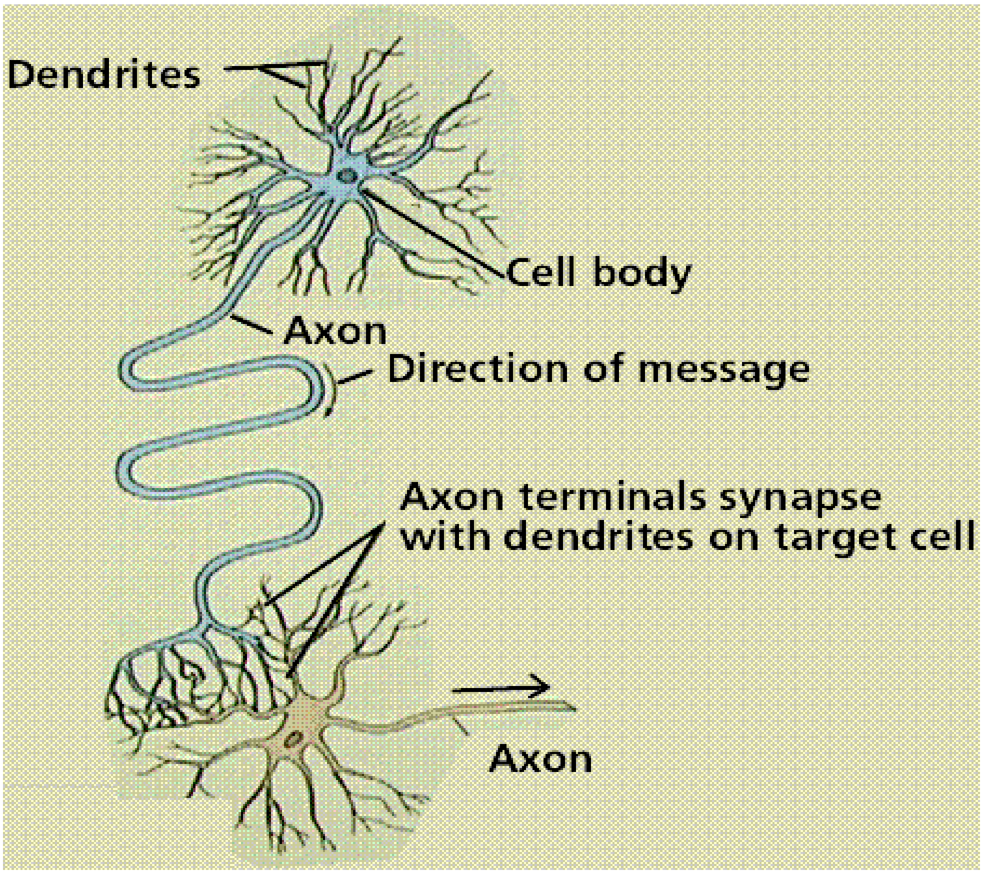

Fig. 3: Structure of a Neuron

Conduction of nerve impulse along the neuron and over the synapse
The conduction of nerve impulse through the nerve fibre is electrical in nature and the one through the synapse is chemical in nature.

A. Along the neuron – electrical signalling

The transmission (moving from one end to another) of the nerve impulse through the nerve fibre is electrochemical. It is not simply a flow of electrons through an electric wire but it travels as a wave of

depolarisation. In normal resting condition the outside of the nerve fibre carries positive (+) charge. In this condition nerve fibre is said to be polarised. The polarisation is due to the presence of more Na+ ions outside the cell membrane. Such state is maintained due to the sodium ions being continuously pumped out by means of the **sodium potassium pump** and operated by **active transport** using ATP for energy.

Sodium potassium pump is a carrier protein on the plasma membrane which transports sodium and potassium ions across the membrane. Normally, ions move from the region of their high concentration to the region of their low concentration.

The changes when a stimulus arrives at the nerve fibre are as follows:
The axon membrane at that spot becomes more permeable to Na+ ions, which move inward and bring about **depolarisation** on that spot.

This point of depolarisation itself becomes the stimulus for the adjoining area of the membrane, which in turn becomes depolarised.
Mean while the previous area becomes repolarised due to active movement of the sodium ions to the outside of the membrane by means of what is called 'sodium pump' and now the fibre is ready for the next wave of depolarisation. Thus, a nerve impulse is a self- propagating wave of depolarisation and repolarisation

B. Over the synapse – chemical signalling

The impulse travelling through a nerve fibre may reach either its destination (muscle or gland) for action or the dendrites of another neuron for further transmission. The meeting place is called **synapse**. The transmission over a synapse is a chemical process. As the impulse reaches the terminal end of the axon, the following events occur:

- a chemical acetylcholine is released by the end of the axon.
- acetylcholine stimulates the next neuron to start the new impulse.
- acteylcholine is soon broken down there to make the synapse ready for the next transmission.

In case the axon endings are branched and in contact with the dendrites of other neurons the impulse will travel through all of them.

'**All or none**' principle

If the stimulus is strong enough (with a minimum threshold) to produce the impulse, the impulse will set up and travel at its own speed. Threshold is the minimum strength of a stimulus that can initiate an impulse. Increasing the intensity of the stimulus cannot raise the speed of transmission.

3.4 Reflex Action

Reflex action is an automatic, quick and involuntary action in the body brought about by a stimulus. For example,

1. You instantaneously withdraw your hand on accidentally touching a hot plate or a sharp thorn.
2. Watering (salivation) of the mouth takes place on seeing or just smelling a familiar tasty food.

Two types of reflexes – simple and conditioned

The two examples of reflex action given above are basically different. The first one is inborn or natural, which did not require previous learning. Such reflexes are called **simple reflexes**.
The other example is the outcome of repeated experience. Here the brain actually remembers the taste of food and works in an unconscious manner- such reflexes are called **conditioned reflexes**.

Some other examples of reflexes are as follows:

(a) Simple reflex

1) **Quick closing of eyelids** on noticing an object suddenly approaching the eye.
2) **Coughing** when the food swallowed enters the windpipe instead of the food pipe.
3) **Narrowing of the eye pupil** in strong light.
4) If the foot of sleeping person is tickled, it is **jerked away.**

(b) Conditioned reflexes

1) **Applying brakes** in your vehicle (car or bicycle) on noticing someone suddenly coming in front of it.
2) **Tying shoe laces** while talking to someone, not knowing whether you are first putting the left lace over the right or the vice versa.
3) **A dog runs away** if it notices you kneeling down as if you are picking up a stone for striking.
4) **Standing up on** seeing the teacher entering the classroom.

Mechanism of reflex action

Some reflexes are brought about through the brain (cerebral reflexes) such as the closing of the eyelids due to approaching objects while others are brought about through the spinal cord (spinal reflexes). The pathway in a simple spinal reflex action is represented in the diagram below.

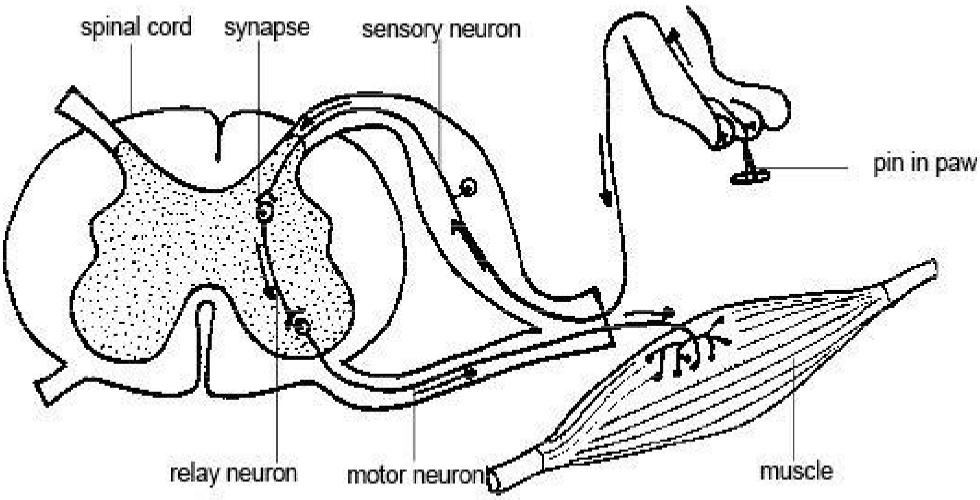

Fig. 4: Nerve Pathways in a Simple Reflex Action

In this, there are five necessary parts:

1. The stimulus (prick, heat, etc.).
2. Receptor in the sensory organ.
3. The afferent (sensory) nerve fibre running through the dorsal root of the spinal nerve bringing the impulse into the spinal cord.
4. A (motor) neuron sending out the command through its efferent fibre in the ventral root of the spinal nerve.
5. A muscle or the gland. Mostly, there occur an **intermediate neuron** between the axon ending of the afferent fibre and the motor neuron inside the spinal cord.

3.5 Sensory Receptors (the sense organs)

Sense organs are the organs through which we sense or detect changes in the external environment. Each sense organ has special sensory cells, which receive the stimuli and transmit the impulses produced through the concerned nerve to the brain or the spinal cord. The brain sorts out the impulses, interprets them and transmits message for the required response. In human there are typically five sense receptors, eyes for seeing, ears for hearing, nose for smelling, tongue for taste and skin for sensing touch, pain, heat, etc.

The Eye (the sense of vision)
The eye is nearly spherical in shape, bulging a little in front, and is able to rotate freely in the bony socket. It is a hollow ball containing several

structures inside. **The wall of the eyeball** is made up of three layers: the sclera, choroid and retina.

Sclera is the outermost tough white layer. In front it is continued as the transparent **cornea**.

Choroid is the middle layer. It is composed of connective tissue having a dense network of blood vessels. Its inner surface is dark brown or black. This prevents reflection, which would otherwise interfere with the clarity of the image.

Retina is the innermost sensitive layer. It contains two kinds of sensory cells– the **rods** (sensitive to dim light) and **cones** (sensitive to bright light and colours).

Yellow spot lying at the visual axis is the place of best vision in the normal eye. It contains maximum number of sensory cells and particularly the cone. The rest of the retina has fewer cones and more rods.

Blind spot is the point where the nerve fibres (axons) from all the sensitive cells of the retina converge to form the optic nerve which connects the eye to the brain. There are no sensory cells at the blind spot and any image formed here is not perceived.

The parts of the eye

Internally, the eye is divided into two main chambers separated by the lens.

Aqueous chamber is the front part containing a watery fluid (**aqueous humour**) and **vitreous chamber** is the back part containing a thick jelly like glassy substance (**vitreous humour**, *vitro*: glass). The aqueous humour keeps the lens moist and protects it from physical shocks. The vitreous humour helps in maintaining the shape of the eyeball and protects the retina.

The **lens** is biconvex in shape and semi-solid. It is composed of soft gelatinous tissue. It is held in position by suspensory ligament, which attaches it to the muscular **ciliary body**. The shape of the lens is influenced by the amount of tension in the suspensory ligament.

Iris is a sort of circular curtain in front of the lens. It is black, brown or blue. The colour of the eye is the colour of its iris. It contains two kinds of muscles: **circular muscles** for narrowing the pupil, and **radiating muscles** for dilating it. The size of the pupil is adjusted involuntarily to control the amount of light entering the eye. Can you think of the situations when the pupil gets narrower and when it becomes wider?

How do we see?

Transmission of light
Reflected light rays from the object enter the eyes through the transparent structures of the eye, i.e. conjucativa, cornea, aqueous humour, lens and vitreous humour.

Formation of image
The curvature of the cornea bends the rays to some extent and the lens bends them further to form an image on the retina.

Nature of image
The image is inverted and real.

Production of nerve impulse and its transmission
The light energy of the image produces chemical changes in the sensory cells (rods and cones). These changes produce nerve impulses, which travel through the optic nerve and reach the brain.

Perception
The brain interprets the image in many ways; e.g. it sees the object vertical although the actual image formed is inverted.

Accommodation (focusing)
Focusing the image on retina is called **accommodation**. Changing the curvature of the elastic lens brings about the accommodation.

For distant vision
The lens is more flattened or thinner; this is the normal condition of the lens, which is kept stretched by the suspensory ligaments.

For near vision
The ciliary muscles which are circular contract and tend to reduce the circumference of the eyeball there. This releases the tension on the suspensory ligament and the lens becomes thicker (more rounded) on account of its own elasticity. A normal eye is constantly accommodating while walking, playing or just looking around.

Binocular vision
In all primates including humans, both eyes are placed forward. Each eye views at a slightly different angle. The images from the two eyes are perceived overlapped inside the brain giving the impression of depth (3-dimensional/stereoscopic vision).

Three common defects of the eye

1. Near- sightedness (Myopia)

Nearby objects are clearly seen but not the distant ones by those suffering from myopia because the image of the object is formed in front of the retina. This can be corrected by using concave lens (worn in frames (spectacles) or as contact lenses).

2. Long sightedness (Hypermetropia)

Distant objects are clearly seen but not the nearby because the image of the object is formed behind the retina. This can be corrected by convex lens (worn in frames as spectacles or as contact lenses).

3. Cataract (opacity of the lens)

The lens usually loses its transparency and turns opaque with age. Such a lens can be surgically removed and either replaced by an intra-ocular lens or by simply using suitable glasses.

The Ear - sense of hearing and balance
The ear serves two sensory functions: hearing and maintenance of body balance. It has three main parts – external ear, middle ear, and internal ear.

i) The **external ear** consists of the following:

- An outwardly projecting ear to be called **pinna** supported by cartilage. It directs the sound waves inwards.
- The **auditory canal** through which the sound waves travel up to the ear drum (tympanic membrane).

ii) The **middle ear** consists of the following:

- An air-filled tympanic cavity.
- The **tympanum** or ear drum.
- Three tiny bones-**malleus** (hammer) connected to the ear drum, incus (anvil) in between and **stapes** (stirrup) forming a contact with the oval window of the internal ear.
- **Eustachian tube** connects the tympanic cavity with pharynx. It equalises the pressure on both sides of the eardrum or tympanum.

iii) The **internal ear** contains two main parts:

- **Cochlea** is a long coiled structure which looks like the coils of the shell of a snail. It has two and a half turns. The inner winding cavity of the cochlea is divided into three parallel tubes of canals separated by membranes. The canals are filled with a fluid called endolymph. The middle canal possesses sensory cells (organ of corti) for hearing.

- **Vestibule** is concerned with physical balance of the body. It consists of three **semicircular canals** arranged at right angles to each other and a part joining the cochlea and differentiated into a **utriculus** and a **sacculus**. One end of each semicircular canal is widened to form an **ampulla**, which contains sensory cells, and the nerve fibres from them continue into auditory nerve.

Mechanism of hearing

- The sound waves enter the auditory canal and cause the eardrum to vibrate.
- The vibrations of the eardrum are transferred to malleus, to incus, and then to stapes. Stapes transfers the vibrations through oval window into the cochlea.
- These vibrations move the fluid in the cochlea. The organ of corti catches the movement of the fluid and transfers it to the auditory nerve that carries the impulses to the brain.

Perception of body balance

Static balance due to gravity – Any bending or change in the body posture causes the fluid inside the semicircular canals to move. The semi circular canals are arranged in different planes. The sensory hairs in the ampulla of the canal pick up these movements and the impulses are transmitted through the auditory nerve. **Balance during motion** – Utriculus and sacculus perceive dynamic equilibrium (while the body is in motion). Fine particles of calcium carbonate present in the endolymph press on the sensory hairs whenever the body is in some motion. The impulses are carried through the auditory nerve.

Tongue and Nose (sense of taste and smell)
The tongue perceives the taste and the nose perceives the smell. The perception depends upon the nature of chemical substance coming in contact with the sensory cells. For taste there is a direct contact of the substance with the sensory cells located in the taste buds on the tongue. For smell, the molecules of the chemical are carried inward by the air

inhaled and they stimulate the sensory epithelium of the nose.

Skin (touch and some other miscellaneous senses)

There are a variety of nerve endings in the skin. Some of these are concerned with touch (gentle pressure), some with deep pressure and others with cold, heat and pain. The sense of hunger is due to receptors in the stomach wall. The sense of thirst is due to stimulation of nerves in the pharynx. And the sense of fatigue is located in the muscles.

4.0 CONCLUSION

In this unit you, learnt about the nervous system, neuro, reflex arc and the structure and functional unit of a neuron. Also, the functions of each sensory organ in the coordination of animals were discussed.

5.0 SUMMARY

You have been introduced to coordination in animals; nervous coordination in animal, for example nervous systems, neuron, reflex arc, sensory organ, etc.

The coordination of body activities inside the body of an organism is brought about by two systems- the nervous systems. The nervous system is composed of the central nervous system (brain and spinal cord) and the peripheral nervous system (cranial and spinal nerves and the autonomic nervous system). The autonomic nervous system consists of a pair of chain of ganglia by the side of spinal cord. It is largely concerned with the normal functioning of the visceral organs. Cerebrum is the largest part of the brain and is the seat of intelligence. Cerebellum is the centre of balance. Medulla oblongata controls breathing and heart beat. Spinal cord is the centre for simple reflexes. The sensitive layer of the eye is the retina which is composed of rods (sensitive to dim light) and cones (sensitive to bright light and for colour vision). The internal ear performs two tasks perception of sound by the cochlea and that of disturbance in body balance by the semicircular canals, utriculus and sacculus. The nose perceives chemical stimuli by the chemicals carried by the air and the tongue by direct contact with them. Skin possesses receptors for touch, pain, heat, cold, etc.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the effect of autonomous nervous systems using the organs and the relative effect of sympa-activity and parasympathetic activity.
2. Explain the two major division of nervous system.

3. Explain the types of central nervous system with diagram and examples.
4. Explain the structural and functional unit of a neuron.
5. What is a reflex action? Give examples and diagram to explain further.
6. Name the main parts of the brain and mention the one functions each of :

    (i) Cerebrum
    (ii) Cerebellum
    (iii) Medulla oblongata
    (iv) Hypothalamus

7. State the functions of the following parts of the eye:

    (i) Iris
    (ii) Ciliary muscles
    (iii) Pupil
    (iv) Vitreous humour
    (v) Retina

8. Name the following:

    (i) Area of sharp vision in the eye.
    (ii) The kind of lens used for correcting near-sightedness.
    (iii) The condition in which the lens of the eye turns opaque.
    (iv) The capacity of eye to focus objects at different distances.

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UNIT 2 ENDOCRINE COORDINATION IN ANIMALS

CONTENTS

1.0 INTRODUCTION

The endocrine system is a collection of glands that secrete chemical messages we call hormones. These signals are passed through the blood to arrive at a target organ, which has cells possessing the appropriate receptor. Exocrine glands (not part of the endocrine system) secrete products that are passed outside the body. Sweat glands, salivary glands, and digestive glands are examples of exocrine glands.

In other words, hormones are secretions from specific cells or glands in the body that are carried by the blood. Their effect is produced in one or more specific parts only. Most hormones are secreted by special glands called the endocrine glands meaning 'secrete internally'. These are also called ductless glands because their secretions are poured directly into the blood and not through ducts. Certain hormones are produced by other glands or body parts also, for example, the stomach and the duodenum.

Nature and functions of hormones

1. Hormones are secreted from their source directly into the blood.
2. Blood carries the hormone to the target cells which respond to it.
3. Hormones regulate the physiological processes.
4. They are produced in very small quantities and are biologically very active. For example, adrenaline is active even at a concentration of 1 in 300 million parts.
5. Their excess and deficiency, both, cause serious disorders.

6. Chemically, the hormones may be water-soluble proteins (peptides), glycoproteins and amines or lipid-soluble steroids.
7. The extra hormones are not stored in the body and are excreted out.

2.0 OBJECTIVES

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

- distinguish between exocrine and endocrine glands
- list various endocrine glands and locate their position in human body
- identify properties of hormones and mention their nature and manner of functioning
- differentiate between hormones and pheromones
- name the various hormones secreted by pituitary, thyroid, parathyroid, thymus, adrenals, pancreas and reproductive organs in humans and mention their functions
- relate the hormonal imbalance with hormone related disorders in human
- state the effects of over functioning (hyperactivity) and hypoactivity (underfunctioning) of pituitary and thyroid.

3.0 MAIN CONTENT

3.1 Hormone Secretors - the Endocrine Glands

In humans there are more than a dozen tissues and organs that produce hormones. These can be listed under two categories;

Exclusively endocrine: the pituitary, the thyroid, the parathyroid, thymus and the adrenals.

Partially endocrine: The pancreas, gastric and duodenal epithelium, the gonads (testis in males and ovary in females) and placenta in females

Pituitary — the master gland
The pituitary gland (also called hypophysis) is a small projection (about the size of a pea) which hangs from the base of the mid-brain. It is connected to the hypothalamus of the brain by the pituitary stalk. The hypothalamus, although a part of the brain, also secretes some hormones one of which is somatostatin which inhibits the secretion of growth hormone from the anterior pituitary.
The pituitary controls most other endocrine glands. It has two distinct parts: the anterior pituitary and the posterior pituitary. Various hormones

produced from these two parts and their actions are listed below in table 1.

Table 1: **Pituitary Hormones, their Actions and Abnormalities due to Oversecretion or Undersecretion**

Source	**Hormones**	**Action and Abnormalities Produced**
Anterior lobe pituitary	Growth hormone (GH), also known as somatotrophic hormone (STH)	Promotes growth of whole body, particularly of the skeleton. Undersecretion in childhood lead to Dwarfism; oversecretion in childhood causes gigantism and in adult, acromegaly.
	Trophic hormones (stimulate other endocrine glands)	1. Thyroid stimulating hormone (TSH) stimulates thyroid. 2. Adrenocorticotrophic hormone (ACTH) stimulates adrenal cortex 3. Follicle stimulating hormone (FSH) stimulates egg formation in females and sperm formation in males. 4. Luteinizing hormone (LH) stimulates ovulation and the formation of corpus luteum which produces the female hormone progesterone and LH stimulates testis to produce the male hormone testosterone. 5. Prolactin stimulates milk production.
	Gonadotropic hormones	
Posterior lobe of pituitary	Antidiuretic hormone(ADH) or vasopressin	Increase absorption of water from the kidney tubules (osmoregulation). Deficiency causes diabetes insipidus.
	Oxytocin	Stimulates contractions of the uterus during childbirth.

Thyroid

Thyroid is a bilobed structure situated in the front region of the neck. It secretes two hormones thyroxine and calcitonin. Thyroxine regulates basal metabolism i.e. the rate of cellular oxidation resulting in heat production. Controls growth and development, ossification of the bones, body temperature, mental development, etc.

Undersecretion of thyroxine (hypothyroidism) produces three conditions; simple goitre. Enlargement of thyroid visible as a swelling in the neck. It is caused due to iodine deficiency in food as iodine is needed for production of thyroid hormones.

Cretinism
Poor body growth (dwarfism) and mental retardation.

Myxoedema
Swelling of the face and hands. General sluggishness.

Oversecretion of thyroxine (hyperthyroidism) produces exophthalmic goitre. This condition causes marked increase in the metabolic rate, rapid heartbeat, shortness of breath and the eyes protrude out together with goitre in the neck.

Calcitonin. It regulates the calcium and phosphate levels in the blood. If the calcium level in blood is high more calcitonin is secreted and the calcium ions are moved from the blood to the bones making them harder. The reverse happens when the calcium level in the blood is low making the bones soft.

Parathyroids
These are two small pairs of glands wholly or partially embedded in the thyroid gland. Their secretion parathormone raises blood calcium level by stimulating release of calcium from bones.

Thymus
It is located at the base of neck. It produces some hormones involved in maturation of T- lymphocytes. It begins to atrophy after puberty.

Adrenals
The adrenals (ad: adjacent, renal; kidney) are a pair of glands situated like caps one above each kidney. Each adrenal consists of two parts: a central medulla and a peripheral cortex.

The **adrenal medulla** secretes adrenaline which:

- increases heart beat accompanied by an increase in the blood pressure
- increases blood supply to the muscles while decreasing blood supply to the visceral organs
- releases more glucose into the blood from the liver.

The adrenal cortex secretes two categories of hormones: glucocorticoids and Mineralocorticoids.

Gonads (testis and ovary)

Testes in males possess two kinds of cells: the sperm-producing germinal cells and the hormone-producing interstitial cells. The hormones produced are called androgens and the commonest one among them is testosterone. The **testosterone** stimulates the development of the male characters during which the body at **puberty** starts developing facial hair**,** and their voice cracks and deepens.

Ovaries in females produce two kinds of hormones **- estrogen** and **progesterone**.

Estrogen is secreted from the follicles of the ovary and stimulates the development of breasts and fat deposition on the hip in a mature woman. Estrogen prepares the wall of the uterus for receiving the fertilised egg. **Progesterone** is secreted by the corpus luteum (follicle left after the release of ovum). It brings about the final changes in the uterus for the retention and growth of the foetus during pregnancy.

Placenta

Placenta of a pregnant woman produces certain hormones. One such hormone is **human chorionic gonadotropin** (HCG), which maintains the activity of corpus luteum in secreting progesterone continuously.

Hormones from stomach and intestine

(i) **Gastrin** is the hormone secreted by the mucus membrane of the pyloric end of the stomach. It stimulates the gastric glands to secrete gastric juice.

(ii) **Secretin** is the hormone secreted by the inner lining of the duodenum. It stimulates the production of pancreatic juice while the hormone **cholecystokinin** stimulates release of bile from gall bladder.

3.2 The Feedback Mechanism (Control of Hormonal Secretion)

The amount of hormone released by an endocrine gland is determined by the body's need for the particular hormone at any given time. The product of the target tissue exerts an effect on the respective endocrine gland. This effect may be positive ('*secrete more*') or negative ('*secrete no more*' or '*slow down*'). This can be explained by taking the example of thyroid gland.

Feedback mechanism of thyroid activity Hypothalamus releases a hormone TSH-RH (TSH- releasing hormone) which instructs the anterior pituitary to release TSH (thyroid stimulating hormone). The TSH stimulates thyroid to release thyroxine. If the level of thyroxine in blood increases, the pituitary stops the release of TSH. If the level of thyroxine becomes still higher, then the inhibition of the release of thyroxine takes place not only at the level of the pituitary but also at the level of hypophysis.

3.3 Pheromones - The Chemical Messengers at Social Level

Pheromones are the secretions given out by an individual into the environment, which bring about a specific response in other members of the same species. Some of the examples of the pheromones are as follows:

- Common ants march on the floor or walls in a trail on an invisible path laid down by a secretion from their bodies. It helps them to reach the destination one after another, as well as to return correctly to their own nest.
- When disturbed honey bees give out an alarm pheromone from their sting at the back and mandibles in the mouth. This alerts the inmates of the hive to face the attack.
- Females of a particular moth give out a scent which can attract a male from as much distance as 3-4 kilometres.
- Introduction of a male mouse into a group of female mice shortens oestrus cycle (cycle of development of eggs in the ovary and ovulation).
- Introduction of a strange male mouse of a different strain disturbs to the extent that the newly pregnant females abort their foetuses. The source of pheromone of the strange male mouse is in its urine.

3.4 Hormonal and Nervous Coordination Compared

The table 2 below lists a few major differences between these two different kinds of control and regulating mechanisms.

Table 2: Differences between Hormonal and Nervous Control Property Hormonal Control Nervous Control

	Property	Hormonal control	Nervous control
1	Nature of signal	All hormones are chemical signal	Nerve impulses are electrical signals. Chemical signalling takes place at synapses
2	Speed of signal	Slow	Rapid. Between 0.7 metres per second and 120 metres per second
3	Effect in the body	General effect. The hormones can influence cells in many different parts of the body	Localised effect – affects only the particular muscle or the gland
4	Effect on growth	Can affect growth	Cannot affect growth
5	Capacity for modification	Cannot be modified by learning from previous experience	Can be modified by learning from previous experiences
6	Duration of effect	Short term or long lasting	Only short–lived

4.0 CONCLUSION

In this unit, you learnt about *the* endocrine coordination for example hormone secretors—*the* endocrine glands, exclusively and partially endocrine, for example; the pituitary, the thyroid, the parathyroid, thymus and the adrenals. The pancreas, gastric and duodenal epithelium, the gonads (testis in males and ovary in females) and placenta in females were discussed.

5.0 SUMMARY

You have been introduced to endocrine coordination in animals; endocrine coordination for example hormone secretors - the endocrine glands, exclusively endocrine and partially endocrine.
Chemical coordination is brought about by hormones produced by the ductless glands, that are carried by the blood and which act on the target cells or organs away from their source.

There is a close link between the nervous and the endocrine systems, shown by the way in which the pituitary gland interacts with the hypothalamus of the brain.

Our endocrine glands include the pituitary, thyroid, parathyroid, thymus adrenals, pancreas, gonads and placenta. The pituitary controls and regulates the activities of almost all other endocrine glands. The under secretion as well as the over secretion of the hormones, both produce ill effects. Hormone level is generally controlled by feedback mechanism. Pheromones are the external secretions, which produce response in other individuals of the same species.

6.0 TUTOR-MARKED ASSIGNMENT

1. Name the hormone and its source glands, whose deficiency leads to diabetes in sipidus.
2. What are pheromones?
3. Name and explain the event that happens immediately when a nerve fibre gets stimulated.
4. Are the endocrine glands and the ductless glands one and the same thing?
5. Describe any one example of condition reflex in the humans.
6. List the functions of medulla oblongata.
7. Differentiate between sympathetic and parasympathetic nervous systems.
8. What are the two principal tasks of insulin?
9. Explain the following terms: (i) synapse (ii) stimulus and (iii) impulse.

7.0 REFERENCES/FURTHER READING

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UNIT 3 HOMEOSTASIS

CONTENTS

1.0 INTRODUCTION

Homeostasis, from the Greek words for "same" and "steady," refers to any process that living things use to actively maintain fairly stable conditions necessary for survival, in other words it regulates the internal environment and tends to maintain a stable, constant condition of living organism like temperature or pH.

All organisms attempt to maintain a relatively stable internal environment; that is, all organisms attempt to maintain homeostasis with varying degrees of success. Living organisms can survive, grow and reproduce only in external environments that provide adequate levels of nutrients, water, oxygen and carbon dioxide, and suitable physical conditions such as light and temperature. Many organisms can adapt to changing external environments, others are unable to and can be damaged or killed when conditions change. Biochemical reactions in living cells can occur only when pH, various salts and nutrients, and physical conditions are within certain limits. Higher evolved multi-cellular organisms are more able to regulate their internal environment as they usually develop a protective outer layer and have specialised cells. Vertebrates are able to precisely regulate the chemical composition and solute concentration of their internal environment. Mammals and birds are also able to regulate their body temperature. Many fish share our ability to regulate our water and solute concentrations

2.0 OBJECTIVES

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

- explain homeostasis with examples
- state and explain the principles of homeostasis
- state organs used for homeostasis in animals and their function
- explain homeostatic control systems
- discuss the two types of feedback mechanism with examples
- explain homeostatic imbalance.

3.0 MAIN CONTENT

3.1 Principles of Homeostasis in Animals

The regulation of body temperature and blood glucose was used to illustrate the following principles; homeostasis provides a constant internal environment and independence from fluctuating external conditions, negative feedback tends to restore systems to their original levels, the possession of separate mechanisms controlling departures in different directions from the original state gives a greater degree of control, control mechanisms must be coordinated.

Regulating body temperature

Humans, together with other mammals and with birds, are *endothermic*; they can maintain relatively constant body temperatures independent of the environmental temperature. When the temperature of your blood exceeds 37°C (98.6°F), neurons in a part of the brain called the hypothalamus detect the temperature change. Acting through the control of motor neurons, the hypothalamus responds by promoting the dissipation of heat through sweating, dilation of blood vessels in the skin, and other mechanisms. These responses tend to counteract the rise in body temperature. When body temperature falls, the hypothalamus coordinates a different set of responses, such as shivering and the constriction of blood vessels in the skin, which help to raise body temperature and correct the initial challenge to homeostasis. Vertebrates other than mammals and birds are *ectothermic*; their body temperatures are more or less dependent on the environmental temperature. However, to the extent that it is possible, many ectothermic vertebrates attempt to maintain some degree of temperature homeostasis. Certain large fish, including tuna, swordfish, and some sharks, for example, can maintain parts of their body at a significantly higher temperature than that of the water. Reptiles attempt to maintain a constant body temperature through behavioural means - by placing themselves in varying locations of sun and shade. That's why you frequently see lizards basking in the sun. Sick lizards even give themselves a "fever" by seeking warmer locations! Most invertebrates do not employ feedback regulation to physiologically control their body temperature. Instead, they use behaviour to adjust their temperature. Many butterflies, for example, must reach a certain body temperature before they can fly. In the cool of the morning they orient so as to maximise their absorption of sunlight. Moths and many other insects use a shivering reflex to warm their thoracic flight muscles.

Regulating blood glucose

When you digest a carbohydrate-containing meal, you absorb glucose into your blood. This causes a temporary rise in the blood glucose concentration, which is brought back down in a few hours. What counteracts the rise in blood glucose following a meal? Glucose levels within the blood are constantly monitored by a sensor, the islets of Langerhans in the pancreas. When levels increase, the islets secrete the hormone *insulin*, which stimulates the uptake of blood glucose into muscles, liver and adipose tissue. The islets are, in this case, the sensor and the integrating centre. The muscles, liver, and adipose cells are the effectors, taking up glucose to control the levels. The muscles and liver can convert the glucose into the polysaccharide glycogen; adipose cells can convert glucose into fat. These actions lower the blood glucose and help to store energy in forms that the body can use later.

3.2 The Organs used for Homeostasis in Animals

Osmoregulatory organs

Animals have evolved a variety of mechanisms to cope with problems of water balance. In many animals, the removal of water or salts from the body is coupled with the removal of metabolic wastes through the excretory system. Protists employ contractile vacuoles for this purpose, as do sponges. Other multicellular animals have a system of excretory tubules (little tubes) that expel fluid and wastes from the body.

In flatworms, these tubules are called *protonephridia*, and they branch throughout the body into bulblike flame cells. While these simple excretory structures open to the outside of the body, they do not open to the inside of the body. Rather, cilia within the flame cells must draw in fluid from the body. Water and metabolites are then reabsorbed, and the substances to be excreted are expelled through excretory pores.

Other invertebrates have a system of tubules that open both to the inside and to the outside of the body. In the earthworm, these tubules are known as *metanephridia*. The metanephridia obtain fluid from the body cavity through a process of filtration into funnel shaped structures called *ephrostomes.* The term *filtration* is used because the fluid is formed under pressure and passes through small openings, so that molecules larger than a certain size are excluded. This filtered fluid is isotonic to the fluid in the coelom, but as it passes through the tubules of the metanephridia, NaCl is removed by active transport processes. A general term for transport out of the tubule and into the surrounding body fluids is *reabsorption.* Because salt is reabsorbed from the filtrate, the urine excreted is more dilute than the body fluids (is hypotonic). The kidneys of mollusks and the excretory organs of crustaceans (called *antennal glands*) also produce urine by filtration and reclaim certain ions by reabsorption. The excretory organs in insects are the Malpighian tubules, extensions of the digestive tract that branch off anterior to the hindgut. Urine is not formed by filtration in these tubules, because there is no pressure difference between the blood in the body cavity and the tubule. Instead, waste molecules and potassium (K+) ions are secreted into the tubules by active transport. Secretion is the opposite of reabsorption—ions or molecules are transported from the body fluid into the tubule.

The secretion of K+ creates an osmotic gradient that causes water to enter the tubules by osmosis from the body's open circulatory system. Most of the water and K+ is then reabsorbed into the circulatory system through the epithelium of the hindgut, leaving only small molecules and waste products to be excreted from the rectum along with feces. Malpighian tubules thus provide a very efficient means of water conservation. The kidneys of vertebrates, unlike the Malpighian tubules of insects, create a tubular fluid by filtration of the blood under pressure. In addition to containing waste products and water, the filtrate contains many small molecules that are of value to the animal, including glucose, amino acids, and vitamins. These molecules and most of the water are reabsorbed from the tubules into the blood, while wastes remain in the filtrate. Additional wastes may be secreted by the tubules and added to the filtrate, and the final waste product, urine, is eliminated from the body. It may seem odd that the vertebrate kidney should filter out almost everything from blood plasma (except proteins, which are too large to be filtered) and then spend energy to take back or reabsorb what the body needs. But selective reabsorption provides great flexibility, because various vertebrate groups have evolved the ability to reabsorb different molecules that are especially valuable in particular habitats. This flexibility is a key factor underlying the successful colonisation of many diverse environments by the vertebrates.

Evolution of the vertebrate kidney

The kidney is a complex organ made up of thousands of repeating units called **nephrons,** each with the structure of a bent tube. Blood pressure forces the fluid in blood past a filter, called the *glomerulus*, at the top of each nephron. The glomerulus retains blood cells, proteins, and other useful large molecules in the blood but allows the water, and the small molecules and wastes dissolved in it, to pass through and into the bent tube part of the nephron. As the filtered fluid passes through the nephron tube, useful sugars and ions are recovered from it by active transport, leaving the water and metabolic wastes behind in a fluid urine. Although the same basic design has been retained in all vertebrate kidneys, there have been a few modifications. Because the original glomerular filtrate is isotonic to blood, all vertebrates can produce a urine that is isotonic to blood by reabsorbing ions and water in equal proportions or hypotonic to blood - that is, more dilute than the blood, by reabsorbing relatively less water blood. Only birds and mammals can reabsorb enough water from their glomerular filtrate to produce urine that is hypertonic to blood - that is, more concentrated than the blood, by reabsorbing relatively more water.

(i) Freshwater fish

Kidneys are thought to have evolved first among the freshwater teleosts, or bony fish. Because the body fluids of a freshwater fish have a greater osmotic concentration than the surrounding water, these animals face two serious problems: (1) water tends to enter the body from the environment; and (2) solutes tend to leave the body and enter the environment. Freshwater fish address the first problem by *not* drinking water and by excreting a large volume of dilute urine, which is hypotonic to their body fluids. They address the second problem by reabsorbing ions across the nephron tubules, from the glomerular filtrate back into the blood. In addition, they actively transport ions across their gill surfaces from the surrounding water into the blood.

(ii) Marine bony fish

Although most groups of animals seem to have evolved first in the sea, marine bony fish (teleosts) probably evolved from freshwater ancestors, They faced significant new problems in making the transition to the sea because their body fluids are hypotonic to the surrounding seawater. Consequently, water tends to leave their bodies by osmosis across their gills, and they also lose water in their urine. To compensate for this continuous water loss, marine fish drink large amounts of seawater. Many of the divalent cations (principally Ca++ and Mg++) in the seawater that a marine fish drinks remain in the digestive tract and are eliminated through the anus. Some, however, are absorbed into the blood, as are the monovalent ions K^+, Na^+, and $Cl^–$. Most of the monovalent ions are actively transported out of the blood across the gill surfaces, while the divalent ions that enter the blood are secreted into the nephron tubules and excreted in the urine. In these two ways, marine bony fish eliminate the ions they get from the seawater they drink. The urine they excrete is isotonic to their body fluids. It is more concentrated than the urine of freshwater fish, but not as concentrated as that of birds and mammals.

(iii) Cartilaginous fish

The elasmobranchs, including sharks and rays, are by far the most common subclass in the class Chondrichthyes (cartilaginous fish). Elasmobranchs have solved the osmotic problem posed by their seawater environment in a different way than have the bony fish. Instead of having body fluids that are hypotonic to seawater, so that they have to continuously drink seawater and actively pump out ions, the elasmobranchs reabsorb urea from the nephron tubules and maintain a blood urea concentration that is 100 times higher than that of mammals. This added urea makes their blood approximately isotonic to the surrounding sea. Because there is no net water movement between isotonic solutions, water loss is prevented. Hence, these fishes do not need to drink seawater for osmotic balance, and their kidneys and gills do not have to remove large amounts of ions from their bodies. The enzymes and tissues of the cartilaginous fish have evolved to tolerate the high urea concentrations.

(iv) Amphibians and reptiles

The first terrestrial vertebrates were the amphibians, and the amphibian kidney is identical to that of freshwater fish. This is not surprising, because amphibians spend a significant portion of their time in fresh water, and when on land, they generally stay in wet places. Amphibians produce very dilute urine and compensate for their loss of Na^+ by actively transporting Na^+ across their skin from the surrounding water. Reptiles, on the other hand, live in diverse habitats.

Those living mainly in fresh water occupy a habitat similar to that of the freshwater fish and amphibians and thus have similar kidneys. Marine reptiles, including some crocodilians, sea turtles, sea snakes, and one lizard, possess kidneys similar to those of their freshwater relatives but face opposite problems; they tend to lose water and take in salts. Like marine teleosts (bony fish), they drink the seawater and excrete an isotonic urine. Marine teleosts eliminate the excess salt by transport across their gills, while marine reptiles eliminate excess salt through salt glands located near the nose or the eye.

The kidneys of terrestrial reptiles also reabsorb much of the salt and water in their nephron tubules, helping somewhat to conserve blood volume in dry environments. Like fish and amphibians, they cannot produce urine that is more concentrated than the blood plasma. However, when their urine enters their cloaca (the common exit of the digestive and urinary tracts), additional water can be reabsorbed.

(v) Mammals and birds

Mammals and birds are the only vertebrates able to produce urine with a higher osmotic concentration than their body fluids. This allows these vertebrates to excrete their waste products in a small volume of water, so that more water can be retained in the body. Human kidneys can produce urine that is as much as 4.2 times as concentrated as blood plasma, but the kidneys of some other mammals are even more efficient at conserving water. For example, camels, gerbils, and pocket mice of the genus *Perognathus* can excrete urine 8, 14, and 22 times as concentrated as their blood plasma, respectively. The kidneys of the kangaroo rat are so efficient it never has to drink water; it can obtain all the water it needs from its food and from water produced in aerobic cell respiration! The production of hypertonic urine is accomplished by the *loop of Henle* portion of the nephron found only in mammals and birds. A nephron with a long loop of Henle extends deeper into the renal medulla, where the hypertonic osmotic environment draws out more water, and so can produce more concentrated urine. Most mammals have some nephrons with short loops and other nephrons with loops that are much longer. Birds, however, have relatively few or no nephrons with long loops, so they cannot produce urine that is as concentrated as that of mammals. At most, they can only reabsorb enough water to produce urine that is about twice the concentration of their blood. Marine birds solve the problem of water loss by drinking salt water and then excreting the excess salt from salt glands near the eyes. The moderately hypertonic urine of a bird is delivered to its cloaca, along with the fecal material from its digestive tract. If needed, additional water can be absorbed across the wall of the cloaca to produce a semisolid white paste or pellet, which is excreted.

Ammonia, urea, and uric acid

Amino acids and nucleic acids are nitrogen-containing molecules. When animals catabolise these molecules for energy or convert them into carbohydrates or lipids, they produce nitrogen-containing by-products called **nitrogenous wastes** that must be eliminated from the body. The first step in the metabolism of amino acids and nucleic acids is the removal of the amino (-NH2) group and its combination with H+ to form **ammonia** (NH3) in the liver. Ammonia is quite toxic to cells and therefore is safe only in very dilute concentrations. The excretion of ammonia is not a problem for the bony fish and tadpoles, which eliminate most of it by diffusion through the gills and less by excretion in very dilute urine. In elasmobranchs, adult amphibians, and mammals, the nitrogenous wastes are eliminated in the far less toxic form of **urea.** Urea is water-soluble and so can be excreted in large amounts in the urine. It is carried in the bloodstream from its place of synthesis in the liver to the kidneys where it is excreted in the urine. Reptiles, birds, and insects excrete nitrogenous wastes in the form of **uric acid**, which is only slightly soluble in water. As a result of its low solubility, uric acid precipitates and thus can be excreted using very little water. Uric acid forms the pasty white material in bird droppings called *guano*. The ability to synthesise uric acid in these groups of animals is also important because their eggs are encased within shells, and nitrogenous wastes build up as the embryo grows within the egg. The formation of uric acid, while a lengthy process that requires considerable energy, produces a compound that crystallises and precipitates. As a precipitate, it is unable to affect the embryo's development even though it is still inside the egg. Mammals also produce some uric acid, but it is a waste product of the degradation of purine nucleotides, not of amino acids. Most mammals have an enzyme called *uricase*, which converts uric acid into a more soluble derivative, **allantoin**. Only humans, apes, and the Dalmatian dog lack this enzyme and so must excrete the uric acid. In humans, excessive accumulation of uric acid in the joints produces a condition known as gout.

3.3 Feedback Mechanism and Homeostatic Control System

Feedback is a mechanism, process or signal that is looped back to control a system within itself. Such a loop is called a feedback loop. In systems containing an input and output, feeding back part of the output so as to increase the input is positive feedback (regeneration); feeding back part of the output in such a way as to partially oppose the input is negative feedback (degeneration).

Generally, a control system has input from an external signal source and output to an external load; this defines a natural sense (or direction) or path of propagation of signal; the feedforward sense or path describes the signal propagation from input to output; feedback describes signal propagation in the reverse sense. When a sample of the output of the system is fed back, in the reverse sense, by a distinct feedback path into the interior of the system, to contribute to the input of one of its internal feedforward components, especially an active device or a substance that is consumed in an irreversible reaction; it is called the "feedback". The propagation of the signal around the feedback loop takes a finite time because it is causal.

The natural sense of feedforward is defined chemically by some irreversible reaction, or electronically by an active circuit element that has access to an auxiliary power supply, so as to be able to provide power gain to amplify the signal as it propagates from input to output. For example, an amplifier can use power from its controlled power reservoir, such as its battery, to provide power gain to amplify the signal; but the reverse is not possible: the signal cannot provide power to recharge the battery of the amplifier.

Feedforward, feedback and regulation are self related. The feedforward carries the signal from source to load. Negative feedback helps to maintain stability in a system in spite of external changes. It is related to homeostasis. For example, in a population of foxes (predators) and rabbits (prey), an increase in the number of foxes will cause a reduction in the number of rabbits; the smaller rabbit population will sustain fewer foxes, and the fox population will fall back. In an electronic amplifier feeding back a negative copy of the output to the input will tend to cancel distortion, making the output a more accurate replica of the input signal.

Positive feedback amplifies possibilities of divergences (evolution, change of goals); it is the condition to change, evolution, growth; it gives the system the ability to access new points of equilibrium.
For example, in an organism, most positive feedback provides for fast autoexcitation of elements of endocrine and nervous systems (in particular, in stress responses conditions) and are believed to play a key role in morphogenesis, growth, and development of organs, all processes that are, in essence, a rapid escape from the initial state. Homeostasis is especially visible in the nervous and endocrine systems when considered at organism level. Chemical potential energy for irreversible reactions or electrical potential energy for irreversible cell-membrane current powers the feedforward sense of the process. However, in the case of morphogenesis, feedback may only be enough to explain the increase in momentum of the system, and may not be sufficient in itself to account for the movement or direction of its parts.

When a public address system is used with a microphone to amplify speech, the output from a random sound at the microphone may produce sound at a loudspeaker that reaches the microphone such as to reinforce and amplify the original signal (positive feedback), building up to a

howl (of frequency dependent upon the acoustics of the hall). A similar process is used deliberately to produce oscillating electrical signals.
Feedback is distinctly different from reinforcement that occurs in learning, or in conditioned reflexes. Feedback combines immediately with the immediate input signal to drive the responsive power gain element, without changing the basic responsiveness of the system to future signals. Reinforcement changes the basic responsiveness of the system to future signals, without combining with the immediate input signal. Reinforcement is a permanent change in the responsiveness of the system to all future signals. Feedback is only transient, being limited by the duration of the immediate signal.

Positive feedback control
Positive feedback is a process in which the effects of a small disturbance on (a perturbation of) a system include an increase in the magnitude of the perturbation. That is, A produces more of B which in turn produces more of A. In contrast, a system that responds to a perturbation in a way that reduces its effect is said to exhibit negative feedback. These concepts were first recognised as broadly applicable by Norbert Wiener in his 1948 work on cybernetics.

Positive feedback tends to cause system instability, divergence from equilibrium, oscillation and often exponential growth. When there is more positive feedback than there are stabilising tendencies, systems will typically accelerate towards a non-linear region, which may stabilise the system or (depending on the system) even damage or destroy it. Positive feedback may end with the system 'latched' into a new stable state. Positive feedback is controlled by signals in the system being filtered, damped or limited, or it can be cancelled or reduced by adding negative feedback.

In the term "positive feedback", "positive" refers to the mathematical sign of the direction of change rather than the desirability of the outcome. To avoid this confusion, it is sometimes better to use other terms such as self-reinforcing feedback. In social and financial systems, positive feedback effects may also be referred to as 'virtuous' or 'vicious' circles.

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

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

Biochemical control occurs when the accumulation of the product stimulates production of an enzyme responsible for that product's production. Positive feedback control occurs when information produced by the feedback increases and accelerates the response.

Negative feedback control mechanisms
Negative feedback mechanisms consist of reducing the output or activity of any organ or system back to its normal range of functioning. A good example of this is regulating blood pressure. Blood vessels can sense resistance of blood flow against the walls when blood pressure increases. The blood vessels act as the receptors and they relay this message to the brain. The brain then sends a message to the heart and blood vessels, both of which are 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, and would cause vasoconstriction.

Another important example is seen when the body is deprived of food. The body would then reset the metabolic set point to a lower than normal value. This would allow the body to continue to function, at a slower rate, even though the body is starving. Therefore, people who deprive themselves of food while trying to lose weight would find it easy to shed weight initially and much harder to lose more after. This is due to the body readjusting itself to a lower metabolic set point to allow the body to survive with its low supply of energy. Exercise can change this effect by increasing the metabolic demand.

Another good example of negative feedback mechanism is temperature control. The hypothalamus, which monitors the body temperature, is capable of determining even the slightest variation of normal body temperature (37 degrees Celsius). Response to such variation could be stimulation of glands that produce sweat to reduce the temperature or signalling various muscles to shiver to increase body temperature.

Both feedbacks are equally important for the healthy functioning of one's body. Complications can arise if any of the two feedbacks are affected or altered in any way.

Negative feedback is the stopping of the synthesis of an enzyme by the accumulation of the products of the enzyme-mediated reaction. Negative feedback control occurs when information produced by the feedback reverses the direction of the response and regulates the secretion of most hormones.

Negative feedback loop is a biochemical pathway where the products of the reaction inhibit production of the enzyme that controlled their formation.

Homeostatic imbalance

Many diseases are a result of disturbance of homeostasis, a condition known as homeostatic imbalance. As it ages, every organism will lose efficiency in its control systems. The inefficiencies gradually result in an unstable internal environment that increases the risk for illness. In addition, homeostatic imbalance is also responsible for the physical changes associated with aging. Even more serious than illness and other characteristics of aging is death. Heart failure has been seen where nominal negative feedback mechanisms become overwhelmed and destructive positive feedback mechanisms then take over.

Diseases that result from a homeostatic imbalance include diabetes, dehydration, hypoglycemia, hyperglycemia, gout, and any disease caused by a toxin present in the bloodstream. All of these conditions result from the presence of an increased amount of a particular substance. In ideal circumstances, homeostatic control mechanisms should prevent this imbalance from occurring, but, in some people, the mechanisms do not work efficiently enough or the quantity of the substance exceeds the levels at which it can be managed. In these cases, medical intervention is necessary to restore the balance, or permanent damage to the organs may result.

According to the following quote, every illness has aspects to it that are a result of lost homeostasis: "Just as we live in a constantly changing world, so do the cells and tissues survive in a constantly changing microenvironment. The 'normal' or 'physiologic' state then is achieved by adaptive responses to the ebb and flow of various stimuli permitting the cells and tissues to adapt and to live in harmony within their microenvironment. Thus, homeostasis is preserved. It is only when the stimuli become more severe, or the response of the organism breaks down, that disease results - a generalisation as true for the whole organism as it is for the individual cell."

4.0 CONCLUSION

In this unit you, you have been introduced to homeostasis in animals; the principles of homeostasis using regulation of body temperature and blood glucose in animals. Also, the organs use for homeostasis; osmoregulatory organ (both in vertebrate and invertebrate), evolution of kidney in different groups of vertebrate animals were learnt. Homeostasis control system, feedback mechanism; open and closed loop in control system, positive and negative feedback mechanism and homeostatic imbalance were discussed.

5.0 SUMMARY

In this unit, the important points considered include: homeostasis in animals; principles and organs used for homeostasis with examples in vertebrate; bony, marine and cartilaginous fish, amphibians and reptiles, mammal and bird etc. and invertebrate, examples are flatworm (earthworm) and insects, etc.

Feedback mechanism and homeostatic control system; homeostatic control mechanisms have at least three interdependent components for the variable being regulated: The receptor is the sensing component that monitors and responds to changes in the environment. When the receptor senses a stimulus, it sends information to a "control centre", the component that sets the range at which a variable is maintained. The control centre determines an appropriate response to the stimulus. In most homeostatic mechanisms, the control centre is the brain. 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 either enhancing it with positive feedback or depressing it with negative feedback

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the principles of homeostasis.
2. Explain osmoregulatory organs in invertebrates.
3. Explain the process of waste formation and list the different group of animals and the form of waste they excrete.

4. Explain the forms and functions of kidney in different group of animals
5. What is homeostatic control mechanism?
6. Explain the two types of feedback mechanism with examples.
7. Explain the term homeostatic imbalance.

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MODULE 5 PLANT-WATER RELATIONS

UNIT 1 DIFFUSION AND OSMOSIS

CONTENTS

1.0 INTRODUCTION

Water is vital to plant life and well being. It forms 80-90% of fresh weight of plants. Plants grow in soil and absorb water and minerals which is available in soil. Therefore water has great importance for plants. Water functions as a reactant as well as a product. Water and dissolved substances are transported within and outside the cell through the process of diffusion and osmosis. An understanding of plant water relations depends upon an understanding of the principle of diffusion and osmosis. Different regions of the plant body maintain varying concentrations of both solute and water molecules. The varying concentrations create gradients through substances must travel. Hence, this unit will focus on the principle of diffusion and osmosis.

2.0 OBJECTIVES

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

- define the terms diffusion and osmosis
- highlight the factors affecting the rate of diffusion
- differentiate between diffusion pressure and osmotic pressure.

3.0 MAIN CONTENT

3.1 Diffusion

Diffusion is the movement of molecules or ions of solid, liquid or gas from an area of its greater concentration to an area of its lesser concentration. Diffusion continues till the dynamic equilibrium is established. At this stage of dynamic equilibrium, the movement of molecules is equal in both directions therefore, diffusion process stops due to equal movement of molecules. On account of their kinetic energy which is present in the molecules, the substances are distributed throughout the available space. The movement of the molecules depends upon kinetic energy during diffusion. The movement of molecules occurs from its higher energy towards its lower energy. The diffusion of one substance is independent of the other.

Diffusion pressure

As molecules diffuse from the region of higher concentration to the region of lower concentration, the diffusing molecules tend to exert a kind of pressure known as diffusion pressure. This is developed due to difference in the concentration of molecules of the materials. Diffusion pressure is high at greater concentration and it is low at lesser concentration. Diffusion pressure of a pure solvent is always higher than its solution. Water molecules moves from its higher concentration to its lower concentration in plants.

Factors affecting the rate of diffusion Temperature

The rate of diffusion is directly proportional to the temperature, it means rate of diffusion increases with rise in temperature. Rate of diffusion α temperature. Diffusion stops approximately at 0°C.

Density

Rate of diffusion is inversely proportional to square root of its relative density. It means rate of diffusion lowers down with increasing density. The diffusion of materials is in the following sequence according to their density. The rate of diffusion is greatest in gas, followed by the liquid and least in solid.

Pressure

The rate of diffusion is directly proportional to the pressure, it means rate of diffusion increases with increase in pressure. Rate of diffusion α pressure.

Size of molecule
The diffused molecules/atoms/ions are inversely proportional to their size and mass. The rate of diffusion decreases with increase in their size.

Significance of diffusion

- Exchange of gases like CO_2, O_2 occurs through diffusion.
- Absorption of essential elements from the soil takes place through this process.
- The distribution of hormones which are synthesised in the plants takes place through diffusion.
- The process of transpiration is a diffusion process. The evaporation of water from the intercellular spaces is linked with diffusion during the transpiration.
- The ions of the mineral materials entered into the plant body only through the diffusion during the passive absorption.
- The process of osmosis is a special type of diffusion process.

3.2 Permeability

Permeability refers to the exchange of materials through a membrane. There are four different types of membranes on the basis of their permeability:

Permeable membranes
These are membranes that allow movement of both - solutes and solvent through them, e.g. cellulosic cell wall.

Impermeable membranes
These are membranes that do not allow the movement of substances through them, e.g. cutinized cell wall.

Semipermeable membranes
These are membranes which allow the passage of solvent molecules but do not allow the passage of solutes, e.g. parchment membrane, celloidin membrane.

Selectively-permeable membrane or differentially permeable membranes
These are membranes which allow selective solutes to pass through them along with the solvent molecules, e.g. plasma membrane, tonoplast. This membrane is permeable for CO_2, N_2, O_2 gases and alcohol, ether and water; but impermeable for polysaccharides and proteins.

3.3 Osmosis

Osmosis is movement of solvent or water molecules from the region of their higher diffusion pressure or free energy to the region of their lower diffusion pressure or free energy across a semi-permeable membrane.

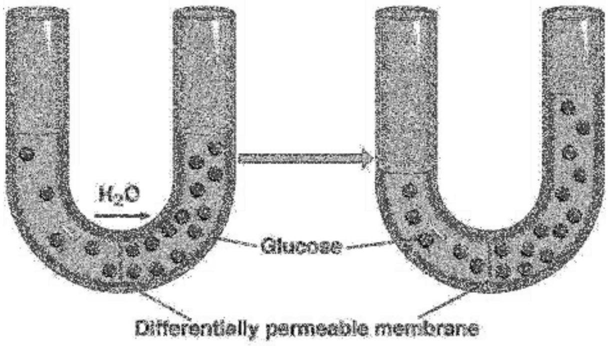

Fig. 1: Passage of Water through the Semi-Permeable Membrane

The passage of water through the semi-permeable membrane shown above is an example of osmosis. When a cell is placed in hypertonic solution, water molecules come out from the cell into the outer solution. This is termed **Exosmosis**. It is the movement water molecules out of the cell. Due to exosmosis, the protoplasm shrinks and leaves the cell wall and thus, cell becomes flaccid, which is called plasmolysed cell and the phenomenon is called **plasmolysis**. Hence, exosmosis leads to plasmolysis. However, **endosmosis** is the entry of water molecules into the cell during osmosis. If the plamolysed (flaccid) cell is placed in hypotonic solution water enters into the cell. Endosmosis makes the restores the turgidity of the cell.

Osmotic pressure

Osmotic pressure can be defined as the pressure which is developed in a solution in which solution and water is separated by semi-permeable membrane or as the hydrostatic pressure developed in a solution which is just enough to stop the entry of the solvent into the solution when the two are separated by a semi-permeable membrane. The osmotic pressure of water is zero. This is due to presence of solute in the solution. The osmotic pressure of a solution is directly proportional to the concentration of solute in it. The osmotic pressure shows maximum variation in the plants cells. The highest osmotic pressure is found in the halophytes. The lowest osmotic pressure is found in aquatic plants or hydrophytes. The osmotic pressure of a solution is measured by osmometer. The value of osmotic pressure depends upon the concentration of the solution, the higher the concentration of solutes in a solution, the greater the osmotic pressure. The osmotic pressure of a solution is calculated mathematically as given below:

OP	=	mRT
where m	=	molar concentration
R	=	Gas constant [0.082 mole/molecules]
T	=	Absolute temperature

Factors affecting osmotic pressure

a) ***Concentration***: The osmotic pressure of a solution increases with increase in the concentration of its solutes.

b) ***Temperature***: Osmotic pressure of a solution is proportional to the temperature. This implies that as temperature increases the osmotic pressure also increases.

c) Dissociation of solutes also increases the osmotic pressure of solution.

Significance of osmosis

- Root hairs of the roots absorb water from the soil through the process of osmosis.
- The conduction of water from one cell to another cell in plant and distribution of water in plant through the phenomenon of osmosis.
- Turgidity is developed by the process of endosmosis which helps to maintain a definite shape of leaves, stem and flowers. Turgidity also provides mechanical strength to the plants.
- The opening and closing of stomata also depends upon the process of osmosis.
- The leaves of *Mimosa pudica* ("Touch me not") are dropping down only by contact and dehiscence of fruits and sporangium, all these, depend upon turgor changes after osmosis.
- The resistance is increased due to high osmotic concentration against the dry climate and cold temperature [below 0ºC].
- The growth of the young cells depends as the result of osmosis. The other daily activities also take place by osmosis and plasmolysis.
- The fresh water growing plants and animals either wilt or die when they are kept in marine water.

4.0 CONCLUSION

Water and solutes materials are crucial for the survival plant life in its habitat. A balanced understanding of the basic principles of diffusion and osmosis is requisite to the understanding of plant water relations of plants as water and dissolved substances are usually transported within and outside the cell through the process of diffusion and osmosis. In this unit, you have learnt that both diffusion and osmosis are significant for the plant life in its environment.

5.0 SUMMARY

Water and solutes are essential for the maintenance and survival of plant life. An understanding of the principle of diffusion and osmosis is important to understanding the principle of plant water relations. Diffusion is the movement of molecules or ions of solid, liquid or gas from an area of its greater concentration to an area of its lesser concentration. Osmosis is movement of solvent or water molecules from the region of their higher diffusion pressure or free energy to the region of their lower diffusion pressure or free energy across a semi-permeable membrane. Osmosis is a type of diffusion.

6.0 TUTOR-MARKED ASSIGNMENT

1. Why is osmosis an important phenomenon in plants?
2. What is plasmolysis? How does it occur?
3. How do you measure the osmotic pressure in plants?

7.0 REFERENCES/FURTHER READING

Dutta, A.C. & Dutta, T.C. (1998): *Botany for Degree Students*. (6th ed.). India: Oxford University Press.

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UNIT 2 OSMOTIC AND WATER POTENTIALS

CONTENTS

1.0 INTRODUCTION

In plants, water moves via membranes. This movement of water through membranes in plants is described as water potential. Water potential is a fundamental term derived from thermodynamics. There are two important factors affecting the water potential of plant cells. They are solute concentration (osmotic concentration) and the pressure generated when water enters and inflates plant cells. These two factors are expressed in the terms **solute or osmotic potential** and **pressure potential**. In this unit, all these terms will be explained.

2.0 OBJECTIVES

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

- differentiate between solute and water potential
- define the following terms
  - Turgor pressure
  - wall pressure
  - diffusion pressure deficit (DPD)
  - suction pressure
- highlight the significance of turgor pressure and imbibition in plants.

3.0 MAIN CONTENT

3.1 Osmotic Potential (Solute Potential) ($-\Psi_s$)

Osmotic pressure is the pressure which exists in a solution, in which the solution and water is separated by semi-permeable membrane. In thermodynamics, the osmotic pressure is called osmotic potential or solute potential. Solute potential is a measure of the change in water potential of a system due to the presence of solute molecules. It is expressed as (Psi) is Greek word Ψ_S is usually negative ($-\Psi_S$). The effect of dissolving solute molecules in pure water is to reduce the concentration of water molecules and hence to lower the water potential. All solutions therefore have lower water potentials than pure water.

Turgor pressure and wall pressure

Turgor pressure is not applicable for free solution. This is only applicable for living cells. Turgor pressure is also known hydrostatic pressure. When a cell is immersed in water, the water enters into the cell because osmotic pressure of the cell sap is higher. The cell content press upon the wall or develop a pressure against the membrane which is called **turgor pressure (T.P.)** The turgor pressure is counter balanced by an equal and opposite pressure of the thick cell wall on the enclosed solution, known as **wall pressure**. It means the amount of pressure exert by cytoplasm on the cell wall is same and in opposite direction as pressure exerted by the cell wall towards the inner side on the cytoplasm. Therefore, wall pressure and turgor pressure are equal to each other. **T.P. = W.P.** An animal cell burst when place in pure water because wall pressure is absent due to absence of cell wall. For example the consequence of endosmosis in the animal cell can be demonstrated by placing RBCs of human blood in distilled water contained in a dish. When examined after some time, the RBCs are found to have burst open leaving their cell membranes as empty cases. A flaccid cell has zero turgor pressure. The highest value of turgor pressure is found in turgid cell and it is equal to the osmotic pressure. Fully turgid cell has **OP = TP**. The value of turgor pressure is negative during the plasmolysis of the cell.

Significance of turgor pressure

i.) The protoplasm of the cell attached with the cell wall due to turgidity of the cell and cell becomes stretched. It maintains the normal shape of the cell in which physiological processes are going on.

ii.) The spatial 3-D structure of mitochondria, chloroplast and microbodies are maintained due to turgor pressure which is essential for their physiological activities.

iii.) Turgor pressure is essential for maintaining the definite shape of delicate organs.

iv.) Turgor pressure helps in cell elongation.

v.) Plant movement like, movement of guard cells of stomata, wilting movement and seismonastic movements etc. are dependent upon turgor pressure.

vi.) Turgor pressure is essential for sprouting plumules and radicles from the seed. Turgor pressure provides essential support to the plumule to come out of the soil and help inpenetration of radical into the soil.

vii.) Turgor pressure help in growth of the plant as well as it is responsible maintaining (erect) position of the plants.

Diffusion pressure deficit (DPD)

The term "diffusion pressure deficit" [DPD] was used by B.S. Meyer. This is characteristic of water in solution. But generally, it is called DPD of solution or cell. The DPD of any solution is the difference between the diffusion pressure of the water which is present in the solution and diffusion pressure of pure water. DPD determines the direction of osmosis and the power of absorption of the cell. In relation to plants, DPD may be defined as the amount of that pressure by which water is sucked into the cell or expels outside the cell. Therefore, it is known by as **suction pressure** or **Absorption potential or suction force.** DPD is also known as **demand of water deficit**. The diffusion of water or solute takes place from the region of lower DPD to the region of higher DPD in the process of osmosis.

Usually in a cell, the osmotic pressure is greater than the turgor pressure. The difference between osmotic pressure and turgor pressure is called **suction pressure or DPD**. The diffusion pressure deficit is the power (capacity) of water absorption. The DPD of any free solution is equal to the osmotic pressure of that solution because it has no turgor pressure. Therefore **-** DPD = OP. However, wall pressure develops due to turgor pressure through the process of osmosis. It increases the diffusion pressure of the solution of cell and decreases the DPD. This relation can be expressed by the following equation:

DPD = OP – WP

DPD = OP – TP (Q TP = WP)

If a cell is placed in pure water or less concentrated of a solution than the cell sap, then water enters into the cell as a result turgor pressure develop in the cell. The cell starts swelling due to the turgor pressure.

Simultaneously, concentration of cell sap decreases due to continuous inflow of water. Therefore OP decreases due to this. Eventually, when value of TP will be equal to the OP then DPD will be zero. At this stage cell becomes in a fully turgid state. Therefore, in a fully turgid cell,

DPD = OP – TP

When OP = TP

So that OP – TP = 0 DPD = 0

If the cell in a flaccid state then its TP and WP would be zero and value of DPD would be equal to OP. If a flaccid cell placed in water then

water enters into cell because DPD of the cell sap is higher.
Sometimes the value of turgor pressure is negative as in plasmolysed cell. In this state
DPD = OP – TP [TP = – ve] DPD = OP – [– TP] = OP + TP DPD = OP + TP
So that the DPD of the plasmolysed cell is greater than osmotic pressure. It means
DPD = OP + TP

Or the demand of water in plasmolysed cell is greater. It means when the osmotic pressure and turgor pressure will be equal, in that time DPD will be zero. Water will not enter in that type of cell. But, when turgor pressure is lesser than the osmotic pressure then some DPD will be definitely present in the cell and water would enter into the cell. When two different concentration of solution is separated by semi permeable membrane then entry of water depends on DPD.

3.2 Water potential (Ψ_W)

Water possesses kinetic energy, which means that in liquid or gaseous form they move about rapidly and randomly from one location to another. The greater the concentration of water molecules in a system, the greater the total kinetic energy of water molecule in that system and the higher the water potential. Pure water therefore has the highest water potential. If two systems containing water are in contact (such as soil and atmosphere, or cell and solution) the random movements of water molecules will result in the net movement of water molecules from the system with the higher water potential (higher energy) to the system with the lower water potential (lower energy) until the concentration of water molecules in both systems is equal. The water potential of pure water is zero, the pure water have greater free energy. The free energy lowers down by are addition of solutes. The difference between the free energy of molecules of pure water and free energy of molecules of water of the solution is called water potential of the system. Water always flows from higher water potential to lower water potential. Water potential is represented by Greek word (Psi) Ψ_W and it is measured in bars. Water potential is equal to DPD but opposite in sign. Its value is negative.

Types of solutions Isotonic solutions

If solution, in which a cell is placed, has equal osmotic pressure to that of cell sap, the outer solution is called **isotonic solution**. In this type osmotic concentration of the both solutions is same. In such type of solution is neither endosmosis nor exosmosis occurs.

Hypotonic solutions

If the osmotic concentration of outer solution is less than that of the cell sap, the outer solution is called **hypotonic solution**. If a cell is placed in such solution endosmosis takes place as a result, a cell swells up; e.g. raisins swell up when placed in distilled water.

Hypertonic solutions

If the osmotic concentration of a solution is higher than that of the other (cell sap) solution the solution is known as **hypertonic solution**. If a cell placed in this type of solution, exosmosis takes place. It means water of the cell sap is diffused out into the outer solution resulting in the cell becoming flaccid; e.g. grapes placed in higher concentration of sugar solution which becomes flaccid (contracts).

Plasmolysis

If a plant cell placed in a hypertonic solution, water molecules diffuse out from the cell. As a result of exosmosis, the protoplasm of the cell is detached from the cell membrane (cell wall) and starts shrinking in the centre. This is called **plasmolysis**. The various sequences of plasmolysis are as follows:
In a turgid cell, the cell sap pushes away the protoplasm so that it remains with contact of cell wall.

When it placed in a hypertonic solution, the volume of the cell reduces due to shrinking of cell because some amount of water of cell sap is diffused out by exosmosis. Turgor pressure decreases by which cell wall is not pushed by the protoplasm, so that shrinking cell wall reduced in total volume of the cell. This situation is called the first stage of plasmolysis or limiting plasmolysis.

If the diffusion of water to the outside is continued by the exosmosis then central vacuole contracts and with this protoplasm also shrinks but cell wall is not contracting. So that protoplasm is seems to detaching from the corners of cell wall. This condition is known as second phase of the plasmolysis or "Incipient plasmolysis". Hypertonic solution is present in between the cell wall and protoplasm.

The shrinking of protoplasm is continuous due to continuous exosmosis, it detached from the cell wall and assumed a spherical shape. This phase is known as "Evident plasmolysis" full plasmolysis.

Types of plasmolysis

Convex plasmolysis: The protoplasm is completely contracted and becomes convex shaped in this stage.

Concave plasmolysis: The protoplasm is not contracted completely and it is attached with the cell wall at some places through the protoplasmic fibres or plasmodesmata. These fibres are called fibres of Hetch. Because of these fibres, protoplasm seems to be concave shaped.

Significance of plasmolysis

(i) A living cell is distinguished from the non living [dead] cell through plasmolysis. This is due to the fact that plasmolysis does occur in dead cell only.
(ii) The osmotic pressure of any one cell can be measured by limiting plasmolysis.
(iii) If the plasmolysis remains for long duration in a cell then it dies. For example, to destroy the weeds, salts are placed in their roots. Fish and meat are prevented from spoilage by salting which inhibits the growth of bacteria and fungus. Also, higher concentration of sugar in jams and jellies stops the growth of bacteria and fungus. High amount of manure near the root causes death of the plant due to plasmolysis.

3.3 Imbibition

Imbibition is best described as the adsorption of undissolved liquid by any solid materials or adsorption of water by hydrophilic colloids. It refers to a physical process by which a dry solid colloid material swells up by absorption of water. The plant’s cell wall is made up of colloidal substances such as cellulose, pectin, hemicellulose, etc. All these are hydrophillic in nature. Hence they tend to imbibe water easily. The adsorption of liquid takes place on the materials in the process of imbibition. Proteins, Agar - agar, starch etc. all substances are imbibants. Agar - agar can absorbs 99 times more water than that of its weight. Some of the proteins absorb 15 times more water. Affinity should be present between imbibants and liquid material. Cellulose comparatively has very less power of imbibition. The seeds have good amount of colloidal materials so that they are good imbibant materials. Imbibition mainly is diffusion of water. The DPD of dry imbibant material is zero. So that when they come in contact of water or solution water starts diffusing into the imbibant materials. When the diffusion pressure of the imbibant material is equal to the diffusion pressure of the outer liquid in a saturation state then kinetic equilibrium is established. Excluding of liquid form, imbibition is also found in vapour forms.

Wooden doors absorb water in the form of vapours and swells up during the rainy season.

Effects of imbibition Swelling

The volume of the materials increased in the process of imbibition. But the total volume is found less by the sum of the both volumes. Imbibant material + water = swelling. 10 + 90 = less than 100 (always)

Liberation of heat

The heat is released during imbibition. The water molecule becomes motionless due to imbibition by which they lose kinetic energy. This energy again appears in the form of heat. This is known as "heat of wetting".

Imbibition pressure

A huge pressure is developed in a material limited in space due to imbibition. The value of this pressure is reaches up to many thousands atmospheric pressure. This method is used in ancient period for breaking of rocks. Dry wood is filled in the natural grooves of rocks and water is poured over them. The rocks are broken due to their swelling.

Factors affecting the imbibition

Temperature: Imbibition is directly proportional to the temperature.

Texture of imbibant: The imbibition is found less in compactly arranged material like wood, and more in lighter or soft material like gelatin.

pH: The negative charged colloids like cellulose shows greater imbibition in alkaline (high pH) environment (medium). Positive charged colloids show more imbibition in acidic medium. Protein because of being amphoteric shows very less imbibition in neutral medium and it shows more imbibition in acidic and alkaline medium.

Electrolytes: Electrolytes neutralise the charges of the imbibants or reduce the imbibition process by influencing osmotic pressure.

Pressure: Imbibition decreases with increasing pressure.

Significance of imbibition

Absorption of water during the seed germination is only through imbibition.

Breakage of seed coat during the seedling is due to imbibition process proteins, fats and starch is present in the kernel. This kernel swells up more as compared to the seed coat which breaks the seed coat. Seed coat is made of cellulose.

Many hydrophillic colloids are present in the cell wall and protoplasm of plant. Absorption of water takes place in young cells through the imbibation process.

Resurrection in many plants like *Selaginella*, Lichen takes place due to the process of imbibition.

Hydrophilic materials reduce the amount of free water which protects the cell during dryness and it protects from the lowest temperature during the winter.

The DPD of the some fruits is higher than their osmotic pressure. Higher DPD is due to imbibation, so that they can absorb water in extreme xeric conditions (dry).

Many dry fruits (cotton balls, pods of Moong, Urad) dehiscence through the absorption of water in dry conditions by imbibition. The water enters into the aerial roots and dry fruit through imbibition.

Newly formed wood swells up in rainy season. pH - value : By Sorrenson it indicates the acidity or alkalinity of substance.

4.0 CONCLUSION

Osmotic potential and pressure potential are two important factors that affect the movement of water across membranes. Osmotic potential is a measure of the change in water potential of a system due to the presence of solute molecules. Water potential is highest in pure water. The effect of dissolving solute molecules in pure water is to reduce the concentration of water molecules and hence to lower the water potential. All solutions therefore have lower water potentials than pure water.

5.0 SUMMARY

Osmotic potential and pressure potential are two important factors that affect the movement of water across membranes. Osmotic potential is a measure of the change in water potential of a system due to the presence of solute molecules. It is otherwise known as solute potential or osmotic pressure. Water potential is highest in pure water. The effect of dissolving solute molecules in pure water is to reduce the concentration of water molecules and hence to lower the water potential. All solutions therefore have lower water potentials than pure water. Turgor pressure (T.P.) is a pressure exerted against the cell membrane by the cell content when a cell is immersed in water and the water enters into the cell because osmotic pressure of the cell sap is higher. Imbibition is a physical process by which a dry solid colloid material swells up by absorption of water.

6.0 TUTOR-MARKED ASSIGNMENT

1. Why is osmotic concentration of a solution the same as its solute concentration?
2. Highlights the significance of turgor pressure to living cells.
3. Outline the factors that affect imbibition?

7.0 REFERENCE/FURTHER READING

Taylor, D.J; Green, M.P.O & Stout, G.W. (1999). *Biological Science.* (3rd ed.). Cambridge: Cambridge University Press

UNIT 3 ABSORPTION OF WATER AND MINERALS

CONTENTS

1.0 INTRODUCTION

Water and mineral nutrients are two essential requirements for plants healthy growth. The former forms a vital component of protoplasm in plants, and it accounts for about 80-90% of fresh weight of the plant. Water participates in several vital activities of the plants. It plays significant roles as a universal solvent in the translocation of both organic and inorganic materials within the plants. Mineral nutrients required by plants exist in the dissolved form ions of salts. While in solution, these ions are capable of dissociating and moving freely. The soil constitutes the primary source of mineral salts for plants and their uptake is carried out via the subterminal meristematic region of the root. This uptake is usually greatest in this region of the root hair. In addition, mineral salts are present with soil particles and water in colloidal form. The dissolved mineral ions are conducted via the xylem as sap by the combined efforts of **passive** and **active absorption.** In this unit, you will find the mechanisms involved in the absorption of water and mineral salts in plants.

2.0 OBJECTIVES

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

- highlight the different types of water in soil
- describe the mechanisms of water absorption in plants
- describe roles of the root in the absorption of water by plants
- describe the mechanism of absorption of mineral salt
- explain the term ascent of sap.

3.0 MAIN CONTENT

3.1 Significance of Water to Plants

Water, as a universal solvent constitutes a necessary requirement for healthy growth and survival in plants. It is a vital constituent of the protoplasm, serves as important medium for a number of metabolic activities and translocation of minerals in plants. Water is essential for germination of seeds. All enzymes in plant can only attain their optimum condition in the presence of water. In addition, water participates in condensation and hydrolysis of water activities which are going in the cells of the plant. It compensates the loss of water in transpiration.

3.2 Plants in Relation to Soil Water

A very good soil is essential for healthy plant growth. The soil derives its water primarily from rain. Some of the rain water goes into the water reservoir, in form of runoffs, while the rest of the water enters into the land. Soil water may exist in different forms;

Gravitational water: In a well saturated soil, the water percolates downward under gravitational influence. This is called soil water table. This water is not available to the plant because it lies far below the reach of the roots, but available by tube-well irrigation.

Hygroscopic water: This thin film of water which is tightly held by the soil particles is called hygroscopic water. This water is also not available to the plants, it is absorbed by some shallow rooted plants.

Chemical water: The amount of water present in the chemical compounds which is present in the particles of soil. This is not available to the plants.

Capillary water: Water exists between soil particles and in smaller capillary pores is called capillary water. It is directly available to the plants and it is usually accessible to the roots of the plants, where they can be assimilated by the plant.

Holard: "It is that total amount of water which is lies in the soil". Holard = Chresard + Echard

Chresard: This is that water which is found in soil, useful to the plants.

Echard: "This water is not absorbed by the plants". The maximum amount of water reaches up to the stable resource due to gravitational force while the remaining amount of water held between the soil particles is called **field capacity**. OR "Accumulation [Holding] capacity of water which is found in soil is known as field capacity". Water holding capacity of smooth clay has higher capacity. Sandy soil has lowest water holding capacity. Minerals occur in soil in form of solution. The osmotic pressure of this solution is dependent on their concentration.

3.3 Water Absorption by Roots

Water is absorbed either by the whole surface of the roots or by the rhizoids. However, in higher plants such as pteridophytes and spermatophytes, absorption of water takes place through the root. In higher plants, the root is divided into four morphologically distinct parts which participate in the absorption of water.

Root cap region
A thin, small and smooth cap-like structure is present at the apex of the root called the **root cap**.

Meristematic region
This region lies just below the root cap. The cells of this region divide continuously. The rate of ion absorption is highest in this region.

Elongation region
This is 3-4 mm thick region which lies behind the meristematic region in which new cells grow in length is called **elongation region**. Absorption of water is very slow from this region.

Maturation region (root hair region)
This region lies behind the elongation region in which differentiation of cell takes place to perform different functions. Root hairs are only found in this region. The maximum absorption of water takes place from this region. These root hairs increase the absorption area of roots.

Path of water absorption

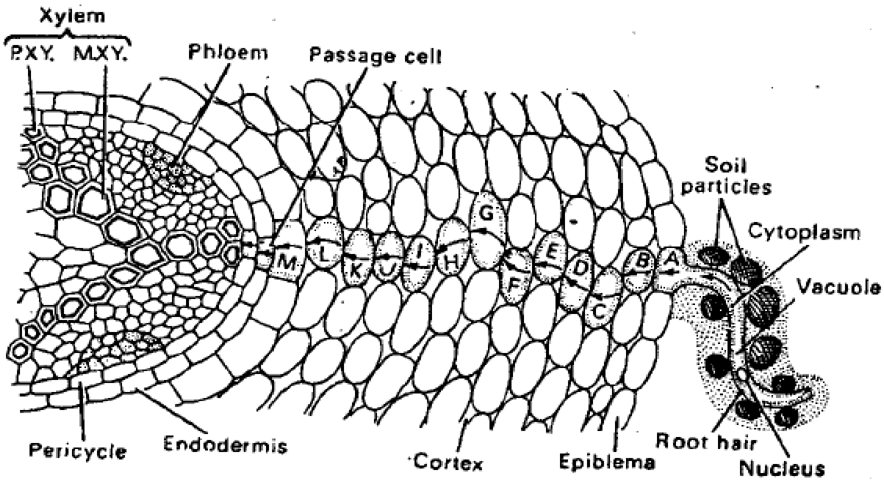

Fig.1: Path of Water Absorption in Root
Source: Taylor *et al.* (1999)

The path of water absorption is best described in the direction of the osmotic gradient. The water situated in the soil is has to reach up to the xylem of root. Root hairs remain in contact with water**.**
The osmotic pressure is greatest in the Soil solution →Root hairs (Epiblema) →Cortex →Endodermis (passage cells) →Pericycle cells →Protoxylem →Metaxylem.

Water enters into the epidermis of root hairs. From here water reaches up to the endodermis through the cortex. The walls of endodermis are suberised. But cells lies in front of the protoxylem are thin walled known as passage cells. These cells transfer water to the xylem. From here water reaches the xylem from endodermal cells through the thin walled pericycle cells.

Mechanism of water absorption
Water is absorbed by two different ways:

(a) Active water absorption.
(b) Passive water absorption.

(a) Active water absorption

This process occurs as a result of activities in the root. This process takes place at that time when transpiration is going slowly and water is sufficient in the soil. In active absorption, water may be absorbed through an expenditure of energy which is produced by metabolic activities. This absorption is of two types.

1. **Osmotic active water absorption**: The cell wall acts as permeable membrane and plasma membrane acts as semi-permeable membrane in root hairs. Water is absorbed through osmosis when the osmotic concentration of soil water is less than that of the cell sap. The outermost pectin layer of root hair absorbs water from the soil solution (Endosmosis). At this time DPD of the soil solution is less than that of the DPD of root hair. Therefore water comes into the root hair from the soil. The absorption of soil solution root hairs becomes turgid and their osmotic pressure decreases DPD of the ‘B’ cell increases due to decreasing of OP and increasing T.P. and water comes into 'A' cell from the ‘B’ cell of the root hair. Magnitude DPD of 'B' cell decreases due to entrance of water and DPD of the adjacent 'C' cell increases. So that water enters into the ‘C’ cell from the ‘B’ cell due to higher DPD. Therefore water reaches up to xylem via ‘C’ cell i.e. cortex, endodermis and pericycle. Hence according to the osmotic theory on the basis of increasing diffusion pressure deficit [DPD] water reaches up to the xylem. In this sequence absorption of water continues.

2. **Non-Osmotic Active Water Absorption**: Water is absorbed in those conditions where the osmotic pressure of soil solution is greater than that of the osmotic pressure of cell sap of root hair. In this situation water is not absorbed by osmotic process. Energy is used in this condition which is produced by metabolic activities of living cells of root. The cells of root produced energy in the form of ATP by which water is absorbed from the soil against the osmotic gradient. A positive (+ ve) pressure is developed in xylem of the roots due to the activity of living cells of roots. This is called "root pressure". This root pressure helps in absorption of water. This pushes water from xylem of root towards the xylem of stem. Root pressure is measured by manometer. It has been found that plant throw out liquid (water) with a force when the stem is cut above the ground this phenomenon is called **bleeding** or **exudation**. This phenomenon occurs due to root pressure.

(b) Passive water absorption

Passive absorption takes place through the fast transpiration in the aerial parts and some force develops in the shoot. Root remains inactive (passive) in passive absorption. It means absorption of water through the root rather than by the root. The amount of water decreases in the mesophyll cells of leaves due to transpiration. This loss of water increases the DPD. For the compensation of this loss, these cell pulls water from neighbouring cells. In this way water is pulled from one cell to another cell and through the endodermis, pericycle and lastly from the xylem. Fast transpiration causes higher DPD in xylem. Resulting a negative tension developed. This tension is known as "suction force" or “transpiration pull". An unbroken water column established from the xylem of the leaves to the xylem of roots is due to transpiration pull. Water absorbed with the help of roots is due to negative transpiration pull. The rate of passive absorption of water is higher. The total loss of water is compensated by only through this absorption. This absorption is neither energy required nor active participation of root. The highest absorption of water takes place in plant only through the passive technique.

Factors affecting water absorption

(1) Available soil water

Plant absorbs capillary water which is present in soil. The absorption of water depends on the amount of capillary water present in the soil. Absorption increases by increasing amount of capillary water. If, water is present in higher amount in the soil then such soil is said to be water logged.

(2) Soil temperature

Soil temperature affects the chemical potential of water, the permeability of cell membrane, the activity of enzymes and the viscosity of capillary water. Increasing or decreasing soil temperature lowers down the rate of absorption of water. If temperature of soil is higher, then enzymes start degeneration and absorption of water decreases. The rate of absorption also decreases with decreasing soil temperature. This is because at low temperature, movement of capillary water decreases and the viscosity of water increases.

(3) Soil air

Absorption of water proceeds more rapidly in well aerated soil. Deficiency of oxygen in soil results in improper respiration in roots. In addition of that bacteria produced toxicity by the formation of CO_2 and organic acids in anaerobic environment. Deficiency of oxygen affects the process of osmosis. It reduces the rate of absorption.

(4) Soil salt

The rate of water absorption in plants is inversely proportional to the concentration of mineral salts present in soil. Water absorption only takes place in appropriate soil solution. When the concentration of soil minerals is more the rate of water absorption, therefore saline soil is physiologically dry. Halophytes grow only in this kind of soil. Hence, for proper absorption, concentration of soil solution should be normally less than that of root hairs.

(5) Transpiration

The rate of water absorption is directly proportional to the transpiration. The rate of absorption increases due to increase in transpiration; hence, passive water absorption increases due to transpiration. Ninety nine per cent of absorbed water is transpired by the plants; only 1% is available to perform the various vital activities of the plants. The rate of the absorption is maximum during the summer noon but water absorption decreases. In this condition plant shows "temporary wilting". This is because cells contract due to decreasing turgidity of cells; hence, plants droop. But, rate of the absorption increases during the evening as compared to the transpiration which increase the turgidity of the cells, and drooping of the plant stops. "Permanent wilting" occurs when wilted plant will not recover after water is added to the soil.

3.4 Mechanism of Absorption of Mineral Salts

The dissolved mineral salts and water are conducted by the root of plants by two mechanisms. These are passive absorption and active absorption.

1. **Passive Absorption:** This occurs when ions move by mass flow and diffusion through the apoplast. Examples of passive absorption include:

Diffusion: Mineral salts are diffused from the higher concentration towards the lower concentration.

Carbonic acid exchange theory: CO_2 is produced by respiration in roots with water to form carbonic acid. The acid formed dissociates into H^+ and HCO_3^- ions. The exchange of negative (-ve) and positive (+ve) ions of the solution take place by the positive and negative ions present in the root.

Contact exchange theory: Exchange in oscillating ions of some charge H^+ or OH^-

Donan Equilibrium: Against concentration gradient without ATP.
Mass flow

2. **Active Absorption:** This kind of uptake is selective and dependent on respiration. Mineral salts enter into the higher concentrated cell sap from the lower concentrated soil solution by expenditure of energy in form of ATP produced from respiration. In this method, certain carriers are present in the plasma membrane which is made up of proteins for negative and positive ions which combines with ions to form ion- carrier complex. It breaks off from the internal surface of the plasma membrane and transfer their ions into the cell with the expenditure of ATP, Cytochrome actsas carrier of molecules and lecithine as carrier of negative and positive ions

Ascent of sap

Plants absorb water through the roots. This absorbed water reached up to leaves through the stem branches. Most of the water is lost by the transpiration from the leaves. Only small amount of water utilised in vital activities of the plant. The upward movement of absorbed water by the underground roots towards aerial parts of the plant against the gravitation is called **ascent of sap**. Experiment no. 1 below shows that water moves upwards through the vessels and tracheids of xylem.

Experiment No. 1 - Balsam

Take aqueous solution of eosine in a beaker and immerse the cut end of (stock) of balsam plant in it. After sometimes strips of red colour are seen in the stem. The transverse section of this stem confirms because only vessels and tracheids are stained with eosine dye. So that it is proved that the ascent of sap takes place through the xylem.

3.5 Transpiration

All the terrestrial plant utilised absorbed water by the roots in various metabolic activities. Although, large amount of water is absorbed by the plants from the soil, but whole of water is not used by the plants for its growth and development. A small fraction of the total water is used up by the plants for its growth and development and remaining amount of water is lost from the aerial part in vapour form and goes into the external atmosphere. Thus, loss of water in vapour forms from the aerial parts (organs) of living plants is known as Transpiration. Only a few percentage [1%] of absorbed water is used by the plants while remaining [99%] of water lost into the atmosphere. The minimum transpiration is found in succulent xerophytes. No transpiration occurs in submerged plants. Maximum transpiration is found in mesophytes. The process of transpiration is like that of evaporation but it differs in few respects.

Similarities and differences between transpiration and evaporation
Table 1 below presents the major similarities and differences between transpiration and evaporation processes in plants.

Table 1: Major Similarities and Differences between Transpiration and Evaporation Processes in Plants

Transpiration	Evaporation
It is vital activity	It is physical process
It occurs only in living plants.	It occurs in both living and nonliving.
Loss of water vapours through the stomata, epidermis and lenticels	Loss of water is only through the moistened surface.
Usually it occurs through the stomata	This process do not occur by any cell
This process is controlled by guard cells.	It is not controlled by guard cells
The surface of cells is dry resulting by this process	The surface becomes dry by this process.
It is affected by various factors	It is affected only by temperature.

3.5.1 Types of Transpiration

There are three different types of transpiration. They are cuticular, lenticular and stomatal transpiration.

Cuticular transpiration

Loss of water takes place through the cuticle which is present on the herbaceous stem and leaves with very thin. A cutinised wax like thin layer is present on epidermis. The function of this layer is to reduce or to stop the transpiration. But a fraction of water lost in vapour forms through the thin cuticle. Of the total amount of water is lost from the plant, approximately 9% is lost through cuticle.

Lenticular transpiration

Minute pore-like structures found in the stem of some woody plants and epidermis of some fruits is called **lenticels**. The process of water loss through the lenticels is known as lenticular transpiration. However, it is approximately 0.1% to 1% of the total water lost.

Stomatal transpiration

Transpiration which takes place through the stomata which are present on the leaves of the plant and green organs is called stomatal transpiration. The maximum amount of total water delicate is lost by this transpiration. Of the total amount of transpiration from the plants about 80% to 90% transpiration is through the stomata. Some amount of transpiration is also takes place through the bark of the plants. But this amount is negligible. Stomata are absent in algae, fungi and submerged aquatic plants.

Factors affecting the rate of transpiration

Factors affecting the rate of transpiration are divided into two types:

(A) External factors
(B) Internal factors

The external factors are closely related to the atmosphere. They include:

Light
It is affected the movement of stomata. Stomata open in the presence of light and the phenomenon of transpiration occurs. Opening of stomata is less in dim light which decreases the rate of transpiration. Action spectrum of transpiration is blue and red. Rate of transpiration is faster in blue light than that of red light. This is because stomata are completely opened in the blue light.

Temperature
The value of quotient of transpiration is – 2. It means by the of increase 10ºC temperature, the rate of 10 transpiration is approximately doubled. Water vapour holding capacity is affected by temperature. Water vapour holding capacity of air is increased at high temperature, resulting in the increased rate of transpiration increased. On contrary vapour holding capacity of air decreases at low temperature hence the rate of transpiration is decreased.

Atmospheric humidity
This is the most important factor the rate of transpiration is higher in low atmospheric humidity while at higher atmospheric humidity, the atmosphere is moistened. This results in decreasing of the rate of transpiration. Therefore, the rate of transpiration increases during the summer and it decreases in rainy season.

Wind velocity

Transpiration is less in constant air but if wind velocity is high the rate of transpiration also increases. This is because wind removes humid air (saturated air) around the stomata and is replaced by unsaturated air. So that transpiration increases. Transpiration increases in the beginning at high wind velocity [30 - 35 km/hour]. But later on it cause closure of stomata due to mechanical effect and transpiration is decreased.

Atmospheric pressure

The speed of the air increases at low atmospheric pressure, due to this rate of the diffusion increase which is the term increases the rate of transpiration. The rate of transpiration is at maximum in the high intensity of light at high attitude. The rate of transpiration decreases at high atmospheric pressure.

Available soil water

The rate of transpiration depends upon the available soil water. The rate of the transpiration decreased due to loss of available soil water.

Anti transpirants

Those substances which reduce the rate of transpiration are known as antitranspirants. Anti transpirants are as follows: Phenyl Mercuric Acetate [PMA], Aspirin, Abscissic Acid [ABA], Oxi – ethylene, Silicon oil, CO and Wax PMA closed the stomata for more than two weeks partially. These antitranspirants are used in dry-farming.

(B) The internal factors are those that deal with the structure of plants. They include:

Transpiring areas

The surface of the leaf is most important. Hence, more transpiration takes place through the large surfaced leaf. The area of leaves of xerophytic plants is reduced due to transformation of leaves in various forms. So that rate of transpiration is decreased. The loss of water from per unit area, in per unit time by transpiration is called rate of transpiration. The rate of transpiration is higher in young leaves as compared to older ones.

Anatomical characteristics of leaf

The structure of the leaf affects transpiration in the following ways:

- The thick cuticle of the leaf reduces transpiration.

- Transpiration is decreased due to the presence of thick epidermal cells and multilayering of epidermal cells.
- The presence of number of hairs and dense hairs decrease the rate of transpiration.
- **Stomatal characteristics**: Transpiration is affected by the structure of stomata, position of stomata, distance between the stomata, and number of stomata per unit area and activity of the stomata. The rate of the transpiration is decreased due to sunken stomata, sunken epidermis, very close stomata, less no. of stomata per unit area, less no of stomata opening for small duration.
- **Leaf orientation**: Heating effect is increased due to the surface area of the leaf being exposed to the right angle of the light. Hence rate of transpiration as increased.
- **Water status of leaves**: If the amount of water is less than that of normal amount it causes closure of stomata and reduce the transpiration.

3.6 Structure of Stomata

Stomata are found on the aerial delicate organs and outer surface (epidermis) of the leaves in the form of minute pores. This stomata is surrounded by two epidermal cells called guard cell. They are kidney shaped. The number of guard cells of a leaf stomata is two. The structure of guard cells in graminae or grass family is dumbbell shaped. Guard cells are epidermal cells. But due to presence of chloroplast they are different from that of epidermal cells. The outer wall of the guard cells are thin and elastic while inner wall is thick and non elastic. Guard cells contain one nucleus, cytoplasm and indefinite chloroplast. These cells are always living and opening and closing of stomata is due their movement. Guard cells are surrounded by some specialised epidermal cells are called subsidiary cells or accessory cells. Stomata are found both upper and lower epidermis. Mesophyll cells lies between both the epidermis. Stomata are attached with air chambers and which forms a cavity which is called sub stomatal cavity. Accessory cells are located above the guard cells in xerophytic plants and due to this the position of stomata is below the surface of the leaf. Stomata present in this position are called sunken stomata.

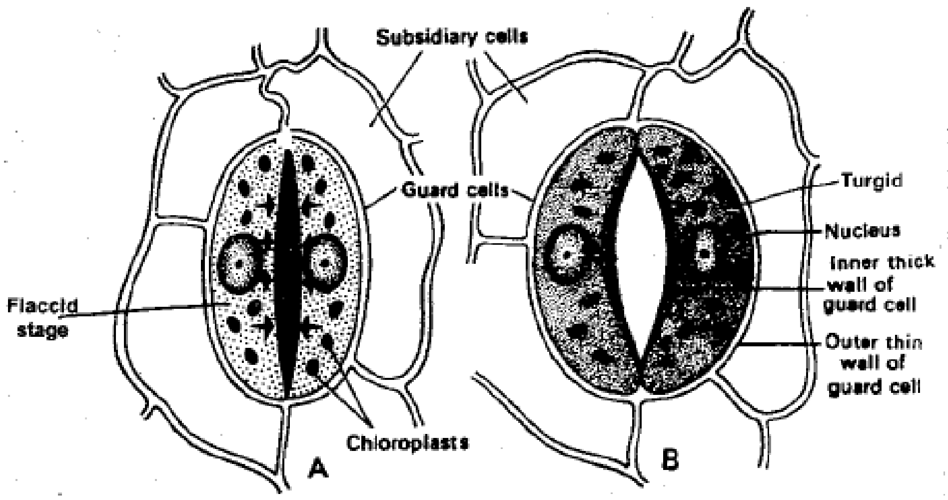

Fig. 2: The Structure of the Stomata. (The Cell Wall Bordering the Stomata Pore is Thicker than that next to the Surrounding Cells –

(A) Aperture Closed (B) Aperture Open Stomata or foliar transpiration

Water absorbed by root hairs, reaches the xylem from the cortical passage (path) through the passage cells of endodermis. Water reaches up to the upper part of the plant from the xylem by the process of ascent of sap. All cells of mesophyll remain in turgid condition due to presence of water. Intercellular spaces are present in between the mesophyll cells and water of moistened walls of mesophyll cells changes into water vapour. This water vapour accumulates in the substomatal cavities from the intercellular spaces and diffuses into the atmosphere due to less water vapour present in the atmosphere. In this way stomatal transpiration is completed.

Mechanism of opening and closing of stomata

The opening and closing of stomata depend upon the osmotic pressure of guard cells. When the guard cells are in turgid state the stomatal aperture opens and when guard cells are in flaccid state the stomatal aperture closes. When the osmotic concentration of the guard cells increases then they absorb water from the accessory cells and become turgid by endosmosis. Thin wall of the guard cell is pushed out side due to this turgor pressure hence a tension is created on the inner thicker wall thus, pulling the inner wall towards the periphery. This happens in both guard cells and stoma and a gap is formed between them and which leads to opening of stomata.

Factors affecting stomata opening and closing

Light

In most of the plants, stomata open during the day except succulent xerophytic plants and close during the dark. Opening and closing of stomata is completed in the presence of blue and red light. Blue light is most effective and causing stomatal opening.

Temperature
The stomata opening and closing occurs at a specific temperature, below which it may not occur.

CO_2 concentration
Stomata are sensitive towards the internal CO_2 in the deficiency of water in the cells of leaves. Stomata open at low concentration of CO_2 while it is close at high concentration of CO_2.

Water contents of leaves
Water potential in leaves varies from – 7 to – 18 when ranging bars reduce the turgidity of guard cells which results closure of stomata.

Mineral concentration
The movement of stomata decreases in the deficiency of N, P and K ions.

3.7 Guttation

Loss of water from the uninjured part or leaves of the plant in the form of water droplets is called guttation. The process of guttation is found in both shrubs and woody type of plants. Exuded liquid of guttation excluding water also contains some organic and inorganic (dissolved) substances. Normally, guttation process is found in some plants like grasses, Tomato, Balsam, *Nasturtium*, *Colocasia*, *Saxifraga* and in some of the plants of Cucurbitaceae family. Guttation occurs from the margins of the leaves through the special pore, called **Hydathodes.** Each hydathode is formed by colourless epidermal cells. Parenchymatous and loose tissue lies beneath the hydathode which is known as **Epithem**. It is also known as **Transfer tissue**. The cells of epithem are soft and without chloroplast. The cells of epithem are involved in absorption and secretion. In the anterior part of epithem, a cavity is present which is called water cavity. It opens out through the hydathode. Hydathodes always remain open. The process of guttation of takes place due to root pressure. The process of guttation occurs in the special circumstances when the higher rate of absorption and transpiration is low.

4.0 CONCLUSION

Plants require certain mineral elements along with the carbohydrates made during photosynthesis. Mineral elements exist as salts which are made up of ions. In solution, these ions are capable of dissociating and are able to move freely. The soil is the main source of mineral salts for plants. The absorption of mineral elements in plants is carried out by the root. They are absorbed by the (subterminal) meristematic region of the root. Uptake is usually greatest in this region of the root hair. The dissolved mineral ions are conducted via the xylem as sap by the combined efforts of passive and active absorption.

5.0 SUMMARY

The soil is the primary source of mineral salts in plants. Mineral salts exist as dissolved ions in the soil. Uptake is highest at the root hairs. The upward movement of absorbed water by the underground roots towards aerial parts of the plant against the gravitation is called ascent of sap. Active uptake is selective and dependent on respiration. Loss of water from the uninjured part or leaves of the plant in the form of water droplets is called guttation.

6.0 TUTOR-MARKED ASSIGNMENT

1. Highlight the different types of water in soil.
2. Describe the mechanisms of water absorption in plants.
3. Describe roles of the root in the absorption of water by plants.
4. Describe the mechanism of absorption of mineral salt.
5. Explain the term ascent of sap.

7.0 REFERENCE/FURTHER READING

Taylor, D.J; Green, M.P.O & Stout, G.W. (1999). *Biological Science.* (3rd ed.). Cambridge: Cambridge University Press