NATIONAL OPEN UNIVERSITY OF NIGERIA

FACULTY OF SCIENCES

CODE: BIO203

COURSE TITLE: General Physiology I

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Reviewed: 2022

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BIO203 GENERAL PHYSIOLOGY I

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NATIONAL OPEN UNIVERSITY OF NIGERIA

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Published By:
National Open University of Nigeria

First Printed 2017

Reviewed 2022

ISBN: 978-058-003-4

Course Guide: BIO 203: General Physiology I

Introduction

BIO 203 General Physiology 1 is a one-semester, two credit- hour course in the Department of Biological Sciences, Faculty of Science. It is a 200 level, first semester undergraduate course offered to students admitted in the Faculty of Science, and other faculties that are offering Biology or related programmes. This course is designed primarily for students in Biology disciplines to provide a comprehensive understanding of the fundamental principles and mechanisms that govern the functioning of living organisms.

The course provides insight into physical and chemical processes in animals and plants; diffusion, osmotic pressure and osmolarity. Water potential, turgor, plasmolysis, Gibbs-Donan relationship. Gas exchange, partial pressures (Tension), Hydrogen-ion concentration (pH). Henderson Hasselbach equation, buffers in physiology. Nutrition; photo-autotrophism, heterotrophism (essential requirements of each), Respiration and photosynthesis; metabolism, photosynthesis, oxygen and carbon dioxide exchange.

It gives you some guidance on your Tutor- Marked Assignments.

There is/are Self-Assessment Exercise(s) within the body of a unit and/or at the end of each unit. The exercise(s) is/are an overview of the unit to help you assess yourself at the end of every unit.

Course Competencies

This course is to provide a generalized introduction to the general physiology of organisms.

Course Objectives

In addition to the course competencies, the course sets an overall objective which must be achieved. In addition to the course objectives, each of the units has its own specific objectives. You are advised to read properly the specific objectives for each unit at the beginning of that unit. This will help you to ensure that you achieve the objectives.
As you go through each unit, you should from time to time go back to these objectives to ascertain the level at which you have progressed.

By the time you have finished going through this course, you should be able to understand:

- osmotic pressure and osmolarity
- Water potential
- turgor
- plasmolysis
- Gibbs-Donan relationship
- Gas exchange
- partial pressures
- photo-autotrophism

- heterotrophism
- Be able to differentiate between qualitative and quantitative tests especially for amino acids and proteins

Working through this Course

In this course, you will be advised to devote your time in reading through the material. You would be required to do all that has been stipulated in the course: study the course units, read the recommended reference textbooks and do all the unit(s) self- assessment exercise (s) and at some points, you are required to submit your assignment (TMAs) for assessment purpose. You should therefore avail yourself of the opportunity of being present during the tutorial sessions so that you would be able to compare knowledge with your colleagues.

References and Further Readings

You would be required to read the recommended references and textbooks in each unit of the course materials.

Presentation Schedule

There is a time-table prepared for the early and timely completion and submissions of your TMAs as well as attending the tutorial classes. You are required to submit all your assignments at the stipulated date and time.

Assessment

There are three aspects to the assessment of this course. The first one is the in-text questions and the second is self-assessment exercises, while the third is the written examination or the examination to be taken at the end of the course. Review the exercises or activities in the unit by applying the information and knowledge you acquired during the course. The work submitted to your tutor for assessment will account for 30% of your total work. At the end of this course you will have to sit for a final or end of course examination of about a two hour duration and this will account for 70% of your total course mark.

How to get the Most from the 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 in-text questions and Self-assessment questions 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 I encourage you to attend these tutorial classes.

This course exposes you to Animal Ecology, a sub-discipline and very interesting field of Biological Science.

Online Facilitation

Eight weeks are provided for tutorials for 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.

The duties of your facilitator is to monitor your progress and provide any necessary assistance you need.

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 you attend the tutorial classes because this is the only chance to have face to face contact with your facilitator and to 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.

Course Information

Course Code: BIO 203
Course Title: GENERAL PHYSIOLOGY 1
Credit Unit: 3
Course Status:CORE
Course Blub: This course provides students with the basic knowledge in Ecology to enable them understand the relationship between animals in their ecosystem and with the environment
Semester: FIRST SEMESTER
Course Duration: 13 WEEKS
Required Hours for Study : 65 h

CONTENTS

MODULE 1

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UNIT 1 CELL AND ITS DISCOVERY

Unit Structure

1.1 Introduction:

Cell is the basic unit of life. All livings are made up of cell(s) and are either prokaryotic or eukaryotic. Its discovery took many years of efforts by diligent scientist using crude tools available at that time.

1.2 Intended Learning Outcomes (ILOs)

At the end of this unit, students should be able to

i) define cell

ii) describe its discovery

iii) explain cell theory

1.3 MAIN CONTENTS

1.3.1 THE CELL

The cell is the fundamental morphological and physiological unit of living organisms. The cell contains all the structures and molecular constituents needed for life. All living organisms in the kingdoms of life are composed of and depend on cells to function normally. Not all cells, however, are alike. There are two primary types of cells: eukaryotic and prokaryotic cells. Examples of eukaryotic cells include animal cells, plant cells, and fungal cells. Prokaryotic cells include bacteria and Achaeans.

Cells contain organelles, or tiny cellular structures, that carry out specific functions necessary for normal cellular operation. Cells also contain DNA (deoxyribonucleic acid) and RNA (ribonucleic acid), the genetic information necessary for directing cellular activities.

Eukaryotic cells grow and reproduce through a complex sequence of events called the cell cycle. At the end of the cycle, cells will divide either through the processes of mitosis or meiosis. Somatic cells replicate through mitosis and sex cells reproduce via meiosis. Prokaryotic cells reproduce commonly through a type of asexual reproduction called binary fission. Higher organisms are also capable of asexual reproduction. Plants, algae, and fungi reproduce through the formation of reproductive cells called spores. Animal organisms can reproduce asexually through processes such as budding, fragmentation, regeneration, and parthenogenesis.

Cell can also be defined as an organized uninucleate mass of protoplasm bounded by a cell wall existing singly or in groups and containing structures of various sorts. The study of cell and its structural components is known as CYTOLOGY.
Recently, emphasis is on the functional aspects of the cellular structures, thus, the term CELL BIOLOGY was coined to include both the structural and functional details of the cell and its components. Cell biology derives inputs from various branches of sciences e.g biophysics, biochemistry, genetics, physiology, molecular biology, e.t.c.
Define a cell.

1.3.2 DISCOVERY OF CELL

Cell was discovered about 1665 when Robert Hooke examined slices of cork under a crude microscope. He found the slices to be made up of small chambers and called them cells. Robert brown in 1831 observed a dense spherical body in the cell which was later termed as nucleus.
M.J Schleiden and Theodor Schwann (1839) proposed the well-known CELL THEORY ''the cell is the structural and basic unit of all the plants and animals''.
Roberts Remark (1841) and Rudolf Virchow (1858) said ''the new cell arise from the division of the pre-existing cells.''
Albrecht Kolliker (1846) found a jelly like substance in the cell as CYTOPLASM while Hugo Von Mohl (1846) suggested that the cytoplasm and nucleus together should be called protoplasm.
Invention of electron microscope in 1931 by E. Ruska and the use of ultracentrifugation and x-ray crystallography brought better understanding of the detailed structure of the cell. New structures like Endoplasmic reticulum, cell organelles, structures of nucleus, etc., which were previously unknown were discovered and studied in great details. *List any three prominent names in the history of cell*

Self- Assessment Exercise 1

i) What is cytology?
ii) Cell Biology is composed of what other fields?

1.3.3 Cell Theory

Scientists once thought that life spontaneously arose from nonliving things. Thanks to experimentation and the invention of the microscope, it is now known that life comes from preexisting life and that cells come from preexisting cells.

In 1665, Robert Hooke published *Micrographia*, a book filled with drawings and descriptions of the organisms he viewed under the recently invented microscope. The invention of the microscope led to the discovery of the cell by Hooke. While looking at cork, Hooke observed box-shaped structures, which he called "cells" as they reminded him of the cells, or rooms, in monasteries. This discovery led to the development of the classical cell theory.

The classical cell theory was proposed by Theodor Schwann in 1839. There are three parts to this theory.

a) The first part states that all organisms are made of cells.

b) The second part states that cells are the basic units of life. These parts were based on a conclusion made by Schwann and Matthias Schleiden in 1838, after comparing their observations of plant and animal cells.

c) The third part, which asserts that cells come from preexisting cells that have multiplied, was described by Rudolf Virchow in 1858, when he stated *omnis cellula e cellula* (all cells come from cells)

Since the formation of classical cell theory, technology has improved, allowing for more detailed observations that have led to new discoveries about cells. These findings led to the formation of the modern cell theory, which has three main additions:

a) First, that DNA is passed between cells during cell division;

b) Second, that the cells of all organisms within a similar species are mostly the same, both structurally and chemically; and

c) Finally, that energy flow occurs within cells.

Modern Cell theory states that cells are the basic structural, functional, and organizational units of both single-celled and multicellular organisms; cells divide and pass on hereditary information; and energy flows within cells. *What did you understand by modern cell theory?*

Self-Assessment Exercise 2

1) What role did microscope invention played in cell biology

4.0. Self-Assessment Questions and Class Activity

4.0.1 Self-Assessment Questions

a) What is a cell?

Answer

The cell is the fundamental morphological and physiological unit of living organisms

b) What are three parts of cell theory?

Answer

The three parts are:

a) The first part states that all organisms are made of cells.

b) The second part states that cells are the basic units of life. These parts were based on a conclusion made by Schwann and Matthias Schleiden in 1838, after comparing their observations of plant and animal cells.

c) The third part, which asserts that cells come from preexisting cells that have multiplied, was described by Rudolf Virchow in 1858, when he stated omnis cellula e cellula (all cells come from cells)

1.4 SUMMARY

Cell is the basic and fundamental unit of all living organisms. Modern technology has made it possible for scientists to look deeper into the cell for more detailed information resulting in cell theory.

1.5 References/Further Readings/Web Sources

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https://www.khanacademy.org/science/biology/structure-of-a-cell/introduction-to-cells/v/cell-theory
https://www.youtube.com/watch?v=zk3vlhz1b6k

1.6 Possible Answers to SAEs

Answers to SAE 1

i)The study of cell and its structural components is known as CYTOLOGY.
ii)Cell biology derives inputs from various branches of sciences e.g biophysics, biochemistry, genetics, physiology, molecular biology, e.t.c.

Answers to SAE 2

Thanks to experimentation and the invention of the microscope, it is now known that life comes from preexisting life and that cells come from preexisting cells.

UNIT 2 STRUCTURE AND FUNCTION OF PLANT CELLS: 1

Unit Structure

2.1 INTRODUCTION

All plants consist of cells, which are the simplest units of plant that can live independently. The smallest organisms are single cells, but plants are made of billions of cells. Plants cells have many shapes and sizes. The smallest of which are the dividing cells at the tips of roots and stems. Each cell in a plant consists of a cell that is surrounded by a plasma membrane, which encloses many smaller parts called organelles. Because each organelle has its own sets of functions, the job of each cell in a plant is determined by how many and which organelles it consists, and what the organelles do.

In this unit, we shall be looking at why cells are so small, the Membranes at cell compartments and the cytoskeleton and how it works. We will then study the wall, the Nucleus and the Ribosomes.

2.2 Intended Learning Outcomes (ILOs)

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

-mention the different components of the plant cell
- explain why cells are so small

- mention the three kinds of filament found in the Cytoskeleton.
- distinguish between the two types of cell wall

-identity the area of connection between cells
- describe the structure of the nucleus

2.3 Main Contents

2.3.1 Components of the Plant Cell

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The plant cell is composed of two basic parts: The cell wall and the protoplast. The cell wall has the following parts.

Middle lamella Primary cell wall Secondary cell wall Plasmodesmata

The Protoplast has two main divisions:

The protoplasm and the Ergastic substances

The Ergastic substances include: Starch grains
Vacuole sap with waste substances such as tannins,
Crystals etc.

The protoplasm has two main divisions Nucleus made up of: Nucleomembrane
Nucleoplasm
Chromalin
Nucleolus.

Cytoplasm made upof:
Plasmalemma
Hyaloplasm
Tonoplasm
Microbodies
Endoplasmic Reticulum (Er)
Dictyosomes
Spherosomes
Mitochondria
Plastids.

Some of the components of the cytoplasm have other smaller components. These are:

Hyaloplasm — ground plasma
Ribosomes
Oil droplets
Cytoskeleton
Microtubules
Peroxysomes
Lysosomes
Glyoxysomes

Microbodies — Peroxysomes
Lysosomes
Glyoxysomes

Spherosome — Lipid bodies Wax bodies Fatty bodies

Plastids — Proplastids Leukoplast
Amyloplasts
Chloroplasts
Chromosplasts

Some of these components of the cell that have functional significance will be treated in this unit and the next (that is, in Units 2 and 3)

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2.3.1.1 Why are Cell so Small

For convince, most of the contents of a cell are referred to as its **cytoplasm.** The only component of the cell that is not part of the cytoplasm is the nucleus. The plasma membrane which surrounds the cytoplasm, is a barrier that protects the cell from harmful substances. It has the consistency of salad oil and must allow the passage of gases and nutrients into and out of the cell. However, the surface area of the membrane can service only so much cellular volume that is the surface- to-volume ratio must have a lower limit. Multicellular organisms avoid this limit by making more but smaller cells for a given volume. Cells are therefore small so as to make room for more plasma membranes.

The need for sufficient amount of plasma membrane for the volume of the cell only partially explains why most cells are so small. Other important factor include the limits on rate of synthesis and transport of molecules within the cell and the requirement that a single nucleus manage the metabolism of the entire cell.

2.3.1.2. Membranes and Cell Compartment

Many metabolic functions in a cell occur in or on membranes. The Plasma membrane alone is inadequate for all of these processes regardless of the cell size. Additional internal membranes attached to the plasma membrane or included in organelles compensate for the insufficiency of the plasma membrane. The other membranes also form compartment that maintain different environments within the cell. For example, incompatible reactions, such as the hydrolysis and dehydration of carbohydrates are isolated from each other in different compartments. These compartments allow many different kinds of reactions to occur in the cell simultaneously.

Biological membranes are usually very small and consist of mostly phospholipids and proteins. In addition to the plasma membrane, there are membranes that surround nuclei, mitochondria, chloroplasts, vacuoles and microbodies. Membranes also pervade the cell between organelle in a complex system that complements the functions of the organellar membranes. You will learn more about the characteristics of organelles and the internal membrane system of cells later.

2.3.1.3. The plant cytoskeleton consists of microtubules and microfilaments

Three major types of cytoskeletal elements have been demonstrated in plant cells: microtubules, microfilaments and intermediate filaments. Each type is filamentous, having a fixed diameter and a variable length, up to many micrometers. These components of cytoskeleton are not static but constantly dissemble into their monomeric subunits and reassemble into protein filaments. Similarly, the location of these components is not fixed in the cell but may change according to the cell's requirement. Cytoskeletal components are modulated by Ca^{2+} and variety of proteins.

a) **Microtubules:** are hollow cylinders with an outer diameter of 25 nm; they are composed of polymers of the protein **tubulin**. The tubulin monomer of microtubules is a heterodimer composed of two similar polypeptide chains (α- and β-tubulin), each having an apparent molecular mass of 55,000 daltons . A single microtubule consists of hundreds of thousands of tubulin monomers arranged in 13 columns called *protofilaments*.

b) **Microfilaments** are solid, with a diameter of 7 nm. They are composed of the monomeric form of the protein **actin**, called globular actin, or G-actin. Monomers of G-actin polymerize to form a single chain of actin subunits, also called a protofilament. The actin in the polymerized protofilament is referred to as filamentous actin, or F-actin. A microfilament is helical, a shape resulting from the polarity of association of the G-actin monomers.

c) **Intermediate filaments** are a diverse group of helically wound fibrous elements, 10 nm in diameter. Intermediate filaments are composed of linear polypeptide monomers of various types. In animal cells, for example, the **nuclear lamins** are composed of a specific polypeptide monomer, while the **keratins**, a type of intermediate filament found in the cytoplasm, are composed of a different polypeptide monomer. List the *three major types of cytoskeletal elements in plant cell?*

Self-Assessment Exercise 1

i)	Ergastic substances include what?

2.3.1.4. Microtubules and Microfilaments Can Assemble and Disassemble

In the cell, actin and tubulin monomers exist as pools of free proteins that are in dynamic equilibrium with the polymerized forms. Polymerization requires energy: ATP is required for microfilament polymerization, GTP (guanosine triphosphate) for microtubule polymerization. The attachments between subunits in the polymer are noncovalent, but they are strong enough to render the structure stable under cellular conditions. Both microtubules and microfilaments are polarized; that is, the two ends are different. In microtubules, the polarity arises from the polarity of the α- and β-tubulin heterodimer; in microfilaments, the polarity arises from the polarity of the actin monomer itself. The opposite ends of microtubules and microfilaments are termed *plus* and *minus*, and polymerization is more rapid at the positive end. **_______** *is required for microfilament polymerization.*

2.3.1.5. Microtubules Function in Mitosis and Cytokinesis

Mitosis is the process by which previously replicated chromosomes are aligned, separated, and distributed in an orderly fashion to daughter cells Microtubules are an integral part of mitosis. Before mitosis begins, microtubules in the cortical (outer) cytoplasm depolymerize, breaking down into their constituent subunits. The subunits then repolymerize before the start of prophase to form the **preprophase band** (**PPB**), a ring of microtubules encircling the nucleus.

The PPB appears in the region where the future cell wall will form after the completion of mitosis, and it is thought to be involved in regulating the plane of cell division. During prophase, microtubules begin to assemble at two foci on opposite sides of the nucleus, forming the **prophase spindle.** Although not associated with any specific structure, these foci serve the same function as animal cell centrosomes in organizing and assembling microtubules.

In early metaphase the nuclear envelope breaks down, the PPB disassembles, and new microtubules polymerize to form the mitotic spindle. In animal cells the spindle microtubules radiate toward each other from two discrete foci at the poles (the centrosomes), resulting in an ellipsoidal or football-shaped, and array of microtubules. The mitotic spindle of plant cells, which lack centrosomes, is more boxlike in shape because the spindle microtubules arise from a diffuse zone consisting of multiple foci at opposite ends of the cell and extend toward the middle in nearly parallel arrays .Some of the microtubules of the spindle apparatus become attached to the chromosomes at their **kinetochores**, while others remain unattached. The kinetochores are located in the **centromeric** regions of the chromosomes. Some of the unattached microtubules overlap with microtubules from the opposite polar region in the spindle midzone.

Cytokinesis is the process whereby a cell is partitioned into two progeny cells. Cytokinesis usually begins late in mitosis. The precursor of the new wall, the **cell plate** that forms between incipient daughter cells, is rich in pectins . Cell plate formation in higher plants is a multistep process . Vesicle aggregation in the spindle midzone is organized by the **phragmoplast**, a complex of microtubules and ER that forms during late anaphase or early telophase from dissociated spindle subunits. *Define cytokinesis.*

2.3.1.6. Microfilaments Are Involved in Cytoplasmic Streaming and in Tip Growth

Cytoplasmic streaming is the coordinated movement of particles and organelles through the cytosol in a helical path down one side of a cell and up the other side. Cytoplasmic streaming occurs in most plant cells and has been studied extensively in the giant cells of the green algae *Chara* and *Nitella*, in which speeds up to 75 µm s–1 have been measured.

The mechanism of cytoplasmic streaming involves bundles of microfilaments that are arranged parallel to the longitudinal direction of particle movement. The forces necessary for movement may be generated by an interaction of the microfilament protein **actin** with the protein **myosin** in a fashion comparable to that of the protein interaction that occurs during muscle contraction in animals.

Myosins are proteins that have the ability to hydrolyze ATP to ADP and Pi when activated by binding to an actin microfilament. The energy released by ATP hydrolysis propels myosin molecules along the actin microfilament from the minus end to the plus end. Thus, myosins belong to the general class of **motor proteins** that drive cytoplasmic streaming and the movements of organelles within the cell. Examples of other

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motor proteins include the **kinesins** and **dyneins**, which drive movements of organelles and other cytoskeletal components along the surfaces of microtubules.

Actin microfilaments also participate in the growth of the pollen tube. Upon germination, a pollen grain forms a tubular extension that grows down the style toward the embryo sac. As the tip of the pollen tube extends, new cell wall material is continually deposited to maintain the integrity of the wall. A network of microfilaments appears to guide vesicles containing wall precursors from their site of formation in the Golgi through the cytosol to the site of new wall formation at the tip. Fusion of these vesicles with the plasma membrane deposits wall precursors outside the cell, where they are assembled into wall material. *How is cytoplasmic streaming achieved?*

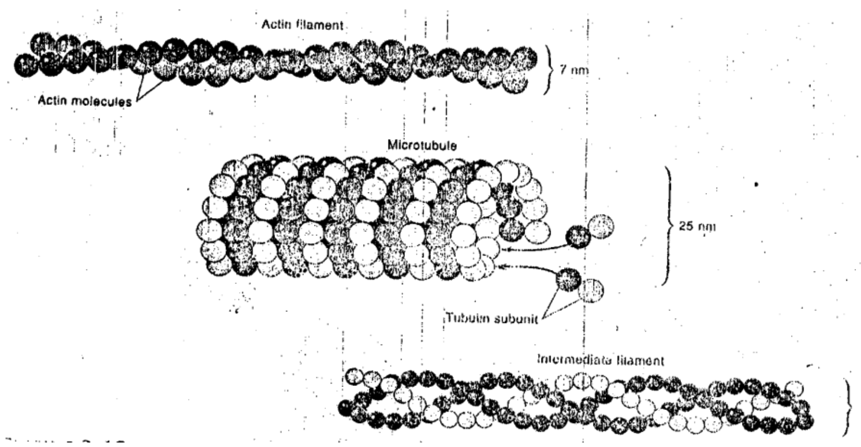

Fig. 2.1
Structural model of the three different kinds of cytoskeletal filaments.

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How the cytoskeleton work

When you hear the word cytoskeleton, what image comes to your mind? If you reason like me, you will immediately think of a stationary lattice of filaments that holds the cells in specific shapes and keeps cell components in specific places. This means that the cytoskeleton cannot be a rigid structure. This assertion is confirmed by observations that expansion of and internal movements in cells occur in conjunction with the growth and breakdown of microtubules and actin filaments. Such observations are indirect evidence that the cytoskeleton has many dynamic functions in the cell.

The least understood parts of the cytoskeleton are the intermediate filaments. Because their proteins are fibrous, intermediate filaments do not have globular subunits that are easily assembled and disassembled like those of microtubules and action filaments. Thus, intermediate filaments may be relatively static, tension bearing structures that are not as dynamic as their larger and smaller counterparts in the cytoskeleton.

The way the various filaments of the cytoskeleton cooperate to control the overall organisation of the cell is still unknown.

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2.3.2 The Cell Wall

The cell wall gives a definite shape and provides protection to the protoplasm. It is non-living in nature and is permeable. The cell wall consists of the three parts.

1. **Middle-lamella**: this consists of PECTIC ACID in the form of Calcium and Magnesium salts. Pectic acid is long chain polygalacturonic acid compound in which α-D galacturonic acid unit are joined together by 1:4 glycosidic linkages. It is hydrophilic in nature.
2. **Primary wall** (1-3 μm thick and elastic): it mainly made up of cellulose, a long straight chain polysaccharide in which β-D glucose units are joined together by 1:4 glycosidic linkages. The cellulose chains which form the crystalline region of the cell wall are associated together forming a network of cellulose strands in the cell wall.. cellulose is hydrophilic in nature. Besides cellulose, primary wall also contains lignin, hemicellulose, some pectic substances and proteins which forms the Amorphous matrix. Some inorganic salts like silica and calcium are also present in primary wall.
3. **Secondary wall** ((5-10 μm thick and rigid): secondary walls are more pronounced in dead cells such as tracheids and sclerenchyma. They consist mainly of lignin and cellulose. Three distinct layers (innermost layer, middle layer and outermost layer) have been identified in secondary wall with different but definite orientation of cellulose strands.

Functions of cell wall:

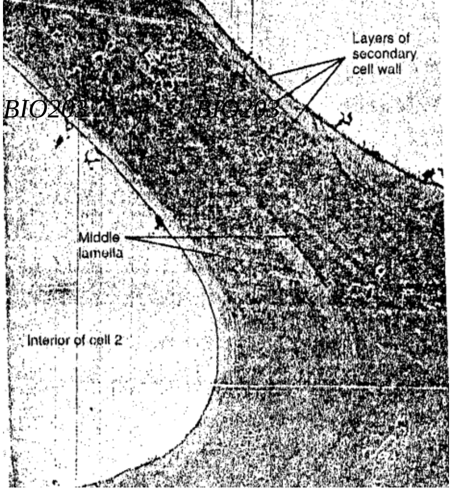
1. It protects the inner contents of the cell.
2. It gives definite shape to the cell.
3. It provides mechanical support to the tissues and act as a skeletal framework of plants.
4. It helps in transport of substances between two cells.
5. The cell wall is hydrophilic in nature and it imbibes water and helps in the movement of water and solutes towards protoplasm. It also acts as a permeable structure during absorption of minerals and solutes.

Their composition varies in different cell types and from one species to another. Up 60% of a cell wall may be cellulose, other components include hemicelluloses, pectins, Lignins and proteins. Almost all plant cells have cellulose – containing cell walls.

Young cells and cells in actively growing areas have primary cell walls that are relatively thin and flexible. Examples of such cells include the dividing cells at tips of roots and shoots. The primary wall is usually less than 25% cellulose, the remainder being hemicelluloses, pectins and glycoproteins. Some primary cell. Cells can change shape, divide or differentiate into other kinds of cells.

Certain kinds of cells stop growing when they reach maturity. When this occurs, these cells form a secondary cell wall inside the primary cell wall (fig. 2.2)

(Fig. 2.2)



(Fig 2.2) Transmission electron micrograph of cell walls. The Primary wall is constructed when the cell is young. Thicker secondary walls are added later when the cell stop drawing, x 3,000

The secondary cell wall is more rigid than the primary cell wall and therefore functions as a strong support structure. Although cellulose is one of their main components, the secondary walls of cell in wood are up to 25% lignin, which adds hardness and resist decay, because of its lignin content, wood is one of the strongest materials known.

Some cell walls, such as those of cork cells also contain suberin. Suberized tissues inhibit water loss through bark, which is why cork form the cork oak (Quercus suber) is useful in making stoppers for wine bottle Secondary cell walls are rigid and lack glycoproteins, which occurs in primary cell walls. Most types of cells that have secondary cell walls die when they reach maturity.

Cells that adjoin one another are probably held together by pectins. The pectin layer between cells is called the middle lamella. (see fig 2.2). Some tissues such as the flesh of apples, are so rich in pectins that these polysaccharides are extracted for use as thickening agents in making jams and jellies.

2.3.2.1 How Cell Walls Grow

All materials necessary for making cell wall come from inside the cell. Dictyosomes play a role in this process by transporting pectins, hemicelluloses, and glycoproteins to the plasma membrane. These substance pass through the membrane in the region of cell-wall synthesis, where they are assembled inside the existing wall. This is how cell walls thicken.

Cellular expansion requires the cell wall to stretch or deform as the cell absorbs more water. As the wall enlarges, the existing cellulose micro fibrils must separate because they cannot stretch. During expansion, new cellulose micro fibrils are deposited inside the loosened cell wall in different patterns, depending on the cell type. In stem cells micro fibrils are oriented mostly perpendicular to the direction of cell expansion comparison, micro fibrils are deposited, in random arrays in cells of storage tissues and tissues and tissue cultures. This pattern enables growth in such cells to be more or less uniform in all directions.

2.3.2.2 Connection between Cells

Primary cell walls have thin areas where many tiny connections, called plasmodesmata (singular plasmodesma), occur between adjacent cells. Plasmodesmata are lined by the plasma membrane, thereby forming an uninterrupted channel for the movement of materials, from one cell to

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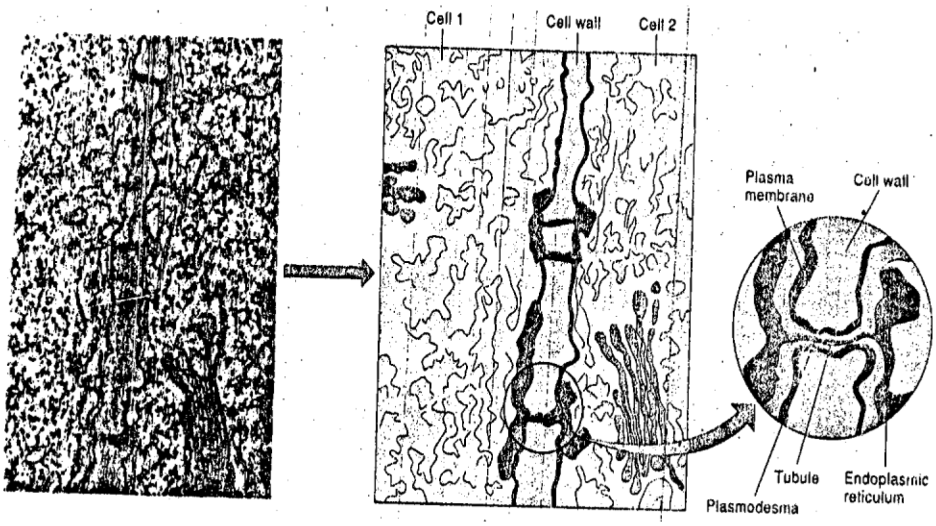
another. This means that all cells in a plant are interconnected and have the potential to exchange substances through the plasmodesmata.

Plasmodesmata often occur in clusters where primary cell walls are particularly thin. These regions are called primary pit-fields (fig 2.3)

(Fig. 2.3)



(fig 2.3) Transmission electron micrograph, x 17,000, and accompanying drawing of primary cell wall show the plasmodesma (which a plasma membrane), and a tubule that connects the endoplasmic reticulum between adjacent cells.

Primary pit-fields and plasmodesmata are abundant in conducting cells and secretory cells, such as those in nectar glands or oil glands.

The structure of plasmodesmata and the frequency of this occurrence in conducting and glandular cells suggest that these connections function in transport between cells. Direct evidence for this function comes from experiments with dyes and electric currents. When a dye that does not easily cross the plasma membrane is injected into one cell, it quickly passes into neighboring cells. Despite such evidence, cells probably do not exchange all materials freely; neighboring cells can differentiate into different cell types and maintain different internal concentrations of various chemicals.

Water-conducting tissue is an important exception to the general Occurrence of plasmodesmata. Cells of this tissue die as they mature, so they have no living material to share between them. Instead, they function as in animals "straws" formed by many cells. In flowering plants, water moves through perforations in the primary cell wall (fig 2.4)

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(Fig. 2.4)

(fig.4) Electron micrograph of a water conducting vessel element, running and printing, x 325

State three functions of cell wall.

2.3.3 The Nucleus

The nucleus is usually a spherical structure consisting of a double layered membrane made up of phospholipids and proteins. This is called a NUCLEAR MEMBRANE. The nuclear membrane is at some places continuous with the endoplasmic reticulum. It is interrupted at some places by NUCLEAR PORES.The nucleus is the most important structure within a cell because here-in resides the whole apparatus of heredity. The nuclei are usually 5-7µm in size.The nucleus contains one or more dense spherical bodies called as NUCLEOLI which are very rich in RNA and proteins. The nucleus controls almost all physiological activities in the cell through the formation of specific enzymatic proteins. Besides being involved in reproduction directly, the nucleus encodes all the genetic information which produces heredity characters in living organisms.

Functions of cell nucleus:

1. It regulates growth and reproduction of cells.
2. The nuclear envelope allows the nucleus to control its contents, and separate them from the rest of the cytoplasm where necessary.
3. The DNA replication, transcription and post transcriptional modification occur in the nucleus.

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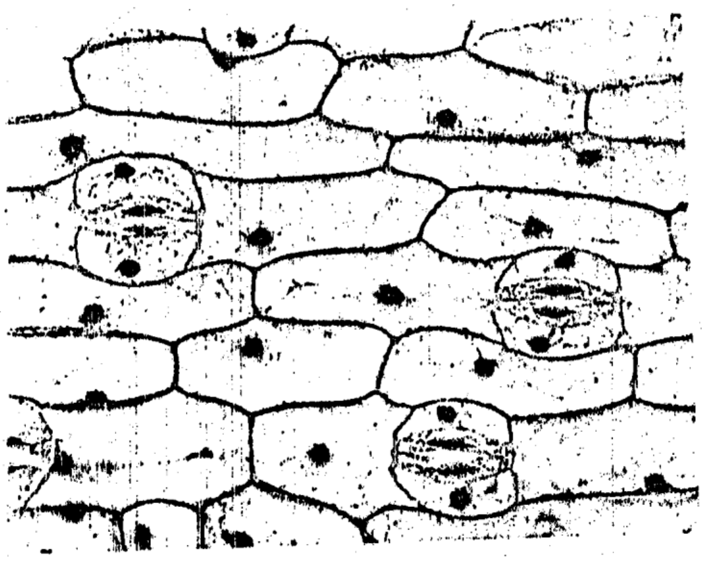
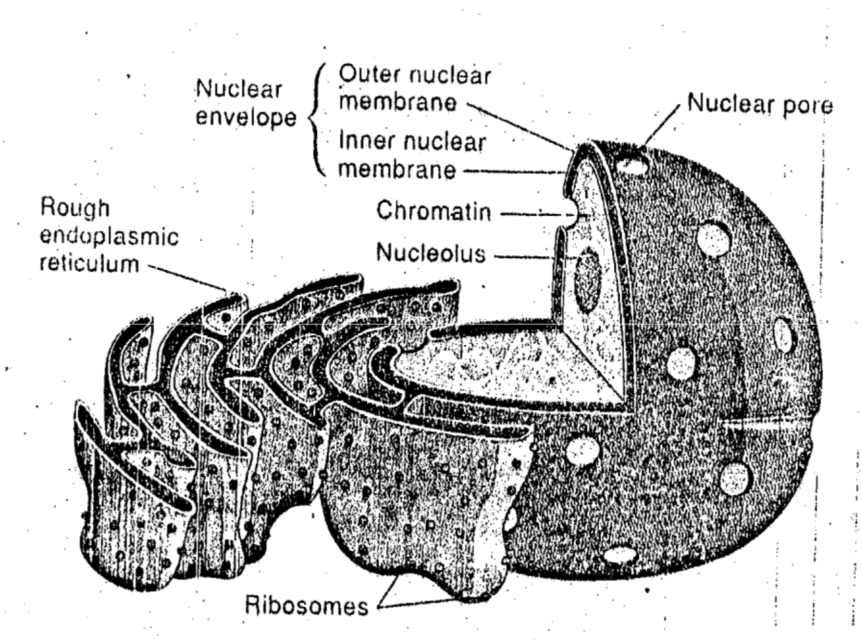
(Fig. 2.5)



(fig 2.5) Right micrograph of leaf cells. Nuclear (dark red) were stained by acto

The nucleus contains most of the cells DNA, which occurs with proteins in threadlike chromosomes. (The nucleus is surrounded by two membranes

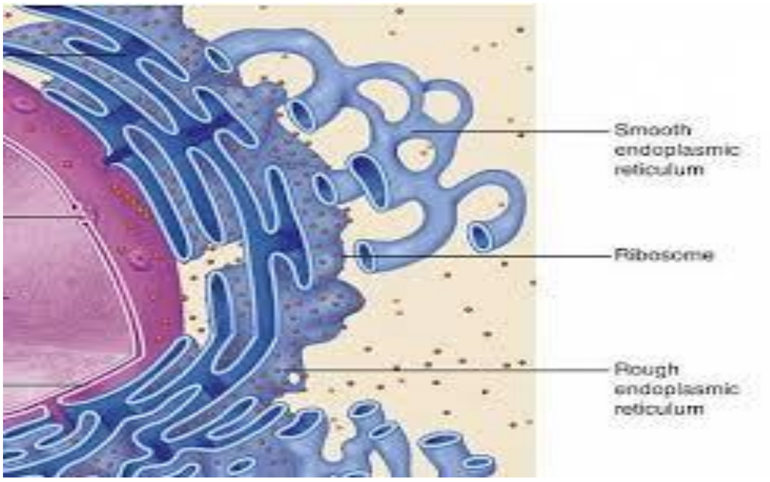
(Fig. 2.6)



(fig. 2.6) The nuclear envelope has pores that link the cytoplasm with the inside of the nucleus. The outer nuclear membrane is continuous with the endoplasmic reticulum

The outer membrane is continuous with the membrane of the endoplasmic reticulum. The inner and outer nuclear membranes are separated by a very small space, but in some cases they fuse to form pores in the envelope. These nuclear pores are small circular openings bordered by proteins that probably influence the passage of molecules between the nucleus and the rest of the cell. For example, certain- proteins move into the nucleus, where they join with ribosomal to make the subunits of ribosomal. In turn, ribosomal subunits and other RNA containing molecules that are made in the nucleus move out into the cytosol through the nuclear pores. The cytosoal is the semi fluid matrix between organelles.
What is the main function of the nucleus?

2.3.4 Ribosomes
Ribosomes are small spherical membrane less organelles. They are the sites of protein synthesis. They are associated with endoplasmic reticulum and also found free floating in the cytoplasm.
They occur in group of two, three, four or five and are called polyribosomes, polysomes, ergosomes, ribosomonal clusters. During protein synthesis, a cluster or a group of ribosomes is often attached to a single M-RNA molecule, each ribosome of the cluster being engaged in the format of separate polypiphyte claim. Such a group or cluster of ribosome is called POLYRIBOSOMES or POLYSOME.



Source: Jain (1974)

The free and attached type of ribosomes performs different functions. The free ribosome plays dominant role in a cell when protein synthesis is required in the cell (e.g haemoglobin, enzymes) which attaches ribosomes on the endoplasmic reticulum are needed when proteins are meant for export (e.g antibodies, digestive enzymes).

Functions of Ribosomes:
1. They provide the platform for protein synthesis
2. They have the machinery for protein synthesis
Define ribosome.

Self-Assessment Exercise 3

Where ribosomes are predominantly found?

SELF ASSESSMENT QUESTIONS
a) *What are intermediate filaments?*
b) *W*hat are the roles of microtubules in mitosis?

2.4 Summary

Plant cell structure includes the cell wall, cytoplasm and the nucleus. Each part works for the success of the cell.

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2.6 Possible Answers to SAEs

Answer to SAE 1

Starch grains,Vacuole sap with waste substances such as tannins, crystals

Answers to SAE 2

All cells in a plant are interconnected and have the potential to exchange substances through the **plasmodesmata**.

Answer to SAE 3

Ribosomes are found in haemoglobin, enzymes and antibodies

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UNIT 3 STRUCTURE AND FUNCTION OF PLANT CELL: II

Unit Structure

3.1 INTRODUCTION

In unit 2, we started the discussion on the structure and function of the plant cell we have identified that each cell of a plant consists of a cell wall that surrounds a plasma membrane, which encloses many smaller parts called organelles. Because each organelle has its own set of functions, the job of each cell in a plant is determined by how many and which organelles it contains, and what the organelles do. For example, leaf cells contain chloroplasts, nectar-secreting cells contain many dictysomes and the storage cells of oil-containing seeds have dglyoxysomes. These organelles have roles in photosynthesis, and oil metabolism, respectively.

Plant cell biology can be reduced to the study of the structure and function of smaller components. By analyzing the anatomy of a cell, we can find clues to how the cell works. In this unit, we conclude our study of the plant cell structure and how it controls cellular processes.

3.2 Intended Learning Outcome (ILOs)

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

-describe the membrane system in a plant cell
-describe the endoplasmic reticulum
-describe the structure of the dictyosomes
-list the major contents of vacuoles
-identify the two most important microbodies
-name the two major organelles for energy conversion

3.3 Main Contents

3.3.1 The Membrane System

All the membranes in all cells are connected either by direct contract with each other or by the exchange of membrane segment. These inter- connected membranes function together as a membrane system that includes the plasma membrane and the various organellar membranes.

Many biochemical processes occur in or on membranes. For example, the enzymes involved in photosynthesis and in ATP synthesis are embedded in membranes. Membranes also provide a framework for making more membranes.

All membranes have a similar structure, which consists of a double payer of phospholipids that is impregnated with protein. However, not all membranes have exactly the same structure and function; for example, the permeability of the plasmas membrane differs from that of the nuclear envelope. Each membrane controls how much and what kind of material pass through it; that is each membrane has a different membrane selectivity, which depends on its composition. Moreover, the composition and physical properties of a membrane can change during cell development.

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In principle, internal membranes increase the ratio of membrane surface cell volume. However, internal membranes do more than this. They are physically and chemically distinct from the plasma membrane and from each other. Furthermore, they divide the cell into functionally distinct compartments (i.e. organelles) that are bounded by their own differentially permeable membranes. Thus, the cell is separated into a set of individual reaction vessels. Each reaction vessel has its own specialized functions, which are performed by a unique set of enzymes bound to or held within the membrane.

3.3.1.1 The Plasma Membrane

All cells are enclosed by a thin, membrane called plasma membrane or plasmalemma (ectoplast). The plasma membrane and sub cellular membrane are collectively called biological membrane. Cell membrane consists of proteins, lipids and other substances.

1. **Proteins**: The proteins present in the membranes can be categorized into two types

a. Intrinsic proteins or integral proteins: - Which are embedded or buried in the lipid layer. These proteins associate with hydrophobic interactions to the tails or fatty acid chains of the lipid layer. In addition to the hydrophobic associations, integral proteins also possess hydrophilic amino acid residues which are exposed at the surface of the membrane. These proteins cannot be removed easily.

b. Extrinsic proteins or peripheral proteins: - They are attached to the membrane surface by weak ionic interactions. These proteins are not much involved in the architecture of membrane. Peripheral proteins are bound to hydrophilic proteins of the integral proteins protruding from the lipid layer.

2. **Lipids**: - The cell membrane consists of phospholipids and glycolipids. The fatty acid chains in phospholipids and glycolipids usually contain 16-20 even numbered carbon atoms. Fatty acids may be saturated or unsaturated.

3. Other substances like polysaccharide, salicylic acid etc. are found attached to the proteins or lipids on the membrane.

Functions of Plasma membrane:

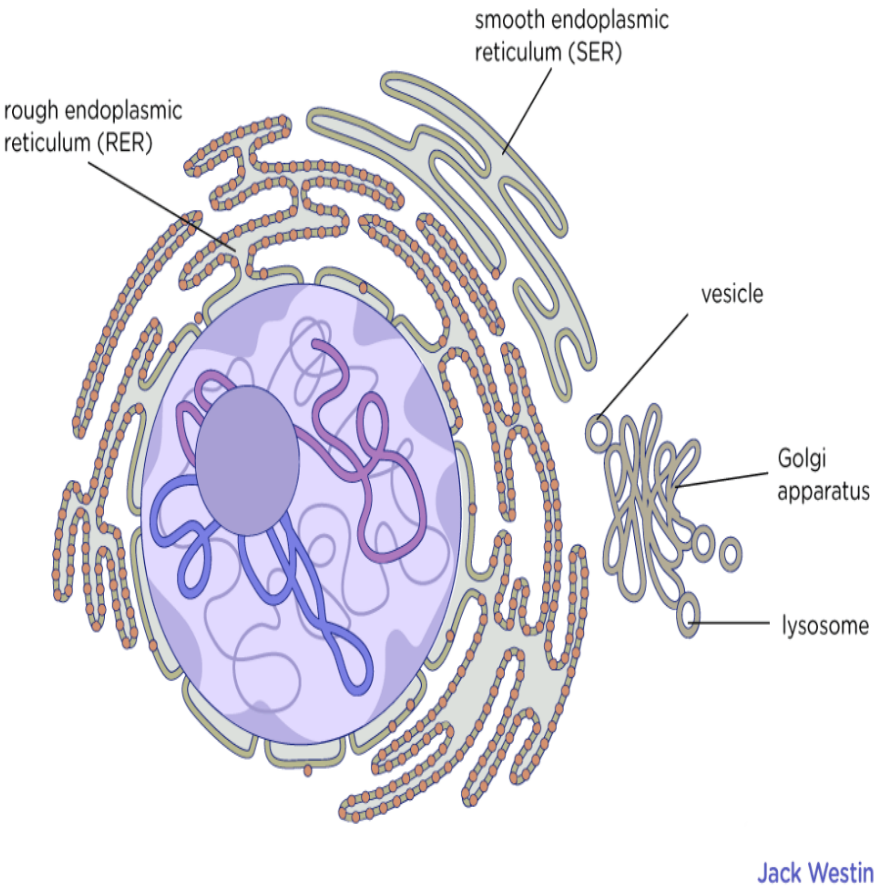
1. The cell membrane surrounds the protoplasm of the cell, thus separating the intracellular components from the extracellular environment.
2. It anchors the cytoskeleton to provide shape to the cell, and in attachment to the extracellular matrix.
3. The plasma membrane is differentially permeable and able to regulate the transport across the membrane.
4. The cell membranes maintain the cell potential.

3**.1.2. Tonoplast:** it forms the innermost boundary of the cytoplasm and surrounds the vacuole, hence, it is also known as **vacuolar membrane**. It is also selectively permeable and lipo-protein in nature. It acts as a barrier between the cytoplasm and the vacuole.

3.1.3. Endoplasmic Reticulum: this is a network of paired membranes folded in different ways and enclosing spaces called **cisternae.** These membranes are lipo-protein in nature and the whole membranous system is called **Endoplasmic Reticulum (ER) or Ergastoplasm.** When the ER is associated with the ribosomes, it is called **Rough Endoplasmic Reticulum** and when its without ribosome it is called **Smooth Endoplasmic Reticulum**

Functions of Endoplasmic Reticulum:

1) It plays significant role in protein synthesis as its associated with ribosomes
2) It helps with the storage, segregation and export of proteins synthesize in the cell to the exterior for extracellular use.
3) It is involved in the synthesis and storage of glycogen
4) It is associated with the synthesis and storage of triglycerides
5) ER is involved in the production and storage of cholesterol and steroids hormones
6) ER is involved in detoxification and elimination of a number of harmful materials like drugs, pollutants and bile salts.



The ground phase of the cytoplasm is known as **cytosol.** The cytosol contains living and non-living substances. The living substances that are membrane bound are called **cell-organelles** while the non-living substances are called **Ergastic substances** or **cell –inclusions.***Mention the three physiological parts of cytoplasm.*

Self –Assessment Exercise 1

What are peripheral proteins?

3.3.1.2 Dictyosomes

The Golgi body (Camilo Golgi) consists of a stock of 3-6 flattened membrane sacs or cisternae which are slightly curved and swollen to the margin. Each cistern encloses a place or lumen. The cisternae in golgi body are not contagious but are located about 10µm apart. Golgi body is also called Golgi apparatus or Golgi complex. In animals, Golgi bodies tend to cluster in one part of the cell and are not under connected with one another through tubules. But in plants, large numbers of separate Golgi bodies are dispersed throughout the cytoplasm. Golgi bodies are found in most secretary cells. The member of the Golgi bodies varies depending on the metabolic

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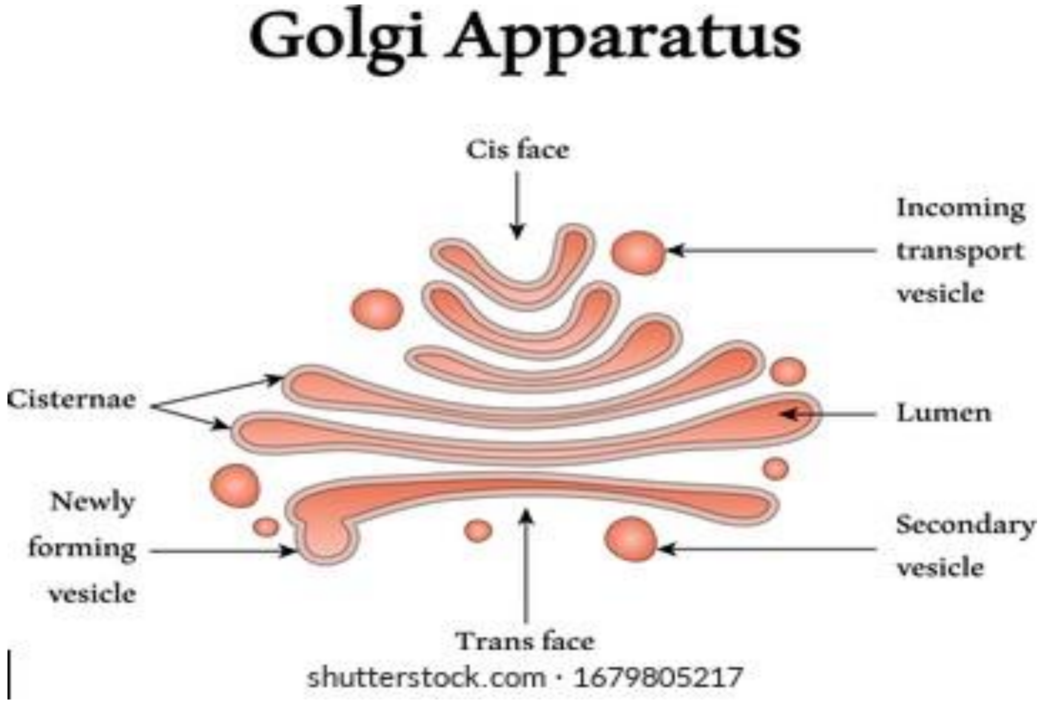
activity of the cell. In animal cell, they are few in number, but in plants, they are dozens to hundreds.



Functions of Golgi Body
1) In plant, the main function of Golgi body is in cell wall formation.
2) Golgi bodies also synthesis non-cellulosic cell wall polysaccharides such as hemi-cellulose and protein.
3) Other functions of Golgi bodies are Suphation (removing radioactive sulphur), lipid metabolism, plasma membrane formation, origin of lysosomes. *Mention the main function of Golgi body in plant.*

3.3.1.3 Vacuoles

It is a membrane bound organelle found in plant cell and occupies most of the area in the plant cell. A vacuole is surrounded by a single layer membrane called tonoplast. It is an enclosed compartment filled with water containing inorganic and organic molecules including enzymes in solution. It maintains the cell's turgor, controls movement of molecules between the cytosol and sap, stores useful material and digests waste proteins and organelles.

Functions of vacuole:
1. Isolating materials that might be harmful or a threat to the cell.
2. Stores waste products.
3. Maintains internal hydrostatic pressure or turgor within the cell.
4. Maintains an acidic internal pH.
5. Exports unwanted substances from the cell.
6. Allows plants to support structures such as leaves and flowers due to the pressure of the central vacuole.
7. Most plants stores chemicals in the vacuole that react with chemicals in the cytosol.
8. In seeds, stored proteins needed for germination are kept in protein bodies which are modified vacuole.

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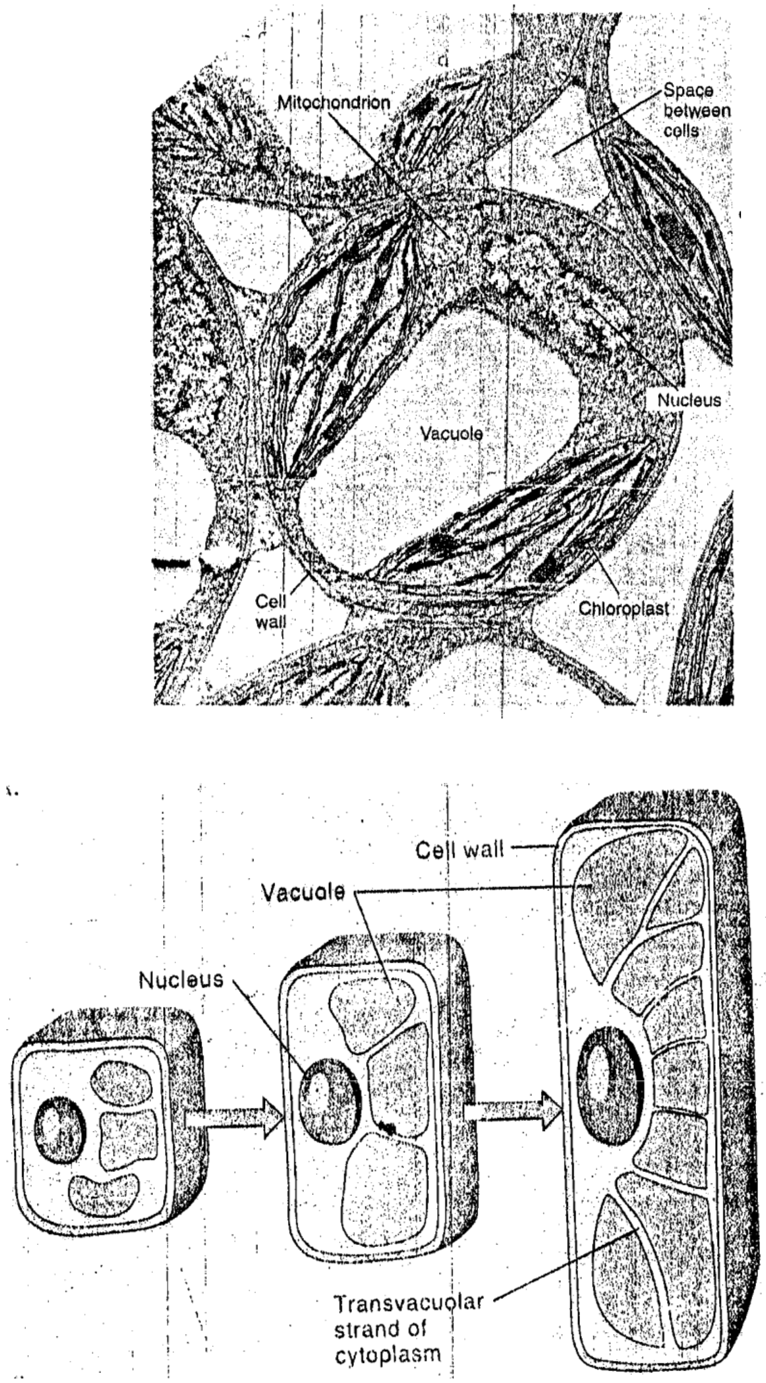

Fig* 3. 4 *Vacuoles. (a) transmission electron micrograph from a coleus leaf (Coleus blumer). The expanding central vacuole compresses the cytoplasm into a small space against the cell wall, x 20,000 (b) schematic diagram of cell growth, showing how an increase in

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cellular volume can occur without a large increase in the amount of cytoplasm. The peripheral layer of cytoplasm may be interconnected through the vacuole by cytoplasm strands that radiate from the region of the nucleus.

As plant cells grow, most of their enlargement results from the absorption of water by vacuoles which expand and push the rest of the cell's content into a thin larger against the cell wall. Vacuoles that are filled with water create pressure called turgor pressure, on the cell walls, which contributes to structural rigidity of the cell. When a plant receives very little water turgor pressure decreased and the plant wilts. We can see the effects of tugor pressure by letting carrots or vegetables dry out. They become flaccid and we can make them crisp again by putting them in water. This reacquired crispness (tugor) is caused by vacuoles that have been filled with water.

Vacuoles are versatile organelles as indicated by the diversity of substances that occur in them. In addition to water, vacuoles contain enzymes and other protein, water soluble pigments, growth hormones and ions. Vacuolar enzymes digest strong materials and components from other organelles for recycling into the cytosol pigments in vacuoles especially red and blue anthocyanins, impart bright colours to flowers, fruits and other plant parts. Some plants may labor toxic alkaloids or other secondary products in their vacuoles. These alkaloids, which are water soluble at the acidic pH of vacuoles, may deter insects and other animals from eating the plants that contain them.

Ions such as potassium and chloride are stored in vacuoles for easy retrieval to the cytosol when needed for cellular metabolism. In plants specialized for high cell habitations, such as those along coastlines and near marine estuaries, vacuole can accumulate chloride salts to concentrations several thousand times grate than in cytosol. The cytoplasm of these plant cells is protected from salt toxicity, enabling the plants to thrive in their harsh environment. ***Mention four functions of vacuole.***

Self- Assessment Exercise 2

What is Suphonation

3.3.1.4 Micro Bodies

The smallest membrane – bound organelles in a cell are called micro bodies Microbodies, which are bound by a single membrane, are usually spherical. These tiny organelles are often associated with membranes of the ER, but they may also be closely associated with chloroplasts and mitochondria. Different types of micro bodies have specific enzymes for certain metabolic pathways. Two of the most important kinds of micro bodies are perioxysomes, which occur primarily in leaves and glyoxysomes, which are common in germinating oil-bearing seeds and the young seedlings that grow from them.

LYSOSOMES

Lysosomes are minute spherical structures bounded by a membrane and containing some enzymes. When the membrane is ruptured the enzymes are released into the cytoplasm causing its disintegration (lysis).

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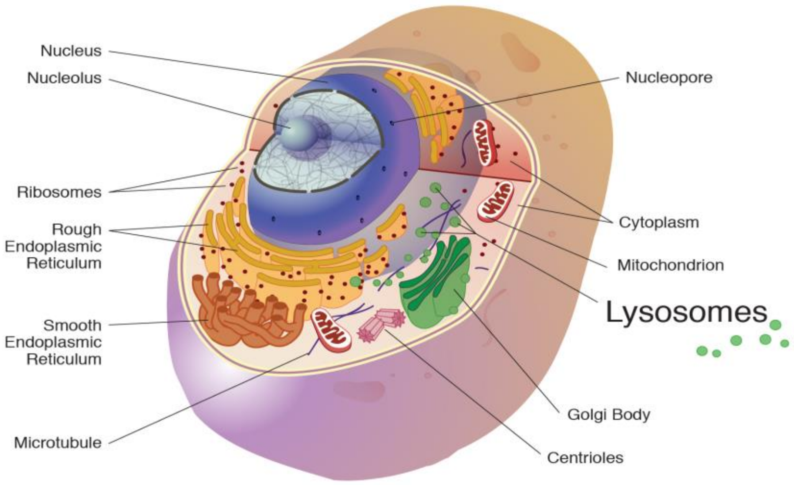

Source: Hopkins (1995)

SPHEROSOMES
Spherosomes are minute spherical structures of about 0.4-3.0µ in size and are surrounded by a membrane. Spherosomes are also called Oleosomes or oil bodies because they store fats. Specific proteins called OLEOSINES are found in membranes that surrounds Oleosome.
These proteins maintain each oleosome as a decreased organelle by preventing their fusion. They also facilitate binding of other proteins to organelle's surface. Spherosomes contain hydrolytic enzymes and function to digest the cell contents.

GLYOXYSOMES
Glyoxysomes are usually spherical in shape, about 0.5-1µm in diameter and consist of five granular strouma surrounded by a single membrane. These particles contain keys enzymes of glyoxylate cycle (isocitratase and malate synthetase) that helps in conversion of fats to sugar (carbohydrates) in germinating fatty seeds.

PEROXISOMES
These particles are similar in shape and size to glyoxysomes (glyoxysomes and peroxisomes are called microbodies). Peroxisomes contain typical enzymes that are involved in glycolate metabolism and photo respiration during photosynthesis. *What are Spherosomes?*

3.3.2 Organelles for Energy Conversion

Cells thrive on the energy of ATP. Two kinds of organelles, chloroplasts and mitochondria, produce most of the ATP needed for cellular metabolism.These organelles are similar in several respects. For example, both are bounded by two membranes and much of their internal membranes is folded and stacked to form complex compartments. Their internal membrane contains the enzyme ATPase, which uses the electrochemical energy of protons to phosphorylate ADP into ATP. Chloroplasts and Mitochondria also contain DNA that controls the synthesis of many of the enzymes necessary for their respective metabolic pathways. Finally, Chloroplasts and Mitochondria are seminautonomous; they grow and divide in the cell on their own.

The different between chloroplasts and Mitochondria include their espective sources or energy for making ATP their appearance, and their composition. Chloroplasts use the energy of light, which mitochondria use energy of chemical bonds, Chloroplasts contain chlorophyll, which makes them green, while mitochondria are colourless. Photosynthesis occurs in chloroplasts, and most of respiration occurs in mitochondria. Each process requires a different

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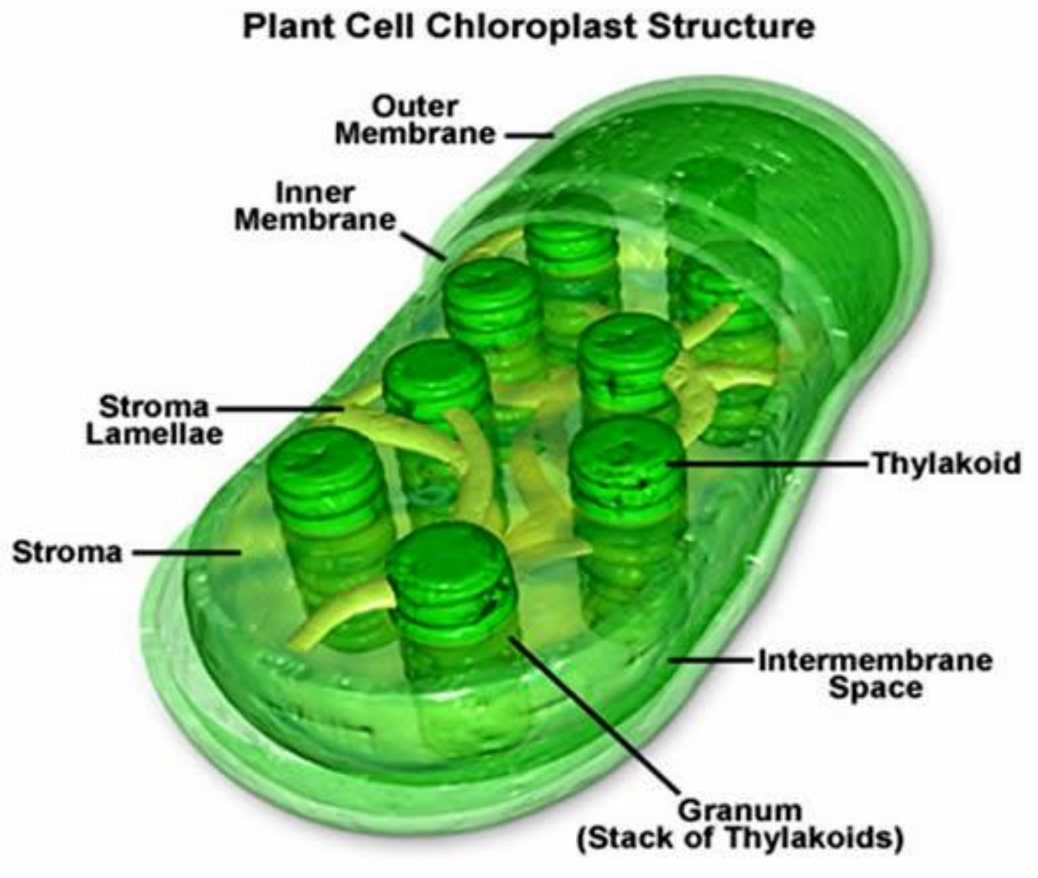
set of enzymes; Chloroplasts have many shapes and sizes, and are generally larger than mitochondria. Mitochondria are often cigar-shaped.

3.3.2.1 Chloroplasts

Chloroplasts are organelles found in plant cells and other eukaryotic organisms that perform photosynthesis because of the presence of green pigment, chlorophyll. They are flattened discs usually 2-10 micrometers in diameter and 1 micrometer thick. The chloroplast is surrounded by double layered membrane. The space between these two layers is called intermembrane space. Stroma is the aqueous fluid found inside the chloroplast. The stroma contains the machinery required for carbon fixation, circular DNA, 70 S ribosomes (that's why called as semiautonomous organelle) etc. within the stroma the stacks of thylakoids are arranged as stacks called grana. A thylakoid has a flattened disc shape and has a lumen or thylakoid space. The light reactions occur on the thylakoid membrane.

Functions of chloroplast:

1. The important processes of photosynthesis, that is, light and dark reactions occur within the chloroplast.
2. The granum is the site of NADP reduction forming NADPH+H+ and photophosphorylation i.e., formation of ATP in presence of light. Thus, light reaction of photosynthesis takes place in the granum region.
3. The stroma is the main site for the dark reaction of photosynthesis.
4. The chloroplast has its own genetic system and is self-replicating. Thus, associated with cytoplasmic inheritance.



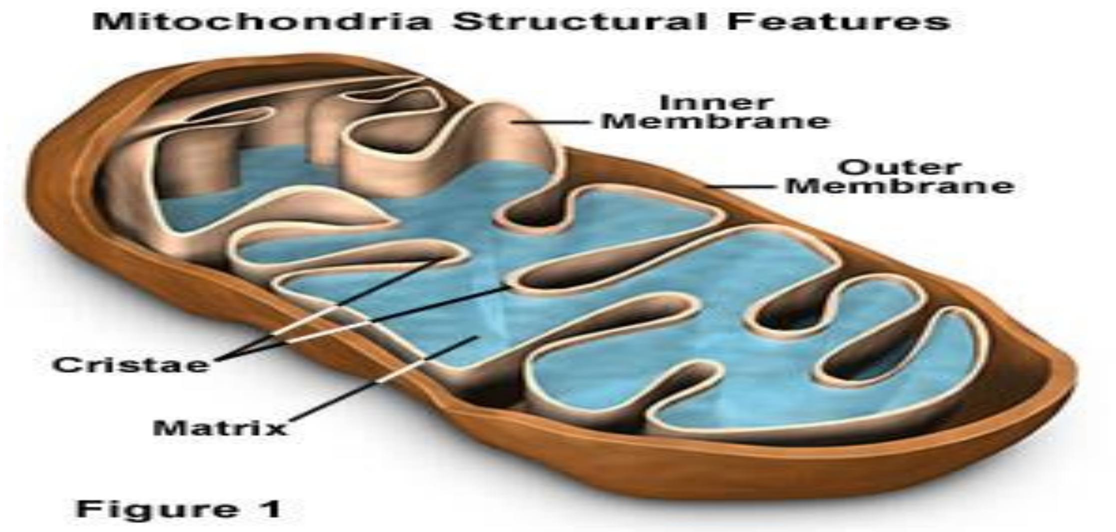
Source: Verma (2009)

What are stroma?

3.3.2.2 MITOCHONDRIA (CHONDRIOSOMES)

Mitochondria are sizes of cellular respiration. They are usually spherical or rod shaped structures ranging from 0.5m-1mμ in diameter and 1mμ to 3.0mμ in length. Mitochondria are rod shaped cytoplasmic organelles, which are main sites of cellular respiration. Hence, they are referred to as power house of the cell. Each mitochondrion is enclosed by two concentric unit membranes comprising of an outer membrane and an inner membrane. The space between the two membranes is called perimitochondrial space. The inner membrane has a series of in foldings known as cristae. The inner space enclosed by cristae is filled by a relatively dense material known as matrix. The matrix is generally homogeneous but may rarely show finely filamentous or fibrous structures. The matrix contains several copies of round or circular DNA molecules and 70 S ribosomes (that's why it is also called as semiautonomous organelle).

Functions of mitochondria:
1. ATP, the readily available form of energy is produced in mitochondria.
2. Krebs cycle takes place in the matrix of mitochondria.
3. The enzymes of electron transport chain are found in the inner membrane or cristae of mitochondria.
4. Heme synthesis occurs in mitochondria.
5. Controls the cytoplasmic Ca^{2+} concentration



Source: Verma, (2009)

Each mitochondrion got an envelope consisting of two double-layered lipooprotein membranes. The space enclosed in between the two membranes is called intermembrane space. The inner mitochondrial membrane is invaginated with plate-like, finger-like feets which are called CHRISTAE. The aqueous ground phase of mitochondrion is called MATRIX. All enzymes necessary for Krebs' cycle are found in the matrix.
The components of electrons transports chain are found in the inner mitochondrial membrane. Mitochondria are often called the power house of the cell because of the huge amount of energy liberated during aerobic respiration is trapped inside the mitochondria in form of ATP molecules which are then utilized in driving off various metabolic activities of the cell. *List three functions of mitochondria.*

Self –assessment Exercise 3

What role do Glyoxysomes play inside the cell

3.3.3 Cell Movement

Cell prepared for study with microscopes are usually arrested in static positions. It is therefore not possible to see that they are in constant motion. When cells are viewed under the light microscopes their internal movements are easily seen. In addition to internal movements, some entire cells are motile, that is they can swim.

3.3.3.1 Internal Movement

Living plant cells as seen under the light microscope have then cytoplasm in constant motion. Organelles and other particles usually move 'in a circle around the central vacuole. This streaming movement is called cyclosis.

Chloroplasts and mitochondria move along definite paths that are associated with actins filaments and microtubules of the cytoskeleton. The outermost region of the cytoplasm is more anchored and relatively immobile, whereas the innermost region is more fluid. Cyclosis enhanced the exchange of materials among organelles, between membranes and organelles and even between cells.

Cell that Swim

Cells that swim have hair like locomotor organelles that protrude into the medium surrounding the cell. In plant cells, these hairs are called flagella (singular flagellum). Such cells are found only in sperm cells of some plants. Example, in the mosses, these sperm cells have two flagella, and in cycads, the flagella may be up to several thousands.

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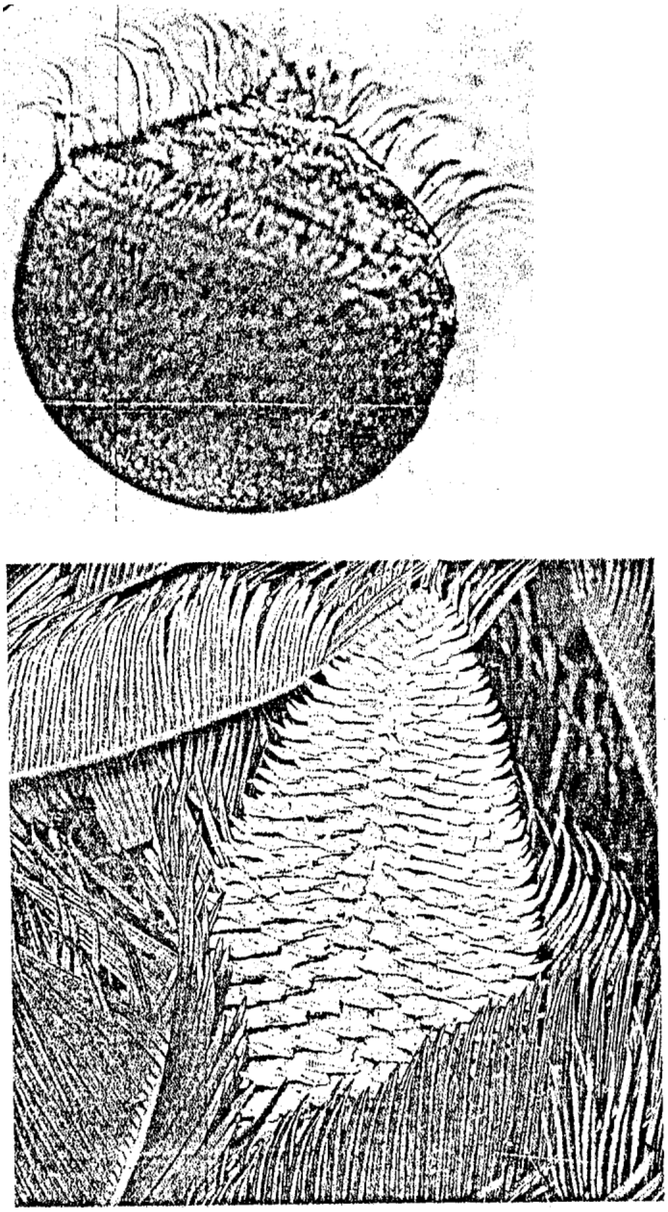
(Fig. 3.7)



Micrograph of sperm cell from showing, x 250, (b) Photo of a that produces sperm di

Some algae, water molds and animals also have flagellated sperm cells. Certain water molds and algae have other kinds of cells that also swim by flagella.

All flagella in plants, animals, fungi and protest have the same internal structure and the same mechanism of action. Each flagellum consists of a membrane that surrounds ten pairs of microtubule. One pair occupies the centre of the flagellum and nine pairs occur in a ring around centre pair.

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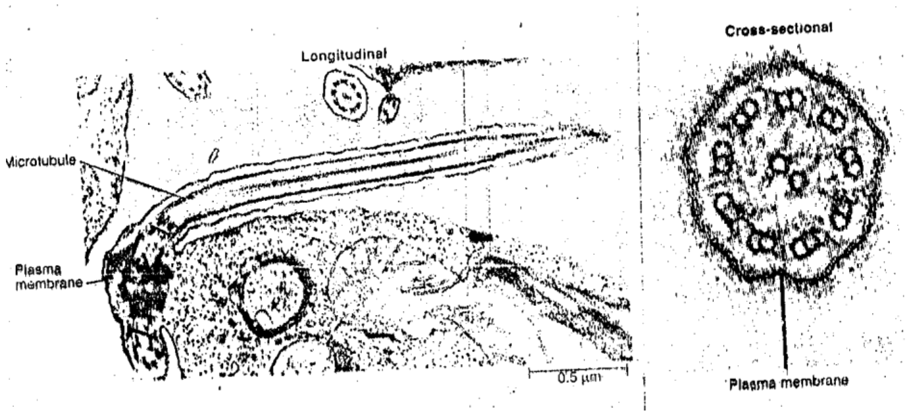
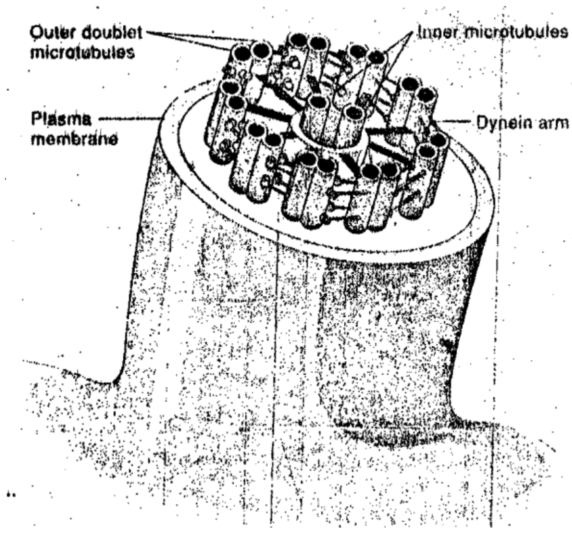


(Flagella. a) Transmission electron micrograph of a flagellum in the. reproductive cell of the green algae. Ulvaria. Longitudinal section shows that the membrane I surrounding the flagellum is continuous with the plasma membrane

Each outer pair of microtubule is connected to its neighbouring pairs by sidearm that are evenly spaced along the length of the flagellum. Similarly, spoke like extensions from the outer microtubules connect to the inner microtubules.



Flagella. a) Transmission electron micrograph of a flagellum in the. reproductive cell of the green algae. Ulvaria. Longitudinal section shows that the membrane I surrounding the flagellum is continuous with the plasma membrane

The sidearm and spokes are made of the protein dynein. ***What is cyclosis and what is it function?***

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3.4 SUMMARY

The cellular components are called cell organelles. These cell organelles include both membrane and non-membrane bound organelles, present within the cells and are distinct in their structures and functions. They coordinate and function efficiently for the normal functioning of the cell. A few of them function by providing shape and support, whereas some are involved in the locomotion and reproduction of a cell. There are various organelles present within the cell and are classified into three categories based on the presence or absence of membrane.

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3.6 Possible Answers to SAEs

Answer to SAE 1

Extrinsic proteins or peripheral proteins: - They are attached to the membrane surface by weak ionic interactions. These proteins are not much involved in the architecture of membrane. Peripheral proteins are bound to hydrophilic proteins of the integral proteins protruding from the lipid layer.

Answers to SAE 2

Suphation is the process of removing radioactive sulphur

Answer to SAE 3

Glyoxysomes help in conversion of fats to sugar (carbohydrates) in germinating fatty seeds

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UNIT 4 STRUCTURE AND FUNCTION OF MEMBRANES: I

Unit Structure

4.1 INTRODUCTION

Most of the important activities of cells are associated with membranes. For example, proteins destined for secretion or for insertion into cell membranes are made by ribosomes that are attached to a membrane system called the endoplasmic reticulum.

Suggestions about the structure of membranes that appeared in the 1920's was based on the soap like properties of phospholipids in artificial membrane. Phospholipids have a dual solubility. Their long hydrocarbon 'tails' are non polar and hydrophobic (water-fearing). In contact the ionic phosphate 'head' of phospholipids is polar and hydrophilic (water loving). In water phospholipids aggregate spontaneously into a bilayer which is a double membrane with an interior of hydrophobic hydrocarbons and an exterior of hydrophilic phosphates. The above explanations was not enough to explain the great diversity of membrane functions. The properties of membranes also depend on proteins, which are their main ingredients.

In this unit, we looked at the general structure of membranes. We then list it various functions and discussed the first one which is movement of water and solutes.

4.2 Intended Learning Outcomes

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

-describe the structure of the cell membrane using the fluid mosaic model
-list 5 important activities of membranes
-discuss the significance of the following to (a) Plant diffusion
(b) Potential energy (c) Water potential
-state the biological importance of osmosis discuss why plants wilt

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-explain the following terms (a) Osmotic pressure (b) Osmotic potential (c) Turgor pressure (d) Plasmolysis.

4.3 Main Contents

4.3.1 Structure of Membranes

Early ideas about the structure of phospholipids bilayers explained how some molecules including non-polar molecules of gases (Nitrogen and Oxygen) and small polar molecules such as water could flow across membranes

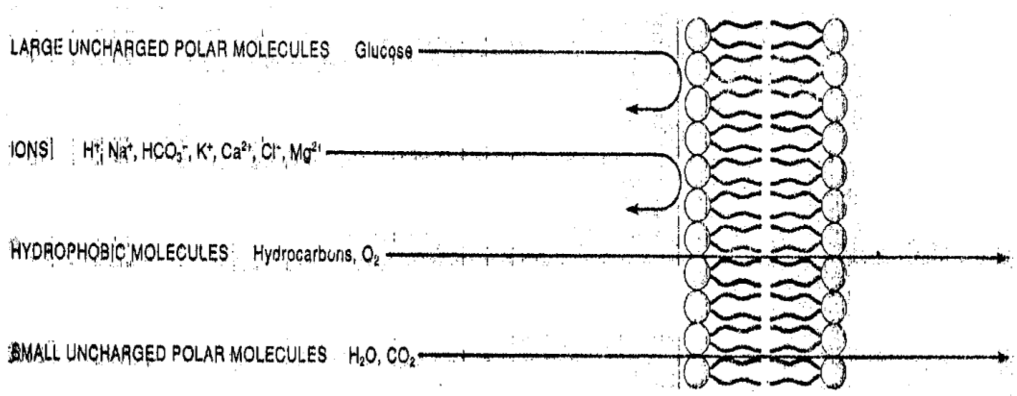

Fig. 4.1 Selective permeability of a phospholipids bilayer. The bilayer is much more permeable to hydrophobic molecules and small unchanged polar molecules than it is to and large polar molecules.

However, lipid bilayers could not account for the ready passage of larger polar molecules such as monosacctarides and amino acids.

The passage of these molecules through membrane was first explained in the 1930s by H. Davson and J.F. Danielli, who suggested that the lipid bilayer was coated on both sides with hydrophilic proteins that were attached to the polar heads of phospholipids. According to this model, the hydrophilic proteins absorbed polar molecules and somehow eased their passage through the non-polar larger of the membrane.

In the 1950s, the first electron micrographs of membranes seemed to confirm this modal.

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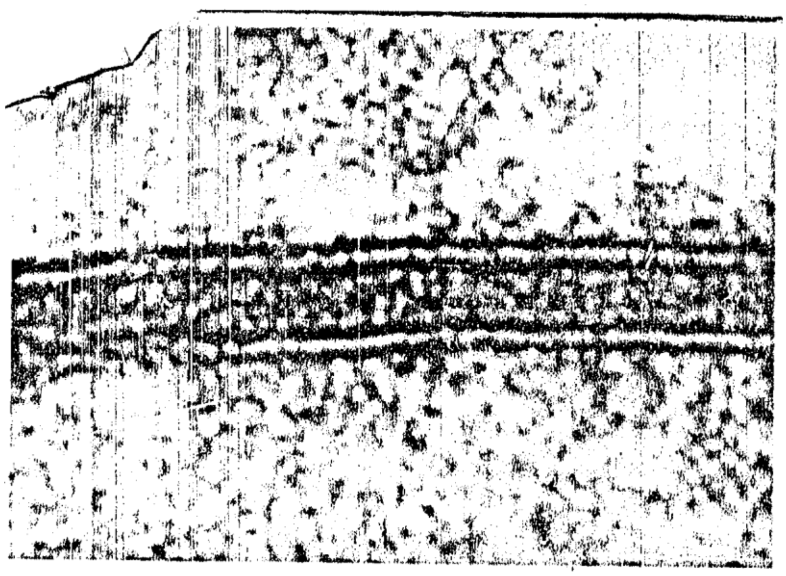

Transmission electron micrograph of two membranes. Each membrane appears as two dark lines that are separated by a lighter region. At first, micrographs of this sort seemed to contain the Davson-Danielli model of membrane structure, but this interpretation was later found to be incorrect.

These pictures showed membranes to have an electron-transparent inner region sandwiched between two electron-dense outer layers. The other layers were assumed to be made of proteins and phospholipids heads, and the inner region was believed to be made of the hydrocarbons in phopholipid tails.

Despite the apparent support from electron microscopy, flaws in the Davson-Danielli model began to accumulate. For example, cell biologists found that this model could not explain structure and biochemical variations found among different kinds of membranes. Mitochondria membrane for instance, are thinner than plasma membranes and contain a higher proportion of protein. This and other findings contradicted the Davson-Danielli model, which held that membrane proteins must be hydrophilic (water loving), and' that all membranes have the general structure of a protein-lipid-protein "sandwich".

The current view of membrane structure has seen the Davson-Danielli model go through a series of modifications. These newer version proposed in 1972 is called the **fluid mosaic model**. It holds that proteins occur as a mosaic in a fluid bilayer of phospholipids.

(Fig. 4.3)

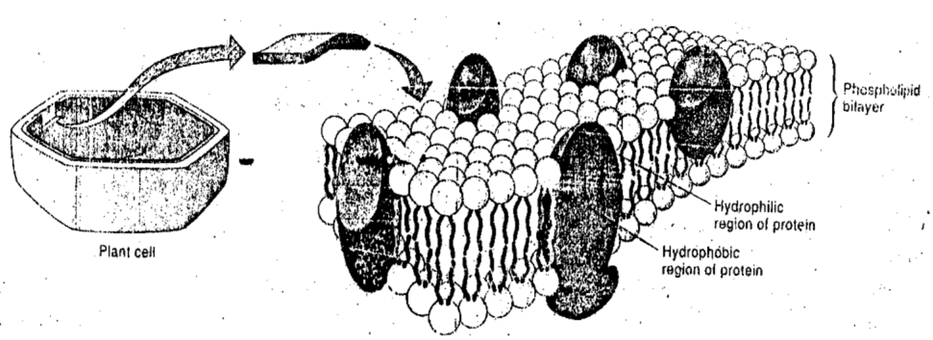

Fig. 4.3 The fluid model of membrane structure. Proteins are dispersed in the phospholipids bilayers according to the model

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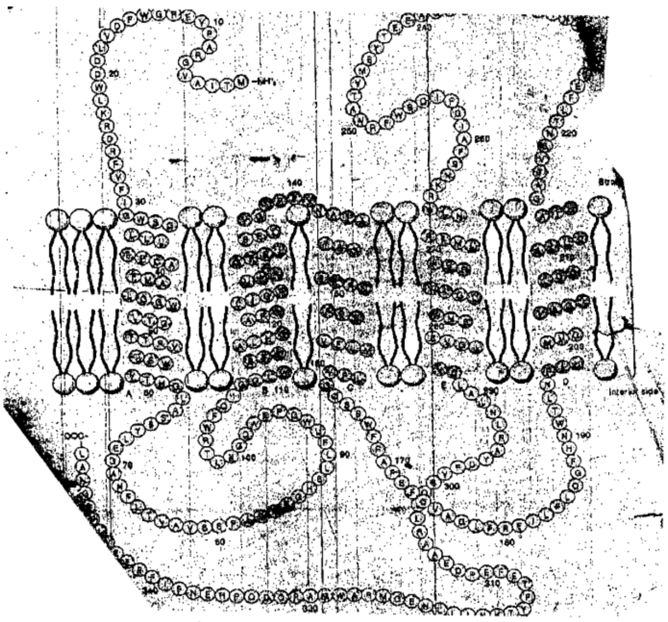
Visual evidence for the fluid mosaic model comes from scanning electron microscopy of freeze-fractured membranes. The interior of the membrane is then seen as a dotted plain. The plain is a sea of lipids and the dots are proteins inserted into them.



Primary structure of a thylakoid protein. Five regions of the protein occur in the membrane. (boxes A – E); the remaining regions provide either into the stoma or into the interior of the thylakoid. This membrane protein consists of 352 amino acids, each designated by a one-letter abbreviation.

Primary structure of a thytakoid protein five regions of the protein occur in the membrane (boxes A-E); the remaining regions provide or into the interior of the thytakoid. This membrane protein consist of 352 each designated by a one-letter.

The name fluid mosaic model implies that the membrane contains liquid. The lipid bilayer is only its fluidity is due to the loose packing of the fatty acid tails of the phospholipids. The mosaic of proteins is a significant feature or the fluid mosaic model. It accounts for the movement and intermingling of proteins that must touch each other to function.

Another important feature of the membrane structure is its asymmetry, that is, on side of a membrane is different from the other. This difference comes mostly from the carbohydrates that are attached to proteins on the outside surface of the membrane proteins with carbohydrates attached to them are called glyco-proteins, and they do not usually occur on the inner surfaces of membranes.

4.3.1.1 Functions of Membranes

Proteins control most of the functions of membranes. These may be fifty or more different kinds of proteins in plasma membranes and perhaps as many in the tonoplast or other organelles membranes.. This diversity of proteins is reflected in the enormous range of activities associated with membranes. Some of the important of these activities are discussed in the sections that follow. We will however give a summary of the activities here.

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a) Movement of water and solutes. The plasma membrane generally allows the unrestricted passage of water and certain dissolved substances into or out of the cell. Water balance is crucial for maintaining tugor pressure, which makes the cell rigid and helps cellular expansion during growth.

b) Differential permeability - Membranes control or block the passage of some kinds molecules such membranes are referred to as differentially permeable membranes.

c) Ion pumps - certain ions, such as K^+ and H^+, are pumped through membranes. Ion pumps in the plasma membranes are energy from ATP to move Ions from the cell while Ion pumps in mitochondria and chloroplast membranes are important for making ATP.

d) Enzyme activity - Enzymes that cooperate in multistep processes such as ATP synthesis or the absorption of light energy often occur together in a particular spot on a membrane.

e) Cellular communication - The plasma membrane contains proteins that bind molecules released from other cells. Once bound to an external molecule, these proteins activate other proteins in the membrane that cause metabolic changes in the cell.

List 4 important activities of membranes

Self-Assessment Exercise 1

What did Dayson and Danielli proposed in 1930 about membrane?

4.3.2 CELLULAR PROCESSES

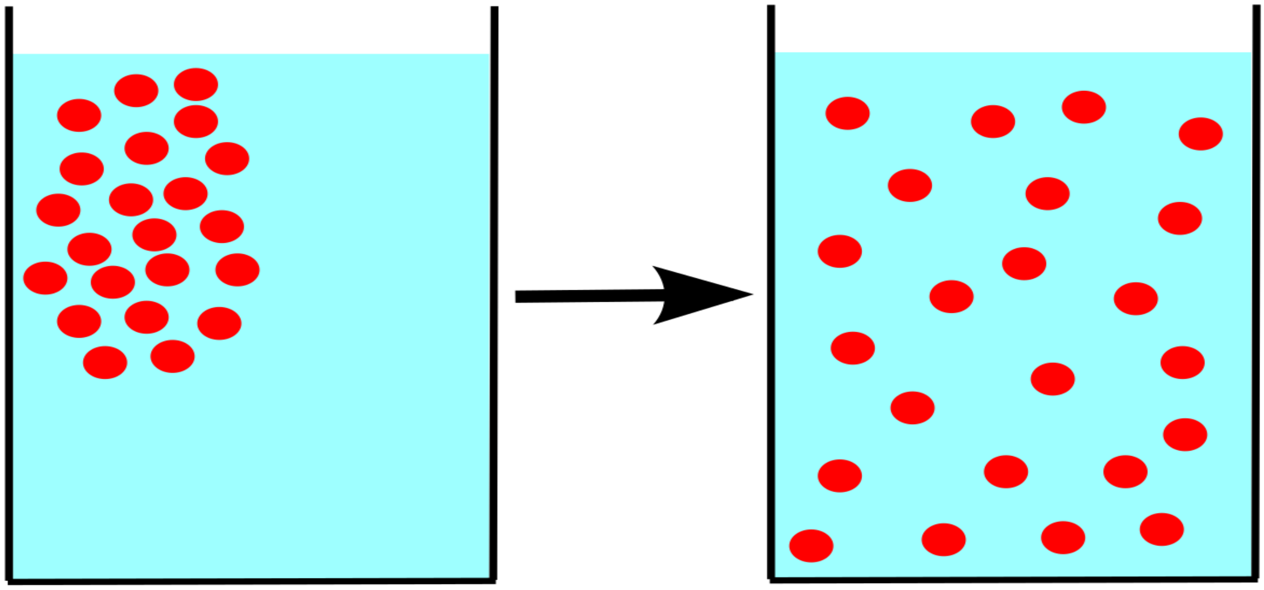
Cellular processes depend on the transport of molecules both to the cell and away from it. The movement of materials in and out of the cells in plants takes place in solution or gaseous form. These movements of materials involve three (3) physical processes: Diffusion, osmosis and imbibition.

4.3.2.1 DIFFUSION

Diffusion is the movements of particles or molecules from a region of higher concentration to a region of lower concentration. The rate of diffusion of gases is faster than liquid or solutes.

In other words, diffusion is the movement of molecules of gases, liquids and solutes from regions of higher concentration to regions of lower concentration until the molecules are evenly distributed throughout the available space.

The diffusing particles have a certain pressure called Diffusion Pressure which is directly proportional to the number or concentration of the diffusing particles.

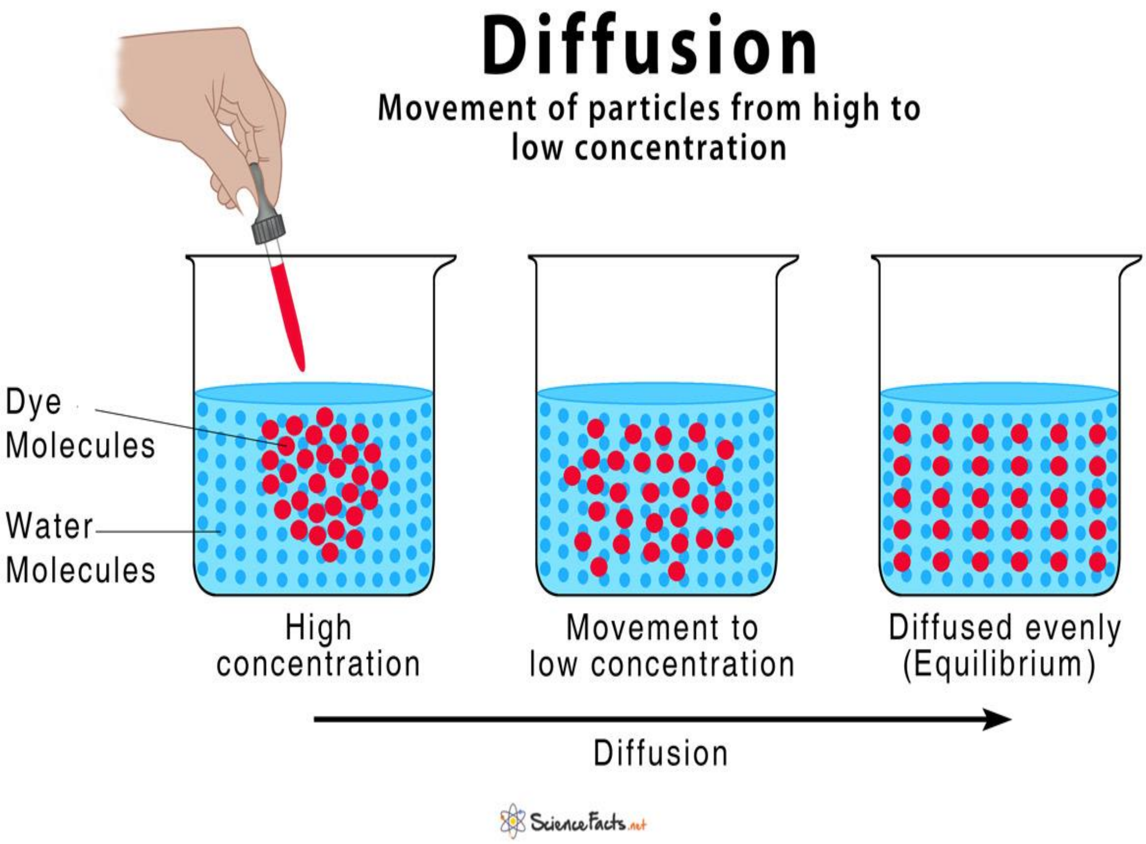


Source: Verma (2009)

Hence, diffusion takes place always from a region of higher diffusion pressure to a region of lower diffusion pressure that is along diffusion pressure gradient. Diffusion can only occur when the concentration of the diffusing substance is not uniform throughout the system and the process can continue only as long as the difference between the concentration is maintained.

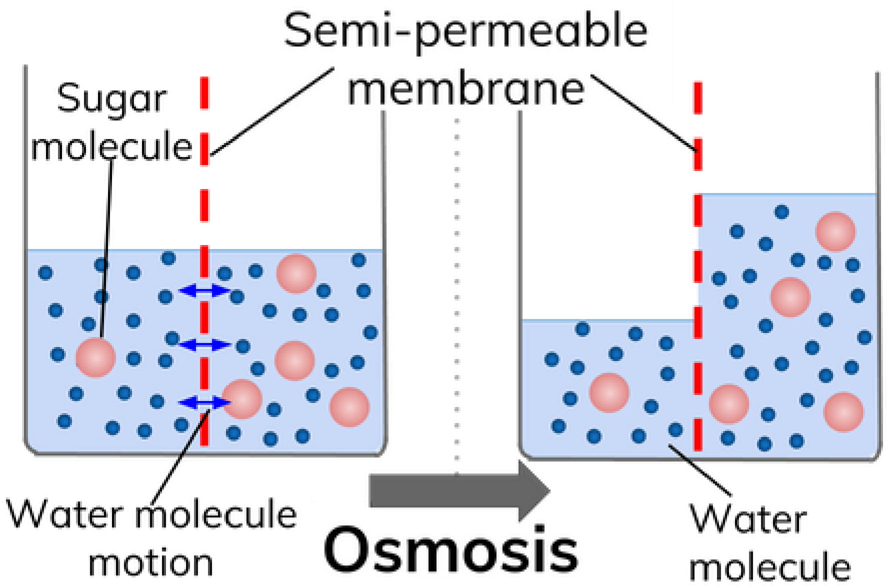
The rate of diffusion increases if the-

a. Diffusion pressure gradient is steeper
b. Temperature is increased
c. Density of diffusing particle is lesser
d. Medium through which the diffusion occurs is less concentrated



Diffusion of more than one substance can occur at the same time and place, maybe also different rate and in different directions but is independent of each other.
Examples of diffusion in plants are in processes like respiration, photosynthesis, passive uptake of ions from the soil and transpiration. *In what ways do plants move substances from one plant to another?*

4.3.2.2 OSMOSIS
Osmosis is a special kind of diffusion of liquid. When two solutions of different concentrations are separated by means of a semi-permeable membrane, the diffusion of water or the solvent from the solution of lower concentration to the solution of higher concentration until the state of dynamic equilibrium is reached. In real sense, diffusion of solvent takes place both ways across the membrane but the diffusion of solvent is more from the solute ion of lesser concentration to that of higher concentration.



Source: Jain (2013)

4.3.2.2.2 Type of Solutions:

1. **Isotonic Solutions**
If the concentration of solute (salt) is equal on both sides of membrane, the water will move back in forth, but it won't have any result on the overall amount of water on either side. "ISO" means the same.

2. **Hypotonic Solutions**
The word "HYPO" means less, in this case there are less solute (salt) molecules outside the cell, since salt sucks, water will move into the cell.
The cell will gain water and grow larger. In plant cells, the central vacuoles will fill, and the plant becomes stiff and rigid, the cell wall keeps the plant from bursting. In animal cells, the cell may be in danger of bursting; organelles called contractile vacuoles will pump water out of the cell to prevent this.

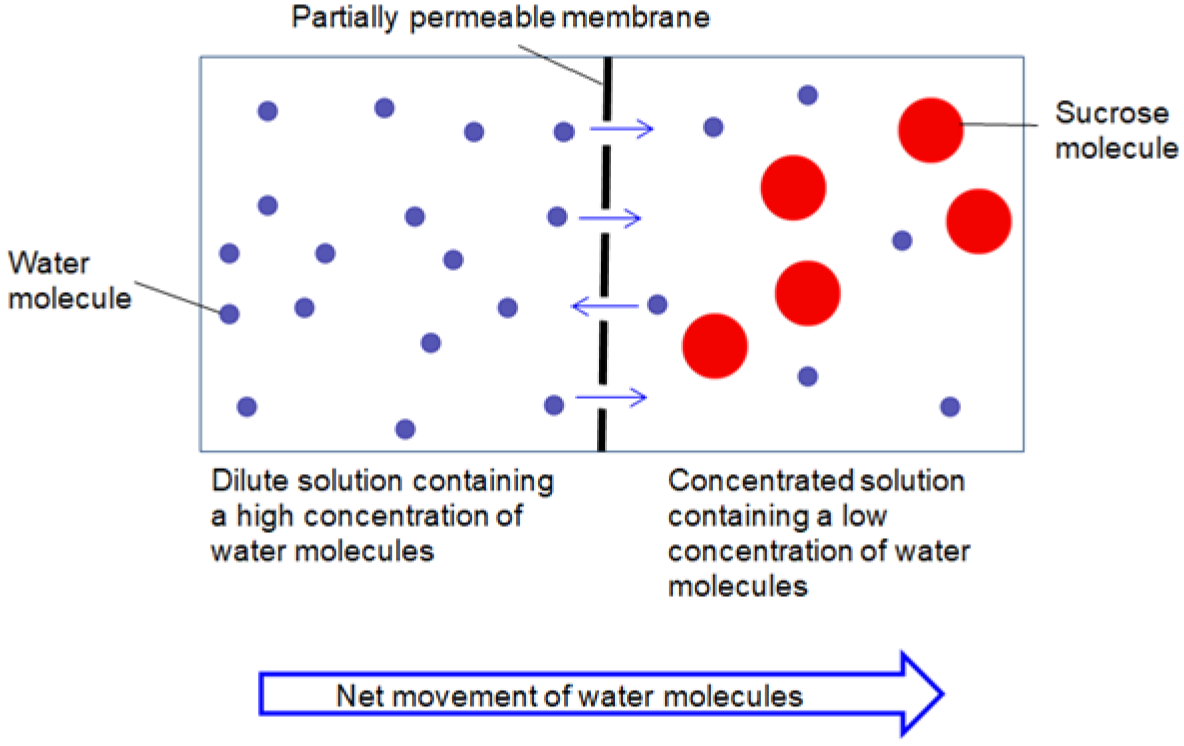
3. **Hypertonic Solutions**
The word "HYPER" means more; in this case there are more solute (salt) molecules outside the cell, which causes the water to be sucked in that direction. In plant cells, the central vacuole loses water and the cells shrink, causing wilting. In animal cells, the cells also shrink. In both cases, the cell may die.
.
Both Diffusion and Osmosis are types of **passive transport**, that is, no energy is required for the molecules to move into or out of the cell. Sometimes, large molecules cannot cross the plasma membrane, and are "helped" across by carrier proteins - this process is called **facilitated diffusion**. *List the three types of solution in the cell environment.*

Self-Assessment Exercise 2

Define diffusion?

4.3.2.2.3 OSMOTIC PRESSURE OR OSMOTIC POTENTIAL

As a result of the separation of the solution from its solvent or the two solutions by semi-permeable membrane, a pressure is developed in solution due to the presence of dissolved solute in it. This is called Osmotic Pressure (OP). Osmotic pressure is measured in terms of atmosphere. O.P is directly proportional to the concentration of dissolved solute in the solution. The higher the solution's concentration, higher the osmotic pressure.
In osmosis, the movement of solvent molecules takes place from the solution whose osmotic pressure is lower (less concentrated or hypotonic) into solution whose osmotic pressure is higher (more concentrated or hypertonic).
Osmotic diffusion of solvent molecules will not occur if the two solution separated by the semi-permeable membrane are of equal concentration having equal osmotic pressures (isotonic).
Living cells in plant form osmotic system due to the presence of semi-permeable membrane and the cell sap having certain osmotic pressure. Plasma membrane is selectively or differentially permeable membrane because it allows certain solute to pass through it. The tonoplast or the vacuolar membrane is also semi-permeable membrane. The solvent in case of plant is always the water.
If a living plant cell or tissue is placed in hypotonic solution (O.P is lower than that of cell sap) water enters into the cell sap by osmosis. This process is called END-OSMOSIS. As a result of water entry, a pressure is developed which presses the protoplasm against the cell wall and then cell becomes turgid. This pressure is called TURGOR PRESSURE. The result of turgor pressure is WALL PRESSURE which is exerted by the elastic cell wall against expanding protoplasm. Hence,
T.P=W.P
On the other hand, if plant cell is placed in hypertonic solution (O.P higher than cell sap) the water comes out of the cell sap into outer solution and the cell becomes FLACCID. The process is known as EXOSMOSIS.
Cell and tissue will remain same in isotonic solution.



Define Turgor Pressure?

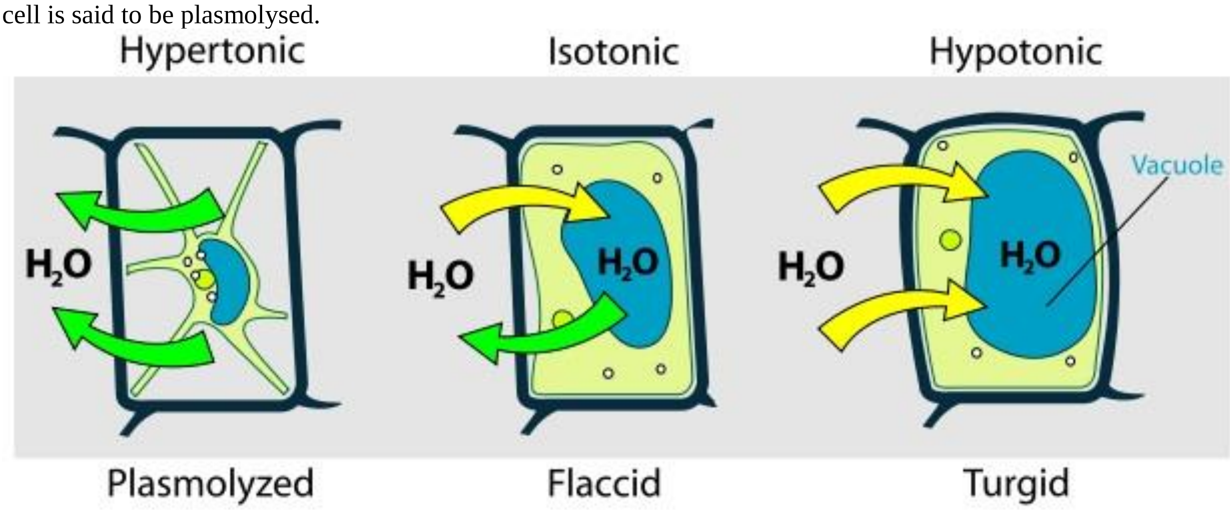
4.3.2.2.4 ROLES OF OSMOSIS IN PLANTS

a. Plants absorbs large amount of water from the soil through the root hairs by osmotic mechanism.
b. Osmosis is involved in the movement and distribution of water across the cells of plant.
c. Osmotic diffusion of water is responsible for the turgidity of plant cells. This pressures allows leaves, flowers and stem tips to maintain their form.
d. The turgor of guard cell is essential for opening of stomata.

e. Growth of young cell is brought about by the osmotic pressure and turgor pressure of these cells.
f. High osmotic concentration helps the plants to resist freezing temperature and desiccation
g. The pressure is responsible for the rise of water to some heights in the stem.

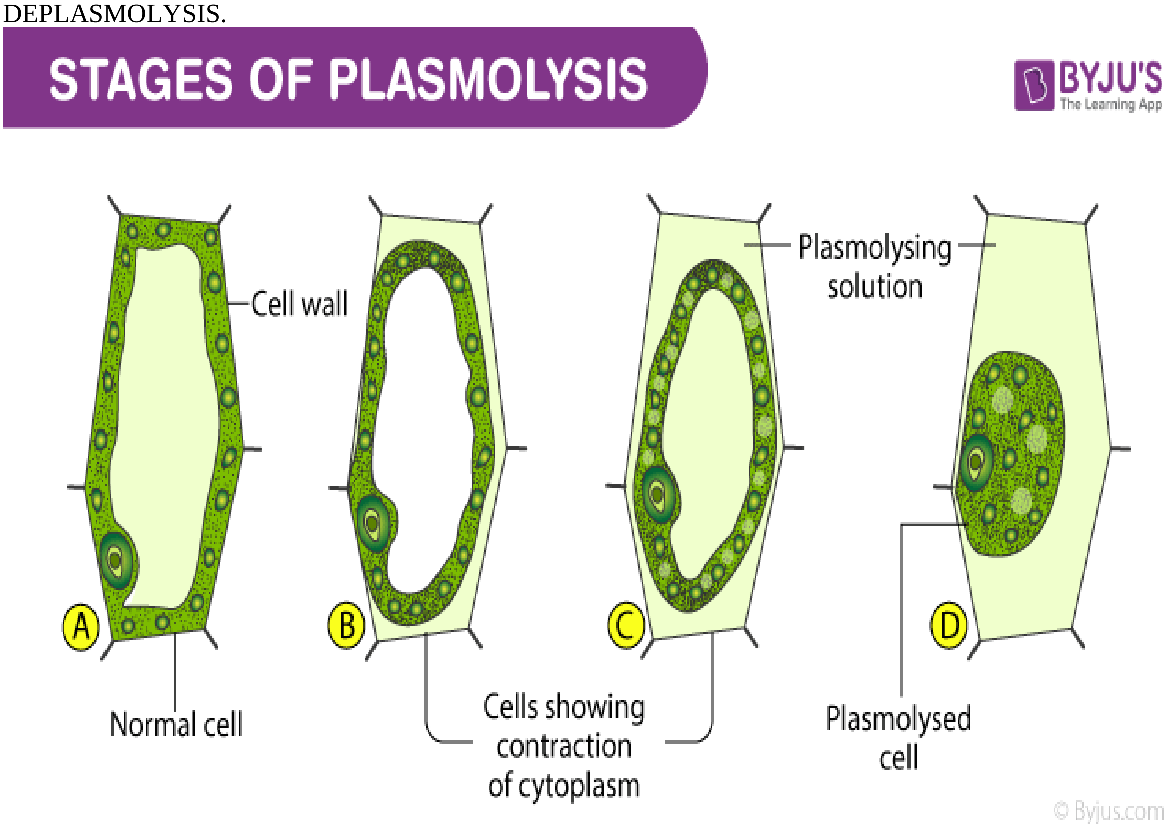
4.3.3 PLASMOLYSIS

During exosmosis, water from within the cell sap diffuses out through the membrane into the outer solution. As water leaves the cell, the cell wall loose its tension. Further loss of water from the cell content causes contraction of the protoplasm, which moves away from the cell. If the hypertonic solution is very strong, the protoplasm will continue to contract and will eventually assume a spherical form. This is plasmolysis and the cell is said to be plasmolysed.



Source: Verma (2009)

The space between cell wall and the contracted protoplasm gets filled up with the external solution. The stage at which first sign of shrinkage of cell contents from the cell wall becomes detectable is referred to the stage of INCIPIENT PLASMOLYSIS. If plasmolysed is placed in water or hypotonic solution, endosmosis takes place and the protoplasm and cell as whole assume their original shape and size respectively. This is called DEPLASMOLYSIS.



What causes plasmolysis?

Self-Assessment Exercise 3

What is Deplasmolysis?

4.3.3.1 DIFFUSION PRESSURE DEFICIT (D.P.D (suction pressure)

Diffusion pressure of a solution is always lower than its pure solvent. The difference between the diffusion pressure of the solution and its solvent at a particular temperature and atmospheric condition is called DIFFUSION PRESSURE DEFICIT (D.P.D). if the solution is more concentrated, its DPD increase, but it decreases with the dilution of the solution.

DPD = concentration of the solution.

If plant cells are placed in pure water, the water will enter into the plant cell due to higher D.P.D of cell sap or water deficit. In other word, the D.P.D of the cell sap or of the cell is a measure of the ability of the cells to absorb water and hence it is often called the SUCTION PRESSURE (S.P). It is related to the osmotic pressure and turgor pressure of cell sap and wall pressure as follows:

D.P.D (S.P) = O.P - W.P

W.P = T.P

:. D.P.D (S.P) = O.P - T.P

Due to entry of the water, O.P of the cell sap decreases while its turgor pressure is increased so much that in a fully turgid cell, turgor is equal to O.P

O.P = T.P

:. D.P.D (S.P) = 0.

On the other hand, the removal of water cell sap (ex-osmosis) results in an increase of its O.P and decrease of the turgor pressure so much that in fully plasmolysed cells, T.P becomes zero.

T.P = 0

:. S.P = O.P

4.3.4 CONCEPT OF WATER POTENTIAL

The chemical potential of water denotes the free energy of water expressed in a quantitative manner. According to law of thermodynamics, the free energy represents the potential to do work. The potential energy of water is termed water potential. This term was coined by Stalyer and Taylor (1960). It is defined as ''the difference between the partial specific Gibbs' free energy of water in the system under consideration and of free, pure water at the same temperature''

Water potential is measured in terms of pressure and the unit of measurement is Pascal Pa. water potential is represented by the Greek letter psi (φ).

Water potential is lowered by the addition of solutes and because water potential value is zero for pure water, all other water potential value will be negative. In other word, the movement of water will take place in osmotic or other system from a region of higher water potential (less negative) to a region of lower water potential (more negative).

There are three factors which affect the water potential of a cell- they are

1. Concentration
2. Pressure and
3. Gravity.

   These factors affect the free energy of water.

   Hence, $\varphi w = \varphi s + \varphi p + \varphi g$

The term φs denotes the concentration of solute and its effect on water potential. It is termed solute potential or osmotic potential. The water potential is equal to the osmotic or solute potential. Water will always diffuse from a cell of higher water or solute potential to a cell of lower water or solute potential.

The entry of water into a cell result in hydrostatic or turgor pressure, which is also called pressure potential (φp). if the pressure potential is positive, it will add to the water potential, but if it is negative, it will reduce the value of water potential.

SOLUTES: The term *Ψ*s, called the **solute potential** or the **osmotic potential**, represents the effect of dissolved solutes on water potential. Solutes reduce the free energy of water by diluting the water. This is primarily an entropy effect; that is, the mixing of solutes and water increases the disorder or entropy of the system and thereby lowers the free energy. This means that *the osmotic potential is independent of the specific nature of the solute*. For dilute solutions of nondissociating substances such as sucrose, the osmotic potential may be approximated by:

$\Psi s = -RTcs$ where *R* is the gas constant (8.32 J mol–1 K–1), *T* is the absolute temperature (in degrees Kelvin, or K), and *c*s is the solute concentration of the solution, expressed as **osmolarity** (moles of total dissolved

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solutes per volume of water [mol L^{-1}]). The minus sign in the equation indicates that dissolved solutes reduce the water potential of a solution relative to the reference state of pure water. The Equation is valid for "ideal" solutions. Real solutions frequently deviate from the ideal, especially at high concentrations—for example, greater than 0.1 mol L^{-1}. Temperature also affects water potential. In our treatment of water potential, we will assume that we are dealing with ideal solutions.

PRESSURE The term Ψ_p, called the **pressure potential**, represents the effect of hydrostatic pressure on the free energy of water. Positive pressures raise the water potential; negative pressures reduce it. Both positive and negative pressures occur within plants. The positive hydrostatic pressure within cells is referred to as *turgor pressure*. Negative hydrostatic pressures, which frequently develop in xylem conduits, are referred to as **tension**. As you will see, tension is important in moving water long distances through the plant. Hydrostatic pressure is often measured as the deviation from atmospheric pressure. Remember that water in the reference state is at atmospheric pressure, so by this definition $\Psi_p = 0$ MPa for water in the standard state. Thus, the value of Ψ_p for pure water in an open beaker is 0 MPa, even though its absolute pressure is approximately 0.1 MPa (1 atmosphere).

GRAVITY: Gravity causes water to move downward unless the force of gravity is opposed by an equal and opposite force. The **gravitational potential** (Ψ_g) depends on the height (*h*) of the water above the reference-state water, the density of water (ρ_w), and the acceleration due to gravity (*g*). In symbols, we write the following:

$$\Psi_g = \rho_w g h$$

where $\rho_w g$ has a value of 0.01 MPa m^{-1}. Thus, raising water a distance of 10 m translates into a 0.1 MPa increase in water potential. The gravitational component (Ψ_g) is generally omitted in considerations of water transport at the cell level, because differences in this component among neighboring cells are negligible compared with differences in the osmotic potential and the pressure potential. Thus, the Equation can be simplified as follows:

$$\Psi = \Psi_s + \Psi_p$$

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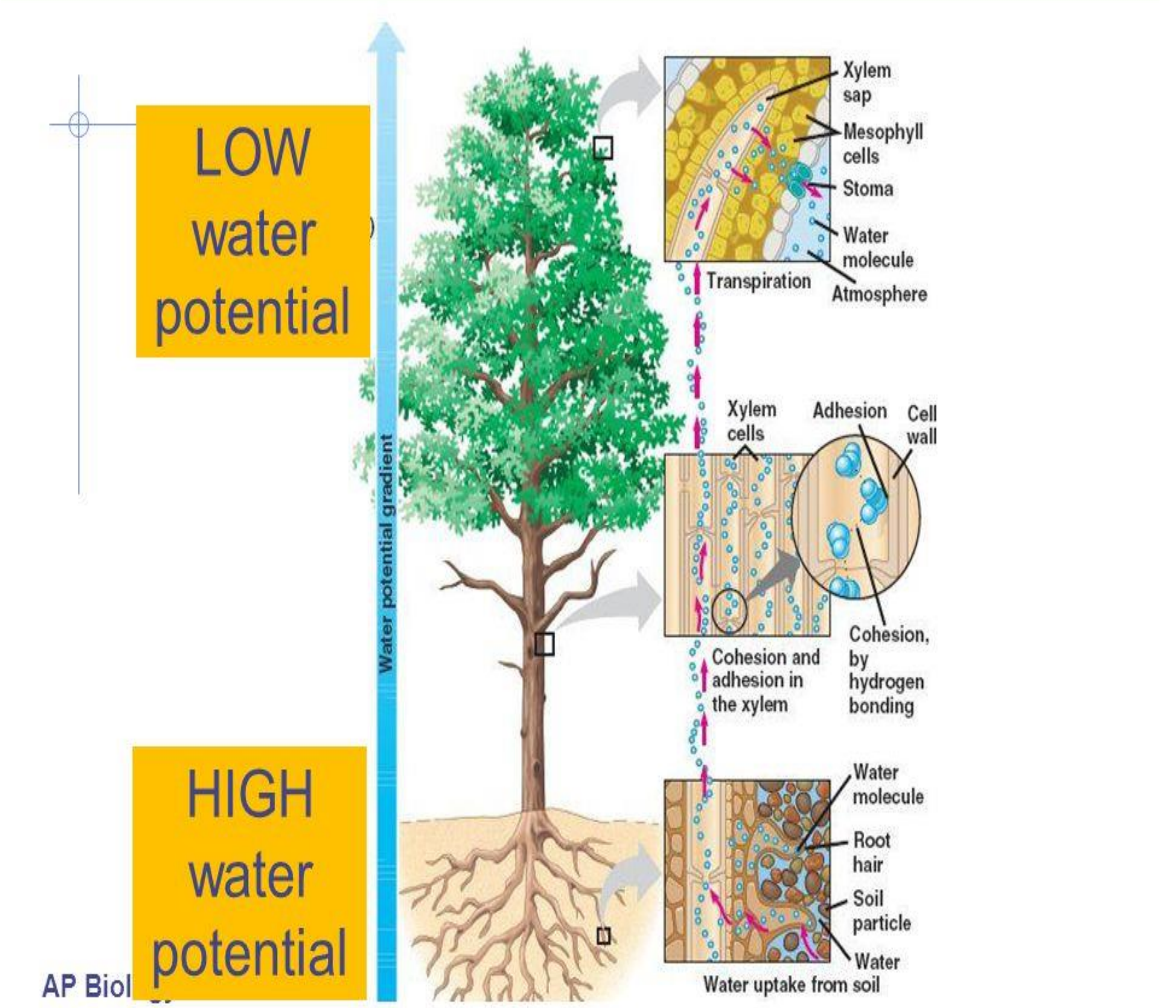

Source: Taiz and Zeiger

The term φg is gravity potential. It denotes the effects of gravity on the water potential of a water column in a vertically growing plant. Its magnitude depends on the height of the plant from the ground level as well as on the density of water and the acceleration due to gravity. In plants of small height (less than 5metres) the φg is negligible and not taken into account.

Hence, $\varphi w = \varphi s + \varphi p$

Water potential values of plant cells under different osmotic conditions are as follows

$\varphi w = \varphi s$ (φp is zero) ……………in plasmolysed cell

$\varphi w = \varphi s + \varphi p$ ……………………..in partially turgid cell

φw = zero………………………...in fully turgid cell

How is water potential measured?

4.3.4.1 IMBIBITION

The ability or act of a piece of dry wood or dry seeds to absorb water quickly when placed in water and seel up considerably so that the volume increase is called IMBIBITION. The dry substances are IMBIBANTS.

A force of attraction exists between the imbibants and the imbibed substance. In plants, hydrophilic colloid such as proteins, carbohydrates (starch, cellulose, pectic substances) have strong attraction towards water.

Imbibition plays key role in germination of dry seeds and absorption of water by root hairs of higher plants. As a result of imbibition, a pressure is developed which is called IMBIBITION PRESSURE. Water moves by imbibition into a substance only when its water potential exceeds that of the imbibant. Imbibition pressure is also called MATRIX POTENTIAL (φm).

The matrix potential in an imbibant is caused by adsorptive forces which bind water molecules to molecules of the imbibant and is similar to osmotic potential of a solution.

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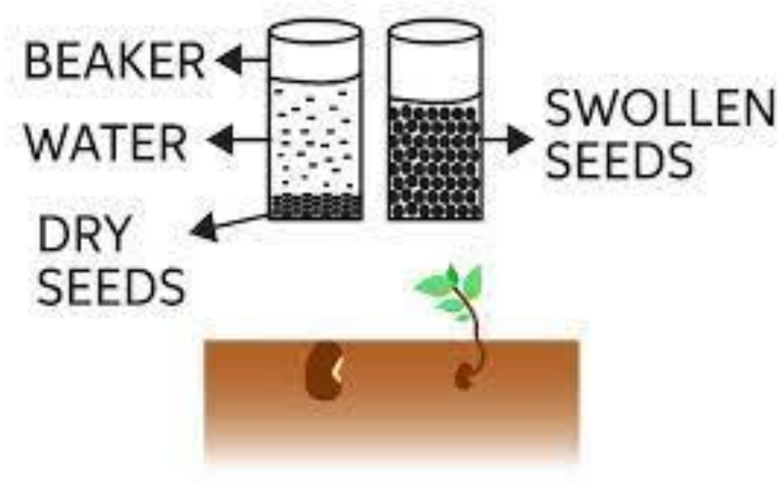
The water potential of an imbibant is equal to its matrix potential (always negative) plus turgor or pressure potential which may be imposed upon the imbibant. ${}^{\varphi}w = {}^{\varphi}4m + {}^{\varphi}p$
If the imbibant is unconfined, no turgor or other pressure is involved, hence the equation becomes: ${}^{\varphi}w = {}^{\varphi}m$.



What are imbibants?

Self-Assessment Questions

Question: What are three factors that affect water potential of a cell?
Answer: a) concentration b) Pressure c) gravity
Question: State three roles of osmosis in plants
Answer:

a. *Plants absorbs large amount of water from the soil through the root hairs by osmotic mechanism.*
b. *Osmosis is involved in the movement and distribution of water across the cells of plant.*
c. *Osmotic diffusion of water is responsible for the turgidity of plant cells. This pressure allows leaves, flowers and stem tips to maintain their form.*
d. *The turgor of guard cell is essential for opening of stomata.*

4.4. SUMMARY:

Membranes consist of two main components; phospholipids and proteins. The structure of membranes is best described by the fluid mosaic model. The phospholipids form a fluid bilayer with the hydrophobic tails of fatty acids at its core and the hydrophilic leads of phosopholipids on both sides. Proteins move in the fluid. The lipid layer allows the unrestricted diffusion of small molecules across the plasma membrane, but membrane lipid block the diffusion of Ions and large polar molecules. This property of membranes is called differential permeability. The diffusion of hydrophilic solutes is facilitated by proteins embedded in the membranes. The diffusion of water through a differentially permeable membrane is called osmosis. Plants regulate osmosis by controlling the uptake of ions or by making osmotically active solutes. In so doing, cells maintain turgor pressure, prevents further uptake of water, the water outside the cell exerts pressure called osmotic pressure. Its counterpart inside the cell is the osmotic potential of the cell, which is expressed as a negative number.

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https://www.youtube.com/watch?v=NIxt4VrcLyc

4.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1

In 1930 H. Davson and J.F. Danielli, hypothesized that the lipid bilayer was coated on both sides with hydrophilic proteins that were attached to the polar heads of phospholipids.

Answers to SAE 2

Diffusion is the movements of particles or molecules from a region of higher concentration to a region of lower concentration. The rate of diffusion of gases is faster than liquid or solutes. In other words, diffusion is the movement of molecules of gases, liquids and solutes from regions of higher concentration to regions of lower concentration until the molecules are evenly distributed throughout the available space.

Answer to SAE 3

If plasmolysed is placed in water or hypotonic solution, endosmosis takes place and the protoplasm and cell as whole assume their original shape and size respectively. This is called DEPLASMOLYSIS.

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UNIT 5 FUNCTIONS OF THE CELL MEMBRANE

Unit Structure

5.1 INTRODUCTION

The interior of a plant cell is separated from the plant cell wall and the environment by a plasma membrane that is only two lipid molecules thick. This thin layer separates a relatively constant internal environment from variable external surroundings. In addition to forming a hydrophobic barrier to diffusion, the membrane must facilitate and continuously regulate the inward and outward traffic of selected molecules and ions as the cell takes up nutrients, exports solutes, and regulates its turgor pressure. Similar functions are performed by the internal membranes that separate the various compartments within each cell. The plasma membrane also detects information about the environment, about molecular signals from other cells, and about the presence of invading pathogens. Often these signals are relayed by changes in ion fluxes across the membrane. Molecular and ionic movement from one location to another is known as **transport**. Local transport of solutes into or within cells is regulated mainly by membrane proteins. Larger-scale transport between plant organs, or between plant and environment, is also controlled by membrane transport at the cellular level

5.2. INTENDED LEARNING OUTCOME

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

-explain the differential permeability of membranes
-explain the following terms (a) facilitated diffusion (b) active transport (c) bypassing membrane transport
-distinguish between exocytosis and endocytosis define the following terms
(a) membrane potential (b) selectrogentic pump
-state the unit of measurement of membrane potential briefly - describe how cells communicate.

5.3 Main Contents

5.3.1 Differential Permeability of Membranes

In unit, 4 you learnt that biological membranes are differentially permeable. This is one of their most important properties because it keeps metabolically important substances inside the cell or organelle and prevents inappropriate or toxic substances include ions and larger polar molecules, such as sugars, which only pass through specific membrane proteins called transport proteins.

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According to Fick's first law, the movement of molecules by diffusion always proceeds spontaneously, down a gradient of free energy or chemical potential, until equilibrium is reached. The spontaneous "downhill" movement of molecules is termed **passive transport**. At equilibrium, no further net movements of solutes can occur without the application of a driving force. The movement of substances against a gradient of chemical potential, or "uphill," is termed **active transport**. It is not spontaneous, and it requires that work be done on the system by the application of cellular energy. One common way (but not the only way) of accomplishing this task is to couple transport to the hydrolysis of ATP.

The driving force for diffusion or, conversely, the energy input necessary to move substances against a gradient can be calculated by measuring the potential-energy gradient. For uncharged solutes this gradient is often a simple function of the difference in concentration. Biological transport can be driven by four major forces: concentration, hydrostatic pressure, gravity, and electric fields.

The **chemical potential** for any solute is defined as the sum of the concentration, electrical, and hydrostatic potentials (and the chemical potential under standard conditions). *The importance of the concept of chemical potential is that it sums all the forces that may act on a molecule to drive net transport*.

Between the two forms, because of their greater number, molecules on the hypertonic acid of the membrane would have more frequent contact with transport proteins than those on the hypotonic side of the membrane, thus, solutes would move down their concentration gradient.

Sugars typically move by facilitated diffusion that involves co-transport with another solute. For example, sucrose moves into conducting cells of leaf veins by hitching ride with hydrogen ion (fig, 5.1). The energy for sucrose transport comes from the force of H^+ diffusion. The force of H^+ diffusion can be powerful enough to move sucrose against its own concentration gradient.

5.3.1.1 Facilitated Diffusion

Like simple diffusion, facilitated diffusion is driven by a concentration gradient. Solutes move through transport proteins from the hypertonic side of the membrane.

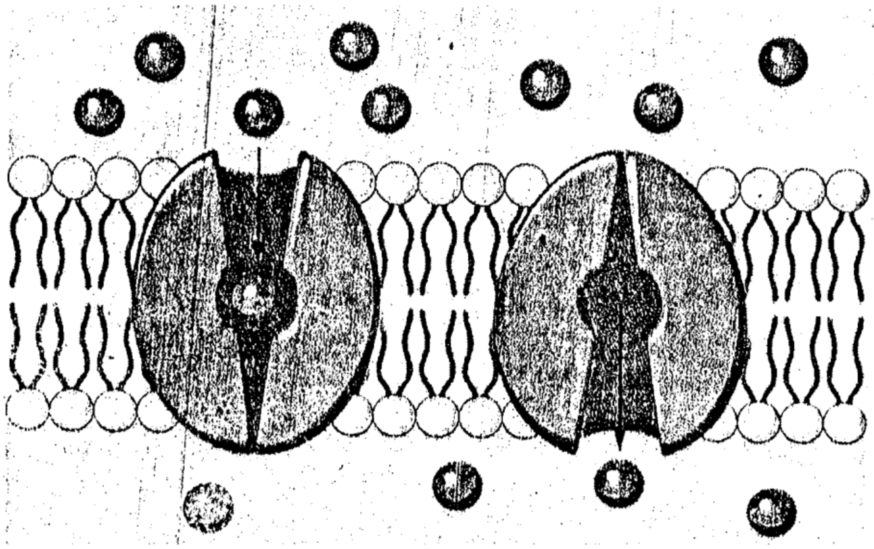

Fig. 5.1 A possible mechanism for facilitated diffusion. The transport protein (purple) accepts solute molecules (red spheres) on one side of the membrane and release them on the other side. The transport protein alternative between two forms, depending whether it is "open" to one side of the membrane or the other.

Each transport proteins from a continuous, hydrophilic pathway for polar molecules. Some proteins allow only one solute to diffuse at a time whereas other only work when two solutes move at the same time, by co-transport.

Little is known about how transport protein work. The best guess is that they alternate between, two forms. One form of the protein accepts a solute molecule on one side of the membrane, which changes the protein to the other form. That second form of the transport protein release the solute on the other side of the membrane. According to this model, we must also assume that "empty" protein flip-flop randomly between the two forms. Because of their greater number, molecules on the hypertonic acid of the membrane would have more frequent contact with transport proteins than those on the hypotonic side of the membrane, thus, solutes would move down their concentration gradient.

Sugars typically move by facilitated diffusion that involves co-transport with another solute. For example, sucrose moves into conducting cells of leaf veins by hitching ride with hydrogen ion.

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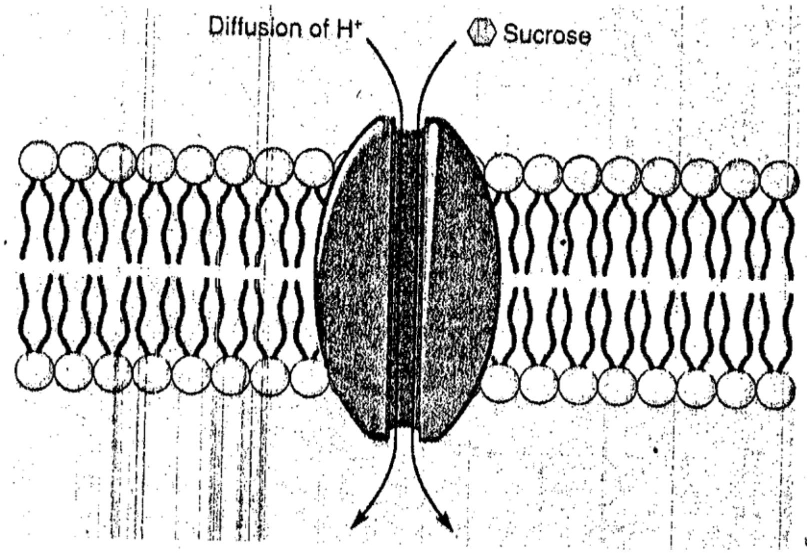

Co transport across membranes uses energy from the force of diffusion of one solute (H^+) to move another solute$^+$ (sucrose) against its concentration gradient.

The energy for sucrose transport comes from the force of H^+ diffusion. The force of H^+ diffusion can be powerful enough to move sucrose against its own concentration gradient.

5.3.1.2 Active Transport

Many substances move into or out of cells and organelles against a concentration gradient without the aid of facilitated diffusion by co- transport. The uptake of potassium mentioned earlier in unit 4, is one example. Likewise, *Marue* algae secrete sodium, even though the sea water surrounding then is much saltier than their cytoplasm. In both cases, the transport of solutes requires energy from the cell to overcome the energy of thermal motion that drives passive transport.

The energy required for active transport usually comes from the hydrolysis of ATP. This reaction is catalysed by membrane bound enzymes called ATP phosphohydrolases (ATPases); which are transport proteins that use the energy of ATP transport ions.

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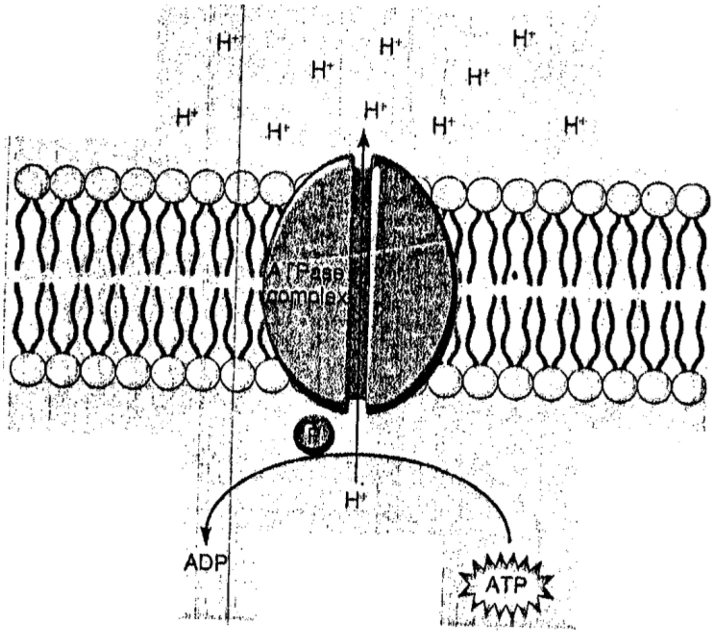


Active transport uses energy released by the hydrolysis of ATP by ATPases in the membrane. This energy is spent in transporting ions (H^+) against their concentration gradient. Phosphate (P) from ATP binds to ATPases during hydrolysis.

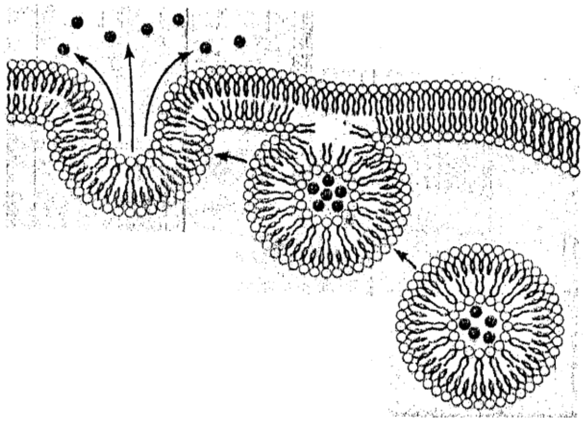
Many ATPases actively transport ions against the ion's concentration gradient, thereby creating potential energy for the passive co-transport of other solutes back across the membranes. The co-transport of sucrose with H^+, depends on a higher concentration of H^+ outside the cell. This gradient is maintained by the active transport of H^+ acrose the plasma membrane. This is an example of coupled cotransport system, so called because it uses energy from active transport to create a gradient that drives the passive co-transport of two solutes.

In addition to a concentration gradient, H^+ and other ions also have an electrical gradient because they are charged particles. Thus, ion transport is also influenced by an electrical gradient. The combination of the concentration gradient and the electrical gradient of ions is called electro- chemical gradient.

5.3.1.3 Bypassing Membrane Transport

Simple diffusion, facilitated diffusion, and active transport all entail direct movement through the phospholipid bilayer or through proteins embedded in its membrane transport is often bypassed by Exocytosis.

(Fig. 5.4)



Exocytosis transports large molecules out of cells. This kind of transport involves membrane bound vesicles that fuse with the plasma membrane.

Plant cells secrete polysaccharides and proteins across the plasma membrane for assembly into cell, walls. Moreover, cells of root trip secrete a slimy polysaccharide that. lubricates their passage through soil as they grow, and cells converting leaves exude waxy substances into their surface to inhibit water loss. leaves of the Venus's flytrap and other insectivorous plants secrete enzymes that digest insect. However, unlike the exocytosis of cell, wall make nail which occurs via dictyosome vesicles, the secretion of digestive enzymes relies on vesicles derived from the endoplasmic reticulum.

Substances can also bypass membrane transport into the cytoplasm by punching of small coated pits in the plasma membrane. This process, called endocytosis, is common in animal cells, but it is not ready observed in plants. Plant cells do have coated pits, which is indirect evidence for endocytosis.

Endocytosis is apparently more difficult in plants than in animals, because; the plasma membrane of plant cells is usually processed against the cell wall by turgor pressure. This turgor pressure hinders the plasma membrane from invaginating into the cytoplasm.

What is passive transport?

Self-Assessment Question 1

Why is Endocytosis is difficult in plants?

5.3.2 Movement of Ions Across Membranes

Plasma and organellar membranes have unequal concentrations of negatively charged ions (anions) and positively charged ions (actions) on one side. For example, the cytoplasm has a higher concentration of anions and a lower concentration of cations than does the matrix of the cell wall. This unequal distribution of ions creates an electrical gradient that is analogous to a concentration gradient. However, because an electrical gradient is based on an electrical charge, the diffusion force of a charge is an electrical potential instead of a chemical potential. Because membranes selectively control the passage of ions, this electrical potential is called the membrane potential. Like any other electrical potential, membrane potential is measured in volts.

5.4.1 Ion Pumps

Membrane potentials are maintained by protons that actively transport ions. A membrane protein that pumps ions is called **electrogenic pump** because it generates voltage across a membrane. Different ions are pumped by different proteins but the main electrogenic pumps of plants are proton pumps, the H^+ -.

ATPases: One function of proton pumps, mentioned earlier, is to provide energy for the coupled cotransport of uncharged solutes such as sucrose. Another function is to regulate pH of chemical reactions in a cell often incorporate or release ions that affect the pH of cells, the uptake of ions from soil also affects pH. Pumping proton out of the cell keep the cytoplasm at a constant pH of about 7.4, similarly pumping protons into vacuoles keeps the pH there are about 5.0, this low pH is ideal for enzymes that break down organic compounds that are dumped into vacuoles for disposal.

Proton pumps also influence cellular elongation. When H^+-ATPases in the plasma membrane are stimulated, the outward transport of hydrogen ions decreases the pH in the surrounding cell wall, this causes certain enzymes in the cell wall, which are activated at the lower pH, to being to degrade cellulose micro-fibrils. This degradation loosens the cell wall, thereby allowing the cell to expand because of turgor pressure. Loosening of the cell wall can also be induced by applying auxin, a plant hormone. Physiologist suspect that auxin stimulates cellular elongation by stimulating the proton pump. You will learn more about auxins and hormones unit.

5.4.2 ATP Synthesis

These are two main types of proton pumps. One type uses ATP and occurs mainly in the plasma-membrane and in the tonoplast, the other produces ATP-synthesizing organelles. ATP is made from ADP and a phosphate group when the diffusion of H^+energy. This is the opposite of what happens in a proton pump that is drives by ATP. ATP is, however, only made when a gradient of H^+ already exists, therefore, energy must be used to maintain this gradient. In chloroplasts, the energy for such a gradient comes from light energy diving photosynthesis. In mitochondria, the energy comes from the re-arrangement of chemical bonds during respiration. *What is Electrogenic pump?*

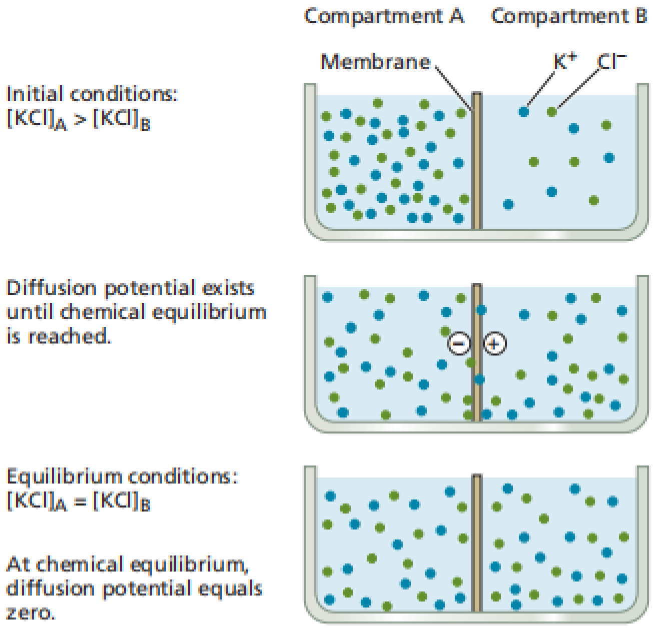
5.3.3 Transport of Ions across Membrane Barriers

If two ionic solutions are separated by a biological membrane, diffusion is complicated by the fact that the ions must move through the membrane as well as across the open solutions. The extent to which a membrane permits the movement of a substance is called **membrane permeability**. Membrane permeability depends on the composition of the membrane as well as on the chemical nature of the solute. In a loose sense, permeability can be expressed in terms of a diffusion coefficient for the solute through the membrane. However, permeability is influenced by several additional factors, such as the ability of a substance to enter the membrane, that are difficult to measure. Despite its theoretical complexity, we can readily measure permeability by determining the rate at which a solute passes through a membrane under a specific set of conditions. Generally, the membrane will hinder diffusion and thus reduce the speed with which equilibrium is reached. For any particular solute, however, the permeability or resistance of the membrane itself cannot alter the final equilibrium conditions.

3.3.3.1 Different diffusion rates for cations and anions produce diffusion potentials

When salts diffuse across a membrane, an electrical membrane potential (voltage) can develop. Consider the two KCl solutions separated by a membrane . The K+ and Cl– ions will permeate the membrane independently as they diffuse down their respective gradients of electrochemical potential. And unless the membrane is very porous, its permeability to the two ions will differ. As a consequence of these different permeabilities, K+ and Cl– will initially diffuse across the membrane at different rates. The result is a slight separation of charge, which instantly creates an electrical potential across the membrane.

In biological systems, membranes are usually more permeable to K+ than to Cl–. Therefore, K+ will diffuse out of the cell faster than Cl–, causing the cell to develop a negative electric charge with respect to the extracellular medium. A potential that develops as a result of diffusion is called a **diffusion potential**. The principle of electrical neutrality must always be kept in mind when the movement of ions across membranes is considered: Bulk solutions always contain equal numbers of anions and cations. The existence of a membrane potential implies that the distribution of charges across the membrane is uneven; however, the actual number of unbalanced ions is negligible in chemical terms. For example, a membrane potential of –100 millivolts (mV), like that found across the plasma membranes of many plant cells, results from the presence of only 1 extra anion out of every 100,000 within the cell—a concentration difference of only 0.001%! All of these extra anions are found immediately adjacent to the surface of the membrane; there is no charge imbalance throughout the bulk of the cell.
In the example of KCl diffusion across a membrane, electrical neutrality is preserved, because as K+ moves ahead of Cl– in the membrane, the resulting diffusion potential retards the movement of K+ and speeds that of Cl–. Ultimately, both ions diffuse at the same rate, but the diffusion potential persists and can be measured. As the system moves toward equilibrium and the concentration gradient collapses, the diffusion potential also collapses.



Source: Taiz *et al* (2018)

How does membrane potential relate to ion distribution?

Because the membrane in the preceding example is permeable to both K+ and Cl– ions, equilibrium will not be reached for either ion until the concentration gradients decrease to zero. However, if the membrane were permeable only to K+, diffusion of K+ would carry charges across the membrane until the membrane potential balanced the concentration gradient. Because a change in potential requires very few ions, this balance would be reached instantly. Potassium ions would then be at equilibrium, even though the change in the concentration gradient for K+ would be negligible.
When the distribution of any solute across a membrane reaches equilibrium, the passive flux, *J* (i.e., the amount of solute crossing a unit area of membrane per unit of time), is the same in the two directions—outside to inside and inside to outside:
This relationship, known as the ***Nernst equation*,** states that at equilibrium**: the difference in concentration of an ion between two compartments is balanced by the voltage difference between the compartments**. The Nernst equation can be further simplified for a univalent cation at 25°C:

All living cells exhibit a membrane potential that is due to the asymmetric ion distribution between the inside and outside of the cell. We can determine these membrane potentials by inserting a microelectrode into the cell and measuring the voltage difference between the inside of the cell and the extracellular medium.
The Nernst equation can be used at any time to determine whether a given ion is at equilibrium across a membrane. However, a distinction must be made between equilibrium and steady state. ***Steady state*** is the condition in which influx and efflux of a given solute are equal, and therefore the ion concentrations are constant over time. Steady state is not necessarily the same as equilibrium. In steady state; the existence of active transport across the membrane prevents many diffusive fluxes from ever reaching equilibrium.

5.3.3.2 Nernst Equation

The Nernst equation distinguishes between active and passive transport. The table below shows how experimental measurements of ion concentrations at steady state in pea root cells compare with predicted values calculated from the Nernst equation. In this example, the concentration of each ion in the external solution bathing the tissue and the measured membrane potential were substituted into the Nernst equation, and the internal concentration of each ion was predicted.
Prediction using the Nernst equation assumes passive ion distribution, but notice that, of all the ions shown in the Table, only K+ is at or near equilibrium. The anions NO^{3-}, Cl^- , $H_2PO^{-4,}$ and SO_4^{2-} all have higher internal concentrations than predicted, indicating that their uptake is active. The cations Na+, Mg2+, and Ca2+ have lower internal concentrations than predicted; therefore, these ions enter the cell by diffusion down their electrochemical-potential gradients and are then actively exported.
The example shown in the Table is an oversimplification; plant cells have several internal compartments, each of which can differ in its ionic composition from the others. The cytosol and the vacuole are the most important intracellular compartments in determining the ionic relations of plant cells. In most mature plant cells, the central vacuole occupies 90% or more of the cell's volume and the cytosol is restricted to a thin layer around the periphery of the cell.
Because of its small volume, the cytosol of most angiosperm cells is difficult to assay chemically. For this reason, much of the early work on the ionic relations of plants focused on certain green algae, such as *Chara* and *Nitella*, whose cells are several inches long and may contain an appreciable volume of cytosol. In brief:
• Potassium ions are accumulated passively by both the cytosol and the vacuole. When extracellular K+ concentrations are very low, K+ may be taken up actively.
• Sodium ions are pumped actively out of the cytosol into the extracellular space and vacuole.
• Excess protons, generated by intermediary metabolism, are also actively extruded from the cytosol. This process helps maintain the cytosolic pH near neutrality, while the vacuole and the extracellular medium are generally more acidic by one or two pH units.
• Anions are taken up actively into the cytosol.
• Calcium ions are actively transported out of the cytosol at both the plasma membrane and the vacuolar membrane, which is called the tonoplast.

Many different ions permeate the membranes of living cells simultaneously, but K+ has the highest concentrations in plant cells, and it exhibits high permeabilities. A modified version of the Nernst equation, the **Goldman equation**, includes all permeant ions (all ions for which mechanisms of transmembrane movement exist) and therefore gives a more accurate value for the diffusion potential.
When permeabilities and ion gradients are known, it is possible to calculate a diffusion potential across a biological membrane from the Goldman equation.
The diffusion potential calculated from the Goldman equation is termed the *Goldman diffusion potential*

Table 6.1 Comparison of observed and predicted ion concentrations in pea root tissue

Ion	Concentration in external medium (mmol L^{-1})	Internal concentration[a] (mmol L^{-1})	
		Predicted	Observed
K^+	1	74	75
Na^+	1	74	8
Mg^{2+}	0.25	1340	3
Ca^{2+}	1	5360	2
NO_3^-	2	0.0272	28
Cl^-	1	0.0136	7
$H_2PO_4^-$	1	0.0136	21
SO_4^{2-}	0.25	0.00005	19

Source: Data from Higinbotham et al. 1967.

Note: The membrane potential was measured as –110 mV.

[a]Internal concentration values were derived from ion content of hot-water extracts of 1- to 2-cm intact root segments.

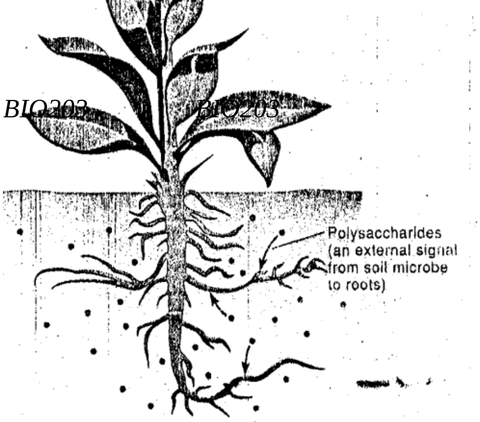
What idid you understand by steady state?

Self-Assessment Exercise 2

What is membrane permeability?

5.3.4 Cellular Communication

Cells in a complex organism interact with their environment (e.g. gravity), with one another and with the cells of other organisms. Cell-to- cell interactions occur where chemical or electrical signals released from one cell are received by another where they exchange some aspect of metabolism. Auxin is an example of an internal chemical signal -that is, a signal that moves from cell to cell in the same plant. External signals are those that pass between different organisms, for example, between plants and bacteria or fungi.



Auxin is an example of an internal signal between cells. Microbial polysaccharides may function as a signal from bacteria to roots.

The reception of chemical signals and the transmission of their messages are important functions of proteins in membranes. Studies of signal transdution in plants have focused on the role of calcium ions (Ca^{2+}) and calmodulin, a protein that is activated when it binds to calcium. In its active form, the Ca^{2+} - calmodium complex activates enzymes in membranes essentially telling them to get to work. As much as 2% of the plasma membrane may be calmodulin.

5.3.4.1 Hormone Receptors

Signal transdution in plant cells begins when a hormone binds to a receptor protein on the plasma membrane. Plants make several different hormones, each of which must be recognized by a different receptor. Studies of plant hormone receptor have concentrated on auxin receptors because auxin has so many effects on plant growth and development. Each auxin receptor causes different metabolic charges depending on where it occurs in a plant.

Furthermore, the amount of binding varies from one tissue to the next, for example, auxin receptors in leaf stalks bind more than one hundred times more auxin than do receptors on fruits. The multiple characteristics of hormone binding mean that there are probably many different receptors for auxin as well as for each of the other plant hormones.

5.3.4.2 Membrane Interactions with other Organisms

Each plant is surrounded by other organisms, including animals, bacteria fungi and other plants and interactions are common among plants and many organisms in their fertilization can occur, if they do not fit together the pollen tubes grow irregularly and incompletely, and fertilization does not occur. In some cases, the pollen and stigma within the same flower do not fit together which makes the plant self-incompatible. *Which hormone has great influence on plant growth and development*

Self-Assessment Questions

1) What is Nernst Equation?

Answer: *Nernst equation* states that at equilibrium**:** the difference in concentration of an ion between two compartments is balanced by the voltage difference between the compartments
2) The energy used in active transport come from where?

Answer: The energy required for active transport usually comes from the hydrolysis of ATP

5.4 SUMMARY

Membrane lipids allow the unrestricted movement of small molecules across the plasma membrane, but block the diffusion of ions and large polar molecules. This property of membranes is called differential permeability. Membranes also allow the transportation of solutes. These energy requiring transport of solutes is called active transport. The most common actively transported solutes are ions, especially hydrogen ion. Transport proteins for hydrogen ions are called ATPases because they use energy from the hydrolysis of ATP.

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Ion transport is affected by the concentration gradient of ions and by the electrical gradient of their charges. Together the gradient creates an electrochemical gradient across a-membrane. The electrical component of this gradient is measured in volts and is called the membrane potential. Ion transport proteins, called electrogenic pump, maintain the membrane potential. The most common electrogenic pumps are proton pumps.

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5.5 References/Further Readings/Web Sources

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https://www.youtube.com/watch?v=R6jfNfNeSzI
https://www.youtube.com/watch?v=NIxt4VrcLyc

5.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1
Endocytosis is apparently more difficult in plants than in animals, because; the plasma membrane of plant cells is usually processed against the cell wall by turgor pressure. This turgor pressure hinders the plasma membrane from invaginating into the cytoplasm

Answers to SAE 2
The extent to which a membrane permits the movement of a substance is called **membrane permeability**. Membrane permeability depends on the composition of the membrane as well as on the chemical nature of the solute. In a loose sense, permeability can be expressed in terms of a diffusion coefficient for the solute through the membrane

Glossary

ER= Endoplasmic Reticulum
RNA= Ribonucleic Acid
DNA= Deoxyribonucleic Acid
ATP= Adenosine Triphosphate
ADP= Adenosine diphoshate
SP= Suction Pressure
DPD= Diffusion Pressure Deficit

End of Module Questions

1) Cells interact with other cells in an organism and their environment (**True or False**)
2) A potential that develops as a result of diffusion is called a diffusion potential. (**True or False**)
3) The energy required for active transport usually comes from the hydrolysis of ATP (**True of False)**
4) . If plasmolysed is placed in water or hypotonic solution, endosmosis takes place (**True or False)**
5) Ribosomes are sites of protein synthesis **(True or False)**

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MODULE 2

Unit 1 Energy and its uses by Plant
Unit 2 Energy Metabolism I
Unit 3 Energy Metabolism II
Unit 4 Respiration I
Unit 5 Respiration II

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UNIT 1 ENERGY AND ITS USES BY PLANT

Unit Structure

1.1 INTRODUCTION

Energy the ability to do work is an important concept of study. Energy and the control of it has been the root of major conflicts between nations. Energy is also an essential component of living organisms began the study of bioenergetics, which is a fascinating discipline that helps us understand life. In this unit, you will learn about what energy is, how it is measured and how the various forms of energy are converted. The laws governing energy use in life termed the laws of thermodynamics will also be treated. Examples will be given from real life example to drive home these laws. The unit will end by identifying how plants transform energy and mention will be made of the chemical reactions that transform energy in plants and other organisms.

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1.2 Intended Learning Outcomes

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

-define energy state the basic unit to measure energy
-name the two basic types of energy
-state the first and second laws of thermodynamics
-list the two primary energy transformations in plants
-give the general name for the chemical reactions that transform energy in cells.

1.3 Main Contents

1.3.1 Energy and How to Measure It

a. What is Energy?

Energy is the ability to do work, that is, to bring about change or move matter against an opposing force such gravity or friction. Because energy is an ability to do work, it is not always as obvious to us as matter, which has mass and occupies space.

We describe energy according to how if affects matter. Humans use energy for conspicuous activities such as dancing, cultivating farmlands, playing football and studying, plants on the other hand expend their energy in subtle, nearly unrecognizable ways. For example the philodendron plant uses its leaves to gather the energy available in sunlight and use it to fuel its metabolism and growth. This plant has large flowers that open for only a couple of days. At night when air temperatures are near freezing, these flowers can reach temperatures exceeding ^{4}6o/1^{1}5o **(by comparison, butter melts at 30oC/88oF).** These furnaces like flowers maintain their high temperature for many hours in the cold night air. Understanding the bioenergetics of the plant helps us to understand how they live. Bioenergetics is the energy relationships of living organisms.

b. Measuring Energy

Energy exists in many forms. It is therefore measured with many units. Most scientists measure energy in calories (cal) or joules (j) Calorie (note the small c) is the amount of energy required to raise the temperature of 1 gram of water by ^{0}C. The most common unit for

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measuring the energy content of food and the hear output of organisms is a **Calorie** (note the large C) which is the energy required to raise the temperature of liter of water by 1^0C.

The Calorie **(written with a capital C)** used to measure the energy content of food is equivalent to 1,000 calories **(written with c)** or 1 Kcal.

A **joule** (j) is the amount of energy needed to move 1 kilogram through 1 metre with an acceleration of 1 metre per second (1m) sec^2, for comparison purposes 1 cal = 4.l2J. To help you put these units into better perspective consider that one piece of meat pie provides enough energy **(1.5 x 10^0 J or 365 Cal)** for a woman to run for an hour or for a typist to enter about 15 million characters on a manual typewriter **(almost 11,000 typewritten pages).**

Others units used in measuring energy include British thermal units (Btu), watts (w) kilowatts hour (kWH) and horsepower (hp).

Energy Interconversions

1 Btu	=	.1055J				
1 cal	=	4.1J	=	0.001 Kcal	=	0.001C
1 hp	=	746W				
1 W	=	0.00134hp.				

What is Energy?

Self-Assessment Exercise 1

What is a Joule?

1.3.2 Energy Conversions and the Laws of the Thermodynamics

a. Energy Conversions

All activities of living organisms such as cellular division, heat production by flowers, moving from pace to place etc. involve the inter converting of energy from one form to another. For example, we convert the energy contained in oil to electricity, and then convert the electricity to light energy to illuminate our homes and streets.

Similarly, plants convert sunlight into chemical energy that they use to reproduce, repair their DNA, and now parts. This conversion of light energy to chemical energy is **photosynthesis**, which sustains almost all life on earth.

Animals stay alive by eating animals and/or plants and their stored energy. All aspects of the lives of organism center on energy and energy conversions.

There are two types of energy, Potential energy and Kinetic energy.

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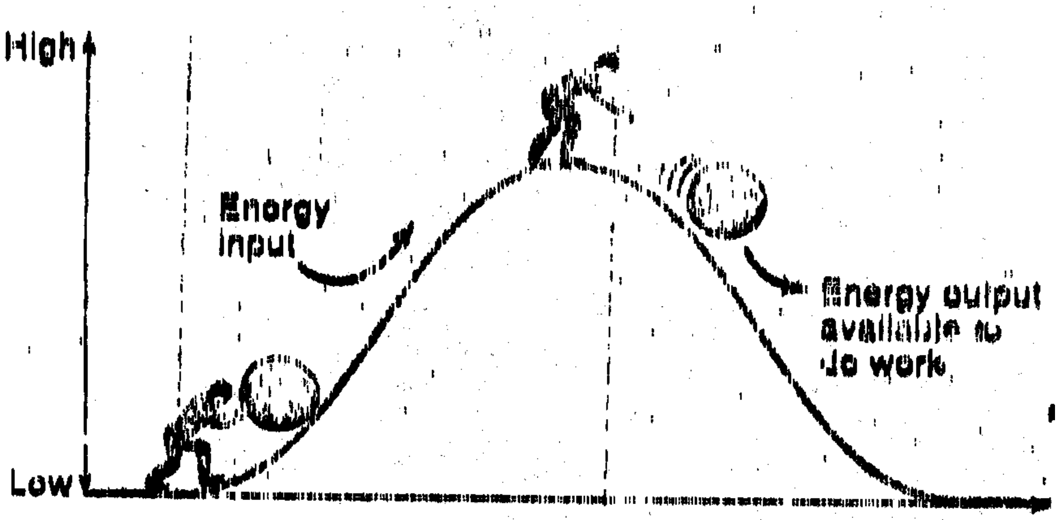

Pushing a builder to the top of a hull requires an input of energy because it increases the potential energy of the builder.

Potential energy is stored energy, that is, energy available to do work, examples of potential energy include a teaspoon of sugar, an unexploded/unlit knockout, and a rock on top of a hill. Potential energy is determined by the position (e.g. water held at an attitude behind a dam) or arrangement (e.g. the type of chemical bonds) of matter. In organisms, potential (i.e. latent) energy is stored in chemical bonds such as those in sugar, starch and fats.

Kinetic energy is energy being used to do work. Examples of kinetic energy include burning sugar, exploding a knockout, or rock rolling down a hill or a nut forcing its way through soil. Kinetic energy effects matter by transferring motion to other matter, just a moving ball transfers kinetic energy to other place, if another man who is running bumps into the man standing at a place, the stationary man acquires some kinetic energy from the running man and then also some distance, until the acquired energy is finished before he stops.) Similarly, a flowing water can be used to turn a turbine, (this is what happens in electricity generation at the Kainji Dam), and a growing root can break a concrete floor. Kinetic energy moves objects, whether they be mountains, molehills or molecules.

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Heat is kinetic energy because it involves the movement by molecules. Now, take another look at (Fig. 5.3). The rock on top of the hill contains much potential energy the capacity to do work because of its position, but since it is a rest, it has no kinetic energy. If the rock were given a little energy a little push, it would spun tenuously roll down the hill transforming its potential energy into kinetic energy, which could be used to do work.

Likewise, winding a watch transformed kinetic energy form the person winding the watch into potential energy stored in the watch's mainspring. Thus under most conditions, potential and kinetic energy are freely inter-convertible.

What is kinetic energy?

1.3.3 The Laws of Thermodynamics

Life depends on energy transformations. For examples, our bodies transform the chemical energy in food to mechanical energy that enables us to study, play and dance and our appliances convert electrical energy to light for reading and to ban for cooking our food. Combustion engines convert the chemical energy in petrol to mechanical energy that sustains life on earth.

Energy transformations are regulated by laws of thermodynamics. These laws involve a system and its surroundings. The collection of matter being studied is called the system, and the rest of the universe is referred to as the surroundings. A closed system, such as that approximated by a thermos bottle, is isolated from. (i.e. does not exchange energy with) its surroundings, conversely, an open system exchanges energy with its surroundings.

The laws of thermodynamics are simple and based on common sense. They are unbreakable laws that apply to all energy transformations, whether they be combustion of petrol in a car, the breakdown of glucose in a cell or the generation of heat by philodendron flowers. These laws govern the existence of all organisms.

a. The First Law of Thermodynamics

The first law of thermodynamics is a law of conservation of energy. The law states that energy cannot be created or destroyed, but only converted to another forms. This law can be stated in other ways:

-In any process, the total amount of energy in a system and its surroundings remains constant.
-The total amount of energy in any isolated (i.e. closed) system is constant.
-The amount of energy in the universe is constant. -You can't get something for nothing.

For example the energy used to wind a watch comes from the person winding the watch. Similarly, a power plant **(generator)** does not create energy. It merely transforms energy from one form **(e.g. petrol)** to another **(e.g. Electricity).** In the same way, green plants are not energy producers, they merely trap and convert the energy in sunlight into chemical bonds. The first law asserts that the energy in sunlight that warms out plants and drives photosynthesis must come from somewhere else in the system. In this case, it comes from the sun.

Energy conversions often generate heat, for example, as you are studying this unit, your body generates the heat of a 100W bulb. Your temperature is neither decreasing nor increasing because the heat generated by your body is radiated into your surroundings. That is, there is no change in the total amount of energy in the system. The energy radiated from your body that heats the room you are in can be traced to the energy contained in the food you ate. According to the first law of thermodynamics, the amount of energy released by your body cannot exceed the amount of the energy contained in the food you eat. If you stop eating you will eventually run out of energy, die and stop releasing heat.

The first law of thermodynamics has tremendous implications for everyday life. For example, it explains why a car can only do a limited distance regardless of its fuel efficiency or mileage rating, the energy used to move the car cannot exceed that contained in the chemical bonds of its fuel. When the car runs out of petrol, it can go no further until more petrol is added. The addition of more petrol to the car (energy) corresponds to a loss of energy from somewhere else - the storage tank at the petrol station.

The first law of thermodynamics also dictates that the energy trapped by leaves during photosynthesis cannot exceed the energy of the absorbed light. For example, if 100 units of light energy strikes of leaf is not more than 100 units of energy can be trapped in the carbohydrates produced by photosynthesis. No matter how hard you tried, you can't get more energy out of a system than you put in.

b. The Second Law of Thermodynamics

The second law of thermodynamics is the law of entropy, or disorder. This law states that all energy transformations are inefficient, that is, that the amount of concentrated useful energy decreases in all energy transformed. This law can be expressed in other energy a follows:

System tends toward increasing entropy (disorder).
-Any system tends spontaneously to become disorganized.
-In all energy transformations, some usable energy is lost as heat. -Any spontaneous change decreases the amount of usable energy.

To better understand this, consider a person throwing a ball or heating a cup of tea. Both of these processes requires energy. According to the first law, no energy has been created or destroyed in throwing the ball or heating the tea, the energy used to heat the tea probably came from breaking the bonds of natural gas, while that used in throwing the ball came from energy in food used to contract muscles. However the energies of the moving ball mid the heating the tea are drastically different. The moving ball heats the air and any object that it strikes, and is in coherent motion all of its parts move together in an orderly way. In contrast, energy in the heated ten is contained in the random, incoherent motion of its molecules. There is no order to it, the heat results only forms of energy; any other form of energy can be converted completely to heat, but heat cannot be completely converted to another forms of energy.

This again goes back to our everyday experience. The thrown ball heats the air and the glove that hit is, but applying the same amount of heat, but heat cannot be completely to heat, but heat cannot be completely converted to another form of energy.

This again goes back to our everyday experience. The thrown ball heats the air and the glove that hit it, but applying the same amount of heat of the air doesn't move the ball.

All energy is ultimately converted to heat and heat is not usable energy.

Consider again the example of a combustion engine in a car. Petrol (Gasoline) is a concentrated, orderly sources of energy, its energy resides in the covalent bonds of octane. However, when these bonds breaks and release energy in the car's engine. Less than one-forth of the energy is used to move the car (i.e. combustion engines are less than 25% efficient). According to the first law of thermodynamics, no energy was lost when the car moved, the amount of energy used to move the car, heat the engine block, (and the air around it), power the radio, ad heat the tyres equals that originally contained in the petrol. However, applying hear to the car does not move the car. That is, the energy contained in the heated tyres, pavement, air and engine-block cannot be recycled to run the car, because heat energy resides in randomly moving molecules and it therefore not a concentrated, useful form. This heat represents the inefficiency inherent in any energy transformation and is the basis for the second law of thermodynamics. Because all energy transformations produce heat (i.e. An unusable form of energy), all things naturally become more disorganized.

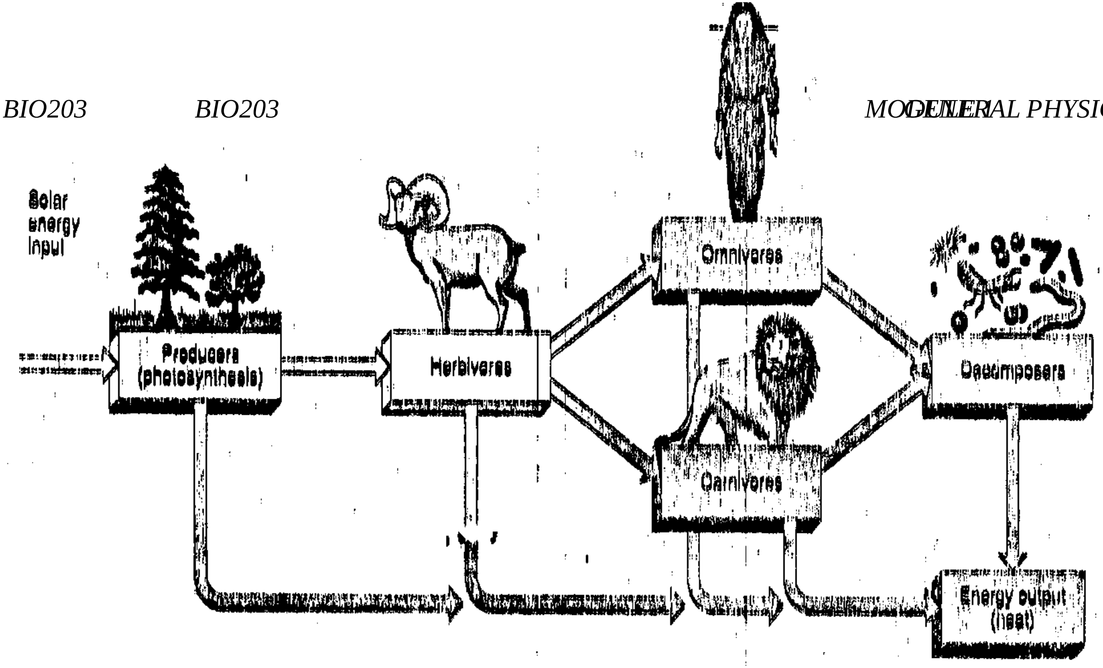
The consequences of the second law of thermodynamics are important and familiar to everyone. For example, rocks tumble downhill rather than up hill, and piece of jigsaw puzzle never spontaneously fall into place when poured from a box. This second law explains why disorder in the massive is increased continually.

Cells derive energy from sugar and fats for growth, repair and reproduction. The chemicals reactions that free this energy are inefficient and release much heat. The cells of most organisms extract only about half of their fuel's energy for useful work (e.g. the energy used to power your brain while you sleep is equivalent to that of a 60W bulb). Thus, although organisms can channel the transformation of energy from one form to another, they can inboard the energy in reserves (e.g. Fat or Starch) or use if for repair, movement, or reproduction-these diversions are only temporarily. Eventually, all energy is transformed to heat.

To loss off useful energy as heat energy transformations increases the entropy in a system, and only process that decrease the amount of useful energy occur spontaneously. Therefore, there is a natural tendency for things to become disorganized. Although the entropy of one system, such as an organisms or cell, may decrease (i.e. the stem may become more organized), the entropy of the universe is always increasing. Once a more local level, or rooms and tables quickly become messy unless we periodically straighten then.

Because organisms are highly ordered it might seem that they are exceptions to the law of thermodynamics. The second law applies only to closed isolated) system.

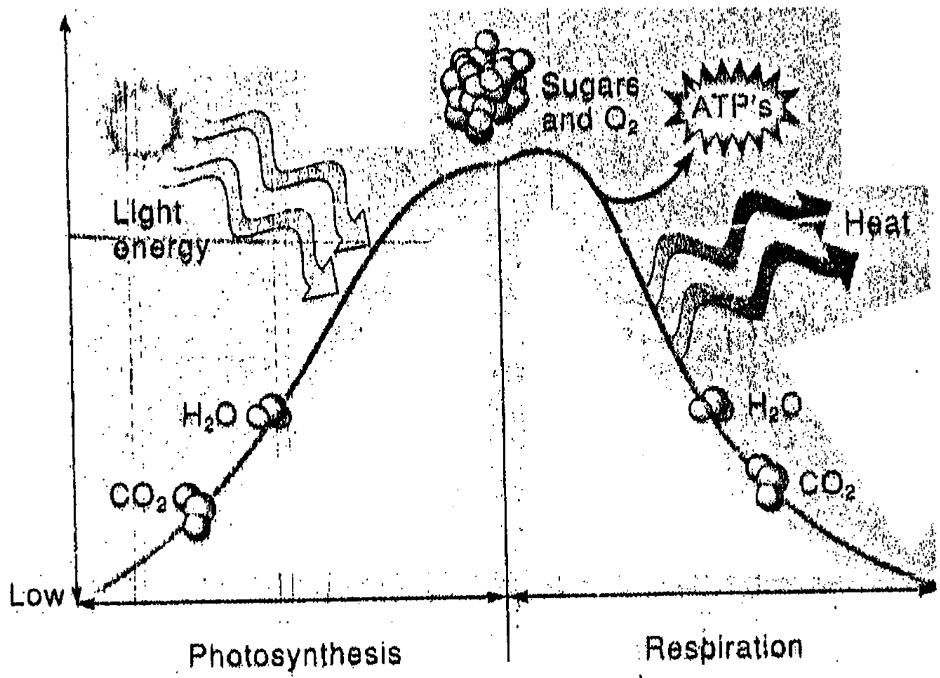
Organism remains organized because they are not closed system, they use inputs of matter and energy such as food and sunlight to reduce randomness (i.e. Decrease entropy) and stay alive. The energy that keeps organisms alive comes ultimately from the sun that is plants transform sunlight into chemical bond of carbohydrates, which humans and other organisms use as an energy source. Life is only possible because organisms temporarily store and later use some of the energy flowing through the system. Plants and plant like organisms such as algae are the first and most important part of the scheme.



Plants are the products, that is, they transform energy in sunlight into chemical energy. This energy then frown through and to used by other

Energy transformations such as explosions, moving vehicles and electricity which we are all familiar with releases large amount of energy at once. However, energy transformations in cells involve small amounts of energy. It is the cumulative effect of these many smell transformation that we see a growth and development.

The two primary energy transformations in plant are photosynthesis and cellular transportation.



Plants use photo synthesis shown here as an uphill reaction, to make energy rich sugars and O_2 from energy pour CO_2 and water. Plants and other organisms use respiration, shown here as a downhill action, to convert sugars to CO_2 and water. Some of the energy released during respiration is conserved in chemical bonds of other molecules, especially ATP.

Photosynthesis uses light energy to convert CO_2 and H_2O (both which are energy- pore) into sugars. In the process, oxygen gas, (O_2) is released.

Cells extract energy from sugar via cellular respirations. Some of this energy is stored in molecules such as ATP (we study ATP in unit 7). If all of energy in the chemical bonds of sugars were released at once (as in explosion), the energy would be converted mostly to heat and produce literally high temperatures. To avoid these problems, cell extract energy from glucose and other molecules by slowly oxidizing the molecules in the series of chemical reactions. During each reaction, there is a drop in the potential energy of the molecules. Some of the energy is lost as heat however much of it is trapped in the chemical bonds of other molecules in the cell. The chemical reactions that transform energy in cells is collectively called **metabolism.**

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What is the first law of thermodynamics

Self-Assessment Question 2

What is the second law of Thermodynamics?

Self-Assessment Questions

a) *What are two primary energy transformation in plants?*

Answer*: The two primary energy transformation in plant are photosynthesis are cellular respiration,*

b) *What is reaction that transform energy in living organisms?*

Answer*r: the chemical reactions that transform energy in plant and other organisms is metabolism*

1.4 SUMMARY

Energy, the ability to do work is an essential aspects of all events. Everything involves energy including music, games, tides, seasons and the orbits of the plants. Plants and animals are no exceptions. All aspect of their lives, ranging from maintenance and repair exotic tasks such as producing beautiful flowers, require energy. Consequently, we can only understand and appreciate plants when we know about energy and how it is used by plant.

All of life's activities require that energy be transformed from one form to another. These energy transformations are governed by the laws of thermodynamics.

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1.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1

A **joule** (j) is the amount of energy needed to move 1 kilogram through 1 metre with an acceleration of 1 metre per second (1m) sec^2. For comparison purposes 1 calorie = 4.l2J.

Answers to SAE 2

The second law of thermodynamics is the law of entropy, or disorder. This law states that all energy transformations are inefficient, that is, that the amount of concentrated useful energy decreases in all energy transformed.

UNIT 2 ENERGY METABOLISM

Unit Structure

2.1 INTRODUCTION

In the last unit, we started the discussion on energy and its uses by plans. You learnt what energy is and the different forms it takes (that is energy conversion). You also learnt the laws of thermodynamics and their relationship with life. We ended that unit by saying that the chemical reactions that transform energy in cells are collectively called metabolism. Plants harvest energy from the sun, convert it to metabolically useful form, and move it in different forms within cells according to energy budget.

Energy is needed for a whole range of things, which include: active transport across membranes, biosynthesis of larger molecules from smaller ones and moving molecules through the cytosol into and out of organelles and cells.

In this unit, you are going to learn how metabolism works to get all the energy needed for life's work; the various reactions involved in metabolism and also the other compounds involved in energy transformation in plants.

2.2 Intended learning outcomes

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

-give the meaning of the term metabolism
-state what a metabolic pathway means
-explain the meaning of the following terms:
(a) Bond energy
(b) Free energy
(c) Enthalpy
(d) Endothermic reaction
(e) Exothermic reaction

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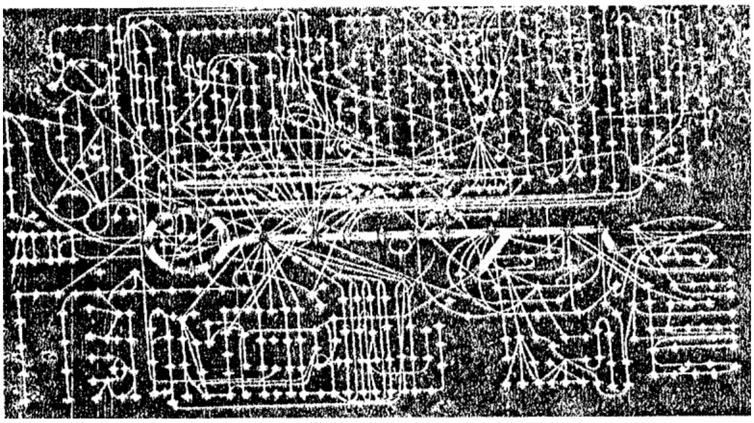
2.3 Main Contents

2.3.1 Metabolism: Energy for Life's Work

Metabolism is a fundamental property of life arising from energy transformations in cells. It is the totality of all the chemical reactions that occur in an organism. These reactions do not occur randomly; rather, they occur in step-by-step sequences called **metabolic pathways.** In these reactions, the product of one reaction becomes another substrate **(that is the starting point)** for another. The various metabolic pathways in a cell are much like the roads on a map.



Cellular metabolism. This diagram traces some of the metabolic reactions that occur in a cell. Thus represent molecules, and lines represent reaction each catalysed by special enzyme-that changes them. The step wise sequences of reactions called metabolism pathways shown in yellow is central to most other pathways.

Each reaction in a metabolic pathway rearranges atoms into new compounds, and each one either absorbs or release energy. The amount of energy required to break a particular bond is equivalent to the amount of energy required for its formation. This amount of energy is called the bond energy. For example, consider the energies of the following bonds.

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Bond	Energy (Kcal Mol^{-1})
C – C	83
C – O	84
C – H	99
C = O	174
O = O	118
O – H	111

Thus C = O bonds are much stronger than C – C bonds. This is important because metabolism continually breaks and reforms these bonds to obtain energy for growth movement and repair.

During chemical reactions, the net release or uptake of energy equals the difference of energy released and energy consumed. For example, burning a mole (16g) of methane releases 160Kcal of energy.

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

This heat of reaction is the heat that you feel from the stove (i.e the net amount of energy released by the reaction) and is represented by H (delta H). It is derived from the total potential energy of the molecules, a measure called **enthalpy.** Therefore, we say that the heat released into the surrounding comes from the enthalpy of the reacting molecules. In the case of burning methane, the products (O_2 and H_2O) have 160Kcal less enthalpy than the reactant (CH_4). Such heat releasing reactions are called **exothermic** reactions and change the molecules so that their energy content decreases.

Although most exothermic reactions are spontaneous, some are not. To accurately predict whether a reaction will occur spontaneously **(that is, without requiring any physical or chemical assistance.** We will have to study a new concept free energy.
What is metabolism?

Self-Assessment Question 1

What is Enthalpy?

2.3.2 Free Energy

The potential energy of a compound is contained in its chemical bonds. When these bonds break, the energy that is released can be used to do work, so as to form other bonds. The amount of energy available to form other bonds is the free energy of the molecule and is represented by G (**for its discover, Joshua Gibbs).**

Josiah Willard Gibbs, an American mathematician, first described Gibbs free energy in the 1870s. According to Gibbs, free energy is the total energy of a system that is available to perform useful work. It is expressed in kilojoules (kJ) and is also called “available energy.”

Another widely accepted definition of Gibbs free energy (which is often denoted by the letter G) is that Gibbs free energy measures the maximum work done by a thermodynamic system at constant pressure and temperature.

The free energy is stored in the bonds present in the reactants and products of a reaction. In a thermodynamic reaction, the change in Gibbs free energy (ΔG) is represented as:

ΔG = *total free energy of products – total free energy of reactants*

When ΔG = 0, the reaction will be in equilibrium, which means the concentration of products and reactants does not change. ΔG < 0, or a decrease in free energy, means energy is released during the reaction, and when ΔG > 0, or an increase in free energy, it means energy is used up in the reaction.

ATP and free energy

Under standard conditions, glucose reacts with oxygen during glycolysis to release Gibbs free energy. This is an exergonic reaction, which means energy is released. In order to use up this free energy, this reaction is coupled to other reactions in our body. One main way in which this free energy is captured in our body is by producing adenosine triphosphate (ATP) from adenosine diphosphate (ADP) by the addition of an inorganic phosphate group. The formation of ATP from ADP is an endergonic reaction, which means energy is used up in the reaction. So by coupling this reaction with the exergonic glycolysis reaction, ATP can be produced.

The oxidation of glucose and the production of ATP in humans results in the storage of large amounts of Gibbs free energy in the phosphate bonds of ATP, which can be released when ATP is hydrolyzed and its phosphate group is removed to form ADP in the cells. This released energy is used up by the body for several cellular processes.

Chemical reactions change the amount of free energy available for work. This change in free energy is called Δ G. (delta G) and is the most fundamental property of a chemical reaction. It is equivalent to the change in the heat content minus the change in entropy.

Those relationships are represented by the following formula:

G= H - T S

Where

G is the change in free energy of the reaction and is the part of the potential energy that can do work. The remaining energy is not available for work because of entropy.

H is the change in enthalpy (heat content), which is the energy in chemical bonds.

T is the temperature measured on a scale of $_0$C above absolute zero

S is the change in entropy or disorder.

Entropy is amplified at higher temperatures because temperatures measure random molecular motion **(i.e. the intensity or potential of heat),** which increases disorder. Therefore higher temperatures speed reactions and increase disorder. This is also why water evaporates faster at higher temperatures. Spontaneous reactions change bond energies and release heat. These reactions usually increase entropy and are called **Exergonic (energy outward)** reactions. They have a G less than zero and therefore form products with less free energy than their reactants. This energy is potentially available for cellular work. All spontaneous reactions decrease the amount of free energy because some energy is dissipated, thereby increasing entropy. Because this energy can do no work. Life is a constant struggle against entropy.

Not all reactions are spontaneous. For example, consider the formation of sucrose (table sugar) and water from glucose and fructose.

Glucose + Fructose → Sucrose + H_2O

This reaction has a G of + 5.5Kcal, meaning that its products have

5.5kcal mol^{-1} more energy than it reactions. This reaction absorbs energy from the surroundings and is not spontaneous. Such reactions are called **endergonic (energy inward)** reactions and will not occur without a net input of energy.

The free energy of a particular reaction determines many of a reaction's properties. Most important, the G of a reaction dictates how much work a reaction can perform. For example consider the oxidation of a mole of glucose to carbon dioxide and water

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

G = 686kcal Mol^{-1}.

Since G of this reaction is less than zero, this reaction is exergonic and spontaneous. The carbon dioxide and water it produces store 686 fewer kcal than does glucose.

Endergonic Versus Exergonic Reactions

If a reaction requires an input of energy to move forward, then the change in free energy, or the ΔG of the reaction is positive and the reaction is considered endergonic—energy has entered the system. In plants, the building of glucose molecules and oxygen from carbon dioxide and water—with the help of sunlight—is considered endergonic. The glucose molecules are considered as energy storage molecules.

Conversely, if energy is released in a reaction, then the change in free energy, or ΔG is negative and the reaction is considered exergonic. The products have less free energy than the reactants—energy has exited the system. This occurs in animals that break down glucose using oxygen to make carbon dioxide and water. The energy in the glucose molecules has been released.

Free Energy and Chemical Equilibrium

When a chemical reaction reaches equilibrium, a G equals zero. Similarly G increase as one moves away from equilibrium. Because all of life's process requires work, cells must remain far from equilibrium to stay alive. They accomplish this by continually preventing the accumulation of any of the reactants of metabolic pathways. For example, the hug difference in free energy between glucose and its oxidation products **(carbon dioxide and water)** pulls cellular metabolism quickly in one direction, as soon as reactants form; they are quickly converted to new compounds by other reactions. *What is endergonic reaction?*

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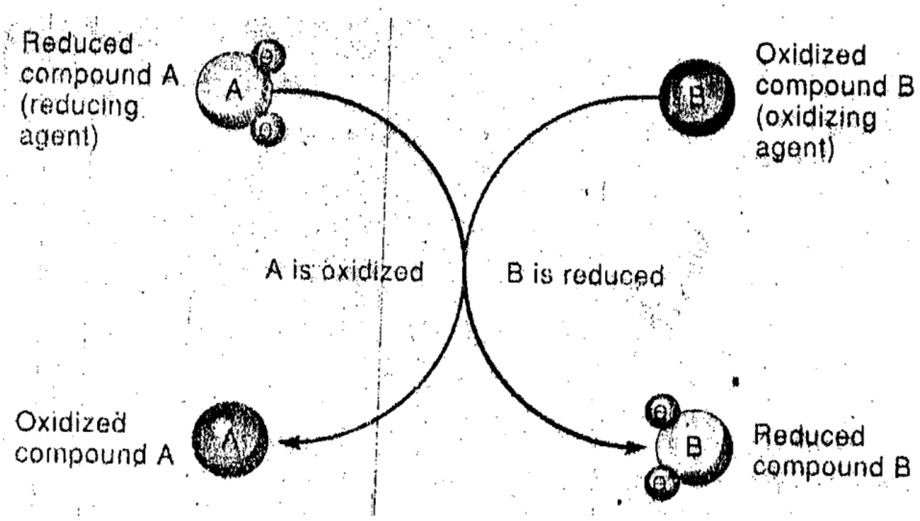
Self-Assessment Exercise 2

What is Free Energy?

2.3.3 Oxidation, Reduction and Energy Content

Most energy transformations in organisms involve chemical reactions called **oxidations** and **reductions.**



Oxidation and reduction occur simultaneously, as compound. A is oxidized (i.e. dissolve electron) compound B is released (i.e. electron)

Oxidation is the loss of electrons either alone or with hydrogen, from a molecule. This is equivalent to adding oxygen because oxygen is strongly electronegative and therefore attracts electrons from the original atom. Oxidation reactions, such as the breakdown of glucose to carbon dioxide and water degrade molecules into simpler products and are therefore examples of catabolism. They are reactions that breakdown compounds to release energy.

Reduction is the addition of electrons either alone or with hydrogen to a molecule. Reduction changes the chemical properties of a molecule, not necessarily in its size. Electrons removed from a molecule during oxidation reduce another molecule. Reduction reactions such as the formation of lipids usually involve synthesis of more complex molecules and are therefore examples of anabolism. They are reactions that build up compound and require energy input. Oxidation and reduction reactions always occur simultaneously; if something is reduced something else must be oxidized.

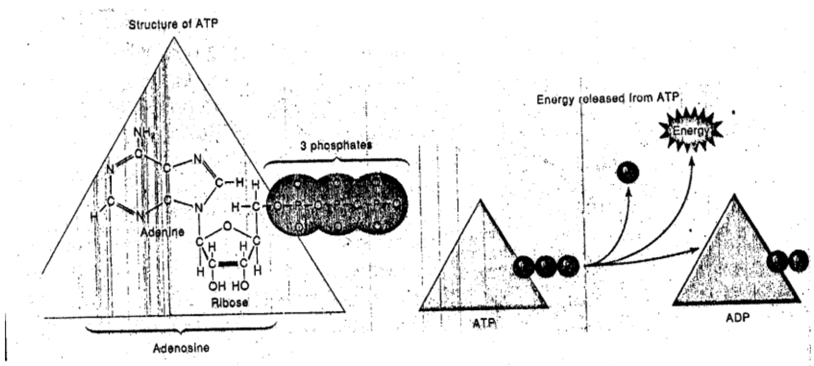
Many energy transformations in living systems involve oxidation and reduction of carbon. Reduced carbon contains more energy than oxidized carbon. This explains why reduced molecules such as methane (CH_4) are explosive, while oxidized molecule such as carbon dioxide (CO_2) are not. The same principle applies to other compounds, the more reduced they are, the more energy they contain. For example

Substance	Energy Content (J kg-I)	
	Hydrogen	122,000,000
	Natural gas	55,000,000
	Gasoline	42,000,000
	Wood (dry)	17,000,000
	Starch	17,000,000
More reduced	Sucrose	17,000,000
More oxidized	Salad oil (or any fat) 37,000,000	
	Wheat flour	15,000,000 (mostly starch)
	Potatoes, raw	3,000,000 (80% water)
	Beef, T-bone steak	17,000,000 (37% fat)
	Chicken (skinless)	4,000,000 (2% fat)

This example should help you better appreciate how the different energy content of foods affects our lives. Most University students require about
3,000 Calories per day **(that is the energy in one pound of butter).**

Organisms extract energy from energy-rich compounds such as sugar and fat via catabolic reactions that do work e.g. building cell walls, and replicating genetic information an important substance through which energy passes during cellular metabolism is **adenosine triphosphate,** a compound more commonly known as ATP .

When cells need energy, they hydrolyse Adenosine triphosphate or ATP. ATP is a nucleoside triphosphate made of adenine (a nitrogen containing base), ribose (a five-carbon sugar) and three phosphate (HPO_4^2) groups (fig 5.9) ATP molecules contain much energy that is released when the terminal phosphate group (represented by a squiggly line,) is cleaved from the molecule. Because the breakdown of ATP links energy exchanges in cells, ATP is the energy currency of the cells. When cells need energy to do something, they "spend" ATP by converting it to adenosine diphosphate (ATP), inorganic phosphate (Pi), and energy.



$ATP + H_20 \longrightarrow ADP + Pi + energy$

$G = -7.3\ kcal\ mol^{-l}$

Several properties of ATP make it ideally suited as the energy currency of cells.

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The amount of energy released by converting ATP to ADP + Pi (7.3 kcal mol^{-l}) is about twice as much as is needed to drive most cellular reactions. The rest of the energy is dissipated as heat.

Much of its energy is immediately available to cells. Although fat and starch also store large amounts of energy, their energy must first be converted to ATP before it can be used. ATP represents the readily available energy “cash” of a cell; fats and starch are analogous to energy stocks and bonds.

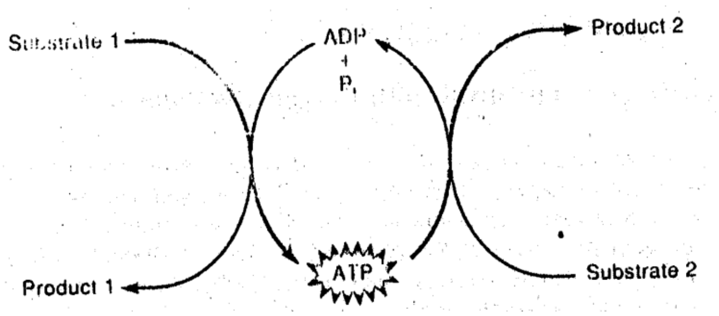
Unlike the covalent bonds linking carbon and hydrogen in molecule such as methane and glucose, the terminal phosphate bond of ATP is unstable, that is why it breaks so easily.

ATP is a common energy currency – All cells of all organisms use ATP for energy transformation. Like all of the different appliances that can plug into an electrical outlet and do different things, so too can different chemical reaction use cell's ATP to do different kinds of work. Organisms use ATP for virtually all of their work including making new cells and macromolecules, pumping materials and moving materials through cells and throughout the organism. Accomplishing all of this work requires huge amounts of ATP. For example, a typical adult uses the equivalent of about 200kg (4401b) of ATP per day, but has only a few grams of ATP on hand at anyone time. ATP is therefore recycled at a very furious pace, turning over the entire supply every minute or so.

ADP + Pi + energy ATP G = + 7.3 kcal mol^{-1}

Since the G for this reaction is positive, each reaction requires an input of energy which comes from molecules that are broken down in other reactions that are coupled to the synthesis of ATP.

Coupled Reactions just as cells couple the breakdown of food to the production of ATP, so too do they. Couple the breakdown of ATP to other reactions that occur at the same time and place in the cell. These coupled reactions drive other reactions that do work or make other molecules.



Coupled reactions. Energy released by an exergonic reaction can be used to make ATP from ADP and PL. This ATP can then be used to drive an endergonic reaction.

For example, consider again the formation of sucrose (table sugar) and water from glucose and fructose.

Glucose + fructose $\longrightarrow$ sucrose + H^{2}0

G = + 5.5 Kcal mol^{-l}

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Because the G for this reaction exceeds zero, the reaction is not spontaneous and will not occur without a net input of energy. This input of energy is provided by two moles of ATP, each of which provide 7.3
Kcal mol-l of energy.

ATP ⟶ ADP + Pi + energy
G = -7.3 Kcal mol^{-1}

This changes the equation for sucrose synthesis to:

Glucoses + fructose + 2ATP Sucrose + H_20 + 2ADP = 2Pi + energy and makes the G = 5.5 – 14.6 = -9.1 Kcal mol^{-l}. Thanks to the expenditure of energy by the cell (i.e. as ATP). The reaction proceeds because it's overall G is negative. In this reaction, the breakdown of ATP is coupled to the formation of sucrose.

ATP accomplishes much of its work by transferring its phosphate group to another molecule in a process called phosphorylation. Phosphorylation energizes the molecules receiving the phosphorylate group so that they can be used in later reactions. The original "cost" of this phosphorylation is returned in subsequent reactions. *What is oxidation?*

Self-Assessment Question 3

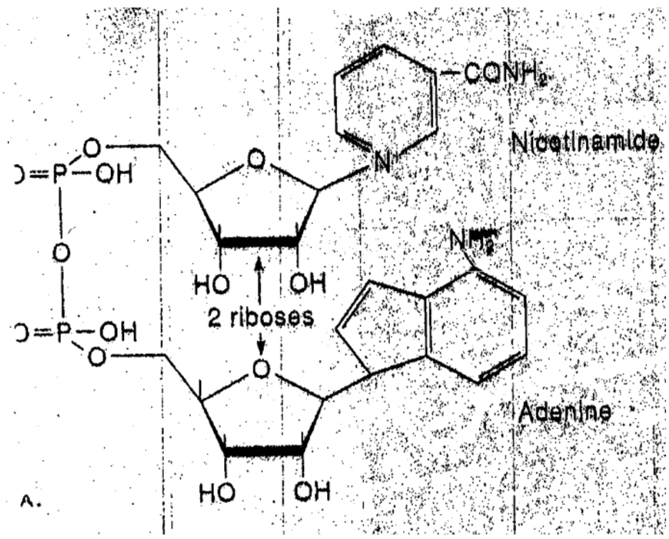
What is Anabolism?

2.3.4 Other Compounds Involved in Energy Metabolism

Several other compounds beside ATP affect energy transformations in plant cells . Cofactors are often ions, for example, Mg^{2+} is a cofactor required to transfer phosphate groups between molecules. Organic cofactors are called co-enzymes and usually carry protons or electrons. These are often nucleotides, unlike ATP, their energy content depends on their oxidation state, not on the presence or absence of a particular phosphate bond. Co-enzymes are vitamins that occur in all cells. Humans and other animals must obtain vitamins from food, plants produce their own vitamins.

a) NAD^+ Nicotinamide Adenine Dinucleotide

NAD^+ is similar to ATP in that it is made of adenine, ribose and phosphate groups.



However, the active part of NAD^+ is a nitrogen containing ring, called nicotinamide, which is a derivative of nicotinic acid (niacin, or vitamin B_3, one of the compounds added to products such as cornflakes to make them "vitamin fortified"). NAD^+ is reduced when it accepts two electron and a proton from the active site of an enzyme or from a substrate.

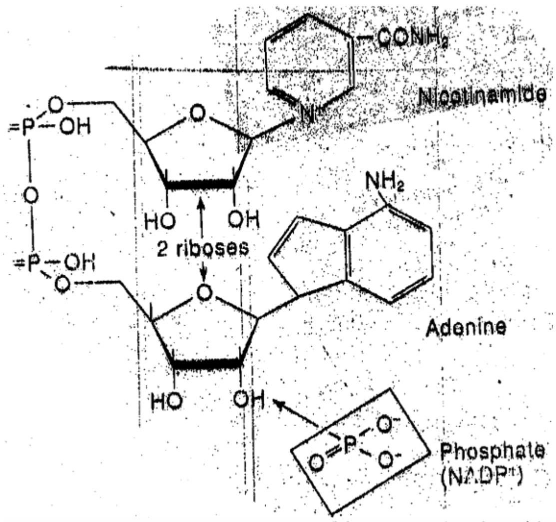
$$NAD^+ + 2h^+ 2^{e-} \longrightarrow NADH + H^+$$

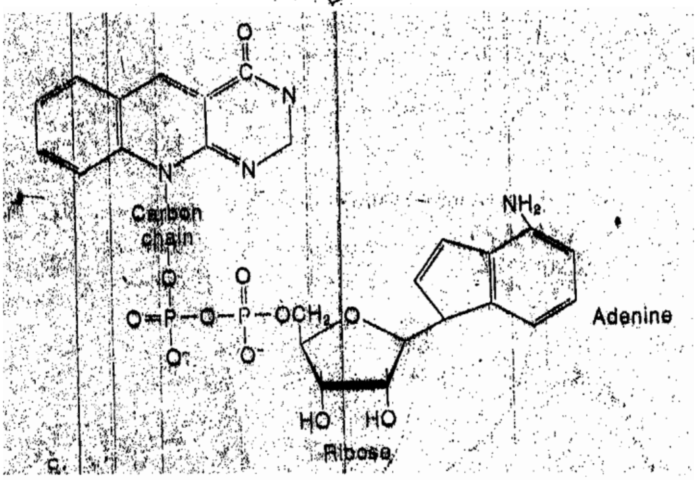
G = -52.6 Kcal mol^{-l}

NADH + H^+ is fully reduced and is therefore energy rich. It is used to make ATP land to reduce other compounds in cells.

b) NADP$^+$: Nicotinamide Adenine Dinucleotide Phosphate

NAD$^+$ has a structure similar to NAD$^+$ with an added phosphate group





NADPH supplies the hydrogen that reduces $C0_2$ to carbohydrate during photosynthesis. NADPH also supplies the hydrogen used to reduce nitrate to ammonia.

c) FAD: Flavin Adenine Dinucleotide

FAD is one of the coenzyme forms of rigo-flavin (vitamin B_2)

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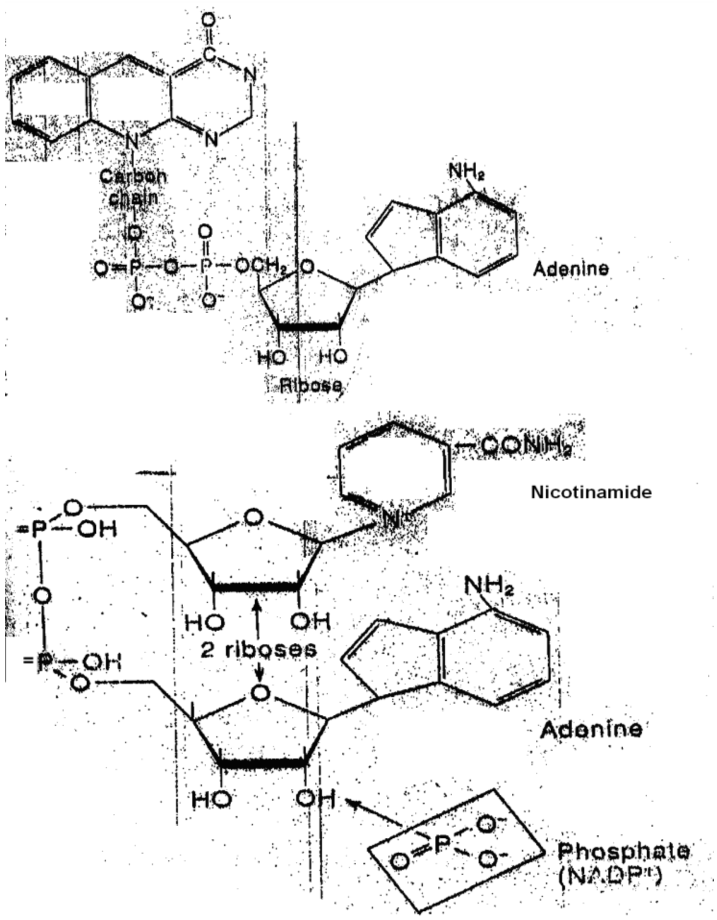

FAD, like NAD, carries two electrons, however 'FAD accepts both protons to become F ADH2 functions in cellular respiration.

d) Other Nucleoside Triphosphates.

Seven other nucleoside triphosphate function in cellular metabolism.
For example uridine triphosphate (UTP) is involved in making cell walls, guanosine triphosphate (GTP) is involved in protein synthesis, and cytidine triphosphate (CTP) is involved in membrane production.

Cytochromes like chlorophyll and haemoglobin, cytochromes are a group of metal-containing molecules that participate in metabolism by transferring electrons.

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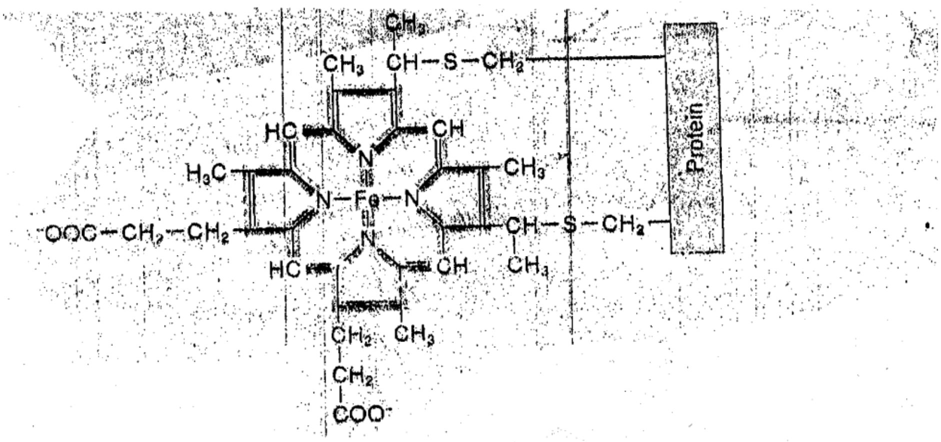

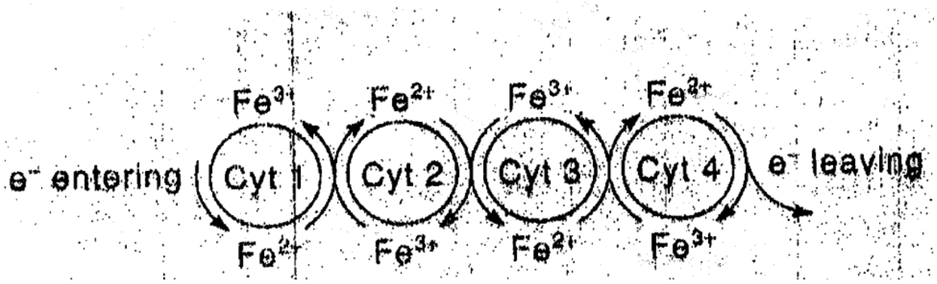

Structures of electron carriers in plant cell (a) NAD (nicotinamide adenine dinucleotide). The nicotinic acid ring is the part of NAD

List other compounds involved in energy metabolism.

Self-Assessment Questions

a) What is NAD?

***Answer**: NAD$^+$ Nicotinamide Adenine Dinucleotide*

b) *What is the function of NADPH?*

***Answer**: NADPH supplies the hydrogen that reduces $C0_2$ to carbohydrate during photosynthesis. NADPH also supplies the hydrogen used to reduce nitrate to ammonia*

2.4 SUMMARY

Metabolism is the sum of the vast array of energy and matter transformation in cells. It occurs in step-by-step sequences called metabolic pathways rearranges atoms into new compounds. Chemical reactions change the amount of free energy available for work. This change in free energy is the amount of energy available to form other bonds.

Many energy transformations in organisms involve chemical reactions called oxidations and reductions. Oxidation is the loss of electron from a molecule, reduction is the addition of electrons to a molecule. Oxidation and reduction reactions always occurs simultaneously.

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2.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1
Enthalpy is the total potential energy of the molecules
Answers to SAE 2
The amount of energy available to form other bonds is the **free energy** of the molecule and is represented by G
Answer to SAE 3
Anabolism is synthesis of more complex molecules. Anabolic reactions build up compound and require energy input.

UNIT 3 ENERGY METABOLISM II

3.1 INTRODUCTION

It was earlier learnt that metabolism of particular note was the two major types of reactions, one of which is the spontaneous or exergonic reactions. In the unit you are going to learn that the spontaneous reaction do not just happen. They still need a little "push" to take off. This little push is what is known as energy of activation and it must be present before any reaction can occur. You will also learn that heat provides energy of activation in some reactions, but in reactions occurring in plants heat will not do. Other things now take over and these other things are enzymes. The unit will end by introducing you to the two vital energy transformation activities in plants. These are respiration and photosynthesis.

3.2 INTENDED LEARNING OUTCOMES

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

-define enzyme
-explain the mechanism of enzyme action
-define energy of activation
-mention the two energy transformation activities in plants.

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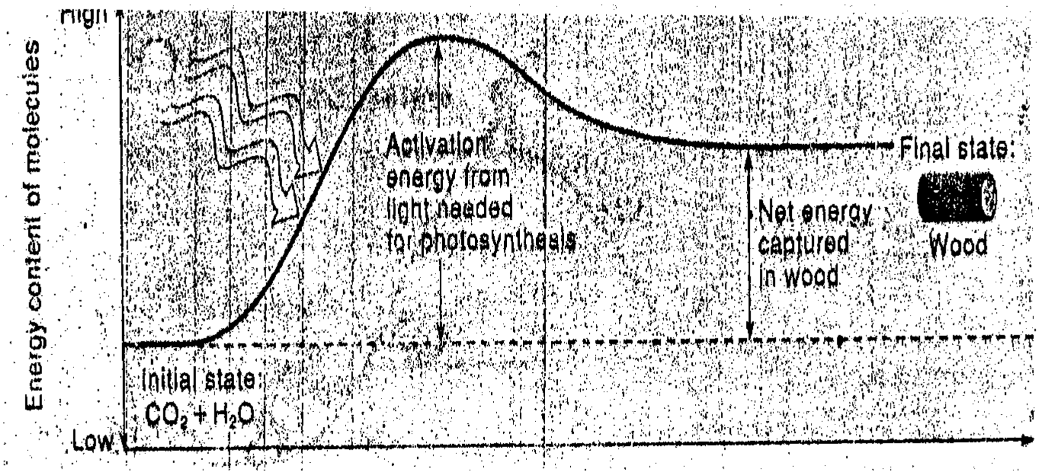
3.3 Main Contents

3.3.1 Enzymes and Energy

Exergonic reactions (e.g. the combustion of methane) are spontaneous. The truth is that these reactions, even though they are spontaneous require an energy input to start.

Many chemicals reactions are similar to the rock on top of the hill, they proceed only when activated by an energy input called energy of activation (E act). In photosynthesis, the energy of activation is provided by sunlight and the net gain of energy is trapped in products such a wood.



Although this wood contains much energy, the wood is too stable to bum spontaneously. That is, although it contains its potential energy, it will not burm unless it is first heated.

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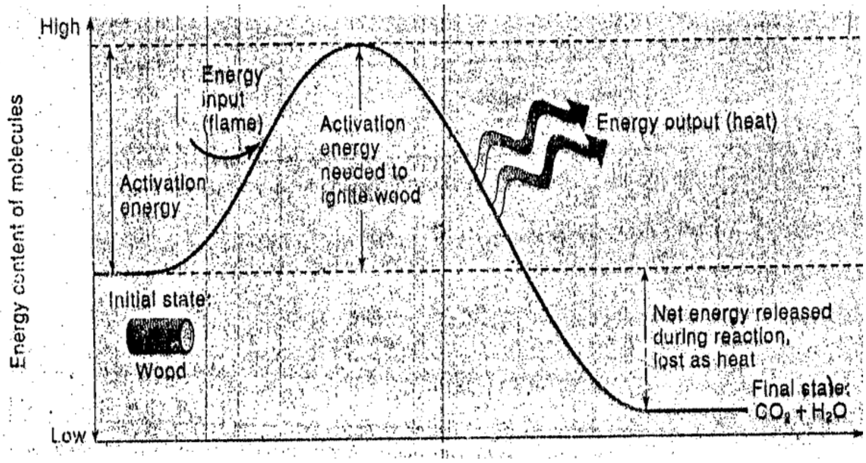
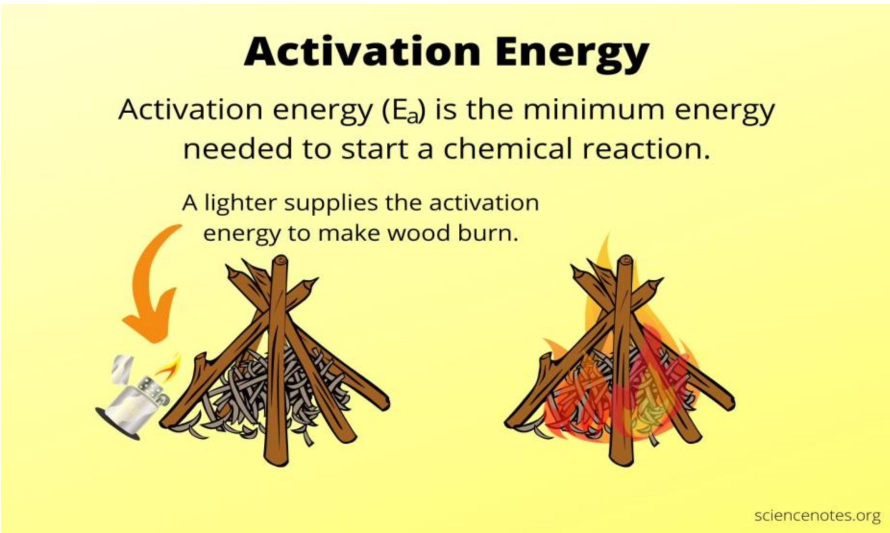


Energy of activation. (a) Plants use photosynthesis for make sugars that are, in turn, used to make products such as wood. The energy to do this that is, the activation energy for photosynthesis – comes from sunlight. (b) The energy captured in wood is released when wood burns. To start this reaction, activation energy must be provided to ignite the wood.

The heat necessary to ignite the wood is the energy of activation. Once ignited, the wood will continue to bum and release energy.



Although heat is generally an effective catalyst, it is usually not effective for cells. Indeed the heat needed to activate most metabolic reaction would kill most cells. Thus cells rely on biocatalyst called enzymes to start their reactions.

Enzymes are globular proteins that speed reactions by decreasing the energy of activation of reaction.

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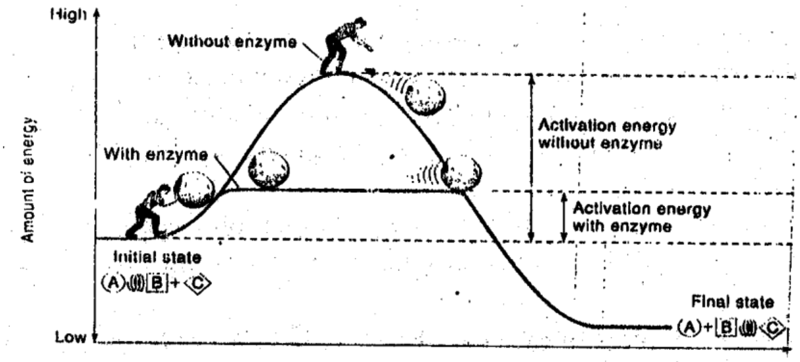
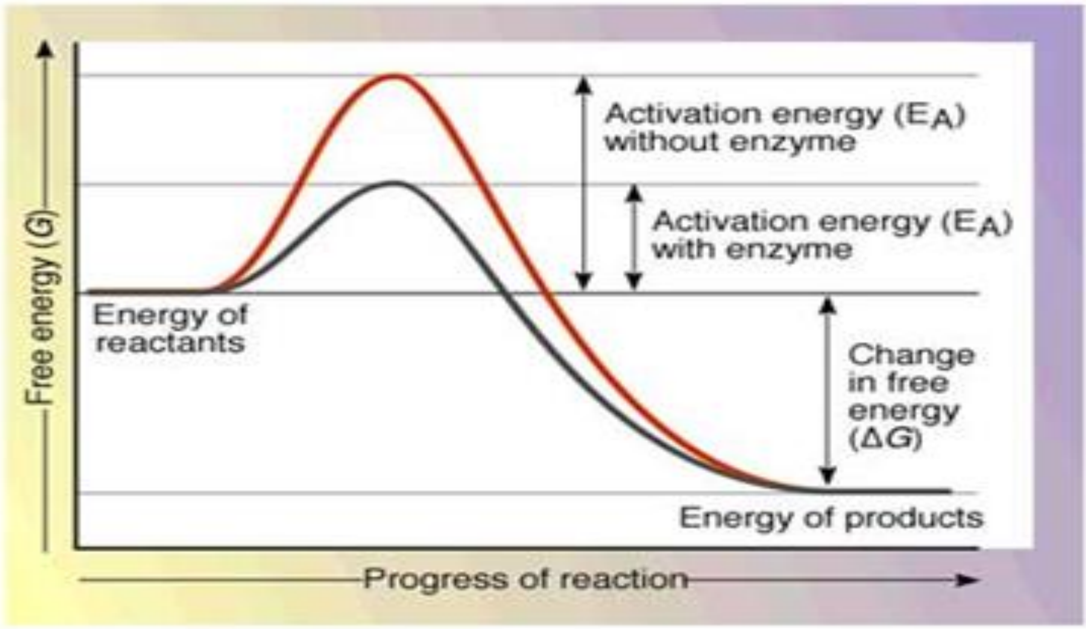


Enzymes speed the rate of chemical reaction by lowering the energy of activation of the reaction. From P. and H. Nature of Life 2nd ed. Copyright @ 1992 McCraw Ltd. Inc., New York



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This they do by binding the substrate so that the reaction can occur. For example, the energy of activation to degrade casein (a protein in milk) is

20,600kca1 mol^{-1} without the reactions enzyme, but only 12,600kca1 mol^{-1} in presence of enzyme. Decreasing the energy of activation greatly speeds the reaction. For example, consider the fornu1ation of H_2CO_3 from CO_2 and H_2O, a reaction involves in gas exchange and catalyzed by carbonic anhydrase.

$$CO_2 + H_2O \xrightarrow[\text{Carbonic anhydrase}]{} H_2CO_2$$

Without carbonic anhydrase, only about 1 molecule forms per second. This is far too slow to be useful to organisms. However, in the presence of carbonic andydrase, H_2CO_3 form at a rate of about 600,000 molecules

per second, an increase of more than 10^7. This emphasizes the

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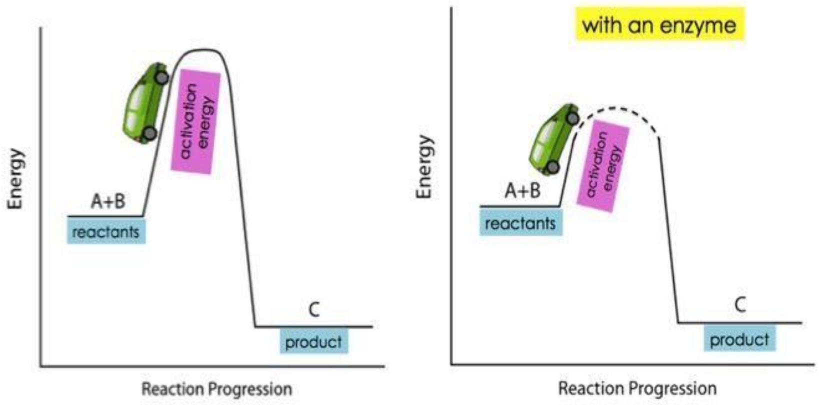
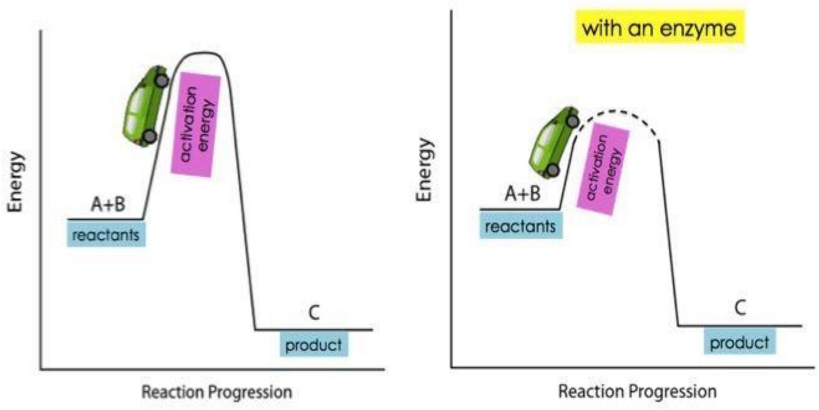
importance of enzymes, they are critical to life because they speed spontaneous reactions to a biological useful rate.





Higher temperatures typically increase enzymatic activity. Up to a point enzymatic activity typically - doubles for every increase of 10°C. However, beyond 60°C, entropy wins out as the protein is denatured and the reactions stops. Although a few organisms can tolerate high temperatures (e.g. some bacteria thrive at a temperature of 70°c), most enzymes work best at lower temperatures. For example, most enzymes in our bodies function best near body temperature (37^{O}C/98.6^{O}F). *What are enzymes?*

Self-Assessment Question 1

What is activating energy?

3.3.2 Regulating Metabolism

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Enzymes regulate energy transformations by controlling metabolic reactions. If metabolism is linked to a series of interconnected roads, then enzymes would function as traffic lights that control the flow of energy in cells. How do enzymes do this?

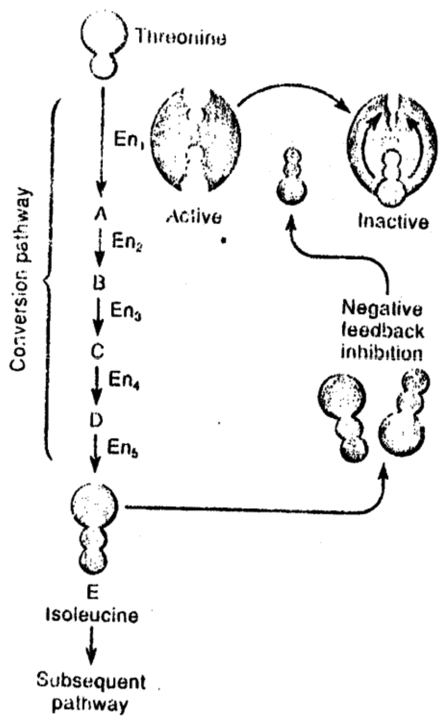
Some hypothesis were postulated as an explanation for enzymes action. We will look at them before going on to discuss how enzymes really work.

Hypothesis 1 - Enzymes decrease the G of a reaction. (G is the amount of energy available to form bonds, also known as free energy)
This hypothesis is not true. Enzymes do not change the G of a chemical reaction.

Hypothesis 2 - Enzymes heat cells to increase reaction rates. This second hypothesis is also not true. Enzymes do not heat cells. The heat required to speed most metabolic reactions to useful rates would kill the cells.

How, Then, Do Enzymes Regulate Metabolic?

The products of a pathway often affect the activity of the pathway. For example, plants use a five -step pathway to make isoleucine from threonine when isoleucine accumulates, it inhibits the first enzymes of the (1) pathway, thereby decreasing production of isoleucine until the current supply is used. This means of slowing a pathway when its products are not needed is called feed back inhibition and is common in plants and animals. Feedback inhibition balances supply and demand in cells, thereby averting unnecessary excesses and deficiencies.



Feedback inhibition. The metabolic conversion of threonine to isolecutine consists of five steps, each controlled by an enzyme (En, En; en,…). An accumulation of isolucine inhibits the first enzyme of the pathway (en,), thereby preventing an unnecessary building of isoleucine.

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One means of feedback inhibition involves **allosteric regulation** in which the product binds weakly to a receptor site on the enzyme that differs from the active site. Allosteric regulation is common in enzymes having more than one subunit. The binding of a molecule to an allosteric site **(usually located** where their subunits join) changes the enzymes activity, thereby affecting the cell's metabolism. For example, isoleucine allosterically inhibits the first enzyme of its synthetic (2) pathway, and thus prevents the unnecessary buildup of isoleucine.

Many enzymes are also inhibited by other molecules that compete for the enzyme's active site. These competitive inhibitors mimic the substrate and can be overcome by increasing the concentration of substrate (i.e. diluting the concentration of the inhibitor). Drugs such as sulfanilamide competitively inhibit enzymes.

Other compounds inhibit enzymes by binding to parts of the enzymes that are different from the active site, thereby preventing the enzymes from binding the substrate at its active site. Compounds that do this, such as lead and nerve gas, called non-competitive inhibitor. Although many non-competitive inhibitors bind reversibly to an enzyme, many do not. For example, penicillin is noncompetitive inhibitors. Although many competitive inhibitors that bind irreversibly to an enzyme (3) may not for example, penicillin in a non-competitive inhibitor that binds irreversibly to any enzyme that makes cell walls in bacteria. This blockage of cell wall synthesis ultimately kills the bacteria, thus accounting for the antibiotic effect or penicillin. *Do enzymes change the G of reaction?*

3.3.3 The Major Energy Transformations in Plants Photosynthesis and Respiration

The energy transformations that sustain life occur similarly in all organisms. The most important energy transformation in plants are photosynthesis and respiration.
The energy-requiring uphill stage of the process, is cellular respiration. During this process, light energy absorbed by chloroplasts is used to release oxygen and reduce carbondioxide **(a low energy compound) to carbohydrate (a high energy compound).**

Carbon dioxide + water + light

↓

Carbohydrate + oxygen

Carbohydrate fuels the activities of plants and other organisms.

The energy-releasing (i.e. exergonic), downhill stage of the process is cellular respiration. During this process, energy -rich molecules such as sugars are oxidized to carbon dioxide and water.

Carbohydrate + oxygen

↓

Carbon dioxide + water + energy

Respiration drives the cellular economy of most organisms.

a. The Flow of Energy

Examine the equations for photosynthesis and respiration again. Each process involves oxidation or reduction of carbon by the addition or removal of hydrogen. Photosynthesis removes hydrogen from water and adds it to carbon, thus, carbon is reduced during photosynthesis. Cellular respiration removes hydrogen from carbon and adds it to oxygen to form water, thus carbon is oxidized during respiration.
Now examine

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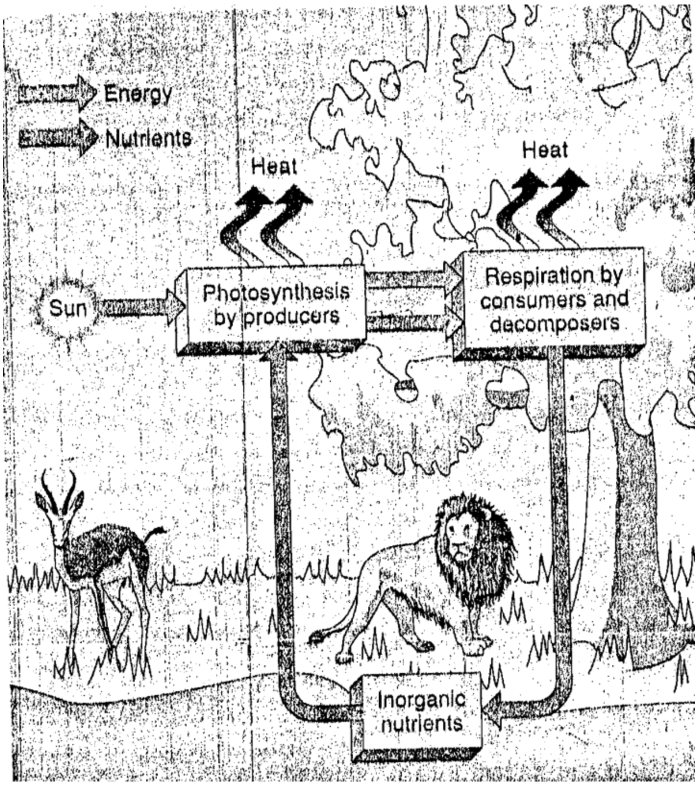

The major transformations of energy by organisms: photosynthesis and respiration. Photosynthesis provides food for virtually all organisms, on earth. Organisms use cellular respiration to extract energy from food. Although nutrients cycle in an ecosystem, energy flows through an ecosystem. All energy is eventually converted to heat.

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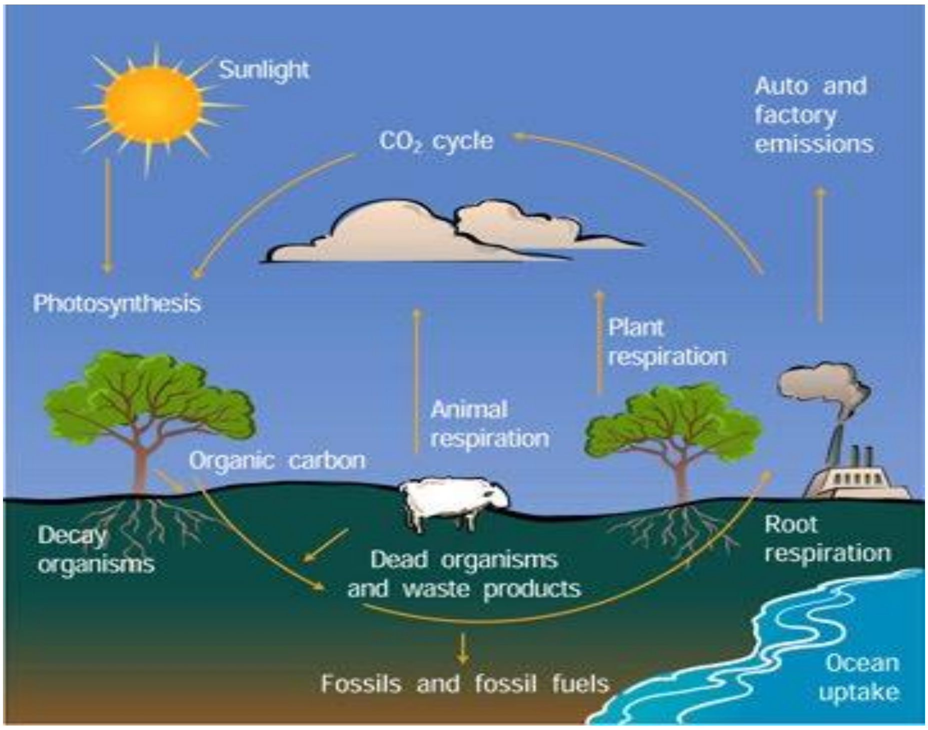
Although one equation is the reverse of the other, they proceed by different mechanisms which shows how photosynthesis and respiration are integrated in nature. This diagram illustrates an important concept about energy. Energy flows through a system and is ultimately converted to heat. For example, sunlight is the energy input that sustains life on earth. This is possible only because plants convert sunlight into chemicals energy (e.g. sugars). Animals stay alive by eating plants (or by eating other animals that ate plants) and using their stored energy to power their activities. These animals are then eaten by another animals to fuel their activities. Ultimately, the organisms die and are decomposed by bacteria and fungi.

In the process, the energy stored temporarily by organisms in this so- called "food chain" is released by heat. Organisms may temporarily store various amounts of the energy, but the net effect is that it flows through the system and is ultimately transformed to heat.



According to the second law of thermodynamics, all of the energy transformations at every step in the food chain are less than 100% efficient. Indeed, there is a 90% loss of usable energy at each stage. This has tremendous implications. For example, consider the corn crop, most of the energy that strikes the plants' leaves is reflected or converted to heat. Only a small amount of the energy is trapped by photosynthesis in sugars. When these sugars are converted to starch, more of the energy is lost. When this starch is feed to cattle, only about 10% of the usable energy is stored by the cow, the rest is lost as heat. By the time we eat beef made from the cow, another 90% of the useable energy has been lost. Thus, the amount of usable energy in the steak is only about 1 % of that contained in the starch of the corn.

100 Units	10 units of	1 unit of energy
energy in corn	energy in a herbivore	in a carnivore

The inefficiency of these transformations, as predicted by the second law of thermodynamics, makes this an inefficient process because much of the energy is converted to heat. By inserting an extra energy transformation between the corn plant and ourselves (i.e. the cow), we lose much of the usable energy.

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Also, although energy moves through the system in the one way flow (i.e. toward heat), nutrients are cycled. That is photosynthesis produces sugars and oxygen from carbon dioxide and water. Thus nutrients cycles in an ecosystem. *What are the major energy transformation activities in organisms?*

Self-Assessment Exercise 2

What is respiration?

Self-Assessment Questions

1) How are respiration and photosynthesis related?

Answer: Photosynthesis removes hydrogen from water and adds it to carbon, thus, carbon is reduced during photosynthesis. Cellular respiration removes hydrogen from carbon and adds it to oxygen to form water, thus carbon is oxidized during respiration.

2) What is the chemical equation for respiration?
Answer: $C_6H_{12}O_6 + O_6 = \quad CO_2 + H_2O + \text{Energy}$

3.4 Summary

Enzymes catalyze biological reactions by lowering the energy of activation of the reaction. Enzymes are critical to life because they speed spontaneous reactions to the biologically useful rate. Enzymes, are controlled by feedback inhibition, competitive inhibition, and non- competitive inhibition.
Photosynthesis and respiration ate the major energy transformed in organisms. Photosynthesis uses light energy to reduce carbon dioxide to carbohydrate, while respiration converts carbohydrate to ATP. Together,

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photosynthesis and respiration comprise a system by which energy flows through an ecosystem and is ultimately converted to heat. Unlike energy, nutrients cycle in an ecosystem.

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3.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1

Activation energy is the minimum energy required to start a chemical reaction

Answers to SAE 2

Respiration is the burning or oxidation of organic food substances to release energy in form of ATP

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UNIT 4 RESPIRATION

4.1 INTRODUCTION

In the unit, you will learn about the first two stages. The first stage is glycolysis in which glucose is split into smaller molecules in the cytosol. The second state, Krebs cycle completely metabolises the products of glycolysis.

4.2 INTENDED LEARNING OUTCOMES

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

-highlight the processes involed in getting energy (ATP) from different substrates in plants
-discuss the Respiratory quotient values of different plant conditions .

4.3 Main Contents

4.3.1 DEFINITION OF RESPIRATION

Respiration is a chemical reaction by which complex organic substances like carbohydrates, fats and proteins are broken down to release carbon dioxide, water and energy. The energy stored in carbohydrate molecules during photosynthesis releases CELLULAR OXIDATION of carbohydrates into CO_2 and H_2O. In respiration, the oxidation of various organic food substances like carbohydrates, fats, proteins takes place. Among these substrates, glucose is the commonest.

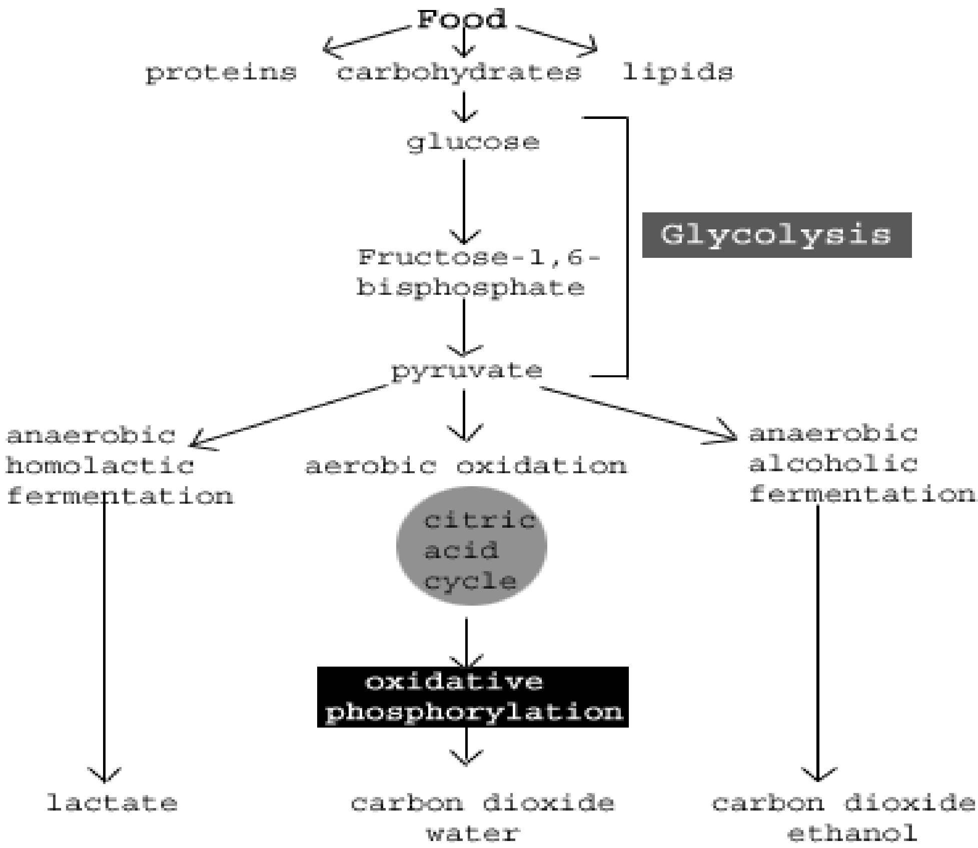
This equation summarizes the process

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{energy}$$

This oxidation is not a simple reaction and does not takes place in one step. Breakdown of the glucose involves many steps releasing energy (in form of ATP) and forming a number of carbon components in a very well organized sequence. Respiration is a catabolic process.

THE RESPIRATORY SUBSTRATE

Respiratory substrates may be carbohydrates, fats and certain conditions, proteins. Carbohydrate includes hexose sugars, glucose, fructose, sucrose and polysaccharides (starch cellulose). However, to utilize these complex carbohydrates, they are hydrolyzed by appropriate enzyme system to the hexose sugar level. If fats are the substrates, they are first hydrolyzed to fatty acids and glycerols by the action of enzyme lipase before they are subsequently oxidized in respiration. Proteins are utilized only when carbohydrates and fats are not available.



Source: **https://www.askiitians.com/biology/respiration-in-plants/**

Give simple equation for respiration

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + energy$$

Self-Assessment Exercise 1

What are Respiratory Substrates?

4.3.2 MECHANISM OF RESPIRATION

GLYCOLYSIS (EMBDEN-MEYERHOF PARANAS) PATHWAY

Glycolysis (sugar lysis/splitting) can take place in presence or absence of oxygen. Here 6-carbon compound is oxidized into two molecules of three carbon compound, the pyruvate (a triose) through a series of 10 enzymatic reactions which occurs in cytosol. The first five reactions constitute the preparatory phase in which 2 molecules of ATP are consumed and glucose is converted into two molecules of glyceraldehyde-3-phosphate. The next five reactions constitutes the pay-off place of glycolysis in which two molecules of glyceraldehyde-3-phosphate are converted into two molecules of pyruvate with concomitant production of 2 NADH and four ATP molecules.

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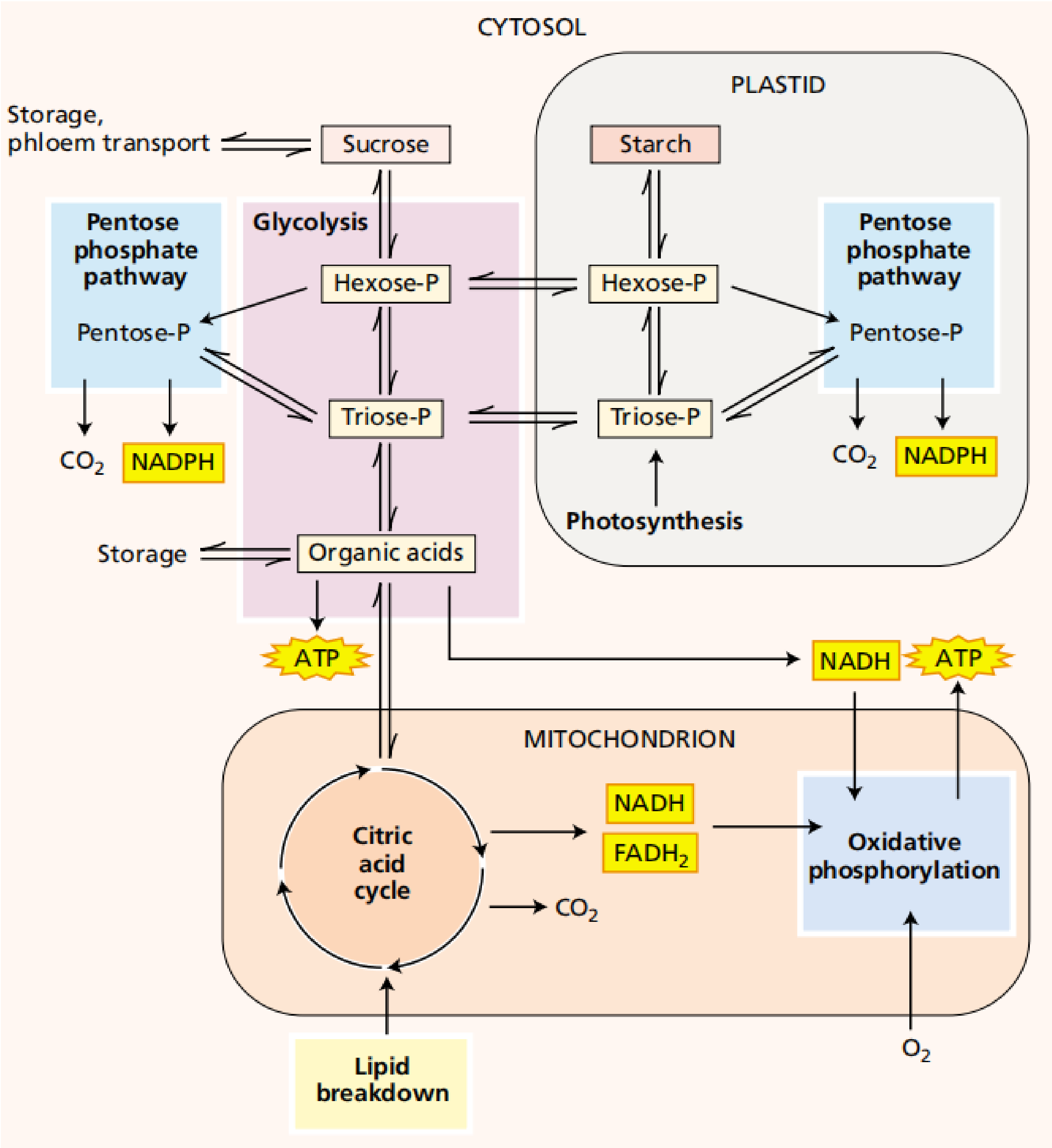

Source: Taiz and Zeiger, (2002)

Various steps of glycolysis are:

1) ANAEROBIC RESPIRATION (FERMENTATION)

In the absence of molecular oxygen, pyruvate undergoes anaerobic respiration of fermentation.
There are 2 types

a. Alcoholic fermentation

The pyruvate is first decarboxylated to acetaldehyde in the presence of the enzymes pyruvate decarboxylase.

$$2CH_3CO.COOH \xrightarrow[\text{decarboxylase}]{\text{pyruvate}} 2CH_3CHO + 2CO_2$$

Acetaldehyde is later reduced to ethyl alcohol by the enzyme alcohol dehydrogenase. Also, coenzyme NADP is oxidized.

$$\underset{\text{Acetaldehyde}}{2CH_3CHO} + 2NADP + H^+ \longrightarrow \underset{\text{ethyl alcohol}}{2CH_3CH_2OH} + 2NAD^+$$

The overall equation for anaerobic respiration involving alcoholic fermentation is as follows:

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$C_6H_{12}O_6 \longrightarrow 2CH_3CH_2OH + 2CO_2$

Glucose Alcohol

b. Lactic acid fermentation

Here, the pyruvate is converted into lactate by the enzymatic lactase – dehydrogenase coenzyme NADH is oxidized.

$2CH_3CO.COOH + 2NADH + 2H^+ \longrightarrow 2CH_3CHOH.COOH + 2NAD^+$

Pyruvate

The overall equation for anaerobic respiration involving lactic acid fermentation is as follows

$C_6H_{12}O_6 \longrightarrow 2CH_3CHOH.COOH$

Glucose lactate

There is net gain of only 2ATP molecules during anaerobic respiration and most of the energy contained in glucose molecules is wasted as heat. *What is glycolysis?*

2) AEROBIC RESPIRATION- KREB'S CYCLE (TCA CYCLE)

Aerobic respiration takes place in the presence of oxygen and the pyruvate produced in the cytosol during glycolysis enters into mitochondrion for further oxidation though Krebs' cycle.

The cycle is named Krebs after the inventor and also called TCA or CAC cycle because citric acid is an early intermediate of this cycle which contains three carboxylic groups.

All necessary enzymes for this cycle are found in the matrix. Various reactions of krebs' cycle are shown below:

The following should be noted form the cycle.

a) All the reactions of the kreb's cycle are reversible (except few).
b) In the cycle, at first, the carbon atom 3 or 4, then 2 or 5 and lastly carbon number 1 or 6 of the glucose molecules are released in the form of CO_2 molecules.
c) Starting from 2 molecules of pyruvate produced in glycolysis per hexose sugar molecule oxidized, the overall TCA cycle is:

   $2(\text{pyruvate}) + 4NAD^+ + FAD + ADP \text{ (or GDP)} + Pi + 2H_2O$

   $\downarrow$

   $2(3CO_2 + 4NADP + 4H^+ + FADH_2 + ATP \text{ (or GTP)}$
d) Much of the free energy released during oxidation of pyruvate is stored in the form of reduced NADP or $FADH_2$ molecules. In terminal oxidation of these reduced coenzymes through mitochondrial electron transport system, each NADH molecule will form 3 ATPs while each $FADH_2$ molecule will yield 2ATP molecules.

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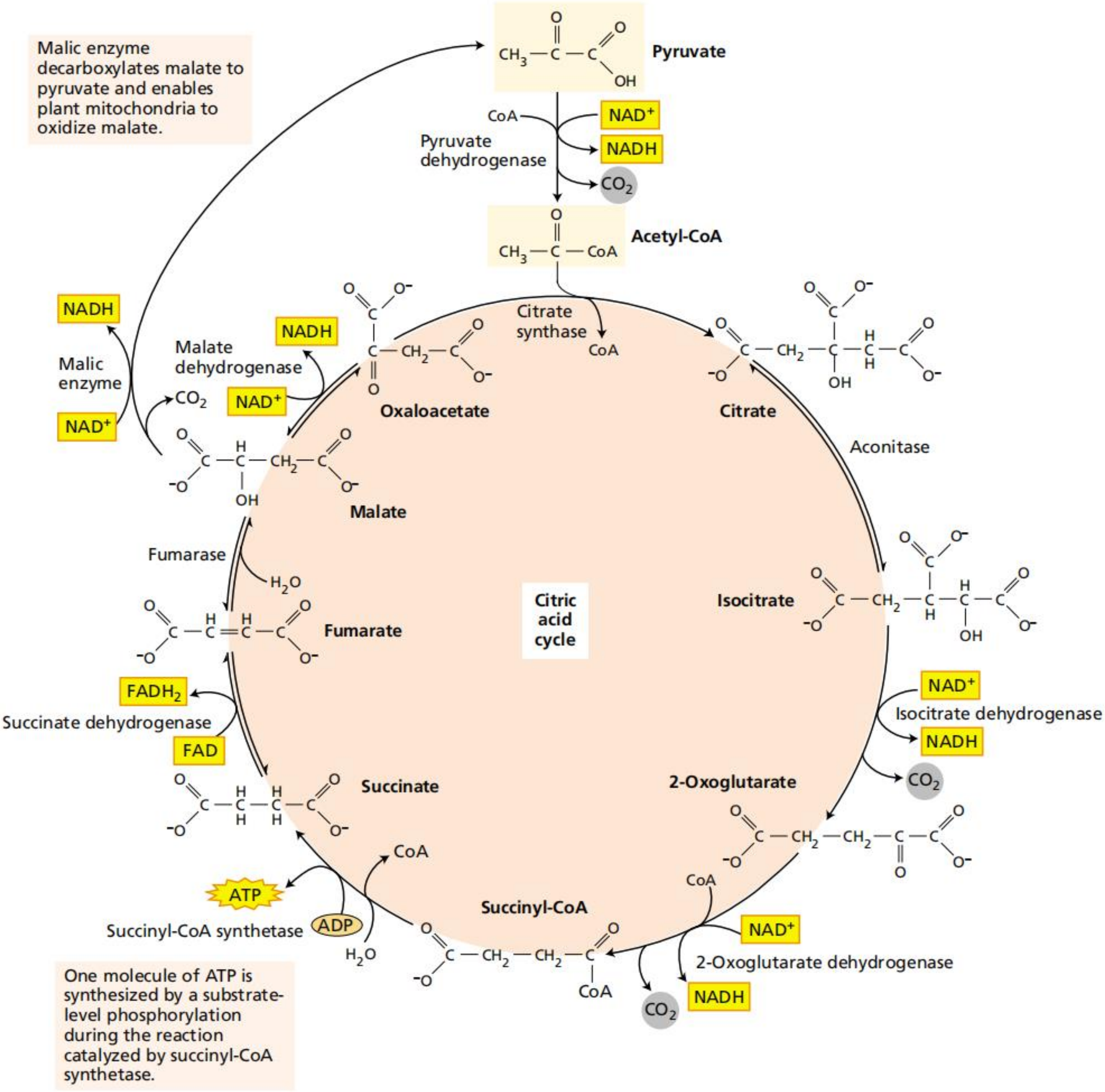

Source:Taiz and Zeiger (2002)

Why is Kreb's cycle also called CAC?

Self-Assessment Exercise 2

What two types of fermentation are in glycolysis?

4.3.3 ELECTRON TRANSPORT SYSTEM

The last step in aerobic respiration is the oxidation of reduced coenzymes produced in glycolysis and krebs' cycle by molecular oxygen through FAD, ubiquimone, cytochrome b, cytochrome c, cytochrome a and cytochrome a_3.

Two H-atoms or electrons from the reduced coenzyme (NADH or NADPH) travel through FAD and the cytochromes each with a more positive oxidation-reduction potential and ultimately combined with ½ O_2 molecules to produce one molecule of H_2O. This is refers to as TERMINAL OXIDATION. The terminal oxidation of each reduced coenzyme requires ½ O_2 molecule and 2H atoms to produce one H_2O molecule. Except for flavoproteins an ubiquimone which are hydrogen carriers, the other

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components of the electron transport chain (cytochromes) are only electron carriers, that is they cannot give or take protons (H^+).

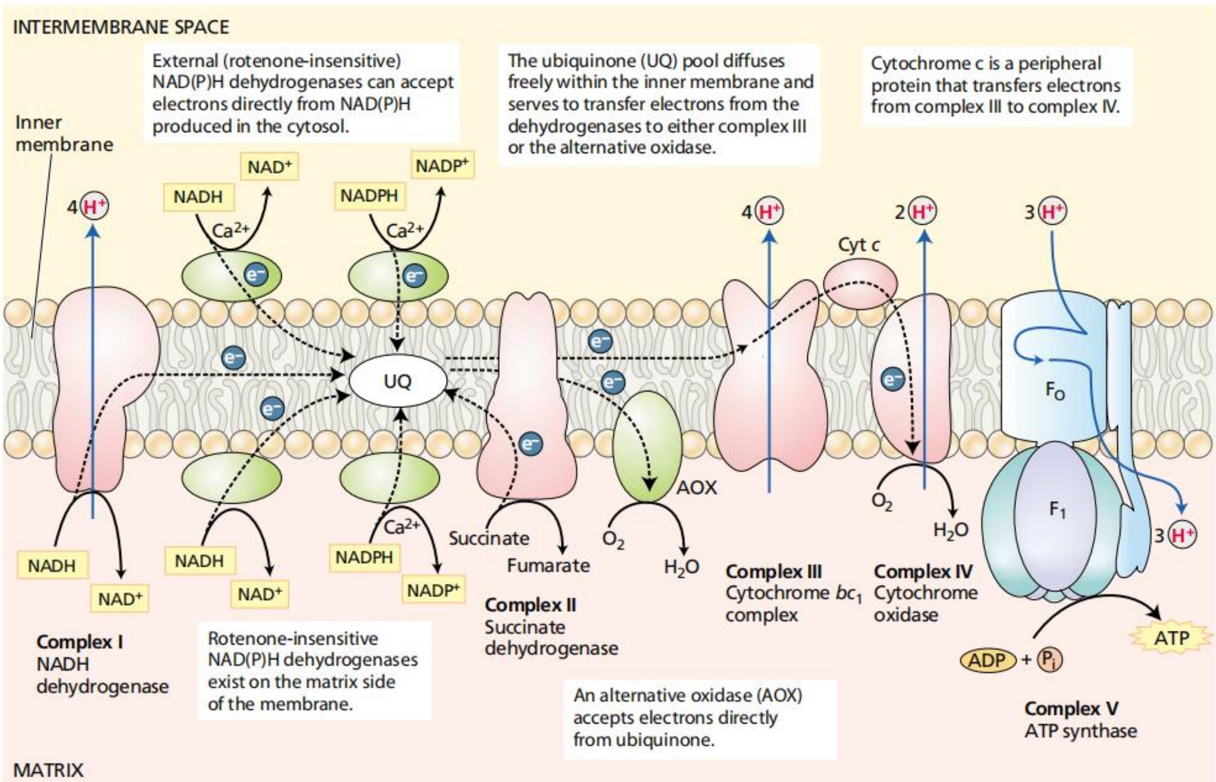
During electron transport, FAD and iron atom of different cytochromes get successfully reduced (FeH) and oxidized (Fe^{+++}) and enough energy is released at some places which is utilized in the phosphorylation of ADP molecules (in the presence of inorganic phosphate) to generate energy rich ATP molecules.

Because this oxidation accompanies phosphorylation, it is called oxidation phosphorylation. It takes place o phosphorylation complexes situated on cristae in the mitochondria. 2,4,-Dinitropherol is uncoupling agent of oxidative phosphorylation and electron transport chain.

One molecules of ATP (which contains 7.6k Cal. energy) is synthesis of each place when electrons are transferred from

i. Reduced NADH or NADPH to FAD
ii. Reduced cytochrome b to cytochrome c
iii. Reduced cytochrome a to cytochrome a_3

The oxidation of one mole of reduced NADH or NADPH will result in the formation of 3 ATP molecules with oxidation of $FADH_3$ will lead to the synthesis of 2 ATP molecules.
In summary, complete oxidation of a glucose molecule (hexose sugar) in aerobic respiration results in the net gain of 36 ATP in most eukaryotes.



Source: Taiz and Zeiger (2002)
What are cytochromes?

4.3.4 SIGNIFICANCE OF GLYCOLYSIS AND KREBS' CYCLE

Glycolysis and krebs' cycle are vital in the metabolism of plants in the following ways:

i. They provide energy in the form of ATP molecules through oxidative phosphorylation.
ii. They provide intermediate carbon components which are precursors for wide variety of metabolic pathways in plants.
iii. Krebs' cycle is primarily a catabolic reaction. But when it provides precursors for biosynthetic pathways. It provides an anabolic pathway too. Krebs' cycle is thus called an amphibolic pathway.

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4.3.5 FACTORS AFFECTING RESPIRATION

A. INTERNAL FACTORS

1. Protoplasmic factors- The amount of protoplasm in the cell and its state of activity influence rate of respiration. The rate of respiration is higher in young meristematic cells than older mature cells, because young cell divides actively and require more energy. Rate of respiration is undoubtedly affected by the terminal structural relationships of various cell organelles and occurrence and distribution of enzyme systems from one type of cell to another. Here, the number of mitochondria in a cell is obviously an important factor affecting rate of respiration.
2. Concentration of respiratory substrate- Increased concentration of respirable food material brings about an increase in rate of respiration. During starvation (e.g etiolated leaf), the rate of respiration slows down considerably.
   When there is ample availability of respirable food material in the cells, the respiration is called FLOATING RESPIRATION. But under acute starvation, where lipids, proteins are oxidized, the respiration is called PROTOPLASMIC RESPIRATION.

B. EXTERNAL FACTORS

1. Temperature- optimum temperature for respiration is 30^0C (minimum is 0^0C at maximum 45^0C). at low temperature, the respiratory enzymes becomes inactives and rate of respiration falls. An increase in temperature from 0^0C to 30^0C brings about an increase rate of respiration. At very high temperature, respiration slows down may even stopped due to denaturation of respiratory enzymes.
2. Oxygen- anaerobic respiration takes place in complete absence of oxygen and the organism might die if this continues for a long time.
   If amount of $O_2$is available, the rate of aerobic respiration will be optimum where anaerobic respiration stops. This is called EXTINCTION POINT.
3. Carbon(IV)oxide- higher concentration of CO_2 in the atmosphere especially in the poorly aerated soil, has retarding effect on the rate of the respiration.
4. Inorganic salts- the rate of respiration increases in presence of salt solutions (salt respiration).
5. Water- rate of respiration decreases with decreased amount of water due to inactivity of enzymes in dehydrated cells.
6. Light- light is necessary for photosynthesis which produces organic food material for plants. This organic food is the substrate for respiration.
7. Injury- wounding of plant organs stimulates respiration in that organ. Injured cells becomes meristematic to form new cells to heal up the wound, hence, they require more energy which is supplied by increased rate of respiration. After healing, the rate of respiration becomes normal.
8. Mechanical effects- mechanical stimulation of respiration by rubbing or bending leaf blade increases respiration rate in plants.
9. Chemical components (respiratory inhibitors) - certain chemicals presence even in low concentration acts as inhibitors of respiratory enzymes and thus retard respiration rate. Examples of such chemicals are cyanides, azides, CO, fluorides, malonates and iotoacetate.
   What is protoplasmic respiration?

Self-*Assessment Exercise 3*

What are the two internal factors affecting Respiration?

4.3.6 LIGHT COMPENSATION POINT

In plants as well as many living organisms, respiration occurs continuously for 24hours while photosynthesis occurs only during the day when light is available. Some organic food produced during photosynthesis is oxidized during respiration while the rest is stored by the plants, it can then be concluded that is faster than respiration.

The rate of photosynthesis is higher at noon when light intensity is higher and is lower during morning or evening when light intensity is low. Therefore, there will be a time either in the morning or evening when the rate of photosynthesis will be as low as to equal the rate of respiration. This is called LIGHT COMPENSATION POINT.

4.3.7 **RESPIRATORY QUOTIENT**

The ratio of the volume of CO_2 released to the volume of O_2 taken in respiration is called RESPIRSTORY QUOTIENT and is denoted as R.Q

R.Q = $\frac{\text{volume of CO2}}{\text{volume of O2}}$

VALUE OF R.Q

The value of R.Q depends upon the nature of the respiratory substrate (organic food) and its oxidation.

1. When carbohydrates such as hexose sugars are oxidized in respiration, the value of R.Q is 1 or unity because, volume of CO_2 evolves/releases equals to the volume of O_2 absorbed.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

$$R.Q = \frac{\text{Volume of CO2}}{\text{volume of O2}} = \frac{6}{6} = 1 \text{ or unity}$$

2. When fats are the respiratory substrates, the value of R.Q becomes less than one because the fats are poorer in oxygen in comparism to carbon and it requires more o_2 for the oxidation.

$$2C_{51}H_{98}O_6 + 145O_2 \longrightarrow 102CO_2 + 98H_2O$$

$$R.Q = \frac{\text{Volume of CO2}}{\text{volume of O2}} = \frac{102}{145} = 0.7$$

The values of R.Q are also less than one, when proteins are the respiratory substrate.

3. When organic acids are oxidized in respiration, the R.Q value becomes more than one, because organic acids are rich in O_2 and require less O_2 for their oxidation,

$$C_4H_6O_5 + 3O_2 \longrightarrow 4CO_2 + 3H_20$$

$$R.Q = \frac{\text{Volume of CO2}}{\text{volume of O2}} = \frac{4}{3} = 1.3$$

4. Partial oxidation of carbohydrates- in some succulent plants like *Opunta*, *bryophylum*, carbohydrates are incompletely oxidized to organic acid in dark with evolution of CO_2, the R.Q value remains zero (0).

$$2C_6H_{12}0_6 + 3O_2 \longrightarrow 3C_4H_6O_5 + 3H_2O$$

$$R.Q = \frac{\text{Volume of CO2}}{\text{volume of O2}} = \frac{0}{3} = 0$$

5. During anaerobic respiration, due to absence of O_2, the value of R.Q is always very high rather infinite.

$$C_6H_{12}O_6 \longrightarrow 2CO_2 + 2C_2H_5OH$$

$$R.Q = \frac{\text{Volume of CO2}}{\text{volume of O2}} = \frac{2}{0} = \text{(infinite)}$$

By determining the respiratory quotient, the nature of respiratory substrate can be known. For example, if the value of R.Q is one, it indicates that carbohydrates are being oxidized during respiration. Also, if R.Q value is less than one, it will be concluded that's organic matter like fats constitute the respiratory substrate. *What is RQ value of hexose sugar?*

Self-Assessment Questions:

State three vital roles of Krebs' cycle and Glycolysis

Answer: (i) They provide energy in the form of ATP molecules through oxidative phosphorylation. (ii) They provide intermediate carbon components which are precursors for wide variety of metabolic pathways in plants. (iii) they are both catalytic and anabolic pathways.

4.4 **Summary**

Respiration is the burning or combustion of organic food substances to produce energy. The process involves three stages, namely: Glycolysis, Krebs Cycle and Electron transfer system.

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4.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1

Respiratory substrates may be carbohydrates, fats and certain conditions, proteins. Carbohydrate includes hexose sugars, glucose, fructose, sucrose and polysaccharides (starch cellulose). However, to utilize these complex carbohydrates, they are hydrolyzed by appropriate enzyme system to the hexose sugar level

Answers to SAE 2

Alcoholic fermentation and lactic acid fermentation

Answer to SAE 3

Internal factors affecting Respiration are a) Protoplasmic factor and (b) concentration of respiratory substrate

Glossary

OP= Osmotic Pressure
TP= Turgor Pressure
WP = Water Pressure
C=Calorie
KWH= Kiliwatt hour
HP= Horse Power
RQ= Respiratory Quotient
NAD= Nicotinamide Adenine dinucleotide
GTP= Guanosine Triphoshate
FAD=Flavin Adenine dinucleotide

End of Module Questions

1. The value of R.Q is always very high rather infinite during anaerobic respiration (**True or False)**
2. All the reactions of the kreb's cycle are reversible (except few). **(True or False)**
3. According to the second law of thermodynamics, all of the energy transformations at every step in the food chain are less than 100% efficient (**True or False)**
4. Enzymes regulate energy transformations by controlling metabolic reactions (True or False)
5. FAD supplies the hydrogen that reduces $C0_2$ to carbohydrate during photosynthesis (**True/ False)**

MODULE 3

UNIT 1 MINERAL NUTRITION IN PLANT

Unit Structure

1.1 INTRODUCTION

Chemical of the dry matter of plants showed that plants contains about forty different elements. Some are indispensable/vital for normal growth and development of the plants and are called Essential elements. Others are elements that are called non-essential elements.

1.2 INTENDED LEARNING OUTCOMES (ILOs)

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

-discuss the mineral requirements of plants.
-explain their deficiency symptoms.

1.3 Main Contents

1.3.1 Mineral Nutrition in Plant.

Unlike **heterotrophic** organisms, which depend for their existence on energy-rich organic molecules previously synthesized by other organisms, plants must survive in an entirely inorganic environment. As **autotrophic** organisms, plants must take in carbon dioxide from the atmosphere and water and mineral nutrients from the soil, and from these simple, inorganic components, make all of the complex molecules of a living organism. Since plants stand at the bottom of the food chain, mineral nutrients assimilated by plants eventually find their way into the matter that makes up all animals, including humans.

Plant nutrition is traditionally treated as two separate topics: organic nutrition and inorganic nutrition. *Organic nutrition* focuses on the production of carbon compounds, specifically the incorporation of carbon, hydrogen, and oxygen via photosynthesis, while *inorganic nutrition* is concerned primarily with the acquisition of mineral elements from the soil.

Mineral nutrients are elements acquired primarily in the form of inorganic ions from the soil. Although mineral nutrients continually cycle through all organisms, they enter the biosphere predominantly through the

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root systems of plants, so in a sense plants act as the "miners" of Earth's crust. The large surface area of roots and their ability to absorb inorganic ions at low concentrations from the soil solution make mineral absorption by plants a very effective process. After being absorbed by the roots, the mineral elements are translocated to the various parts of the plant, where they are utilized in numerous biological functions. Other organisms, such as mycorrhizal fungi and nitrogen-fixing bacteria, often participate with mots in the acquisition of nutrients. The study of how plants obtain and use mineral nutrients is called **Mineral Nutrition**.
Plant nutrition is divided into what two topics?

Self-Assessment Exercise 1

Differentiate between organic and inorganic nutrition

1.3.2 Mineral nutrition

The chemical compounds required by an organism are termed as nutrients. Nutrition may be defined as the supply and absorption of chemical compounds needed for plant growth and metabolism. For plant growth and metabolism, 17 elements are essential. They are C, H, O, N, P, K, Ca, S, Mg, Fe, Mn, Zn, B, Cu, Mo, Cl and Ni. These essential elements are classified into two groups

1. Major elements (macro nutrients)
2. Minor elements (Micro nutrients) (Trace elements)

1.3.2.1 Major elements:
The essential elements which are required by the plants in comparatively large amounts are called as major elements or macro nutrients. According to another definition minerals found in >1000 ppm concentration are macronutrients. They are C, H, O, N, P, K, Ca, S, Mg.
1.3.2.2 Minor elements:
The essential elements which are required in very small amounts or traces by the plants are called as minor elements or micronutrients or trace elements. According to another definition minerals found in <100 ppm concentration are micronutrients. They are Fe, Zn, Mn, B, Cu and Mo. Si is now transferred from list of beneficial elements to essential elements.
Essential nutrients
Only certain elements have been determined to be essential for plants. An **essential element** is defined as:
• one that is intrinsic component in the structure or metabolism,

• whose absence causes several abnormalities in plant growth, development, or reproduction.

If plants are given these essential elements, as well as water and energy from sunlight, they can synthesize all the compounds they need for normal growth. Hydrogen, carbon, and oxygen are not considered mineral nutrients because they are obtained primarily from water or carbon dioxide.
Essential mineral elements are usually classified as *macronutrients or micronutrients* according to their relative concentrations in plant tissue. In some cases the differences in tissue content between macronutrients and micronutrients are not as great as indicated in the literature. For example, some plant tissues, such as leaf mesophyll, have almost as much iron or manganese as they do sulfur or magnesium. Often elements are present in concentrations greater than the plant's minimum requirements.
The essential elements can be classified instead according to their biochemical role and physiological function. Plant nutrients have been divided into four basic groups:
1. Nitrogen and sulfur constitute the first group of essential elements. Plants assimilate these nutrients via biochemical reactions involving oxidation and reduction to form covalent bonds with carbon and create organic compounds.

2. The second group is important in energy storage reactions or in maintaining structural integrity. Elements in this group are often present in plant tissues as phosphate, borate, and silicate esters in which the elemental group is covalently bound to an organic molecule (e.g., sugar phosphate).

3. The third group is present in plant tissue as either free ions dissolved in the plant water or ions electrostatically bound to substances such as the pectic acids present in the plant cell wall. Elements in this group have important roles as enzyme cofactors and in the regulation of osmotic potentials.

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4. The fourth group, comprising metals such as iron, has important roles in reactions involving electron transfer.
Some naturally occurring elements, such as aluminum, selenium, and cobalt, that are not essential elements can also accumulate in plant tissues. Aluminum, for example, is not considered to be an essential element, but plants commonly contain from 0.1 to 500 ppm aluminum, and addition of low levels of aluminum to a nutrient solution may stimulate plant growth. Many species in the genera *Astragalus, Xylorhiza, and Stanleya* accumulate selenium, although plants have not been shown to have a specific requirement for this element. Cobalt is part of cobalamin (vitamin B12 and its derivatives), a component of several enzymes in nitrogen-fixing microorganisms. Crop plants normally contain only relatively small amounts of such nonessential elements. *What are minor elements?*

1.3.3 Classification of plant mineral nutrients according to biochemical function
1.5.1 Mineral nutrient Functions
Group 1 Nutrients that are part of carbon compounds
N Constituent of amino acids, amides, proteins, nucleic acids, nucleotides, coenzymes, hexosamines, etc.
S Component of cysteine, cystine, methionine. Constituent of lipoic acid, coenzyme A, thiamine pyrophosphate, glutathione and biotin.

Group 2 Nutrients that are important in energy storage or structural integrity
P: Component of sugar phosphates, nucleic acids, nucleotides, coenzymes, phospholipids, phytic acid, etc. Has a key role in reactions that involve ATP.
Si: Deposited as amorphous silica in cell walls. Si contributes to cell wall mechanical properties, including rigidity and elasticity.
B: Complexes with mannitol, mannan, polymannuronic acid, and other constituents of cell walls. Involved in cell elongation and nucleic acid metabolism.

Group 3 Nutrients that remain in ionic form
K: Required as a cofactor for more than 40 enzymes. Principal cation in establishing cell turgor and maintaining cell electroneutrality.
Ca: Constituent of the middle lamella of cell walls. Required as a cofactor by some enzymes involved in the hydrolysis of ATP and phospholipids. Ca acts as a second messenger in metabolic regulation.
Mg: Required by many enzymes involved in phosphate transfer. Constituent of the chlorophyll molecule.
Cl: Required for the photosynthetic reactions involved in O2 evolution.
Zn: Constituent of alcohol dehydrogenase, glutamic dehydrogenase, carbonic anhydrase, etc.
Na: Involved with the regeneration of phospho*enol*pyruvate in C4 and CAM plants. Na substitutes for potassium in some functions.

Group 4 Nutrients that are involved in redox reactions
Fe: Constituent of cytochromes and nonheme iron proteins involved in photosynthesis, N2 fixation, and respiration.
Mn: Required for activity of some dehydrogenases, decarboxylases, kinases, oxidases, and peroxidases. Involved with other cation-activated enzymes and photosynthetic O_2 evolution.
Cu: Component of ascorbic acid oxidase, tyrosinase, monoamine oxidase, uricase, cytochrome oxidase, phenolase, laccase, and plastocyanin.
Ni: Constituent of urease. In N2-fixing bacteria, constituent of hydrogenases.
Mo: Constituent of nitrogenase, nitrate reductase, and xanthine dehydrogenase.

1.3.4 Mineral deficiencies disrupt plant metabolism and function
An inadequate supply of an essential element results in a nutritional disorder manifested by characteristic deficiency symptoms. In hydroponic culture, withholding of an essential element can be readily correlated with a given set of symptoms. For example, a particular deficiency might elicit a specific pattern of leaf discoloration. Diagnosis of soil-grown plants can be more complex for the following reasons:
• Deficiencies of several elements may occur simultaneously in different plant tissues.
• Deficiencies or excessive amounts of one element may induce deficiencies or excessive accumulations of another element.
• Some virus-induced plant diseases may produce symptoms similar to those of nutrient deficiencies.
Nutrient deficiency symptoms in a plant are the expression of metabolic disorders resulting from the insufficient supply of an essential element. These disorders are related to the roles played by essential elements in normal plant metabolism and function.

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Although each essential element participates in many different metabolic reactions, some general statements about the functions of essential elements in plant metabolism are possible. In general, the essential elements function in plant structure, metabolism, and cellular osmoregulation. More specific roles may be related to the ability of divalent cations such as Ca^{2+} or Mg^{2+} to modify
the permeability of plant membranes. In addition, research continues to reveal specific roles for these elements in plant metabolism; for example, calcium ions act as a signal to regulate key enzymes in the cytosol. Thus, most essential elements have multiple roles in plant metabolism.

An important clue in relating an acute deficiency symptom to a particular essential element is the extent to which an element can be recycled from older to younger leaves. Some elements, such as nitrogen, phosphorus, and potassium, can readily move from leaf to leaf; others, such as boron, iron, and calcium, are relatively immobile in most plant species. If an essential element is mobile, deficiency symptoms tend to appear first in older leaves. Conversely, deficiencies of immobile essential elements become evident first in younger leaves. Although the precise mechanisms of nutrient mobilization are not well understood, plant hormones such as cytokinins appear to be involved.

Self-Assessment Exercise 2

What are main functions of Calcium and Magnesium to plants?

GROUP 1: DEFICIENCIES IN MINERAL NUTRIENTS THAT ARE PART OF CARBON COMPOUNDS

This group consists of nitrogen and sulfur. Nitrogen availability in soils limits plant productivity in most natural and agricultural ecosystems. By contrast, soils generally contain sulfur in excess.

Despite this difference, nitrogen and sulfur are similar chemically in that their oxidation–reduction states range widely. Some of the most energy-intensive reactions in life convert highly oxidized inorganic forms, such as nitrate and sulfate, that roots absorb from the soil into highly reduced organic compounds, such as amino acids, within plants.

NITROGEN

Nitrogen is the mineral element that plants require in the greatest amounts. It serves as a constituent of many plant cell components, including chlorophyll, amino acids, and nucleic acids. Therefore, nitrogen deficiency rapidly inhibits plant growth. If such a deficiency persists, most species show leaf **chlorosis** (yellowing of the leaves), especially in the older leaves near
the base of the plant. Under severe nitrogen deficiency, these leaves become completely yellow (or tan) and fall off the plant. Younger leaves may not show these symptoms initially because nitrogen can be mobilized from older leaves.

Thus, a nitrogen-deficient plant may have light green upper leaves and yellow or tan lower leaves. When nitrogen deficiency develops slowly, plants may have markedly slender and often woody stems. This woodiness may be due to a buildup of excess carbohydrates that cannot be used in the synthesis of amino acids or other nitrogen-containing compounds. Carbohydrates not used in nitrogen metabolism may also be used in anthocyanin synthesis, leading to accumulation of that pigment. This condition is revealed as a purple coloration in leaves, petioles, and stems of nitrogen-deficient plants of some species, such as tomato and certain varieties of maize (corn; *Zea mays*).

SULFUR

Sulfur is found in certain amino acids (i.e., cysteine and methionine) and is a constituent of several coenzymes and vitamins, such as coenzyme A, *S*-adenosylmethionine, biotin, vitamin B1, and pantothenic acid, which are essential for metabolism. Many of the symptoms of sulfur deficiency are similar to those of nitrogen deficiency, including leaf chlorosis, stunting of growth, and anthocyanin accumulation. This similarity is not surprising, since sulfur and nitrogen are both constituents of proteins. The chlorosis caused by sulfur deficiency, however,
generally arises initially in young and mature leaves, rather than in old leaves as in nitrogen deficiency, because sulfur, unlike nitrogen, is not easily remobilized to the younger leaves in most species. Nonetheless, in some plant species sulfur chlorosis may occur simultaneously in all leaves, or even initially in older leaves

GROUP 2: DEFICIENCIES IN MINERAL NUTRIENTS THAT ARE IMPORTANT IN ENERGY STORAGE OR STRUCTURAL INTEGRITY

This group consists of phosphorus, silicon, and boron. Phosphorus and silicon are found at concentrations in plant tissue that warrant their classification as macronutrients, whereas boron is much less abundant and is considered a micronutrient. These elements are usually present in plants as ester linkages between an inorganic acid group such a phosphate (PO4

3–) and a carbon alcohol (i.e.X–O–C–R, where the element X is attached to a carbon-containing molecule C–R via an oxygen atom O).

PHOSPHORUS Phosphorus (as phosphate, PO_4^{3-}) is an integral component of important compounds in plant cells, including the sugar–phosphate intermediates of respiration and photosynthesis as well as the phospholipids that make up plant membranes. It is also a component of nucleotides used in plant energy metabolism (such as ATP) and in DNA and RNA. Characteristic symptoms of phosphorus deficiency include stunted growth of the entire plant and a dark green coloration of the leaves, which may be malformed and contain small areas of dead tissue called **necrotic spots**.
As in nitrogen deficiency, some species may produce excess anthocyanins under phosphorus deficiency, giving the leaves a slight purple coloration. Unlike in nitrogen deficiency, the purple coloration of phosphorus deficiency is not associated with chlorosis. In fact, the leaves may be a dark greenish purple. Additional symptoms of phosphorus deficiency include the production of slender (but not woody) stems and the death of older leaves. Maturation of the plant
may also be delayed.

SILICON Only members of the family Equisetaceae—called *scouring rushes* because at one time their ash, rich in gritty silica, was used to scour pots—require silicon to complete their life cycle. Nonetheless, many other species accumulate substantial amounts of silicon in their tissues and show enhanced growth, fertility, and stress resistance when supplied with adequate amounts of silicon. Plants deficient in silicon are more susceptible to lodging (falling over) and fungal infection. Silicon is deposited primarily in the endoplasmic reticulum, cell walls, and intercellular spaces as hydrated, amorphous silica ($SiO_2 \cdot nH_2O$). It also forms complexes with polyphenols and thus serves as a complement to lignin in the reinforcement of cell walls. In addition, silicon can lessen the toxicity of many metals, including aluminum and manganese.

BORON Although many of the functions of boron in plant metabolism are still unclear, evidence shows that it cross-links RG II (rhamnogalacturonan II, a small pectic polysaccharide) in the cell wall and suggests that it plays roles in cell elongation, nucleic acid synthesis, hormone responses, membrane function, and cell cycle regulation. Boron-deficient plants may exhibit a wide variety of symptoms, depending on the species and the age of the plant.
A characteristic symptom is black necrosis of young leaves and terminal buds. The necrosis of the young leaves occurs primarily at the base of the leaf blade. Stems may be unusually stiff and brittle. Apical dominance may also be lost, causing the plant to become highly branched; however, the terminal apices of the branches soon become necrotic because of inhibition of cell differentiation. Structures such as the fruits, fleshy roots, and tubers may exhibit necrosis or
abnormalities related to the breakdown of internal tissues.

GROUP 3: DEFICIENCIES IN MINERAL NUTRIENTS THAT REMAIN IN IONIC FORM
This group includes some of the most familiar mineral elements: the macronutrients potassium, calcium, and magnesium and the micronutrients chlorine, zinc, and sodium. These elements may be found as ions in solution in the cytosol or vacuoles, or they may be bound electrostatically or
as ligands to larger, carbon-containing compounds.

POTASSIUM
Potassium, present in plants as the cation K^+, plays an important role in regulating the osmotic potential of plant cells. It also activates many enzymes involved in respiration and photosynthesis.
The first observable symptom of potassium deficiency is mottled or marginal chlorosis, which then develops into necrosis primarily at the leaf tips, at the margins, and between veins. In many monocots, these necrotic lesions may initially form at the leaf tips and margins and then extend toward the leaf base. Because potassium can be mobilized to the younger leaves, these symptoms appear initially on the more mature leaves toward the base of the plant. The leaves may also curl and crinkle. The stems of potassium-deficient plants may be slender and weak, with abnormally short inter nodal regions. In potassium-deficient maize, the roots may have an increased susceptibility to root-rotting fungi present in the soil, and this susceptibility, together with effects on the stem, results in an increased tendency for the plant to be easily lodged.

CALCIUM Calcium ions (Ca^{2+}) have two distinct roles in plants: (1) a structural/ apoplastic role whereby Ca^{2+} binds to acidic groups of membrane lipids (phospho- and sulfolipids) and cross-links pectins, particularly in the middle lamellae that separate newly divided cells; and (2) a signaling role whereby Ca^{2+} acts as a second messenger that initiates plant responses to environmental stimuli. In its function as a second messenger, Ca^{2+} may bind to **calmodulin**, a protein found in the cytosol of plant cells. The calmodulin–Ca^{2+} complex then

binds to several different types of proteins, including kinases, phosphatases, second messenger signaling proteins, and cytoskeletal proteins, and thereby regulates many cellular processes ranging from transcription control and cell survival to release of chemical signals.
Characteristic symptoms of calcium deficiency include necrosis of young meristematic regions such as the tips of roots or young leaves, where cell division and cell wall formation are most rapid. Necrosis in slowly growing plants may be leaves may also appear deformed. The root system of a calcium-deficient plant may appear brownish, short, and highly branched. Severe stunting may result if the meristematic regions of the plant die prematurely.

MAGNESIUM In plant cells, magnesium ions (Mg2+) have a specific role in the activation of enzymes involved in respiration, photosynthesis, and the synthesis of DNA and RNA. Mg2+ is also part of the ring structure of the chlorophyll molecule. A characteristic symptom of magnesium deficiency is chlorosis between the leaf veins, occurring first in older leaves because of the high mobility of this cation. This pattern of chlorosis occurs because the chlorophyll
in the vascular bundles remains unaffected longer than that in the cells between the bundles. If the deficiency is extensive, the leaves may become yellow or white. An additional symptom of magnesium deficiency may be senescence and premature leaf abscission.

CHLORINE The element chlorine is found in plants as the chloride ion (Cl–). It is required for the water-splitting reaction of photosynthesis through which oxygen is produced (see Chapter 7). In addition, chlorine may be required for cell division in leaves and roots. Plants deficient in chlorine develop wilting of the leaf tips followed by general leaf chlorosis and necrosis. The leaves may also exhibit reduced growth. Eventually, the leaves may take on a bronzelike color ("bronzing"). Roots of chlorine-deficient plants may appear stunted and thickened near the root tips. Chloride ions are highly soluble and are generally available in soils because seawater is swept into the air by wind and delivered to soil when it rains. Therefore, chlorine deficiency is only rarely observed in plants grown in native or agricultural habitats. Most plants absorb chlorine at concentrations much higher than those required for normal functioning.

ZINC Many enzymes require zinc ions (Zn2+) for their activity, and zinc may be required for chlorophyll biosynthesis in some plants. Zinc deficiency is characterized by a reduction in internodal growth, and as a result plants display a rosette habit of growth in which the leaves form a circular cluster radiating at or close to the ground. The leaves may also be small and distorted, with leaf margins having a puckered appearance. These symptoms may result from loss of the ability to produce sufficient amounts of the auxin indole-3-acetic acid (IAA). In some species (e.g., maize, sorghum, and beans), older leaves may show chlorosis between the leaf veins and then develop white necrotic spots. This chlorosis may be an expression of a zinc requirement for chlorophyll biosynthesis.
SODIUM Species using the C4 and crassulacean acid metabolism (CAM plants, Na+ appears vital for regenerating phospho*enol*pyruvate, the substrate for the first carboxylation in the C4 and CAM pathways. Under sodium deficiency, these plants exhibit chlorosis and necrosis, or even fail to form flowers. Many C3 species also benefit from exposure to low concentrations of Na+. Sodium ions stimulate growth through enhanced cell expansion and can partly substitute for
potassium ions as an osmotically active solute.

GROUP 4: DEFICIENCIES IN MINERAL NUTRIENTS THAT ARE INVOLVED
IN REDOX REACTIONS This group of five micronutrients consists of the metals iron, manganese, copper, nickel, and molybdenum. All of these can undergo reversible oxidations and reductions (e.g., Fe2+ ↔ Fe3+) and have important roles in electron transfer and energy transformation. They are usually found in association with larger molecules such as cytochromes, chlorophyll, and proteins (usually enzymes).
IRON Iron has an important role as a component of enzymes involved in the transfer of electrons (redox reactions), such as cytochromes. In this role, it is reversibly oxidized from Fe2+ to Fe3+ during electron transfer.
As in magnesium deficiency, a characteristic symptom of iron deficiency is intervenous chlorosis. This symptom, however, appears initially on younger leaves because iron, unlike magnesium, cannot be readily mobilized from older leaves. Under conditions of extreme or prolonged deficiency, the veins may also become chlorotic, causing the whole leaf to turn white. The leaves become chlorotic because iron is required for the synthesis of some of the chlorophyll– protein complexes in the chloroplast. The low mobility of iron is probably due
to its precipitation in the older leaves as insoluble oxides or phosphates. The precipitation of iron diminishes subsequent mobilization of the metal into the phloem for long-distance translocation.

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MANGANESE Manganese ions (Mn^{2+}) activate several enzymes in plant cells. In particular, decarboxylases and dehydrogenases involved in the tricarboxylic acid (Krebs) cycle are specifically activated by manganese ions. The best-defined function of Mn^{2+} is in the photosynthetic reaction through which oxygen (O_2 is produced from water. The major symptom of manganese deficiency is intervenous chlorosis associated with the development of small
necrotic spots. This chlorosis may occur on younger or older leaves, depending on plant species and growth rate.

COPPER Like iron, copper is associated with enzymes involved in redox reactions, through which it is reversibly oxidized from Cu^{+} to Cu^{2+}. An example of such an enzyme is plastocyanin, which is involved in electron transfer during the light reactions of photosynthesis. The initial symptom of copper deficiency in many plant species is the production of dark green leaves, which may contain necrotic spots. The necrotic spots appear first at the tips of young leaves and then extend toward the leaf base along the margins. The leaves may also be twisted or malformed. Cereal plants exhibit a white leaf chlorosis and necrosis with rolled tips. Under extreme copper deficiency, leaves may drop prematurely and flowers may be sterile.

NICKEL Urease is the only known nickel-containing (Ni^{2+}) enzyme in higher plants, although nitrogen-fixing microorganisms require nickel (Ni^{+} through Ni^{4+}) for the enzyme that reprocesses some of the hydrogen gas generated during fixation (hydrogen uptake hydrogenase) Nickel-deficient plants accumulate urea in their leaves and consequently show leaf tip necrosis.
Nickel deficiency in the field has been found in only one crop, pecan trees in the southeastern United States, because plants require only minuscule amounts of nickel.

MOLYBDENUM Molybdenum ions (Mo^{4+} through Mo^{6+}) are components of several enzymes, including nitrate reductase, nitrogenase, xanthine dehydrogenase, aldehyde oxidase, and sulphite oxidase. Nitrate reductase catalyzes the reduction of nitrate to nitrite during its assimilation by the plant cell; nitrogenase converts nitrogen gas to ammonia in nitrogen-fixing microorganisms. The first indication of a molybdenum deficiency is general chlorosis between veins and necrosis of older leaves. In some plants, such as cauliflower or broccoli, the leaves may not become necrotic but instead may appear twisted and subsequently die (whiptail disease). Flower formation may be prevented, or the flowers may abscise prematurely. Because molybdenum is involved with both nitrate assimilation and nitrogen fixation, a molybdenum deficiency may bring about a nitrogen deficiency if the nitrogen source is primarily nitrate or if the plant depends on symbiotic nitrogen fixation. Although plants require only tiny amounts of molybdenum , some soils (for example, acidic soils in Australia) supply inadequate concentrations. Small additions of molybdenum to such soils can greatly enhance crop or forage growth at negligible cost.

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DEFICIENCIES OF NUTRIENT ELEMENTS											
Symptoms	**Suspected Element**										
	N	**P**	**K**	**Mg**	**Fe**	**Cu**	**Zn**	**B**	**Mo**	**Mn**	**OF**
Yellowing of Younger Leaves					✓					✓	
Yellowing of Middle Leaves									✓		
Yellowing of Older Leaves	✓		✓	✓			✓				
Yellowing Between Veins				✓						✓	
Old Leaves Drop	✓										
Leaves Curl Over				✓							
Leaves Curl Under			✓			✓					✓
Younger Leaf Tips Burn								✓			
Older Leaf Tips Burn	✓						✓				
Young Leaves Wrinkle/Curl			✓				✓	✓	✓		
Necrosis			✓	✓	✓		✓			✓	
Leaf Growth Stunted	✓	✓									
Dark Green/Purple Leaf & Stems		✓									
Pale Green Leaf Color	✓								✓		
Molting							✓				
Spindly	✓										
Soft Stems	✓		✓								
Hard/Brittle Stems		✓	✓								
Growing Tips Die			✓					✓			
Stunted Root Growth		✓									
Wilting						✓					

Source: Taiz and Zeiger

Nitrogen deficiency leads to what?

Self-Assessment Exercise 3

What are deficiency symptoms of Phosphorus?

Self-Assessment Questions

1) What are nutrients that are involved in redox reactions?
Answer: Fe, Cu, Mn,Ni, Mo

1) What are the deficiency symptoms of iron?
Answer: As in magnesium deficiency, a characteristic symptom of iron deficiency is intervenous chlorosis. This symptom, however, appears initially on younger leaves because iron, unlike magnesium, cannot be readily mobilized from older leaves. Under conditions of extreme or prolonged deficiency, the veins may also become chlorotic, causing the whole leaf to turn white. The leaves become chlorotic because iron is required for the synthesis of some of the chlorophyll– protein complexes in the chloroplast

1.4 **Summary**:

Mineral nutrients can be classified as:

a) Nutrients that are part of carbon compounds
b) Nutrients that are important in energy storage or structural integrity
c) Nutrients that remain in ionic form
d) Nutrients that are involved in redox reactions

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1.6 Possible Answers to SAEs

Answer to SAE 1

Organic nutrition focuses on the production of carbon compounds, specifically the incorporation of carbon, hydrogen, and oxygen via photosynthesis, while *inorganic nutrition* is concerned primarily with the acquisition of mineral elements from the soil.

Answers to SAE 2

Calcium is constituent of the middle lamella of cell walls. Calcium is required as a cofactor by some enzymes involved in the hydrolysis of ATP and phospholipids. Ca acts as a second messenger in metabolic regulation.
Mg is required by many enzymes involved in phosphate transfer. Magnessium is constituent of the chlorophyll molecule.

Answer to SAE 3

Characteristic symptoms of phosphorus deficiency include stunted growth of the entire plant and a dark green coloration of the leaves, which may be malformed and contain small areas of dead tissue called **necrotic spots**.

UNIT 2 PHYSIOLOGY OF NUTRIENT UPTAKE

Unit Structure

2.1 INTRODUCTION:

Mineral nutrients are found either as soluble fractions of soil solution or as adsorbed ions on the surface of colloidal particles. Various theories proposed to explain the mechanism of mineral salt absorption can be placed in two broad categories: I) Passive Absorption II) Active Absorption

2.2 INTENDED LEARNING OUTCOMES:

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

-discuss the Various mechanisms for nutrients uptake.

2.3 Main Contents

2.3.1 Ion uptake

After several decades of research on this process of ion uptake it is now believed that the process involves both passive and active uptake mechanisms.

Whether a molecule or ion is transported actively or passively across a membrane (casparian band, plasma membrane or tonoplast) depends on the concentration and charge of the ion or molecule, which in combination represent the electrochemical driving force.

Passive transport across the plasma membrane occurs along with the electrochemical potential. In this process ions and molecules diffuse from areas of high to low concentrations. It does not require the plant to expend energy.

Active transport, (in contrast, to passive transport) energy is required for ions diffusion against the concentration gradient (electro chemical potential). Thus, active transport requires the cell to expend energy.

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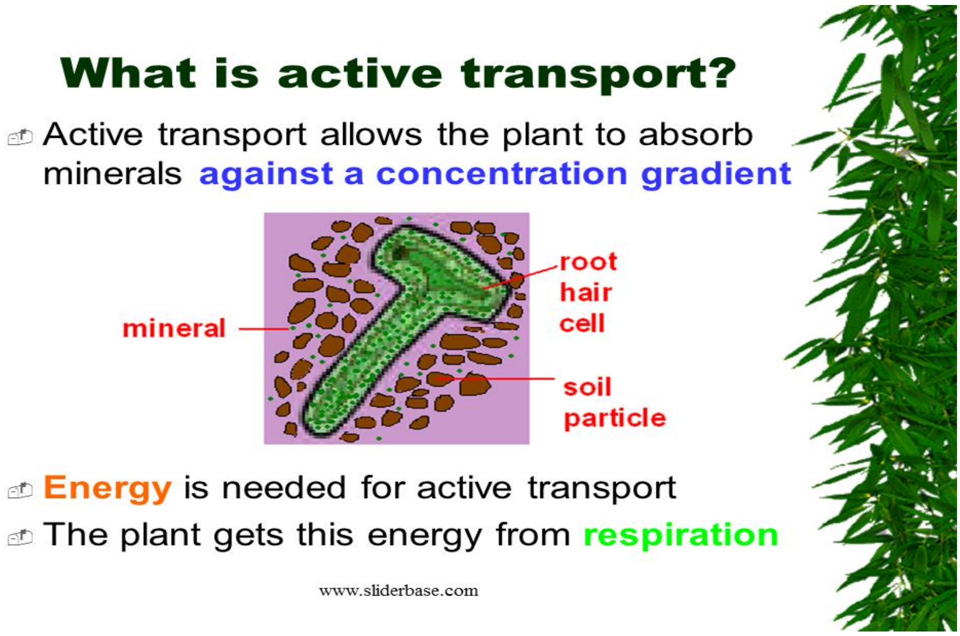

What is passive transport?

2.3.2 Passive transport mechanism:

A) Diffusion: Simple diffusion to membranes occurs with small, non-polar molecules (i.e. O^2, CO^2). In this process ions or molecules move from the place of higher concentration to lower concentration. It needs no energy.

B) Facilitated diffusion: For small polar species (i.e. H_2O, Ions and amino acids) specific proteins in the membrane facilitate the diffusion down the electrochemical gradient. This mechanism is referred to as facilitated diffusion.

a) Channel proteins: The specific proteins in the membrane form channels (channel proteins), which can open and close, and through which ions or H_2O molecules pass in single file at very rapid rates. A K^+ and NH^{4+} channel also operates by the same process of facilitated diffusion. In addition, Na+ can also enter the cell by this process.

b) Transporters or Co-transporters or carriers: Another mechanism involves transporters or co-transporters responsible for the transport of ions and molecules across membranes. Transporter proteins, in contrast to channel proteins, bind only one or a few substrate molecules at a time. After binding a molecule or ion, the transporter undergoes a structural change specific to a specific ion or molecule. As a result, the transport rate across a membrane is slower than that associated with channel proteins.

Three types of transporters have been identified:

1. Uniporters: transport one molecule (i.e. glucose, amino acids) at a time down a concentration gradient.

2. Antiporters: catalyze movement of one type of ion or molecule against its concentration gradient. This is coupled with the movement of a different ion or molecule in the opposite direction. Examples of antiporter transport are H+/Na+ and H+ /Ca+2 transport into the vacuole.

3. Symporters: catalyze movement of one type of ion or molecule against its concentration gradient coupled to movement of a different ion or molecule down its concentration gradient in the same direction. The high H+ concentration in the apoplast provides the energy for symporter transport of NO3- and the other anions.

Therefore, the energy for antiporter and symporter transport originates from the electric potential and/or chemical gradient of a secondary ion or molecule, which is often H+. *What are passive transport mechanisms?*

Self-Assessment Exercise 1

What is Antiporter?

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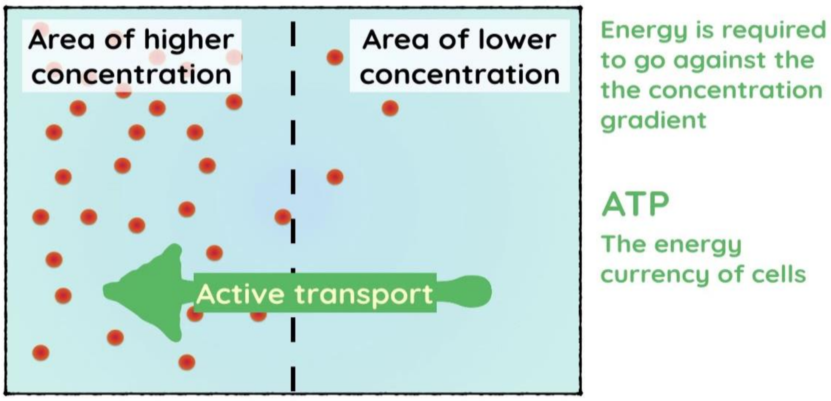
2.3.3 Active transport mechanism

Larger or more-charged molecules have great difficulty in moving across a membrane, requiring active transport mechanisms (i.e., sugars, amino acids, DNA, ATP, ions, phosphate, proteins, etc.). Active transport across a selectively permeable membrane occurs through ATP-powered pumps that transport ions against their concentration gradients. This mechanism utilizes energy released by hydrolysis of ATP. The Na+,K+ -ATP pump transports K+ into the cell and Na+ out of the cell, another example is the Ca^{+2} -ATP pump.
Thus, it can be understood from the above discussion that the ion transport mechanisms operate both actively and passively. For some of the ions the uptake mechanism is active and for some others it is passive.



What is active transport?

Self-Assessment Exercise 2

Diagrammatically illustrate active transport

Self-Assessment Questions
QUESTION: what is the form of energy used in active transport
ANSWER: ATP
QUESTION: describe the three types of transporters
ANSWER: a). Uniporters: transport one molecule (i.e. glucose, amino acids) at a time down a concentration gradient. (b) 2. Antiproters: catalyze movement of one type of ion or molecule against its concentration gradient. This is coupled with the movement of a different ion or molecule in the opposite direction. (c) Symporters: catalyze movement of one type of ion or molecule against its concentration gradient coupled with movement of a different ion or molecule down its concentration gradient in the same direction.

2.4 SUMMARY:

Active transport is the net movement of particles against a concentration gradient. Energy is therefore required. During active transport, molecules are transported from a low concentration to a high concentration. Passive transport does not need energy. The particles move randomly, with a net movement towards an area of lower concentration. Passive transport is a naturally occurring phenomenon and does not require the cell to expend energy to accomplish the movement.

2.5 References/Further Readings/Web Sources

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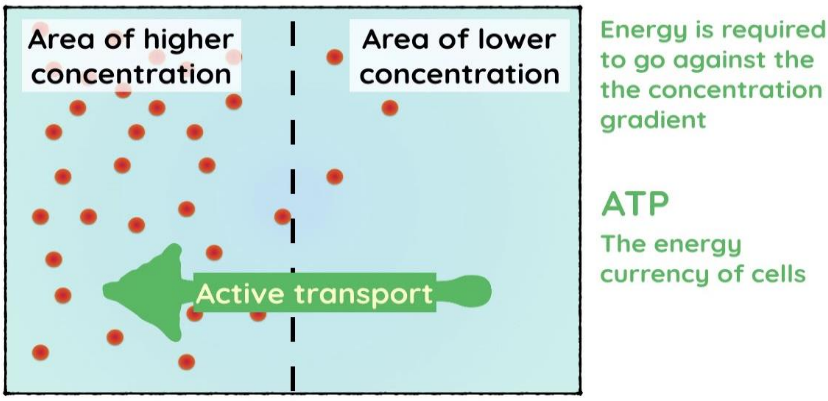
Possible Answers to SAEs

2.6 Answer to SAE 1

Antiporters is a catalyze movement of one type of ion or molecule against its concentration gradient. This is coupled with the movement of a different ion or molecule in the opposite direction. Examples of antiporter transport are H^+/Na^+ and H^+ /Ca^{+2} transport into the vacuole.

Answers to SAE 2



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UNIT 3 PHOTOSYNTHESIS I

Unit Structure

3.1 INTRODUCTION:

Literally photosynthesis is synthesis with the help of light. It can also be defined as the process by which the green plants synthesis organic matter in the presence of light. It is represented by this equation:

$$6CO_2 + 6H_20 \xrightarrow[green\ plant]{light} C_6H_{12}O_6 + 6O_2$$

During the process of photosynthesis, light energy is converted into chemical energy and is stored as organic matter (carbohydrate) along with O_2 as the end product of photosynthesis. CO_2 and H_2O constitute the raw material for the process and it is an anabolic process.

2.2 INTENDED LEARNING OUTCOMES

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

-narrate the history of photosynthesis.
-describe the process of photosynthesis in plant.

3.3 Main Contents

3.3.1 HISTORY OF PHOTOSYNTHESIS

a. Van Helmont (1648) proposed that increase in weight of willow tree come from water alone.
b. Stephan Hales (1727) pointed out that plants obtained a part of their nutrition from the air and that sunlight plays a role.
c. Priestley (1772) proposed that plants might restore the air laden with CO_2 by the burning of candles
d. Ingen Houz (1779) noticed that only the green parts of plant can purify the air in the presence of sulight.
e. Jean Senebier (1783) observed that the air-purifying activities of plants depend on the presence of CO_2.
f. Nicolas Theodore de Saussure (1804) concluded that CO_2 and water must constitute the raw material for this process.
g. Meyer (1845) recognized the role of light as a source of energy for the process.
h. Julius Sachs (1862) proved that the process of photosynthesis takes place in the chloroplasts and result in the production of organic matter.

3.3.2 IMPORTANCE OF PHOTOSYNTHESIS TO MAN

a. It provides food directly to man and indirectly as meat or milk of animal.
b. It maintains equilibrium of O_2 in the atmosphere.

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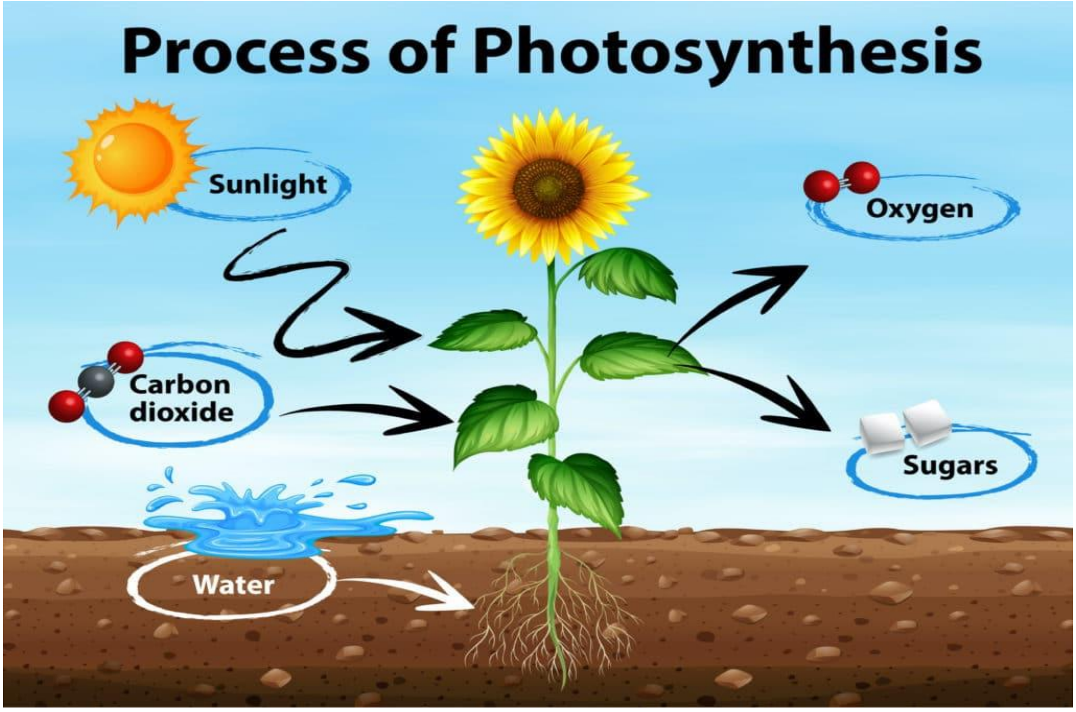
c. It provides least resources of energy to man as fuel such as coal, oil, wood and dung.



Mention four scientists that worked on photosynthesis

Self-Assessment Exercise 1

What are the four conditions necessary for photosynthesis?

3.3.3 PHOTOSYNTHETIC PIGMENTS

There are three types of photosynthetic pigments:

a. Chlorophylls
b. Carotenoids
c. Phycobillins

-Chlorophylls and carotenoids are insoluble in water and can be extracted only with organic solvents.
-Phycobillins are soluble in water.
-Carotenoids include carotenes and Tanthophylls (carotenols).
Different pigment absorbs light of different wavelength and show characteristics absorption peak in vivo and in vitro.
-Pigments also show florescence property.
Name three types of photosynthetic pigment

3.3.4 ABSORPTION AND UTILIZATION OF LIGHT ENERGY BY PHOTOSYNTHETIC PIGMENTS

Sun is the chief source of light energy for photosynthesis. The plant receives only 40% of the total solar energy, the rest is either absorbed by the atmosphere or is scattered into the space.
Not all the light energy falling on green parts of plants is absorbed and utilized by pigments. Some of the light is reflected, some is transmitted through the plants while only a small portion is absorbed by the pigments.
Photosynthetic pigment absorb light energy only in the visible part of the spectrum ranging usually between 400-700mμ (nm). Such radiations are called Photosynthetically Active Radiations (PAR).

Only about 1% of the total solar energy received by the earth is absorbed by the pigments and is utilized in photosynthesis.
There is very weak absorption by pigments in green part of the spectrum, thus, the chloroplast appears green in green plants. *What is the main source of energy in photosynthesis?*

Self-Assessment Exercise 2

What is the fate of light energy from sunlight?

3.3.5 MECHANISMS OF PHOTOSYNTHESIS

The process of photosynthesis is the oxidation of water and reduction of CO_2. The mechanism of photosynthesis consists of two parts:

1) Primary photochemical reaction or light reaction or Hill's reaction.
2) Dark reaction or black man's reaction or part of carbon in photosynthesis.

A. Light reaction or Hill's reaction

Light reaction which is faster than the dark reaction takes place only in the presence of lipids in the grains portion of the chloroplasts. The reaction follows these steps:

I. Different chloroplast pigments absorb light in different regions of the visible part of the spectrum.

II. The light energy absorbed by the pigments is transferred by resonance to chlorophyll-a which alone takes place in the light reaction.

III. The chlorophyll becomes an excited molecule having more energy than the ground state energy. It is this excited form of Chlorophyll-a that takes part in the light reaction. It expels its energy along with an electron and a positive charge comes on the chlorophyll-a which is now oxidized.

IV. When pigment system II is active, that is, it receives light, the water molecules split into OH^- and H^+ ions (photolysis of water). The OH^- ions unite to form some water molecules again and release O_2 electrons

$4H_20 \longrightarrow 4H^- + 4(OH^-)$
$4(OH) \longrightarrow 2H_2O + O_2 + 4^{e-}$
$2H_20 \longrightarrow 4H^+ + O_2 + 4^{e-}$

V. The electron released by the excited chlorophyll-a travels through a number of electron carrier system where it is either recycled or consumed in reducing NADP to NADPS + H^+. The extra light energy carried by the electron is utilized in the formation ATP molecules at certain places during its transport. This process of the formation of ATP from ADP and inorganic phosphate (Pi) in photosynthesis is called PHOSPHORYLATION or PHOTOPHORYLATION.

B. Dark reaction / Black man's reaction

The dark reaction of photosynthesis is purely enzymatic and slower than the light reaction or primary photochemical reaction. It takes place in stroma portion of the chloroplast and is independent of light, that is, it can place either in presence or absence of light provided the assimilatory power is available.
It involves the conversion of CO_2 to carbohydrate with the help of assimilatory power (NADPH + H^+ and ATP) in dark reaction.
By using ^{14}C labeled carbon(IV)oxide ($^{14}CO_2$) in photosynthesis and observing the appearance of characteristics radiation in different reaction intermediates and products, Calvin Melvin and others formulated the complete pathways of carbon assimilation in the form of a cycle called Calvin cycle.
Mechanism of photosynthesis involves what two reactions?

3.4 SUMMARY:

Photosynthesis is the process by which green plants synthesize organic matter in presence of sunlight. During the process, the light energy is converted to chemical energy and is stored in organic matter which is usually carbohydrate and oxygen .

3.5 References/Further Readings/Web Sources

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3.6 Possible Answers to SAEs

Answer to SAE 1
Carbon (IV) oxide, water, sunlight and chlorophyll
Answers to SAE 2
Not all the light energy falling on green parts of plants is absorbed and utilized by pigments. The plant receives only 40% of the total solar energy, the rest is either absorbed by the atmosphere or is scattered into the space. Some of the light is reflected, some is transmitted through the plants while only a small portion is absorbed by the pigments.Only about 1% of the total solar energy received by the earth is absorbed by the pigments and is utilized in photosynthesis.

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UNIT 4 PHOTOSYNTHESIS II

Unit Structure

4.1 INTRODUCTION:

the process of photosynthesis is a complicated redox reaction resulting ultimately in the oxidation of water and reduction of $CO_{2.}$ The mechanism of photosynthesis consists of two parts: a) light or Hill's Reaction and (b) Dark reaction or Blackman's reaction.

4.2 INTENDED LEARNING OUTCOMES

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

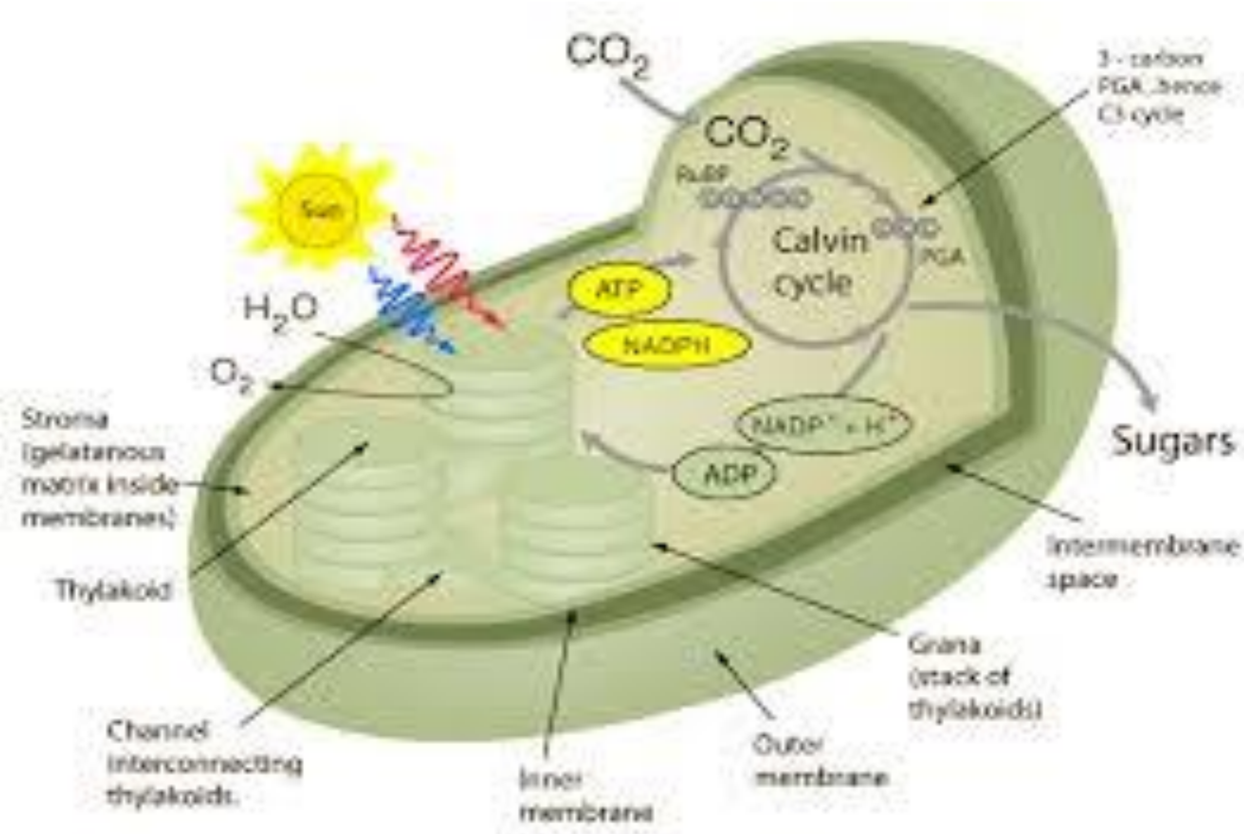
- to describe different pathways of photosynthesis in different plants.
- explain special modes of nutrition.

4.3 Main Contents

4.3.1 THE CALVIN CYCLE (C_3 PATHWAY)

The following steps are followed in Calvin cycle:

a. Carboxylation- the CO_2 is accepted by ribulose 1,5-biphospahte (RUBP) already present in the cells and an unstable 6-carbon addition is formed. The 6-carbon compound is hydrolysed into 2 molecules of 3-phosphoglyceric acid (3PGA).
b. Reduction- 3PGA is reduced to 3-phosphoglyceraldehyde by the assimilatory power in the presence of triose phosphate dehydrogenate.
c. Formation of hexose sugar and regeneration of RUBP- some molecules of 3-phosphoglyceraldehyde isomerise into dihydroxyacetone phosphate, which unite in the presence of aldolase to form fructose 1,6-biphosphate.
d. Fructose 1, 6-biphosphate is converted into fructose 6-phospahte in the presence of phosphatase.
e. The fructose 6-phosphate (Hexose sugar) is taken off the Calvin cycle and is converted into glucose, sucrose of starch.
f. Some of the molecules of 3-phosphoglyceraldehyde produced in step (b) are diverted ton regenerate ribulose 1,3-biphosphate.
The first visible product of Calvin cycle is 3-phosphoglyceride acid which is a 3-C compound. Hence it is also called C_3 pathway or PCR (photosynthetic carbon reduction) pathway. Calvin cycle is also known as Reductive Pentose Phosphate (RPP) cycle.



Source: Taiz *et al* (2018)

What is the first product of the Calvin Cycle?

4.3.2 C_4 –DICARBOXYLIC ACID PATHWAY (HATCH-SLACK PATHWAY)

For many years the Calvin cycle was thought to be the only photosynthetic reaction sequence operating in higher plants and algae. But in 1965 Kortschak, Hartt and Burr reported that 4-C containing dicarboxylic acids, malate and aspertase where major labeled products when sugarcane leaves were allowed to photosynthesize for short period of time in $^{14}CO_2$. It was thus established that CO_2 reduction has another pathway which is called Hatch-Slack pathway and because C_4 dicarboxylic acids are the earliest product, it is also called C_4 dicarboxylic acid pathway.

Plants using this pathway (c_4 plants) are sugarcane, maize, sorghum, amaranthus. These plants are different from other plants by

I. Absence of photo-respiration
II. Anatomical similarities of the leaves (cane type)

The anatomy of the C_4 plants is also called Krantz' anatomy because of the presence of partially arranged cells of bundle sheath around their vascular bundle which look like a ring or wreath.

Steps in Hatch-Slack pathway involves 2 carboxylation reactions, one taking place in chloroplasts of mesophyll cells and another in chloroplast of bundle sheath cells. Hatch-Slack pathway is significant in

I. It is a modification of Calvin cycle and beneficial for growing plants in tropical vegetation where Co_2 concentration is reduced.
II. It is adaptation to plants due to plants due to reduction in CO_2 concentration in the atmosphere due to photosynthesis.
III. It proves existence of alternative pathway to Calvin cycle.

4.3.3 FACTORS AFFECTING PHOTOSYNTHESIS

The rate of photosynthesis is affected by external and internal factors

A. External factors
I. Light
II. Temperature

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III. CO_2
IV. Water
V. O_2
B. Internal factors
I. Chlorophyll content
II. Protoplasmic factors
III. Anatomy of leave
IV. Accumulation of end product of photosynthesis
V. Microstructure of chloroplasts.

List three examples of C_4 plants.

Self-Assessment Exercise 1

What are the benefits of Hatch-Slack pathway?

4.3.4 CHEMOSYNTHESIS

There are some aerobic bacteria that carry on assimilation of CO_2 without the help of radiant energy. These bacteria lack chlorophyll, but use chemical energy which evolved during the oxidation of some inorganic substances by them. The process of manufacturing organic food matter by bacteria using chemical energy is called CHEMOSYNTHESIS.

Some examples are:

I. Nitrifying bacteria

Nitrosomonas and Nitrosococuss oxidize ammonia to Nitrite and chemical energy is released

$2NH_3 + 3O_2 \longrightarrow 2HNO_3 + 2H_2O$ + chemical energy

Nitrobacter oxidizes nitrite to nitrate and releases chemical energy.

$2HNO_2 + O_2 \longrightarrow 2HNO_3$ + chemical energy

II. Sulphur bacteria

Beggiatra and Thiothrize oxidise H_2S to sulphur and release chemical energy for food synthesis

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

III. Iron bacteria

Ferrobacillus, leptothris oxidize ferrous ion to ferric ion and release chemical energy

$4FeCO_3 + O_2 + 6H_2O \longrightarrow 4Fe(OH)_3 + 4CO_2$ + chemical energy

IV. Carbon bacteria (*Baccilus oligocarbophilus*)

$2CO + O_2 \longrightarrow 2CO_2$ + chemical energy

V. Hydrogen bacteria

$2H_2 + O_2$ $2H_2O$ + chemical energy

What is chemosynthesis?

4.3.5 SPECIAL MODE OF NUTRITION

Green plants are capable of synthesizing organic foods and are not dependent on others for their nutrition. On the other hand, fungi, bacteria and some other plants are incapable of photosynthesizing their own food due to lack of chlorophyll.

Such plants are dependent on other sources for their nutritional requirements. Such plants are called HETEROTROPHIC PLANTS.

A. PARASITIC PLANT

These plants obtain their nourishment from other living plants called hosts (which are angiosperm) by means of special root called **Haustoria.** The Haustoria penetrate the tissue of the host to make connections with its vascular tissue to draw readymade food from the phloem as well water and mineral salts from xylem.

Some common examples of stem and roots parasites in flowering plants are as follows:

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a. Total stem parasite e.g Dodder or *Cuscuta*

Cuscuta Europaea

b. Partial stem parasite e.g Loranthus, Viscum or Mistletoe.

Viscum album

c. Total root parasite e.g Orobauche, Striga, Balanophora, Rafflesia.

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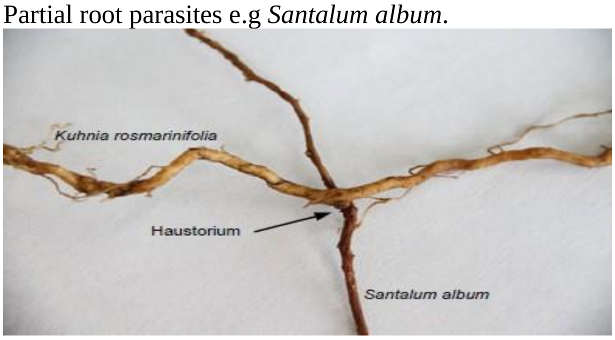
Rafflesia arnoldii

d. Partial root parasites e.g *Santalum album*.



B. INSECTIVOROUS PLANTS

Insectivorous plants are partly autotrophic and partly heterotrophic. They can manufacture carbohydrates themselves but are incapable of synthesizing protein. The soil in which they grow is waterlogged and swampy. It is deficient in nitrogenous compounds. They have poorly developed roots. They supplement their nitrogen requirements by capturing and digesting insects.

The leaves of these plants are modified in several ways for the purpose of capturing insects. Examples are;

1. The Pitcher plants (Neperithes)

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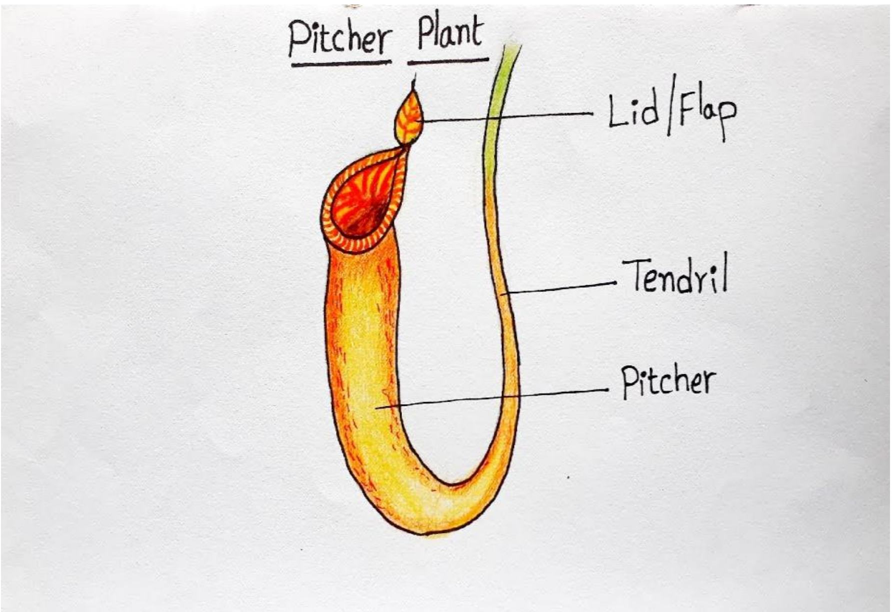

2. The Bladderwort (utricularia)

3. Drosera (the sundew)

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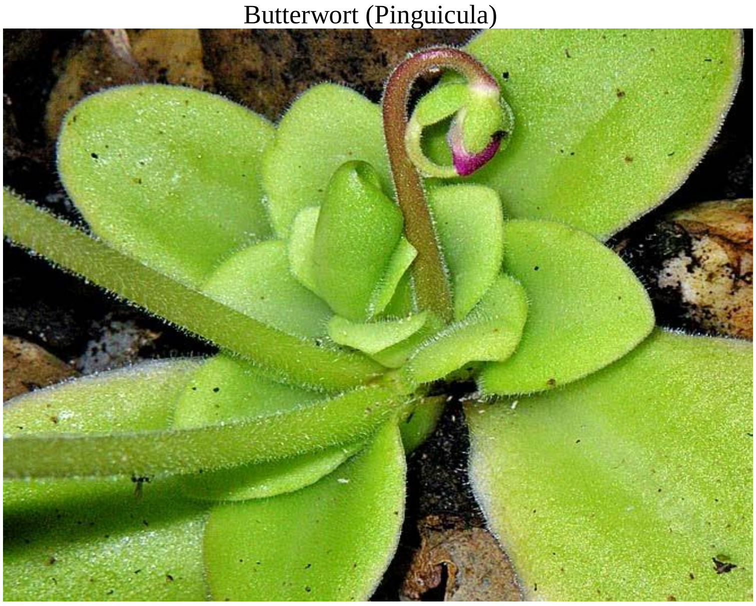
4. Butterwort (Pinguicula)



5. Venus' fly trap (Dionaea)

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6. Aldrovanta

C. SAPROPHYTIC PLANTS

Saprophytes absorb nutrition from dead and rotting organic substances. Many fungi and bacteria have saprophytic mode of nutrition. They break up the complex organic matters into simple compounds. The alcoholic fermentation, lactic acid fermentation, fermentation of cheese, ripening of tobacco and the disposal of sewage are some of the useful effects of this type of nutrition. Among the flowering plants, Neottia and Monotropa are examples of saprophytes. In these cases, the root of the plant forms a mycorrhizal with the fungal mycelium to help in the absorption process.
What are heterotrophic plants?

Self-Assessment Exercise 2

What are parasitic plants?

Self-Assessment Questions
QUESTION: what major factor assists insectivorous plants in their mode of feeding?
ANSWER: The leaves of these plants are modified in several ways for the purpose of capturing insects.

QUESTION: *List five external factors affecting photosynthesis*
ANSWER: *Light, temperature, oxygen, water, carbon (IV) oxide*

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4.4 SUMMARY

Green plants are capable of synthesizing their organic food and do not depend on others for their nutrition. Such plants are called Autotrophs. On the other hand, fungi, some bacteria and certain higher plants are not capable of manufacturing their own food due to lack of chlorophyll and thus depend on others for their nutrition. Such plants are called Heterotrophs. These heterotrophs make use of special mode of nutrition.

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4.6 Possible Answers to SAEs

Answer to SAE 1

Slack pathway is significant in

a) It is a modification of Calvin cycle and beneficial for growing plants in tropical vegetation where Co_2 concentration is reduced.
b) It is adaptation to plants due to plants due to reduction in CO_2 concentration in the atmosphere due to photosynthesis.
c) It proves existence of alternative pathway to Calvin cycle.

Answers to SAE 2

These plants obtain their nourishment from other living plants called hosts (which are angiosperm) by means of special root called **Haustoria.** The Haustoria penetrate the tissue of the host to make connections with its vascular tissue to draw readymade food from the phloem as well water and mineral salts from xylem.

Glossary

RUBP= Riboluse biphoshate
DNA= deoxyribonucleic Acid
RNA= Ribonucleic Acid

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ATP= Adenosine triphosphate
RPP= Reductive Pentose Phoshate
PCR= Photosynthetic Carbon Reduction
3PGA= 3-Phosphoglyceric acid

End of Module Questions

1) Many fungi and bacteria have saprophytic mode of nutrition (**True or False**)
2) Green plants are capable of synthesizing organic foods and are not dependent on others for their nutrition (**True or False**)
3) One of this is not an external factor affecting photosynthesis a) CO2 b) Light c) Water d) Chlorophyll
4) The dark reaction of photosynthesis is purely enzymatic and slower than the light reaction **(True or False)**
5) All these are photosynthetic pigments , except a) caroteroids b) chlorophyll c) iodine d) Phycobillins

Module 4 PLANT HORMONES

UNIT 1: Discovery and chemical nature of Auxin

UNIT 2: Discovery and chemical nature of Gibberelin

UNIT 3: Discovery and chemical nature of Cytokinins, Ethylene and ABA

UNIT 4: Other plant hormones

UNIT 1: Discovery and chemical nature of Auxin

Unit Structure

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1.1 INTRODUCTION

The form and function of multicellular organism would not be possible without efficient communication among cells, tissues, and organs. In higher plants, regulation and coordination of metabolism, growth, and morphogenesis often depend on chemical signals from one part of the plant to another. This idea originated in the nineteenth century with the German botanist Julius von Sachs (1832–1897). Sachs proposed that chemical messengers are responsible for the formation and growth of different plant organs. He also suggested that external factors such as gravity could affect the distribution of these substances within a plant. Although Sachs did not know the identity of these chemical messengers, his ideas led to their eventual discovery.
Many of our current concepts about intercellular communication in plants have been derived from similar studies in animals. In animals the chemical messengers that mediate intercellular communication are called **hormones**. Hormones interact with specific cellular proteins called *receptors*. Most animal hormones are synthesized and secreted in one part of the body and are transferred to specific target sites in another part of the body via the bloodstream. Animal hormones fall into four general categories: proteins, small peptides, amino acid derivatives, and steroids. Plants also produce signaling molecules, called *hormones* that have profound effects on development at vanishingly low concentrations. Until quite recently, plant development was thought to be regulated by only five types of hormones: auxins, gibberellins, cytokinins, ethylene, and abscisic acid. Plant development is regulated by nine major hormones or hormone families: auxins, gibberellins, cytokinins, ethylene, abscisic acid, brassinosteroids, jasmonates, salicylic acid, and strigolactones . In addition, several small peptides function in cell-to-cell communication in plant development and in signaling in response to mineral nutrient deficiencies.
A variety of other signaling molecules that play roles in resistance to pathogens and defense against herbivores have also been identified, including jasmonic acid, salicylic acid, and the polypeptide systemin. Thus the number and types of hormones and hormonelike signaling agents in plants keep expanding.The first plant hormone we will consider is auxin. Auxin
deserves pride of place in any discussion of plant hormones because it was the first growth hormone to be discovered in plants, and much of the early physiological work on the mechanism of plant cell expansion was carried out in relation to auxin action.

1.2. INTENDED LEARNING OUTCOMES

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

-state how auxins was discovered
-name the scientists that pioneered research effort in this direction
-describe how auxins is transported
-list the effect of auxins

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1.3 Main Contents

1.3.1 Auxins Discovery

During the latter part of the nineteenth century, Charles Darwin and his son Francis studied plant growth phenomena involving tropisms. One of their interests was the bending of plants toward light. This phenomenon, which is caused by differential growth, is called **phototropism**. In some experiments the Darwins used seedlings of canary grass (*Phalaris canariensis*), in which, as in many other grasses, the youngest leaves are sheathed in a protective organ called the **coleoptile.**
Coleoptiles are very sensitive to light, especially to blue light. If illuminated on one side with a short pulse of dim blue light, they will bend (grow) toward the source of the light pulse within an hour. The Darwins found

that the tip of the coleoptile perceived the light, for if they covered the tip with foil, the coleoptile would not bend. But the region of the coleoptile that is responsible for the bending toward the light, called the **growth zone**, is several millimeters below the tip.

Thus they concluded that some sort of signal is produced in the tip, travels to the growth zone, and causes the shaded side to grow faster than the illuminated side. The results of their experiments were published in 1881 in a remarkable book entitled *The Power of Movement in Plants*.

There followed a long period of experimentation by many investigators on the nature of the growth stimulus in coleoptiles. This research culminated in the demonstration in 1926 by Frits Went of the presence of a growth-promoing chemical in the tip of oat (*Avena sativa*) coleoptiles. It was known that if the tip of a coleoptile was removed, coleoptile growth ceased. Previous workers had attempted to isolate and identify the growth-promoting chemical by grinding up coleoptile tips and testing the activity of the extracts. This approach failed because grinding up the tissue released into the extract inhibitory substances that normally were compartmentalized in the cell. Went’s major breakthrough was to avoid grinding by allowing the material to diffuse out of excised coleoptile tips directly into gelatin blocks. If placed asymmetrically on top of a decapitated coleoptile, these blocks. Because the substance promoted the elongation of the coleoptile sections. it was eventually named **auxin** from the Greek *auxein*, meaning “to increase” or “to grow.”

In 1913, another Danish plant physiologist, **Peter Boysen-Jensen** took up the study after cutting of the tip of the coleoptiles, replacing it alone, replacing it on agar, and replacing it on butter, he concluded that the tips of coleoptiles do not have to be in their normal position to affect growth, and the "influence" that controls phototropism can move through agar.

Boysen-Jensen reasoned that this "influence" was probably water soluble chemical since it could move through agar. Later he tested it with butter and it did not work, he also tested it with pieces of platinum foil to see if it has any electrical signal, and again it did not work.

In 1918, the Hungarian plant physiologist **Arpad Paal** took up the effort. Paal's study involved replacing the cut off coleoptiles on other side and also manipulating light situations. His findings suggested that the tip of the coleoptiles produces a substance that moves down and

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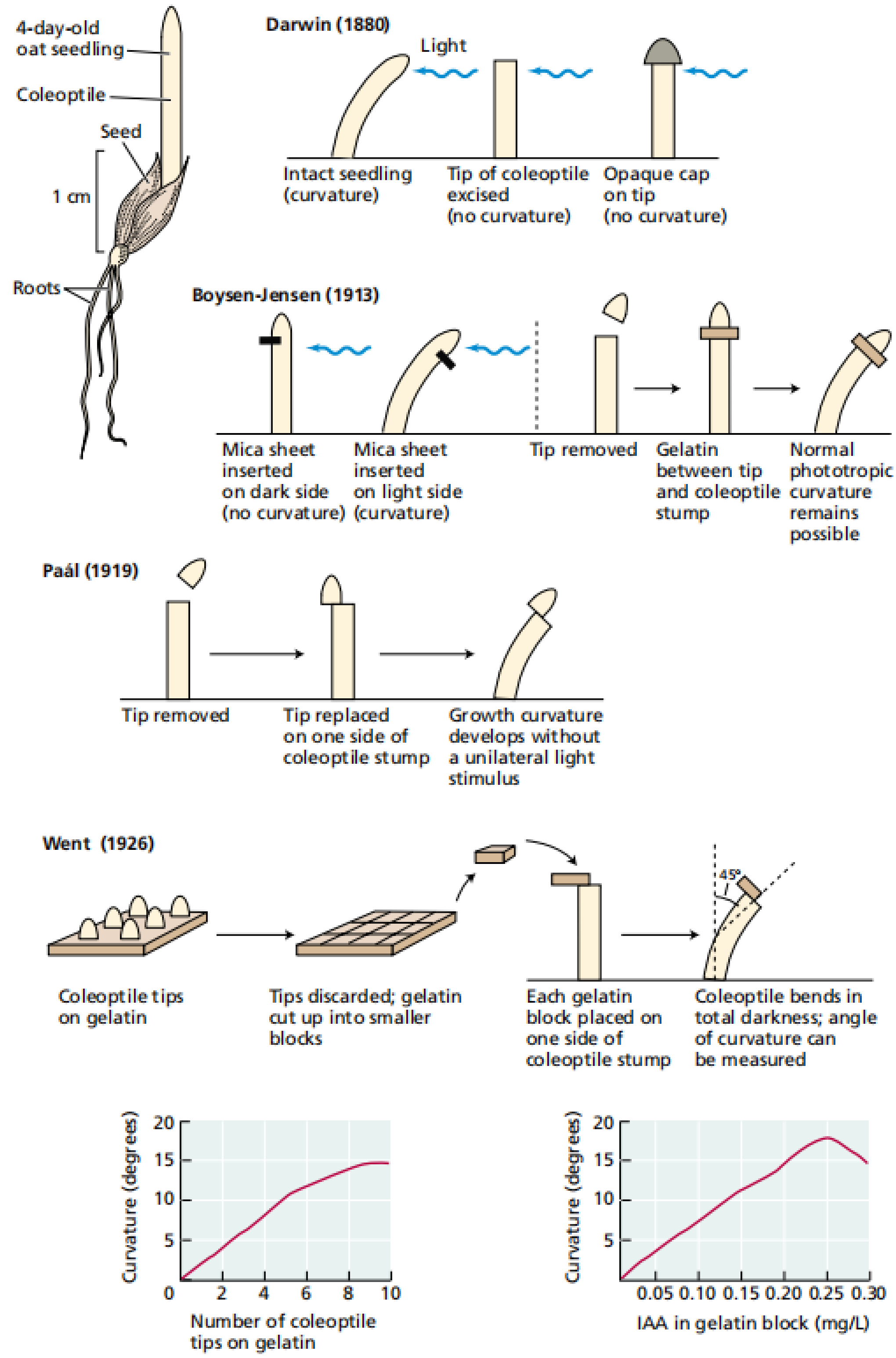
stimulate growth, and more importantly, that light must cause it to accumulate on the shaded side of the coleoptiles.



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Decapitated coleoptiles without agar blocks did not grow. Agar blocks that had not contacted cut tips of coleoptiles elicited no response when they were placed on decapitated coleoptiles. When agar blocks that had contacted cut tips were placed on the center of the decapitated. Coleoptiles, they grew straight up. Thus the coleoptiles tips had produced a chemical that diffused into the agar, and this chemical stimulated the growth of coleoptiles.
When agar blocks that had contacted cut tips were placed on one side of the decapitated coleoptiles, they curved away from the agar blocks. This growth away from the agar blocks was similar to phototropic curvature even though the plants were kept in the dark, and the tips were absent. These results indicated that the agar blocks contained a chemical that stimulated the growth of coleoptiles.

Went concluded that phototropic curvature was not due to the mere presence of coleoptiles tip, but rather due to a chemical coming from the coleoptiles tip that stimulated growth. He named this chemical **AUXIN (from the Greek word auxein, meaning "to grow").**

Auxin does, infact, influence phototropism; light striking one side of a coleoptiles causes auxin to migrate to the shaded side of the coleoptile, where it stimulates growth and causes growth toward light.

According to Went's explanation, auxin fit the definition of a hormone, it was made in one part of the plant **(the tip of the coleoptile)** and transported to another part (the growing region of the coleoptile),m where it caused a response **(increased growth).**
Who pioneered the efforts that led to the discovery of auxin?

Self-Assessment Exercise 1

What was arpad Paal’s contribution to the discovery of Auxins?

1.3.2 Synthesis of Auxin

The most active naturally occurring auxin in plants is **Indole-3-acetic acid,** or **IAA.** The most active areas of IAA synthesis are shoot tips, embryos, young leaves flowers, fruits and pollen.

There are two other naturally occurring Auxins: 4-chloro-IAA and phenylacetic acid. The precise roles of these auxins in plant growth and development are unknown, and they are generally less active than IAA.

1.3.2.1 Synthetic Auxins

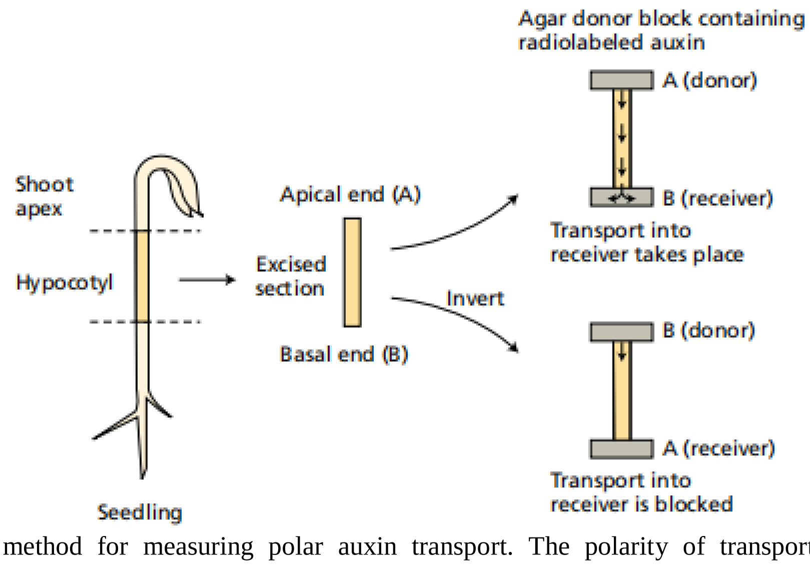
Although IAA is the most naturally occurring auxin, several synthetic compound have auxin-like effects. Synthetic auxins like 2, 4-D (2,4- dichlorophen-oxyacetic acid) and NAA **(Naphthalene acetic acid)** have structures that resemble IAA

Synthetic auxins such as 2,4-D are used extensively as herbicides because they are inexpensive, relatively non-toxic to humans and have selective effect, they kill broadleaf dicots but not monocots. The exact mechanism for this selectivity is unknown. Synthetic auxins are also used to prevent preharvest dropping of fruit, to produce roots on cuttings, and to inhibit sprouting of lateral buds ("eyes") on Irish potatoes.

Unfortunately, the effects of synthetic auxins on human physiology have not all been positive. Agent Orange **(a1:1 mixture of 2,4,5-T and 2, 4- D)** that was used during the Vietnam war destroyed forests, and thousands of pilots and Vietnamese citizen who were exposed to it had increased occurrence of miscarriages, birth defects, leukemia, and other types of cancer.

1.3.3 Transport of Auxin

IAA moves primarily through parenchyma cells of the cortex, pith and vascular tissues. It moves polarly in roots and stems



The standard method for measuring polar auxin transport. The polarity of transport is independent of orientation with respect to gravity

The polar transport of auxin (shaded).

(a) ***When the coleoptile section remains right-side-up auxin moves through to the acceptor block below.***

(b) ***No auxin moves through an inveried coleoptile section.***

Polar transport requires energy; thus inhibitors of ATP synthesis block the transport of IAA. In stems, IAA is transported basicpetally, meaning that it moves towards the base. Basipetal transport in stem continueseven if the stem is inverted so that the apex is pointing down wards in roots, IAA is transported **acropetally**, meaning that it moves towards the tip. IAA made in mature leaves moves non-polarly in the phoem.

1.3.4 Physiological Effects of Auxin

Auxins affect plants in many ways,

1. Cellular Elongation in Grass Seedlings and Herbs

This will be looked at from two perspectives.

(a) Short-term Effects

There are two requirements for cellular elongation

1. Positive Tugor Pressure:
2. Increased plasticity (stretch-ability) of the cell wall. Tugor pressure in cell result primarily from the presence of dissolved solutes and is not significantly affected by IAA. However, IAA does increase the plasticity of the, cell wall. IAA does this in several ways:

i. IAA stimulates H+ pumps in the plasmalemma
ii. Once activated, these pumps secret H^+ into the cell wall decreasing its pH to 5.0
iii. This acidification of the cell wall' activates pH dependent enzymes that break bonds between cellulose micro fibrils.
iv. When these bonds break, the wall "loosens" and tugor pressure causes the cell to expand.

b. Long-Term Effects

Growth induced by acid stops after 1-3 hours, while growth induced by IAA continues much longer. Therefore, acid-growth may account for only the early stages of IAA induced growth, whereas, the long term growth continues. This suggests that IAA may act at the gene level possibly by activating a gene required for making a protein necessary for growth.

2. Apical Dominance:

IAA stimulates the production of ethylene, another plant hormone. IAA coming from the shoot tip stimulates cells around lateral buds to make ethylene and this ethylene made in response to the promptings of IAA inhibits bud growth. Cytokinins (another plant hormone) coming from rot also influence apical dominance .

These observation emphasize another generalization we can make about plant hormones namely, a single aspect of growth and development can be influenced by several hormones, a particular response probably results from changing ratios of hormones rather than from the presence or absence of an individual hormone.

3. Abscission

Another example of the interaction of IAA and other plant hormones is abscission which is the shedding of leaves or fruits by a plant.

Abscission occurs like this

i. Actively growing leaves and fruit produce large amount of IAA which is transported to the stem. This IAA along with cytokinin and gibberellins from the roots retard the onset of senescence and abscission.
ii. Environmental stimuli drought, wounds or nutrient deficiency may cause decreased production of IAA. This begins senescence (aging).
iii. Some signals stimulated cells in the abscission zone to expand, suberize and produce cellulose and pectinase.
iv. Cellulose and pectinase digest the middle lamella, which usually cements cells of the abscission zone together.
v. As a result of the wall digestion and concurrent cellular expansion, the cells.

4. Differentiation of Vascular Tissues

The vascular cambium is activated in the spring by IAA produced by young developing leaves. Gibberellin is also involved. A high auxin/gibberellin ratio promotes the differentiation of xylem, while a low ratio favours differentiation of phloem.

Non-hormonal factors such as sugars produced in leaves also influence the effect of IAA on celluar differentiation for example:

Auxin plus small amounts (2%) of sucrose favour differentiation of xylem
Auxin plus moderate amounts 93%) of sucrose favour differentiation of xylem and phloem.
Auxin plus large amounts (4%) of sucrose favor differentiation of phloem.

These observations illustrate our next generalization about plant hormones. Physiological responses elicited by hormones are strongly influenced by non hormonal factors.

5. Fruit Development

The sources of auxins that stimulate fruit development are seeds in fruit. For example fruits of strawberry are dispersed across a swollen receptacle, IAA from the seed in each fruit triggers development of the adjacent portion of the receptacle. Thus strawberries do not develop when the fruits (i.e the sources of IAA are removed. (Similarly when fruits are removed from the half of the strawberry, only the remaining half develops normally.

6. Formation of Adventitious Roots

Nurseries and amateur gardeners exploit the ability of auxin to stimulate the formation of adventitious roots to propagate plants. The procedure is simple: cut surfaces of pieces of parent plant are dipped in a solution of synthetic auxin. The auxin stimulates the formation of adventitious roots at the cut surface. *List the 3 naturally occurring auxins*

Self-Assessment Exercise 2

How do Auxins help in formation of adventitious roots?

Self-Assessment Questions

1) What is the main benefit of synthetic auxin?

Answer: *Synthetic auxins such as 2,4-D are used extensively as herbicides because they are inexpensive, relatively non-toxic to humans and have selective effect, they kill broadleaf dicots but not monocots*

*2.**How is Auxin transported?***

Answer: *IAA moves primarily through parenchyma cells of the cortex, pith and vascular tissues. It moves polarly in roots and stems.*

1.4 SUMMARY:

Most of the physiological activities and growth in plantsare regulated by action and interaction of plant hormones, also called phytohormones. Plant hormones are organic substances produced naturally in higher plants , controlling physiological functions at a site remote from its place of production and active in minute amounts.

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1.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1

In 1918, the Hungarian plant physiologist **Arpad Paal** study involved replacing the cut off coleoptiles on other side and also manipulating light situations. His findings suggested that the tip of the coleoptiles produces a substance that moves down and stimulate growth, and more importantly, that light must cause it to accumulate on the shaded side of the coleoptiles.

Answers to SAE 2

The procedure is simple: cut surfaces of pieces of parent plant are dipped in a solution of synthetic auxin. The auxin stimulates the formation of adventitious roots at the cut surface.

UNIT 2 DISCOVERY AND CHEMICAL NATURE GIBBERELLINS

Unit Structure

2.1 INTRODUCTION

In the 1950s the second group of hormones, the gibberellins (GAs), was characterized. The gibberellins are a large group of related compounds (more than 125 are known) that, unlike the auxins, are defined by their chemical structure rather than by their biological activity. Gibberellins are most often associated with the promotion of stem growth, and the application of gibberellin to intact plants can induce large increases in plant height. However, gibberellins play important roles in a variety of physiological phenomena.

We begin this unit by describing the discovery, chemical structure, and role of gibberellins in regulating various physiological processes, including seed germination, mobilization of endosperm storage reserves, shoot growth, flowering, floral development, and fruit set. We then examine biosynthesis of the gibberellins, as well as identification of the active form of the hormone.

2.2 INTENDED LEARNING OUTCOMES

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

- describe how gibberellins was discovered
-explain how gibberellins are synthesized in plants
-discuss gibberellins' physiological effects

2.3 Main Contents

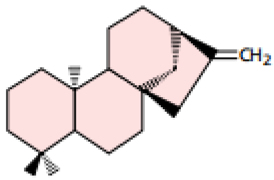
2.3.1 DISCOVERY OF GIBBERELLINS

Although gibberellins did not become known to American and British scientists until the 1950s, they had been discovered much earlier by Japanese scientists. Rice farmers in Asia had long known of a disease that makes the rice plants grow tall but eliminates seed production. In Japan this disease was called the "foolish seedling," or *bakanae*, disease. Plant pathologists investigating the disease found that the tallness of these plants was induced by a chemical secreted by a fungus that had infected the tall plants. This chemical was isolated from filtrates of the cultured fungus and called *gibberellin* after *Gibberella fujikuroi*, the name of the fungus.

In the 1930s Japanese scientists succeeded in obtaining impure crystals of two fungal growth-active compounds, which they termed *gibberellin A* and *B*, but because of communication barriers and World War II, the information did not reach the West. Not until the mid-1950s did two groups—one at the Imperial Chemical Industries (ICI) research station at Welyn in Britain, the other at the U.S. Department of Agriculture (USDA) in Peoria, Illinois—succeed in elucidating the structure of the material that they had purified from fungal culture filtrates, which they named *gibberellic acid*.

At about the same time scientists at Tokyo University isolated three gibberellins from the original gibberellin A and named them gibberellin A1, gibberellin A2, and gibberellin A3. Gibberellin A3 and gibberellic acid proved to be identical. It became evident that an entire family of gibberellins exists and that in each fungal culture different gibberellins predominate, though gibberellic acid is always a principal component. The structural feature that all gibberellins have in common, and that defines them as a family of molecules, is that they are derived from the *ent* kaurene ring structure.

Because the concentration of gibberellins in immature seeds far exceeds that in vegetative tissue, immature seeds were the tissue of choice for gibberellin extraction. However, because the concentration of gibberellins in plants is very low (usually 1–10 parts per billion for the active gibberellin in vegetative tissue and up to 1 part per million of total gibberellins in seeds), chemists had to use truckloads of seeds. As more and more gibberellins from fungal and plant sources were characterized, they were numbered as gibberellin AX (or GAX), where *X* is a number, in the order of their discovery. This scheme was adopted for all gibberellins in 1968. However, the number of a gibberellin is simply a cataloging convenience, designed to prevent chaos in the naming of the gibberellins. The system implies no close chemical similarity or metabolic relationship between gibberellins with adjacent numbers.



ent-Kaurene

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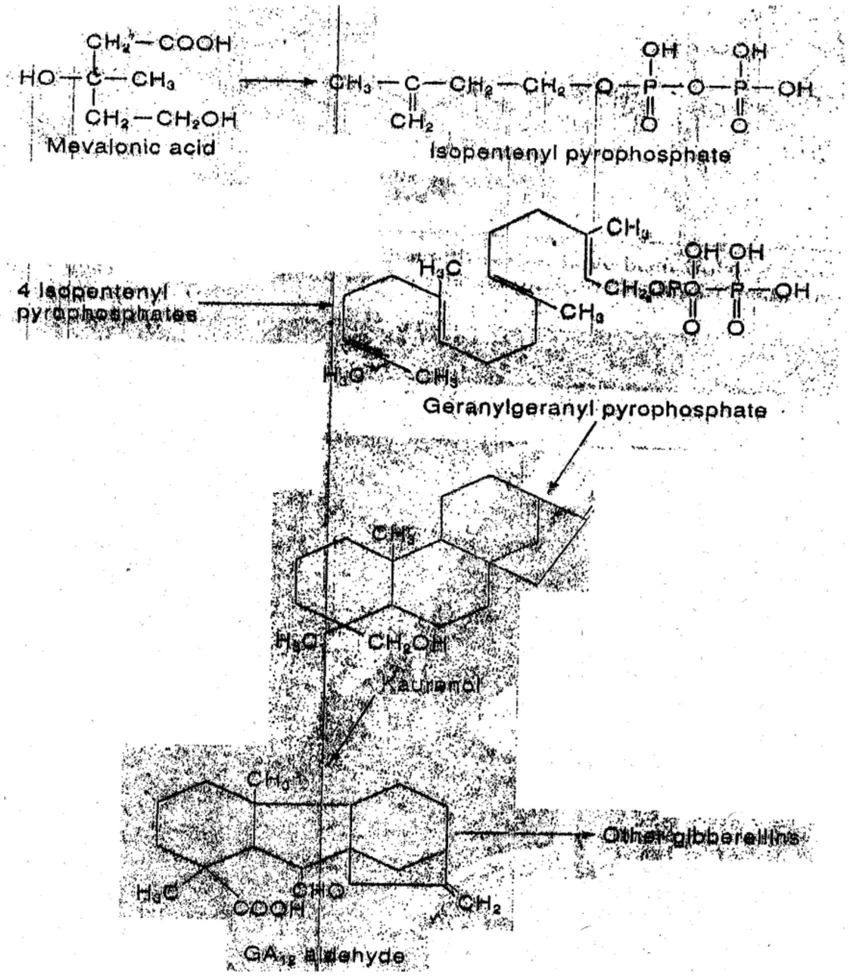
2.3.2 Synthesis and Transport

Gibberelin is made through the mevalonic acid pathway



Gibberellin is made via the mevalonic acid pathway

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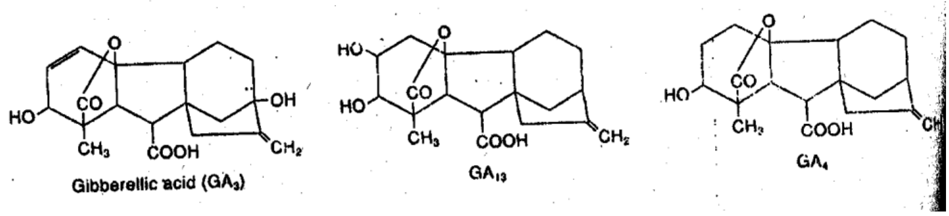
More than eighty gibberellins have been isolated from various fungi and plants. Each of the gibberellins has an inter locking ring structure and one or more carboxyl groups that impart acidic properties to the molecule.



Three of the more than 80 gibberellins that have been isolated from various fungi and j plants. All gibberellins have an interlocking structure and one or more carboxyl groups that impart acidic properties to the molecules.

Gibberellins are abbreviated GA (for gibberellic acid) and assigned subscripts; that distinguish them from each other. For example. GA_3 is isolated from Gibberella fujikuroi and is the most intensively studied gibberellin. Several commercial compounds inhibit the synthesis of gibberellins. These inhibitors are called growth retardants and include phosphon D, Cycocel (CCC) and Ancymidol. Growth retardants inhibit stem elongation.

Most gibberellins are active and are precursors of more active ones GA, is probably the only gibberelin that controls stem elongation in angiosperms.

Gibberellins occur in angiosperms, gymnosperms, mosses, ferns, algae and fungi but are unknown in bacteria in angiosperms, they occur in immature seeds, spices of root and polar, it moves in all direction in the xylem and phoem. *Who pioneered the effort that led to the discovery of giberellin.*

Self-Assessment Exercise 1

Why are seeds preferred source of Gibberellins?

2.3.3 Effects of Gibberellins

1. Extensive growth of intact plants

Many dwarf mutants normally grow if given GA, and their sensitivity to GA is striking. For example, dwarf pea seedling, response to as little as one-billionth of a gram of gibberellin. Dwarfism does not result from the absence of GA, but rather from the absence of active GA. Some dwarf plants contain a lot of GA but of the inactive variety.

GA induces cellular division and cellular elongation IAA induces cellular elongation only.

GA – stimulated elongation does not involve the cell-wall acidification characteristic of IAA induced elongation.

Thus we identify another generalization about plant hormones. Different hormones can elicit similar effects via different mechanisms.

2. Seed Germination

GAs play a critical role in seed germination in cereal grasses such as barley in this way.

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i. The sequence of events leading to seed germination begins with **imbibition** which is the absorption of water by a seed. Imbibition causes the embryo to release GA.

ii. These GA stimulate transcription of genes of hydrolytic enzymes in the seeds' **aleurone layer,** a specialized layer of the endosperm
2-4 cells thick located just inside the seed coat. GA enhances the
transcription of amylase mRNA.

iii. The hydrolytic enzymes are secreted by dictyosomes into the seeds endosperm. One of the hydrolytic enzymes produced by the aleurone layer amylase catalyses the conversion of starch to sugar, which is used as an energy source for the growing seeding.

3. Juvenility

Many plants have a juvenile stage and an adult stage of growth. For example juvenile stages of eucalyptus have leaves that are shaped differently than those of adult stages.

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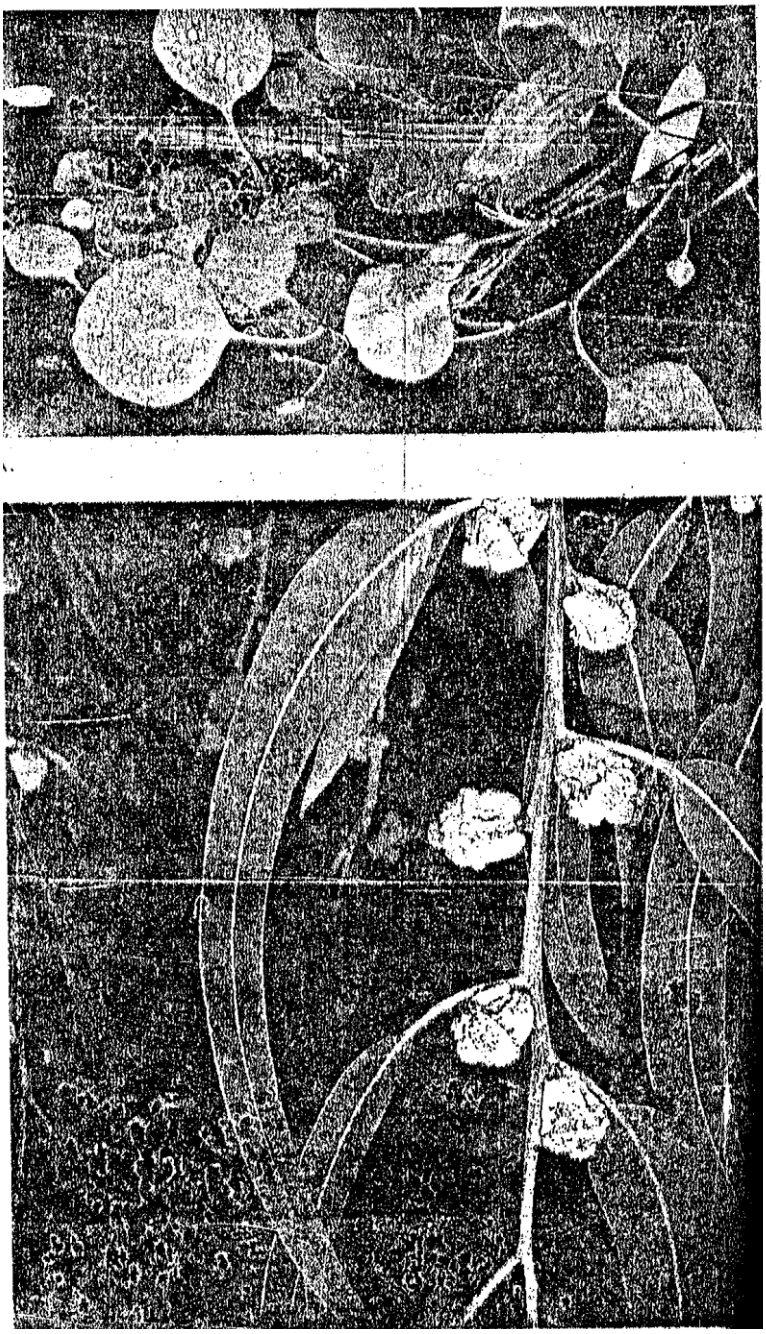

(a) Juvenile and (b) mature leaves in Eucalyptus globules are shaped differently. Juvenile leaves are softer and opposite each other, with spirally arranged and have palisade on both sides.

Gibberllins may help determine whether a particular part of a plant is juvenile or adult. For example, the buds of adult branches, usually develop only into adult branches but treating them with GA causes them to grow into juvenile branches.

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4. Flowering

During their first year of growth, biennial plants such as cabbage have short internodes. These plants are called rosettes because their tightly paced leaves are arranged like the petals of a rose. The rapid expansion of internodes and formation of flower by rosette plants in response to cold is referred to as **bolting**. Applying GA to rosette plants also induces bolting, suggesting that cold temperatures somehow stimulates the synthesis of GA during the following season.

5. Fruit Formation

The most important commercial use of gibberellin involves their ability to increase the size of seedless grapes. Indeed, almost all vines of the "Thompson seedless grape grown in California are sprayed with GA each year. As a result the grapes increase in size almost three fold and are more loosely paced making them less susceptible to fungal infections.
How does GA help in germination?

Self-Assessment Exercise 2

What is Bolting?

Self-Assessment Questions

1) List 5 effects of Giberrellins
Growth, seed germination, juvenility, flowering and fruit formation

2.4 SUMMARY

Gibberellins stimulate extensive growth of intact plants, the transition from juvenile to adult growth, bolting of biennials, fruit formation and germination and germination of some cereal grains.

2.5 References/Further Reading/Web Sources

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2.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1

Because the concentration of gibberellins in immature seeds far exceeds that in vegetative tissue, immature seeds were the tissue of choice for gibberellin extraction. However, because the concentration of gibberellins in plants is very low (usually 1–10 parts per billion for the active gibberellin in vegetative tissue and up to 1 part per million of total gibberellins in seeds), chemists had to use truckloads of seeds

Answers to SAE 2

The rapid expansion of internodes and formation of flower by rosette plants in response to cold is referred to as **bolting**

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UNIT 3 : Discovery and chemical nature of Cytokinins, Ethylene and Abscisic acid

Unit Structure

3.1 INTRODUCTION

Plant hormones are organic compounds made in small amounts in one part of the plant and transported to another part where they initiate physiological response. The five major classes of hormones are auzin, gibberellins, cytokinins, abscisic acid, and ethylene. These hormones have several characteristics features: they are made by the plant, are active in small quantities, are transported to other parts of the plant, and can elicit a response.

In this unit, we will conclude our discussion of plant hormones by looking at cytokinins, ethylene and Abscisic Acid (ABA). From our discussions, you will notice some generalization about plant hormones. We will try to fit in the characteristics/effect of the hormones that we study into these general characteristics as we go along.

3.2 INTENDED LEARNING OUTCOMES

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

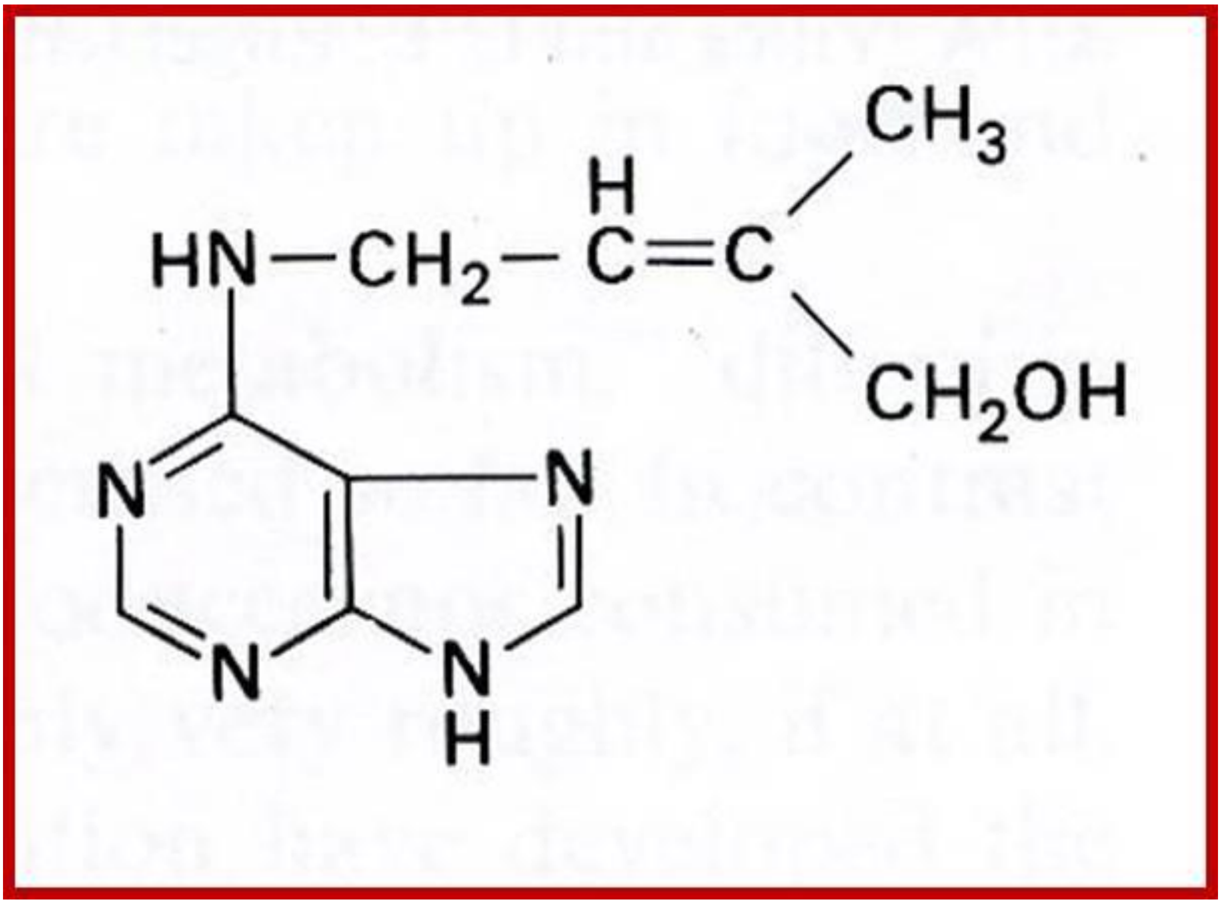
-state how cytokinins, ethylene and ABA were discovered
-describe how cytokinins, ethylene ABA are transported
-list the effect of cytokinins ethylene and ABA
-compare the mode of action of cytokinins, ethylene and ABA
-explain why calcium is regarded as a messenger in hormone transport?
-explain why botanists find it difficult to accept oligosaccharins as plant hormone
.

3.4 Main Contents

3.3.1 CYTOKININ DISCOVERY

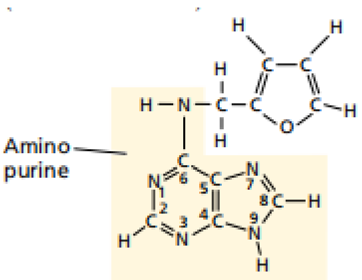
The trail leading to the discovery of cytokinins can be traced to **Gottlie Haberlandt** who reported in 1913 that an unknown compound in vascular tissue stimulated cellular division. In the 1940s, botanist **Johannes Van Overbeek** observed that plant embryos grew faster when supplied with coconut milk. Later in the 1950s. **Folke Skoog** and Carlos **Miller** started another set of studies at the University of Wisconsin After a series of attempt. They were able to isolate the growth factor responsible for cellular division from a DNA preparation. They named this substance Kinetin. And they named the class to which Kinetin belong cytokinins because these substance stimulated cytokinesis, or cellular division.

The first naturally occurring cytokinins was isolated in 1964 from com (Zean mays) and was named **zeatin**.



Cytokinins

Soon thereafter, the influence of coconut milk on cellular division was explained when it was shown to contain zeatin and zeatin riboside, another cytokinins. Since then, botanists have isolated other naturally occurring cytokinins (e.g. kinetina and 6-benzylamino purine). All of these cytokinins have structures similar to adenine: that is, they have a side chain rich in carbon and hydrogen attached to nitrogen protruding from the top of the purine ring. Cytokinins are often minor components of RNA but we do not know if these cytokinins are related to free cytokinins in cells.



Kinetin

3.3.2 SYNTHESIS AND TRANSPORT

Contrary to what was believed, cytokinins are not breakdown products of DNA rather, they are made via mevalonate pathway, the same pathway used to make gibberellins. Cytokinins are widespread, if not universal, in plants: they have been isolated from angiospers. Gymnosperms. Mosses, and ferns. In angiosperms mot cytoinins are made in rots, and also occur in seed, fruit and young leaves. Cytokinins move non-polarly in xylem, phloem, and parenchyma cells.

3.3.3 EFFECTS OF CYTOKININS

Although cytokinins have relatively few uses in agriculture, they do strongly affect plant growth and development.

i. Cellular Division

Cytokinins stimulate cellular division by hastening the transition of cells from the G2 phase (the growth phase following DNA replication) to the M phase (mitosis) of the cell cycle. This effect depends on the presence of auxin. For example, cytokinins alone have no effect on cultured tobacco cells; cellular division begins only when auxin is added to the culture medium.

The discovery that cytokinins promote cellular division raised another interesting question: could cytokinins be responsible for animal cancers, which result from uncontrolled cellular division. Research has demonstrated repeatedly that cytokinins have no effects on animal cells and that here is not direct link between animal cancers and cytokinins.

ii. Effect on Cotyledons

Cytokinins promote cellular division and expansion in cotyledons. Cellular expansion result from cytokinin-induced increase in wall plasticity that do not involve wall acidification. Cytokinins also increase the amount of sugars (especially glucose and fructose) in cells, which may account for the osmotic influx of water and the resulting expansion of cytokinins-treated cells in cotyledons.

iii. Organogenesis

Cytokinis and IAA affect organogenesis, which is the formation of organs shows the influence of changing amounts of cytokinins and IAA on the formation of shoots and roots. Cultured cells grow only in the presence of cytokinin and IAA. High cytokinin/auxin ratio favour the formation of shoots while low ratios favor the formation of roots. Thus, a plant can be completely regenerated from single cells by varying the amounts of cytokines and IAA. This hormonally controlled means of pant regeneration has been used to propagate plants that are resistant to pathogens, drought and other stresses.

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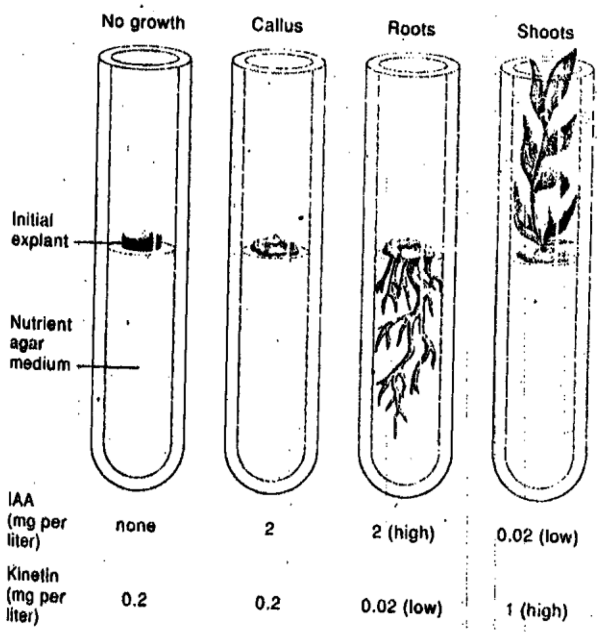

The responses of plant tissue culture to kinetin and auxin. The initial explant is a small piece of sterile tissue cut from the path of a tobacco plant. High ratios of auxin/cytokinia favor the formation of roots, while low ratios of auxin/cytokinin favor the formation of shoots.

iv. Senescence

Cytokines delay the breakdown of chlorophyll in detached leaves, apparently by preventing genes that stimulate chlorophyll formation form being turned off. Cytokines treated areas of leaves remain healthy as the remaining plants of the leaf senesce. This effect of cytokines may be due to its ability to establish a "sink" to which nutrients move. However, the cytokine induced delay in leaf senescence occur only in detached leaves. Leaf senescence is also delayed by the formation of adventitious roots. Roots you will recall, are rich in cytokines; and the transport of these cytokines to leaves could account for the delayed senescence.

Cytokinins are sometimes used commercially to maintain the greenness of excised plant parts, such as cut flowers. Their use on edible crops is banned because it could be a potential carcinogen.

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BIO203

Which scientist pioneered research effect in chytokinins discovery

Self-Assessment Exercise 1

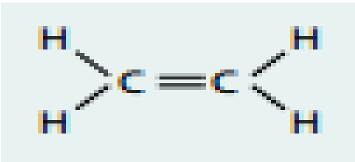
What is the effect of cytokinins on cotyledon

3.3.4 Ethylene Discovery

During the 1800s, the city streets of Germany were illuminated by lamps that burned "illuminating gas" soon after these lamps were installed, city residence made a curious observation, plants growing near the lamps had short, thick steams. Furthermore, the leaves fell off of most of these plants. Where these effects caused by the lamps light, heat or some other factors?

This question was answered in 1901 when Soviet plant physiologist **Dimitry Neljubow** identified ethylene as the combustion product of "illumination gas" that was responsible for defoliating and inhibiting the elongation of plants growing near the lamps.

In 1910 an annual report to the Japanese Department of Agriculture recommended that oranges not be stored with bananas. This "something" was not identified until 1934, when **R. Gane** showed that ethylene is made by plants and that it causes faster ripening of many fruits, including bananas. Substances research showed that ethylene met the requirements of plant hormone; it is made in one part of a plant and transported to another, where it induces a physiological response. Thus, was discovered the first gaseous plant hormone; ethylene.



Ethylene

3.3.5 Synthesis and Transport of Ethylene

Ethylene is made from methionine an amino acid

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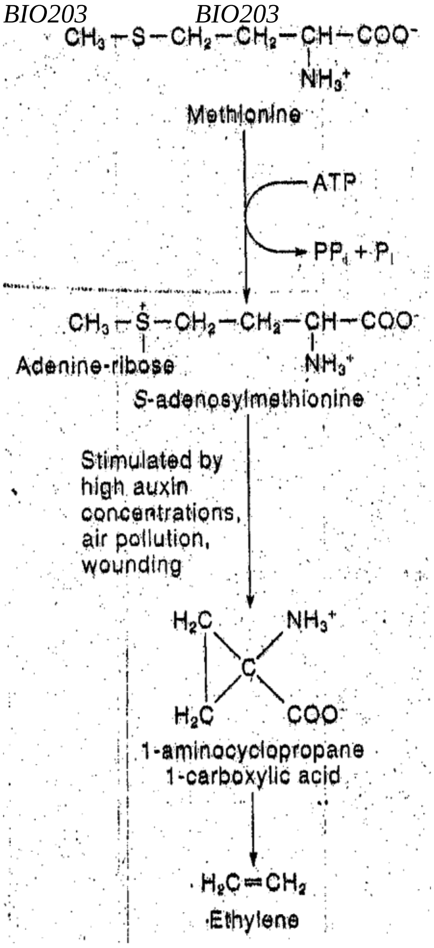


Bio synthesis of ethylene from Methionine , which serves as a precursor of ethylene in a pi- higher plant tissues. I-amino cyclopropane-I-carboxylic acid is the immediate precursor of ethylene.

Its synthesis is inhibited by CO_2 and requires oxygen. When plants are placed in pure CO_2 or O_2 free air, ethylene synthesis decreases dramatically.

All parts of angiospenns make ethylene but especially large amounts are released into the air by roots, the shoot apical meristems, nodes, senescing flowers and ripening fruits (e.g the dark flecks on a ripening banana peel are concentrated pockets of ethylene). Because most ethylene induced effects result from ethylene in the air, the effects of ethylene can be contagious. Ethylene made by one "bad" (i.e, overripe) apple can "spoil" (i.e induce rapid ripening of) an entire bushel of apples.

3.3.6 Effects of Ethylene

i. Fruit Ripening

The ancient Chinese knew that fruit would ripen faster if placed rooms containing burning incense. The factor responsible for this hastened ripening was not heat" but ethylene released as the incense burned. This stimulation of fruit ripening by ethylene is multifaceted and includes the breakdown of chlorophyll and synthesis of other pigments. **(i.e apples changing from green to red during ripening).** Fruit softening due to the breakdown of cell walls by cellulose and pectinase, production of volatile compounds associated with the scent of fruit, and conversion of starches and acids to sugar. Ethylene stimulates each of these aspects of fruit ripening.

In fruits such as tomatoes and apples, there is a conspicuous increase in respiration immediately before fruit ripening. This increase in respiration is called a **climacteric**, and fruits that display it are referred to as **climacteric fruits** (e.g Apples). The climacteric begins after a huge increase in ethylene production. Thus the climacteric and fruit ripening are triggered by ethylene.

Not all fruit can be ripened by exposure to ethylene, however. Such fruits (e.g grapes) are called Non-climacteric fruits and are insensitive to ethylene.

ii. Flowering

Ethylene inhibits flowering in most specier but promotes it in few plants including mangoes, pineapples and some ornamental plants. This effect was known long ago by Puerto Rican pineapple growers and Filipino, mango growers who set bonfire near their crops. The fires produced ethylene, which initiated and synchronized flowering of their plants.

Ethylene also promotes senescence of flowers. When pollens germinate, the stigmas of flowers produce large amounts of ethylene that trigger senescence of floral part.

iii. Abscission

The increased production of ethylene at the abscission zone triggers the breakdown of the middle lamella, and thereby initiates abscission.

iv. Sex Expression

The sex of flowers on monoecious plant (that is, plants that have male and female flowers on the same individual) is determined by ethylene and gibberellins. For example, cucumber buds treated with ethylene become carpellate flowers whereas those treated with gibberellins become staminate flowers. Correspondingly, buds that ultimately become carpellate flowers produced more ethylene than do buds that become staminate flowers.

v. Stem Elongation

Mechanical disturbances such as shaking decrease elongation. This effect called thigmomorphogenesis is mediated by ethylene. Mechanical disturbances increase ethylene production several fold which causes cells to arrange their cellulose micro-fibrils into longitudinal hoops. This lengthwise reinforcement inhibits cellular elongation, causing cells to expand radically and form short, thick stems. This effect is the opposite of that of auxins which causes cells to orient their microfibrils more transversely, thereby accounting for cellular elongation.

vi. Water Logging

Ethylene synthesis is greatly reduced in water logged plants, because these plants do not have access to enough oxygen which is required in ethylene production. The small amount of ethylene that is made in these roots is trapped where it accumulates and eventually stimulates the activity of cellulose and pectirose. These enzyme break down, the cell wall and in *so* doing, form the many intercellular spaces characteristic of hydrophytes. Meanwhile ethylene precursors in the shoot are converted to ethylene, which causes parenchyma cells on the upper side of the petiole to expand and point the leaf down, a response called **episnasty.**

3.3.7 Ethylene and Auxin

IAA stimulates ethylene production, thereby linking the responses of these two hormones. But ethylene does not account for all of the effect elicited by applying IAA. Several responses of plants to IAA are unrelated to ethylene. For example, IAA's stimulation of cellular elongation occurs independently of ethylene. Conversely, leaf epinasty and decreased elongation of roots are responses to ethylene rather than IAA. *What is relationship between auxin and ethylene?*

Self-Assessment Exercise 2

How does Etylene bring about fruit ripening?

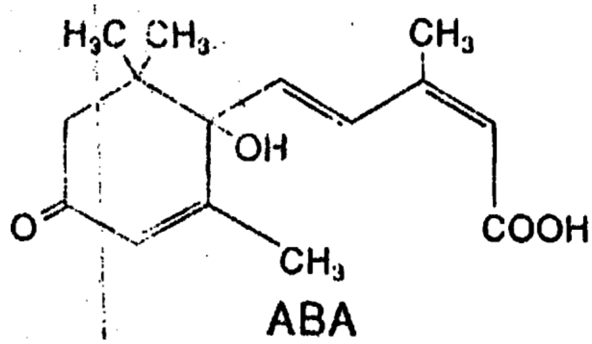
3.3.8 Abscisic Acid Discovery

By the 1940s botanists suspected that some aspects of plant growth and development resulted from inhibition rather than stimulation of growth. Near the end of that century, **Torsten Hemberg** of Sweden confirmed that dormant buds of ash and potato contained inhibitors that blocked the effects of IAA. When the buds germinated the amount of these inhibitors decreased. Hemberg named these inhibitors **Dormins.**

In the early 1960's, **Philip Wareing** confirmed Hemberg's finding and reported that applying dormin to a bud induced dormancy. At about the same time, F. T. **Addicot**t discovered a compound that stimulated abscission of cotton fruit. He named this substance **abscisin**. Botanists later were surprised to discover that dormin and abscisin were the same compound. This compound was renamed **abscisic acid or ABA** and unfortunately name, because subsequent research has shown that ethylene rather than ABA controls abscission.

3.3.9 Synthesis and Transport

ABA in Plants is made from caratenoids. It occurs in angiosperms gymnosperm, and mosses, but apparently not in liveworts. Once synthesized ABA moves throughout a plant in xylem, phloem and parenthyma. Like gibberel1ims and cytokinin, ABA moves non polarly.



The structure of abscisic (ABA)

ABA in plants is made from carotenoids. It occurs in angiosperms, gymnosperms, and mosses, but apparently not in liverworts. Once synthesized ABA moves throughout a plant in xylem, phloem and parenchyma. Like gibberellins and cytokinin ABA moves non polarly. There are no synthetic abscisic acid.

3.10 Effects of Abscisic Acid

1. Closure of Stomata

During drought, leaves make large amounts of ABA which causes stomata to close. Thus ABA functions as a messenger that enables plants to conserve water during drought. Because ABA closes stomata within
1-2 minutes, this effect probably occurs independently of protein synthesis. A plants tolerance to drought may, related to its ability to make ABA. In some species the levels of ABA increases by as much as 10-fold within minutes after wilting occurs.

2. Bud Dormancy

ABA was initially thought to control bud dormancy, but recent evidence questions this conclusion. Affected leaves are treated with radioactive ABA, no radioactivity can be detected in buds. In several plants, the induction and breaking of dormancy do not correlate with changes in endorgenous amounts of ABA Treatments that induce dormancy do not alter the amounts of ABA in buds.
These results suggest that dormancy is not controlled by ABA alone, but is probably influenced by cytokinins and IAA induced synthesis of ethylene.

3. Seed Dormancy

Applying ABA delays seed germination in many species. Similarly, the amount of ABA in the seeds of many plants decreases when seeds germinate. Thus, ABA may control seed dormancy in certain species. This condition may not apply to all plants, however, since germination of many seeds occurs without any changes in the amount of ABA.

4. ABA Counteracts Stimulatory Effects of Other Hormones

ABA usually inhibits the stimulatory effects of other hormones. For example ABA

i. Inhibits amylase produced by seeds treated with gibberellins ii. Promotes chlorosis that is inhibited by cytoinins
iii. Inhibits wall elasticity and cell growth promoted by IAA.

ABA is a Ca^{2+} antagonist, thus its inhibition of the stimulatory effects of IAA and cytokinin may be due to its interference with CA^{2+} metabolism. *In what areas do ABA counteracts the effects of other hormones?*

3.3.11 Other Plant Hormones

Investigations have identified other compounds that function as hormones in various groups of plants. These include:

(a) Oligosaccharins

Oligosccharins control plant growth, differentiation, reproduction and defense against disease. To this extent they function as plant hormones. But unlike hormones they elicit specific effects from different species. For example oligosaccharins that inhibit flowering and promote vegetative growth in one species have the same effects another species. Also, they are released from cell walls by enzymes. Different oligosaccharins are released by different enzymes and each one transmits a message that regulates a specific function. This specificity has prompted several botanists to suggest that the many effect of hormones like IAA and gibberellins may be due to the activation of enzymes that release specific oligosaccharins.

(b) Batasins

This is contained in yam and induces dormancy of bulbils (vegetative reproductive structures) that form from lateral buds.

(c) Brassosteroids

Are plant hormones in tea, bean and rice plants that stimulate growth of stems. *What are the less known plant hormones?*

Self-Assessment Questions

1) ***How is ABA transported?***

Answer*: Once synthesized ABA moves throughout a plant in xylem, phloem and parenthyma. Like gibberel1ims and cytokinin, ABA moves non polarly.*

2) ***What are the physiological effects of Ethylene****?*

Answer*: Fruit ripening, leaf epinasty, flowering, inhibition of root growth, senescence, abscission*

3.4 SUMMARY

This unit concludes the series on plant hormones. Plant hormones are organic compounds that are made in one part of a plant and transported to another part were they elicit a response. Their general characteristics are as follows:

i) Although a hormone may have some characteristic effects, it also has many other effects. That is, a single hormone can elicit many responses.
ii) The responses elicited by a hormone depend on many factors including the presence of other hormones, the amount of hormone present, non-hormonal factors, and the sensitivity of the tissues to the hormone.

3.5 References/Further Readings/Web Sources

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https://www.youtube.com/watch?v=KMLVNE_ruvM

3.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1
Cytokinins increase the amount of sugars (especially glucose and fructose) in cells, which may account for the osmotic influx of water and the resulting expansion of cytokinins-treated cells in cotyledons.

Answers to SAE 2
This stimulation of fruit ripening by ethylene is multifaceted and includes the breakdown of chlorophyll and synthesis of other pigments. **(i.e apples changing from green to red during ripening).** Fruit softening due to the breakdown of cell walls by cellulose and pectinase, production of volatile compounds associated with the scent of fruit, and conversion of starches and acids to sugar. Ethylene stimulates each of these aspects of fruit ripening.

Glossary
IAA= indole-3- acetic aci

NAA=Naphthalene acetic acid

ABA= Abscisic Acid

DNA= Deoxyribonucleic acid

GA= gibberellins

End of Module Questions

1) Oligosccharins control plant growth, differentiation, reproduction and defense against disease (**True or False)**
2) ABA moves throughout a plant in xylem, phloem and parenchyma. (**True or False)**
3) _____________ promote cellular division and expansion in cotyledons. (a) Auxins (b) cytokinins (c) ABA (d) Ethylene
4) Gibberelin is made through the mevalonic acid pathway (**true or False)**
5) ____________ moves primarily through parenchyma cells of the cortex, pith and vascular tissues (a) Auxin (b) Ethylene (c) Gibberellins (d) ABA

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MODULE 5

UNIT 1 PLANTS RESPONSIVE TO ENVIRONMENTAL STIMULI

Unit Structure

1.1 INTRODUCTION

Plants have evolved an intricate and elaborate set of intricate and dramatic responses to the environment. These responses allow plants not only to survive adverse conditions that would kill most animals, but also to coordinate their growth and development with appropriate environmental conditions.

Responses of plants to environmental stimuli such as light, gravity and touch occur in many ways and include such diverse events as flowering and the growth of stems towards light. Some of these behaviors are short-term responses eg. the closing of the leaf of *Mimosa pudica* when touched takes about a second or less, and curvature of a stem towards light is usually completed within a few hours. Other behavior such as flowering takes longer and are usually associated with changing seasons. Environmental signals trigger all of these seemingly unrelated responses. The key element in these responses is growth. The growth produces a variety of responses, among the most obvious of which are tropisms. All these and more will be discussed in this unit.

1.2 INTENDED LEARNING OUTCOMES

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

-state what tropism is
-distinguish between phototropism, gravitropis, hydrotropism and thymotropism
-describe nastic movements
-differentiate between seismonasty and nyctinasty.
-describe what photoperiodism is
-mention one of the responses controlled by photoperiodism

1.3 Main Contents

1.3.1 Tropism

When a plant exhibits some growth movement in response to a stimulus, it is referred to as **TROPISM**. Tropism is specific to the direction of the stimulus. Plants can either display a negative or positive movement in response to a stimulus. It is positive tropism when the movement is towards the direction of stimuli while it is negative tropism when the movement is away from the stimuli.

1.3.1.1 Phototropism

Plants grow towards or away from the light; the type of tropism in the response to light is called phototropism. In general, the stems usually show positive phototropism, while roots show negative phototropism. Leaves also positively respond toward the source of light.

Phototropism Mechanism

The mechanism of phototropism is as follows:

1. Light of wavelength 450 nm illuminates the plant.
2. The photoreceptor receives the light, reacts to it, and initiates a response.
3. Phototropins are the proteins that receive blue light during phototropism.
4. Auxin moves to a darker side in the stem when exposed to light.
5. Auxin releases hydrogen ions in the shaded region of the stem which causes a decrease in the pH. This decrease in pH activates expansin that causes the cells to swell and forces the stem to bend towards the light.

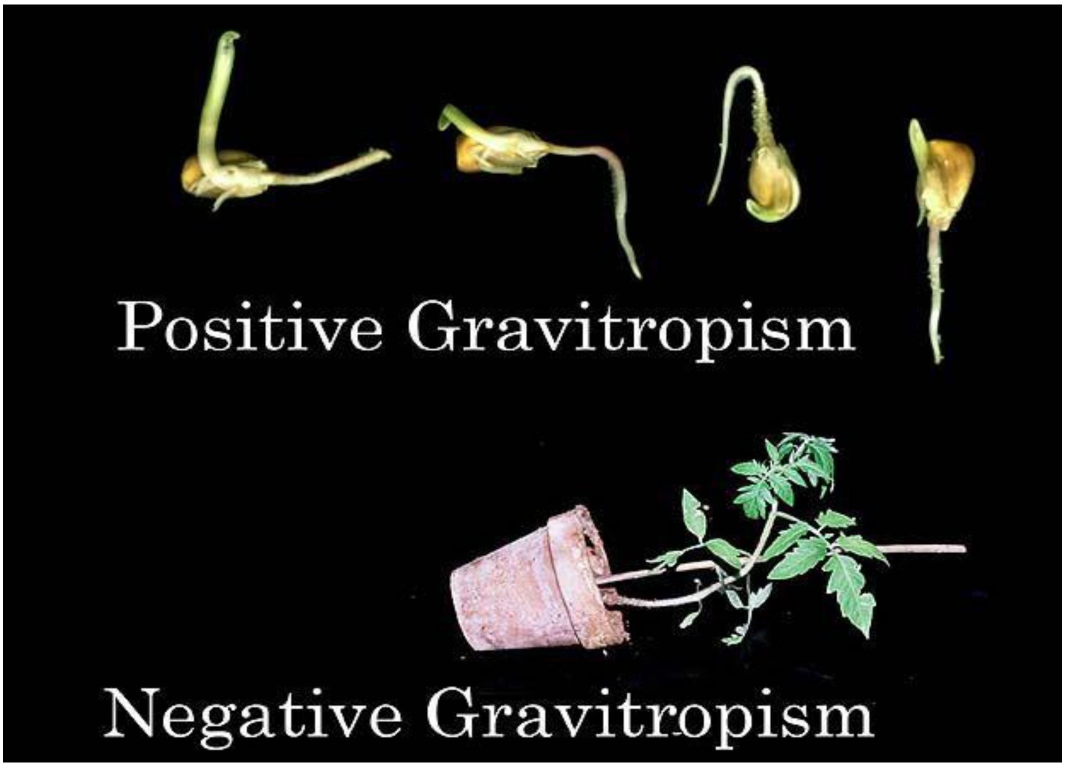
What is phototropism?

Self-Assessment Exercise 1

What is auxins' role in phototropism?

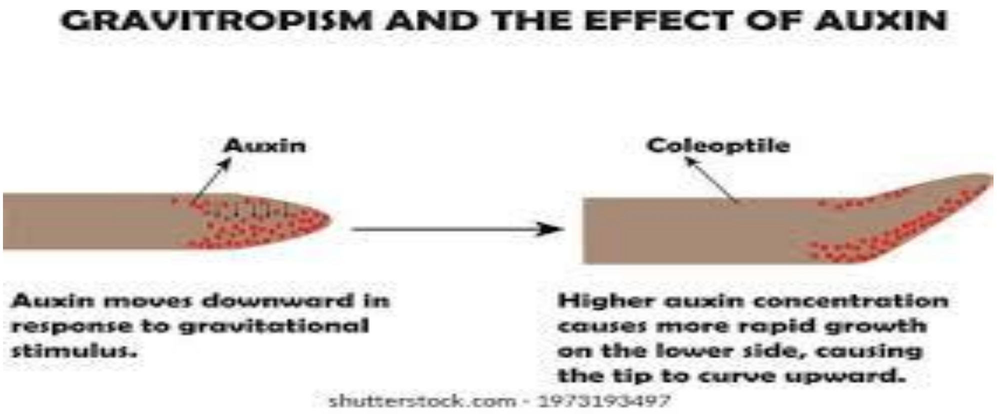
1.3.1.2 Gravitropism

It is a type of tropism where plants show some growth in response to gravity. Stems are negative to the gravitropism while roots are positive to the gravitropism. This is also referred to as geotropism. Among different parts of plants**,** the primary roots and certain other portions of the root system show positive geotropism by growing directly towards the centre of gravity. The stems are called as the negatively geotropic as they grow away from the centre of gravity. The leaves are transversely geotropic as they select their positions at right angles to the centre of gravity.



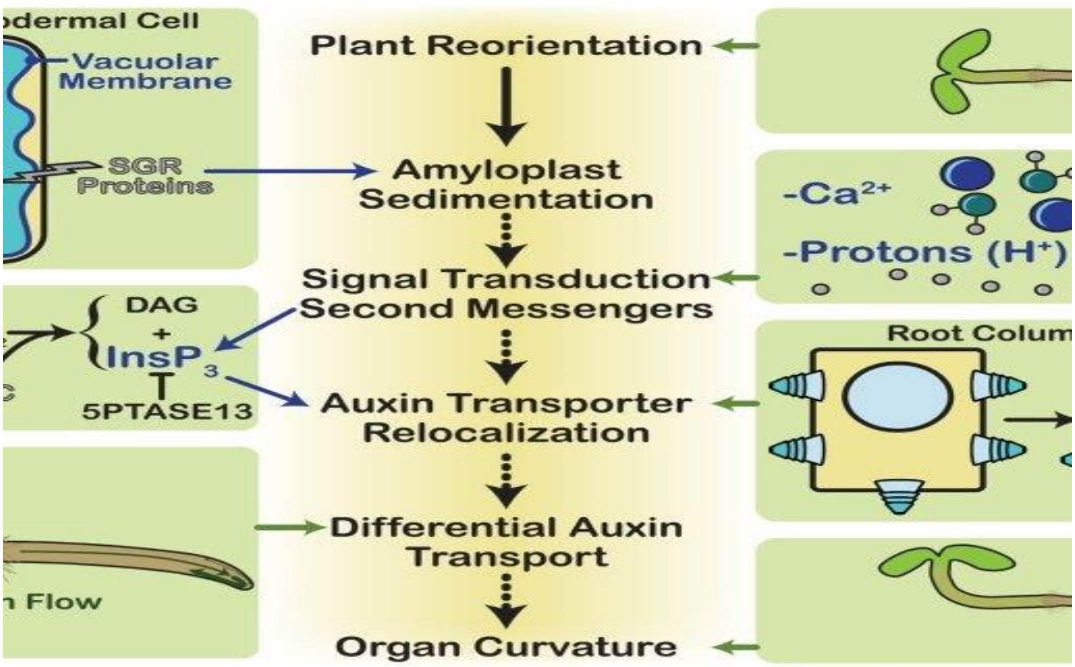
The phenomena is now called gravitropism because it is clearly a response to gravity and not to the earth (prefix "geo") as such. In shoots that are placed horizontally, differences in auxin concentration soon develop between the upper and lower sides with greater concentrations on the lower side. Auxin is a powerful inhibitor of root growth, and very small concentration induce a root to curve toward the side where the auxin concentration is greater. These differences cause the growth responses that are responsible for the shoots growing upwards against the force gravity - negative gravitropism. In some - what horizontally growing roots, the upper sides grow more rapidly than the lower sides, causing the root ultimately to grow down-wards- this phenomenon is know as positive gravitropism.

One of the earliest experiment done to learn gravitropism was by Charles Darwin. The experiment involved the responses of roots when caps had been surgically removed. These roots continued to grow but did not respond to gravity. The experiments showed that the root cap is necessary for root gravitropism.



Other researchers followed the Darwin lead. They soon made an exciting discovery cells in the centre of the cap contain numerous starch- laden amyloplasts which, under the influence of gravity, sediment to the lower side of the cells. Could this gravity - dependent sedimentation of amyloplasts be how plants sense gravity? Several subsequent experiments suggested that this was true, which further intensified the study of amyloplasts are gravity- sensors in plant roots. More recent research by Randy Wayne and his colleague at Cornell University suggest that roots respond to gravity by sensing gravitational pressures exerted by the photoplast, not the sedimentation of amyloplasts.

Although we do not understand full, how roots perceive gravity, we are beginning to understand how they respond to gravity. When roots are oriented horizontally, growth slows along the lower side of the elongating zone, thereby causing the root to curve downward. One of the first events that ultimately cause the differential growth is the accumulation, not of hormones, but of calcium ions (CA^{2+}). Ca^{2+} moves to the lower side of the cap and elongating zone of horizontally oriented roots. This accumulation of Ca^{2+} along the lower side of the root triggers an accumulation of IAA along the lower side of the root tip. Such IAA inhibit cellular elongation in roots, the lower side of roots grow lower than the upper side of the root and the roots curve down-ward.



When the root reaches a vertical position, the lateral asymmetries of Ca2+ and IAA disappear, and straight growth resumes.

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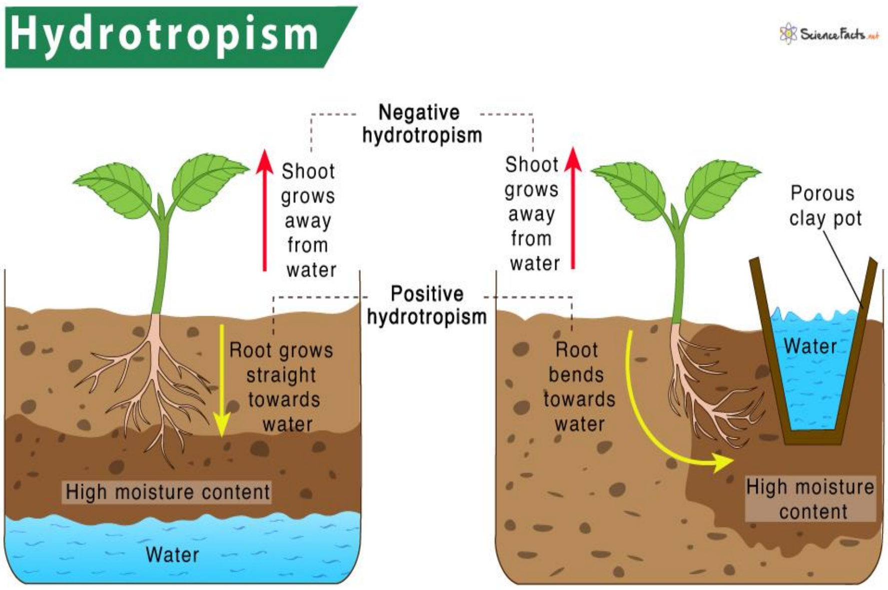
IAA and Ca^{2+} also direct the negative gravitropism of shoots. IAA accumulates along the lower side and Ca^{2+} along the upper side of horizontally oriented stems. Also, auxin induced MRNA disappear from the cortex and epidermis of the upper (i.e , the more slowly growing) side and accumulate on the lower (i.e more rapidly growing) side of horizontally oriented hypocotyls. These mRNAs, or encoded proteins, stimulate cellular elongation along the lower side of the stem, thereby producing upward curvative. *What is gravitropism?*

Self-Assessment Exercise 2

Why are root positive geotropic and stem negative geotropic?

1.3.1.3 Hydrotropism

The growth of roots toward soil moisture is called hydrotropism. Roots whose caps have been removed are not responsive to moisture gradients, which suggest that the root cap is the site of moisture perception by roots. Interactions between light, gravity and soil moisture could therefore account for the occasional mending growth of roots through soil.



1.3.1.4 Thigmotropism

This is a growth response of plants to touch. The most common example is the coiling of tendrils or an entire stem of plants such as morning glory. Before touching an object, tendrils and twining stems often grow in a spiral pattern called Circumulation that increases their chances of contacting an object to which it can cling. Contact with an object is perceived by specialized epidermal cells, which induce differential growth in the tendril. Such growth can be extremely rapid; a tendril can encircle an object with 5 - 10 minutes.

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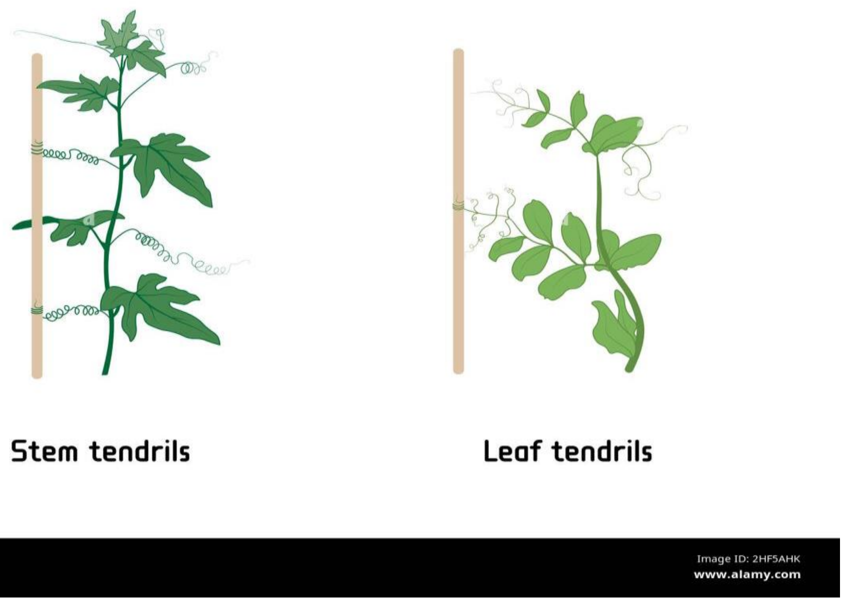
Furthermore, thigmotropism is often long lasting. Stroking a tendril of garden pea for only a couple of minutes can induced a curling response that lasts for several days. Thigmotropism,is probably influenced by IAA and ethylene, these hormones induce thigmotropic-like curvature of tendril even in the absence of touch tendrils can also store the "memory" of touch. Tendrils that are touched while growing in the dark do not respond until they are illuminated. Thus, although tendrils can store the sensory information received in the dark, light is required for the growth response to proceed. This light-induced expression of thigmotropism may be due to a requirement for ATP, since ATP will substitute for light inducing thigmotropism of desk-stimulated tendrils. Various degrees of thigmotropism are exhibited not only by tendrils, but also by leaves, stems, petioles and roots.



What is Thigmotropism?

***Answer**: This is a growth response of plants to touch. The most common example is the coiling of tendrils or an entire stem of plants*

1.3.2 Nastic Movements

These are movements that also occur in response to environmental stimuli. Unlike tropisms, nastic movements are independent of the direction of the stimulus. They occur in an atomically predetermined direction, rather than toward or away from the stimulus. Nastic movements include some of the most unusual plant kingdom.

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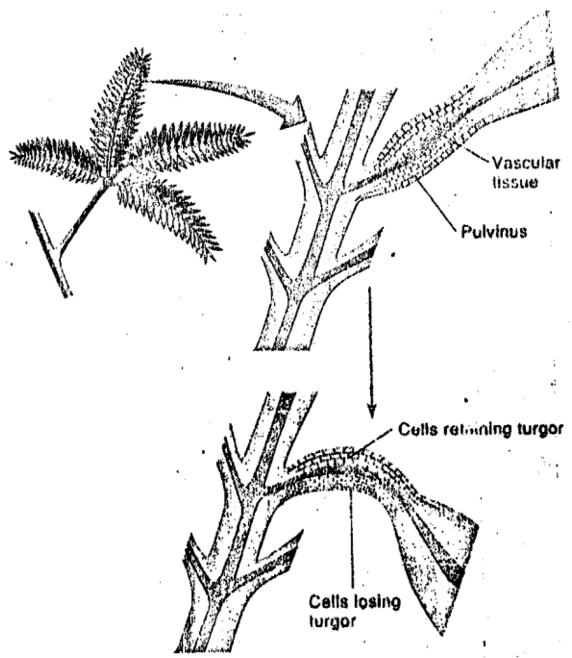
1.3.2.1 Seismonasty

This is a nastic movement resulting from contact or mechanical disturbances such as shaking. Seismonastic movements are based on a plant's ability to rapidly transmit a stimulus from touch-sensitive cells in one part of the plant to responding cells located elsewhere. Among the most dramatic of these responses are those exhibited by the sensitive plant (*Mimosa pudica*) touching a leaf causes the leaflets to fold and the petiole to drop.

Leaves are erect. Touching a leaf causes leaflets to fold and the petiole to drop. The response occur in the following ways:

i. Touching a leaf generates an electrical signal that moves along the petiole
ii. This electrical signal is translated into a chemical signal that causes cell membranes to become more permeable to K^+ and other ions. The cell that are affected are called motor cells, which are large, thin- walled parenchyma cells located in a joint-like structure called a pulvinus. In the sensitive plant, a pulvinus is
located at the base of each leaflet petiole.



***Seismonasty in the sensitive plant is due to turgor changes in pulvint, which are swollen structures located at the bases of leaflets and petioles. Turgor changes on one side of the pulvinus cause cells there to shrink, thereby producing movement*.**

iii. The movement of ions out of motor-cells decreases the water potential in the surrounding extra cellular space, which causes water to move out of motor cells via osmosis.
iv. The loss of water causes the motor cells to shrink, thereby producing the seismonastic movement.

The unfolding of leaves take 15-30 minutes and is accompanied by reversing the process. Motor cells take up K^+ and other ions, causing water to enter the cells via osmosis. This influx of water inflates the cells to their original size, thereby unfolding the leaves to their original position.

1.3.2.2 Nyctinasty

This is a nastic response caused by daily rhythms of light and dark. One of the most common nyctinactic responses occur in the prayer plant (Maranto species), and ornamental houseplant. During the day, leaves of the prayer plant are horizontal, thereby maximizing their interception of light. At night, the leaves fold vertically into a shape resembling a pair of praying hands. This movement of leaves in response to light and dark results from changes in the tugor of motor cells in a pulvinus located at

the base of each leaf. In the dark, K^+ ions are transported from cells of the upper side of the pulvinus to cells along its lower side. This movement of ions causes water to move via osmosis into cells along the lower side of the pulvinus. Thus, in turn causes cells along the lower side of the pulvinus to lose water and shrink as the cells along the lower side gain water and expand. Taken together, this changes in cellular volume, over the leaf to a vertical position. At sunrise, the process is reversed and the leaf again assumes its horizontal position.
What is Seismonesty movement?

1.3.3 Photoperiodism

All eukaryotic organisms are affected by the cycle of night and day and many features of plant growth and development are keyed to the changes in the proportions of light and dark in the daily 24-hour cycle. Such responses constitute photoperiodism, a mechanism whereby organisms measures seasonal changes in relative day and night length. One of the most obvious of these photoperiodic reactions concerns the production of flowers by angiosperms.
Day length changes with the seasons; the farther from the equator one is, the greater the variation. The flowering responses of plants fall into two basic categories in relations to day length. Short-day plants being to form flowers when the days become shorter then an critical length. Long-day plants on the other hand, initiate when the days become longer then a critical length. In both kinds of plants, it is actually the length of darkness (night) that is significant, and not the length of day.

In addition to the long-day and short-day plant, a number of plants are described as day neutral. These plants produce flowers whenever environmental conditions are suitable, without reference to day length. Day- neutral plants include roses and tomatoes.
What is photoperiodism?

Self-Assessment Questions

1) What is the mechanism of phototropism?

***Answer**: Phototropism, a growth response to uni-directional light, results from IAA moving to the shaded side of a coleoptile. The resulting accumulation of IAA on the shaded side stimulates cellular elongation these, and causes the coleoptile to curve toward the light.*

2)what is seismonasty?

***Answer**: Seismonasty is a nastic movement resulting from contact or mechanical disturbances*

1.4 SUMMARY

Plants adjust their growth and development in response to environmental signals and rhythms. Tropisms are short-term growth responses determined by the direction of an environmental stimuli. Tropisms result from differential growth and are important because they increase a plant chances of intercepting more light for photosynthesis and encountering water and minerals in the soil.

Phototropism, a growth response to uni-directional light, results from IAA moving to the shaded side of a coleoptile. The resulting accumulation of IAA on the shaded side stimulates cellular elongation these, and causes the coleoptile to curve toward the light.

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1.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1

Auxin moves to a darker side in the stem when exposed to light. Auxin also releases hydrogen ions in the shaded region of the stem which causes a decrease in the pH. This decrease in pH activates expansin that causes the cells to swell and forces the stem to bend towards the light.

Answers to SAE 2

Among different parts of plants**,** the primary roots and certain other portions of the root system show positive geotropism by growing directly towards the centre of gravity. The stems are called as the negatively geotropic as they grow away from the centre of gravity.

UNIT 2 MOVEMENT OF WATER AND MINERALS

Unit Structure

2.1 INTRODUCTION

Life in Earth's atmosphere presents a formidable challenge to land plants. On the one hand, the atmosphere is the source of carbon dioxide, which is needed for photosynthesis. On the other hand, the atmosphere is usually quite dry, leading to a net loss of water due to evaporation. Because plants lack surfaces that can allow the inward diffusion of CO2 while preventing water loss, CO_2 uptake exposes plants to the risk of dehydration. This problem is compounded because the concentration gradient for CO_2 uptake is much smaller than the concentration gradient that drives water loss. To meet the contradictory demands of maximizing carbon dioxide uptake while limiting water loss, plants have evolved adaptations to control water loss from leaves, and to replace the water lost to the atmosphere with water drawn from the soil.

In this unit we examine the mechanisms and driving forces operating on water transport within the plant and between the plant and its environment. We will consider how water moves from the soil into the roots and from the roots up through specialized transport cells to the leaves from which water is lost to the atmosphere. We will end the unit by considering the ways in which the leaf can control the loss of water, as well as the entry of CO2, by regulating the opening and closing of stomata, the small openings through which the major water loss occurs.

2.2 INTENDED LEARNING OUTCOME

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

-discuss water movement through the xylem
-describe the leaf architecture and how it affects -transpiration
-explain the mechanism of water potential
-identify the hypothesis that best describes water movement up a tree
-list the environmental factors that affect transpiration -discuss the structural adaptations that affect transpiration.

2.3 Main Contents

2.3.1 Moving Water in the Xylem

Water is the most abundant compound in plant cells; it accounts for 85%

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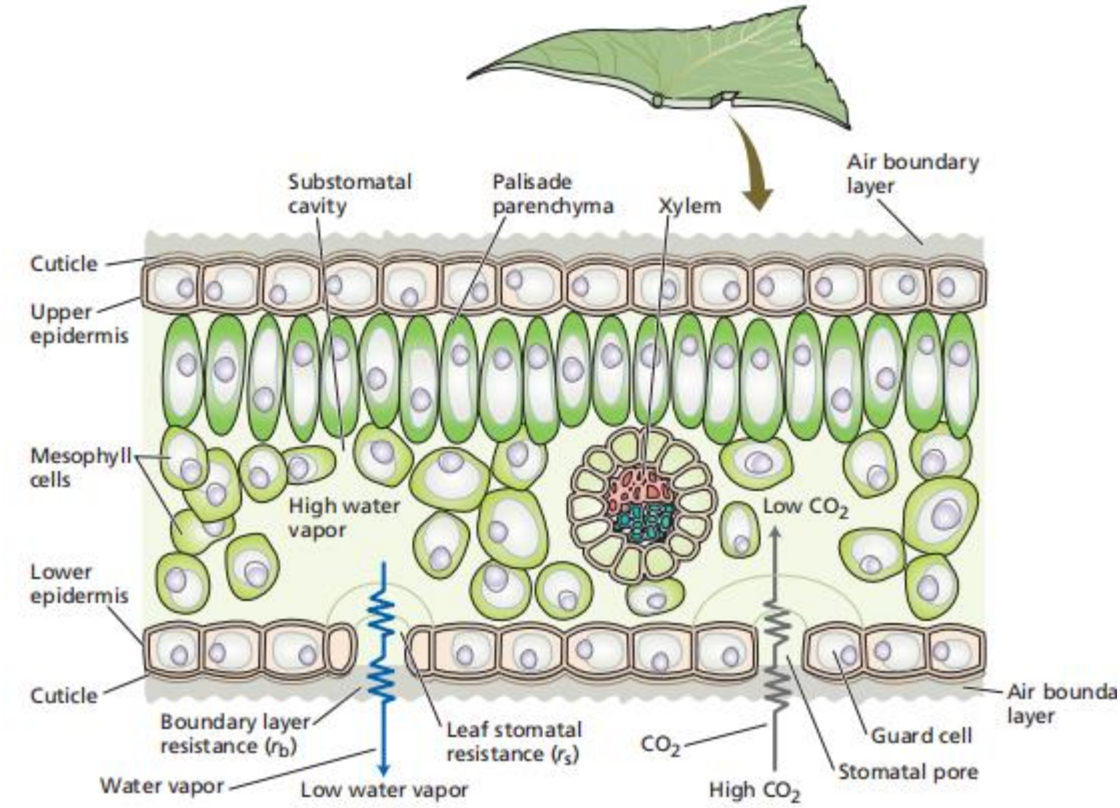
- 95% of the weight of most plants, and 5%-10% of the weight of seeds. Water is used to make organic compounds (e.g. sugars) support the plant
(via tugor pressure), as a solvent in which important reaction occurs, and
as the medium in which solvents move. Given the critical roles played by water in plants, it seems peculiar that more than 95% of the water gathered by a plant evaporates back into the atmosphere, often within only a few hours after being absorbed. This evaporation of water from the shoot of a plant is known as **Transpiration.** Most transpiration from leaves is through stomata and is a result of leaf architecture.

2.3.2 Leaf Architecture

Leaves are exquisitely adapted for photosynthesis. However, the adaptations that enhance photosynthesis also enhance a plants greatest threat, dehydration for example the rate of gas exchange depends among other things on the amount of surface area available for exchange and evaporation. The loose internal arrangement of cells in leaves produces a large internal surface area for transpiration.



Water pathway through the leaf. Water is pulled from the xylem into the cell walls of the mesophyll, where it evaporates into the air spaces within the leaf. Water vapor then diffuses through the leaf air space, through the stomatal pore, and across the boundary layer of still air found next to the leaf surface. CO2 diffuses in the opposite direction along its concentration gradient (low inside, higher outside)

The internal surface area of a leaf may be more than two hundred times greater than its external surface area; this amplifies transpiration by increasing the surface area for evaporation.

The internal surface area of a leaf is linked to the atmosphere by intercellular spaces that occupy as much as 70% of the volume of a leaf. The gates that lock the internal surface area with the atmosphere are the stomata. These gates are abundant; one leaf, for example, may have more than 80 million stomata. Leaves also have an efficient plumbing system of veins for distributing water to their internal evaporative surface: one square centimeter of leaf can have as many as 6,000 vein endings. As a result of this leaf

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architecture, a well-watered plant can lose tremendous amount of water via transpiration; for example, a corn plant transpires almost 500 1itres of water during a few-month growing season.

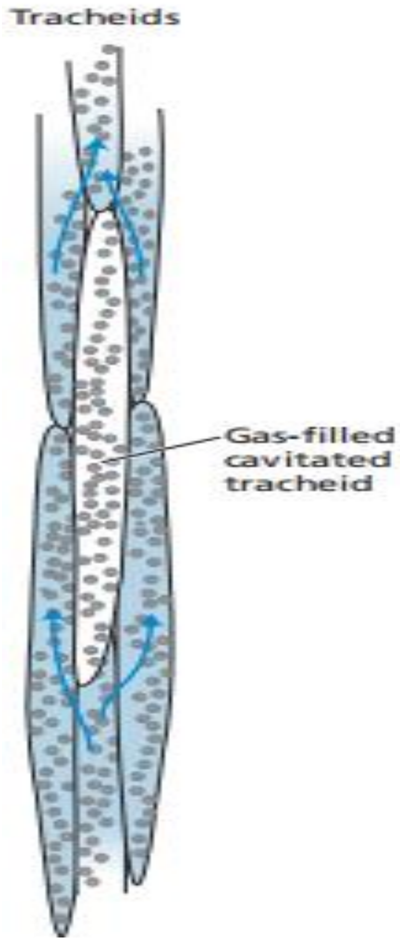
Water lost via transpiration is replaced by water absorbed from the soil by roots. This water moves to the leaves as fast as 75cm min^{-1}, which is about the speed of the tip of a second hand sweeping around a wall clock. Despite their huge requirement for water, plants have no active mechanism for acquiring water when they are stressed. Thus losses of water via transpiration do not indicate an excess of water; on the contrary, water is the primary factor that limits plant growth in most areas.

2.3.3 Structure of the Conducting Cells

Water must move rapidly though plants to replace the water lost by transpiration. Through what tissues does water move? To answer this question, consider the result of two simple experiments:

1. Removing the back from a tree does not significantly alter transpiration.
2. When roots are exposed to a soluble dye, only xylem elements in the stem, contain the dye.

These results suggest that water and dissolved minerals move from roots to leaves though xylem elements. there are two kinds of xylem elements in plants: **tracheids** and **vessel** elements.



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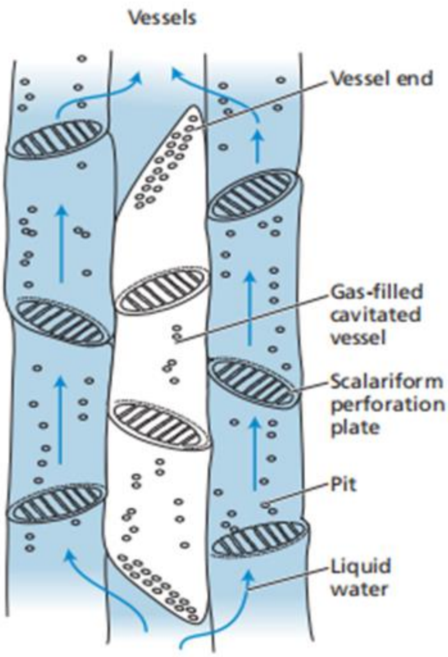
Vessels
Vessel end
Gas-filled cavitated vessel
Scalariform perforation plate
Pit
Liquid water

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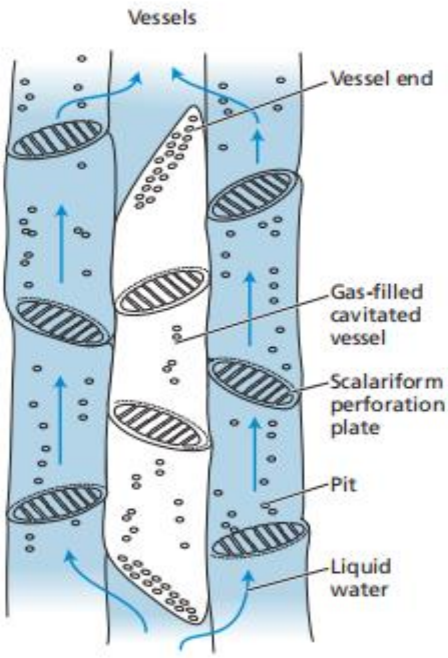

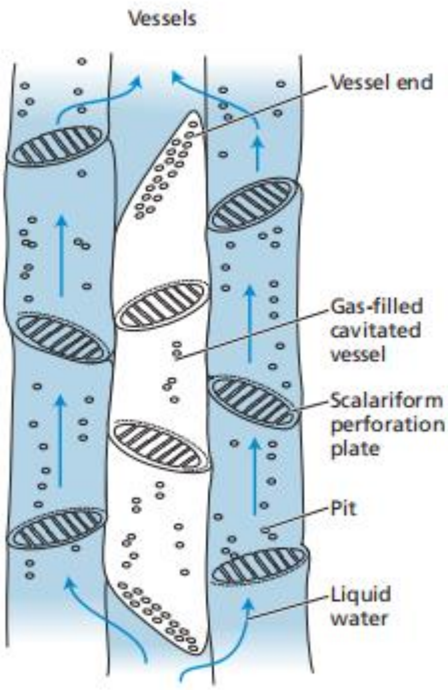

Both of these types are well designed for conducting water: they are hollow and dead at maturity, and therefore have no cellular organelles to retard water flow. Furthermore, both have thick cell walls and can therefore withstand changes in pressure associated with water flow caused by transpiration. However, tracheids are usually long (up to 10mm) and thin (10-15 m in diameter), and they overlap each other. Their walls contain many thin areas called **bordered pits** which are valve like structures that are especially abundant in portions of the walls where tracheids overlap. Pits link tracheids into long water-conducting chains and allow a slow flow of water through xylem.

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Vessel elements are shorter and wider than tracheids ; their diameter are usually between 40 and 80 m, and may be as large as 5000 m. Vessels are stacked end to end and the end walls separating adjacent vessel elements are often either whole or partially dissolved as a result, vessel element form cellulose pipes called vessels ranging in length from a centimeter to more than a meter. Water can move longer distances in vessels than in tracheids before having to travel a pit. Moreover, their larger diameter and dissolved end walls allow water to move faster than in tracheids. The increased flow rate in vessels may help explain why angiospeffils dominate today's landscape. Angiosperms contain both tracheids and vessels, while gymnosperms contain only tracheids. *What is transpiration?*

Self-Assessment Exercise 1

How does leaf architecture affect transpiration

2.3.4 Water Potential

The force responsible for water movement. The movement of water though plant is a physical process that require no metabolic energy. Rather, water flows passively from one place to another because of difference in potential energy. The potential energy of water in a particular system compared to pure water at atmospheric pressure, and at the same temperature is termed the **water potential** and is abbreviated by the Greek letter psi, Lowering the potential energy of water lowers the water potential, and increasing the potential energy of water increases the water potential. Differences in water potential determine the direction that water moves: water always flow passively from areas of high water potential to areas of lower water potential. The movement of water into, through and out of plants is regulated by water potentials.

How does water move in plants?

Any hypothesis for water movement in plants must be based on water moving from areas of high water potential to areas of lower water potential. It must also account for an even more obvious requirement: movement must reach tops of all trees. The forces involved in lifting water to treetops are considerable. For example imagine the force of water required to move water to the leaves of a tall iroko tree. Some hypotheses have been proposed for water movement in plants.

Hypothesis 1

Water moves up xylary elements via capillarity. Capillarity results from the adhesion of water to the surfaces of small tubes. This adhesion pulls water up the tube, and is visible as the curved meniscus atop the water column in a glass tube. However in tubes having the diameters of a xylary element, capillarity raises water less than 1m. Therefore, capillarity alone cannot account for the movement of water to the top of trees.

Hypothesis 2

Water is pushed up xylary elements by atmospheric pressure. To understand this hypothesis, imagine filling a long hollow tube with closing it at one end, and placing the tube open-end down, in a tub of water. Movement of the water column is balanced by two opposing forces: the weight of the water in the tube pulls the water column down, while atmospheric pressure pushes water up the tube. These counteracting pressures reach equilibrium when the water column is about 10.4m high (fig 17.4). When the length of the tube exceeds 10.4m, the water column cavitates, meaning that it forms a partial vacuum filled with water vapour in the upper closed end of the tube. Because atmospheric pressure raises a column of water only about 10.4m, it cannot account for the movement of water to the tops of tall trees.

Hypothesis 3

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Water is pumped up the xylary elements. Water in xylem moves in xylary elements which are dead. Furthermore there are no "pumping cells" in xylem. Therefore water is not actively pumped through the xylem.

Hypothesis 4

Water is pushed up by root pressure.

On many mornings you have probably seen that have water droplets at their edges. This loss of water from the leaves of intact plants is called **guttation** and is common in herbaceous plants growing in moist soil on cool damp morning. Guttation is caused by root pressure that is generated as follows:

1. Minerals actively absorbed at night are pumped into the apoplast surrounding xylary element
2. The influx of solutes decreases the water potential of the xylary element, thereby causing water to move into it from surrounding cells.
3. Since there is only negligible transpiration at night, the pressure in the xylem increases as high as +0.2 Mpa.
4. Eventually, this pressure forces liquid water out of the leave through hydathodes.

Guttation continues as long as the plant is kept under conditions favoring rapid absorption of minerals and minimum transpiration, such as in wet soils at night. Although most pressure can push water several meters up a plant, it cannot push water to tree tops.

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Guttation in a leaf from lady's mantle (*Alchemilla vulgaris*). In the early morning, leaves secrete water droplets through the hydathodes, located at the margins of the leaves.

Hypothesis 5

Water is pulled up plants by evaporation.
This hypothesis was formulated more than a century ago, and today is referred to as the transpiration-cohesion hypothesis for water movement. It is describes as follows:

1. Solar-powered transpiration of water dries the cell wall of mesophyll cells.
2. This loss of water from wall lowers the water potential of the cell, thereby causing it to take up water from neighboring cells that have a higher water potential because they are farther away from the air space.
3. Cells farther away from the site of evaporation have even larger water potentials, thus causing water to move from cell to cell toward the air spaces.
4. Cells bordering tracheids replace their water with water from the xylem. This loss of water with water from xylary elements creates a negative pressure thereby lifting the water column up the plant.
5. The negative pressure decreases the water potential all the way down to the tips of roots, even in the tallest trees. The tension lowers the water potential in the root xylem so much that water flows passively from the soil, across the root cortex and into the stele. Water in the stele is then pulled up the xylem to leaves to replace water lost via transpiration.

Which hypothesis best explains water movement in xylem. Describe it.

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2.3.5 Factors Affecting Transpiration

i. Environmental Factors

a) Atmospheric humidity

Transpiration occurs as long as the water potential of the atmosphere is less (i.e. more negative) than the water potential of the leaf. Dry air increases the gradient and therefore increases transpiration. Similarly, transpiration typically slows in humid air.

b) Internal concentration of CO_2

The concentration of CO_2 in the atmosphere rarely deviates much from the O.O3%. However the CO_2 concentration in leaves changes considerably, especially when stomata close and photosynthesis removes CO_2 from the intercellular spaces of the leaf. Low concentration of CO_2 in leaves cause stomata to open, whereas high concentrations cause them to close. Thus a reduced supply of CO_2 for photosynthesis (i.e. a low internal concentration of CO_2) opens stomata and as a result, increases transpiration.

c)Wind

The thin moist layer of air adjacent to a transpiring leaf is called a boundary. A thick boundary layer decreases the diffusion gradient and therefore decreases transpiration. Wind usually replaces the boundary layer with drier air, thereby increasing the water-potential gradient and increasing transpiration.
The leaves of many grasses can temporarily reduce transpiration. The upper epidermis of leaves of many grasses contains vacuolated cells called **bulliform cells,** which are sensitive to water loss. These cell shrink when they desiccate, thereby rolling the leaf into a cylinder. This shape increases the leaf's boundary layer and reduces the amount of light that reaches the leaf, thereby decreasing transpiration.

d) Air Temperature

In direct sunlight, the temperature of a leaf may exceed that of the air by as much as 10°C. Increasing the leaf temperature increases the water vapour pressure in the leaf, which in turn increases its water potential and leads to faster rates of transpiration. Transpiration is most rapid at 20°C-30°C.

e) Soil

Any factor that affects water availability also affects transpiration; therefore transpiration is affected the water contents of soil. Plants can absorb water from soil as long as their vapour potential is less then that of the soil.
Plants functions as wicks that evaporate sub-surface water from soil, which explains why soils covered by plants lose water faster than does bare soil. Almost all water lost below 15cm in the soil is lost via transpiration. Weeds therefore compete with crop plants, not only for light and nutrients, but also decrease the availability of water to soil.

f) Light intensity

Light usually causes stomata to open and therefore increases transpiration. Although stomata typically open at sunrise and close at sunset, these are not “all-or-nothing” effects, instead stomata open gradually in the morning over a period of about one hour and gradually close through out the afternoon. The effect of light on stomata opening is indirect. Light promotes stomata opening by stimulating photosynthesis which

decreases the internal concentration of CO_2 in the leaf. The regulation of transpiration by light is important, since it prevents plants from needlessly losing water when it is too dark for photosynthesis.
List the factors that affect transpiration.

Self-Assessment Exercise 2

How does CO2 affect Transpiration?

2.3.6 Structural Adaptations

Apart from the environmental factors listed there are other structural adaptations that affect transpiration by reducing it. These are:

Cuticle: The retention of water and the survival would be almost impossible for plants without a cuticle. The cuticle is an effective means of conserving water: less than 5%of the water lost by a plant evaporates through the cuticle. In general, thicker cuticle provides more protection from desiccation than these ones. The desert plants typically have thick cuticles, while those of aquatic plants are thin.

Trichomes: Although trichomes increase the thickness of the boundary layer overlying a leaf the primary means by which trichomes decrease transpiration i.e. by reflecting light and thus decreasing the temperature of a leaf.

Sunken Stomata

Sunken Stomata increase the boundary layer surrounding guard cells. Therefore, plants with sunken stomata typically transpire less than do plants with raised stomata.

Reduced Leaf Area

Many desert plants have greatly reduced leaves, thereby decreasing their evaporative surface. In these plants, succulent stems that store large amounts of water replace leaves as the primary photosynthetic organs. *List four (4) structural factors that affect transpiration.*

Self-Assessment Questions

1) *What is the force responsible for conduct of water up the plant?*
Answer: *The driving force for water movement is the evaporation of water from the walls of leaf cells, which decreases the water potential of the leaf and thus pulls replacement water from the xylem.*
2)what vascular system is responsible for movement of water and subtances in plant?
Answer*: The vascular systems responsible for this transport are xylem, which moves water and dissolved minerals from the soil to leaves, and phelem which, moves sugars and other organic compounds throughout a plant.*

2.4 SUMMARY

Multicellularity of plants and their colonization of the land corresponded with the evolution of systems for long-distance transport. The vascular systems responsible for this transport are xylem, which moves water and dissolved minerals from the soil to leaves, and phelem which, moves sugars and other organic compounds throughout a plant. Water movement in both of these systems occurs because of differences in water potential, which is a measure of the potential energy of the water in the system. Water potential is the sum of the energy attributable to pressure, solutes and wettable surfaces. Water always moves from areas of high water potential to areas of lower water potential.

Water moves from roots to leaves in tracheds and vessels of xylem. These conducting cells are dead and hollow at maturity, and have thick walls that can withstand the negative pressures characteristic of xylary transport. Leaves expose large evaporative surface areas to the dry atmosphere. This evaporation of water from shoots is called transpiration.

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2.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1

The loose internal arrangement of cells in leaves produces a large internal surface area for transpiration.

Answers to SAE 2

. Low concentration of CO_2 in leaves cause stomata to open, whereas high concentrations cause them to close. Thus a reduced supply of CO_2 for photosynthesis (i.e. a low internal concentration of CO_2) opens stomata and as a result, increases transpiration.

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UNIT 3 TRANSPORTATION OF FOOD SUBSTANCES IN PLANTS

Unit Structure

3.1 INTRODUCTION

Survival on land poses some serious challenges to terrestrial plants,foremost among these challenges is the need to acquire and retain water. In response to such environmental pressures, plants evolved roots and leaves. Roots anchor the plant and absorb water and nutrients; leaves absorb light and exchange gases. As plants increased in size, the roots and leaves became increasingly separated from each other in space. Thus, systems evolved for long-distance transport that allowed the shoot and the root to efficiently exchange products of absorption and assimilation. . The **phloem** is the tissue that transports (*translocates*) the products of photosynthesis—particularly sugars—from mature leaves to areas of growth and storage, including the roots. Along with sugars, the phloem also transmits signals in the form of regulatory molecules, and redistributes water and various compounds throughout the plant body. All of these molecules appear to move with the transported sugars. The compounds to be redistributed, some of which initially arrive in the mature leaves via the xylem, can be either transferred out of the leaves without modification or metabolized before redistribution. The fluid that flows through the phloem—the water plus all its solutes—is called *phloem sap*. (*Sap* is a general term used to refer to the fluid contents of plant cells.)

3.2 INTENDED LEARNING OUTCOMES

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

-discuss the movement of organic solutions in phloem describe the structure of the conducting cells
-explain how substances move in the phloem
-discuss the models proposed for phloem transport explain the Munch pressure-flow model
-describe the system of phloem loading and unloading
-list the environmental factors affecting phloem transport

3.3 Main Contents

3.3.1 Transporting Organic Solutes in the Phloem

The first serious students of how organic solutes move in plants were done in the l800s by **Theodor Hastig**, a German botanist. His interest was in determining how the products of photosynthesis move in trees. In 1837, he discovered a new cell type in the back of trees. He called them **sieve tube members** and suspected that they were the conduits for moving sugars from leaves to roots. To test his hypothesis,

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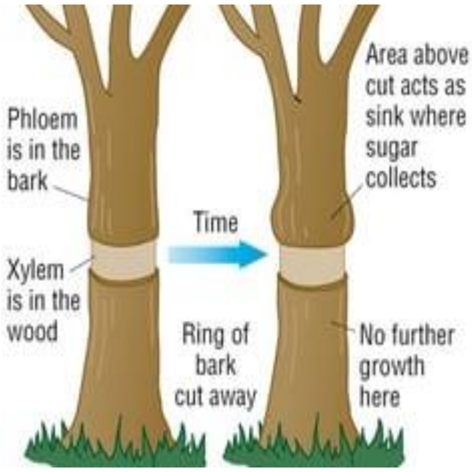
Hastig reasoned that if sieve tubes of back were the cells through which nutrients moved, then removing a ring of back from the tree trunk should cause nutrients to accumulate above the so called girdle. This is exactly what happened.



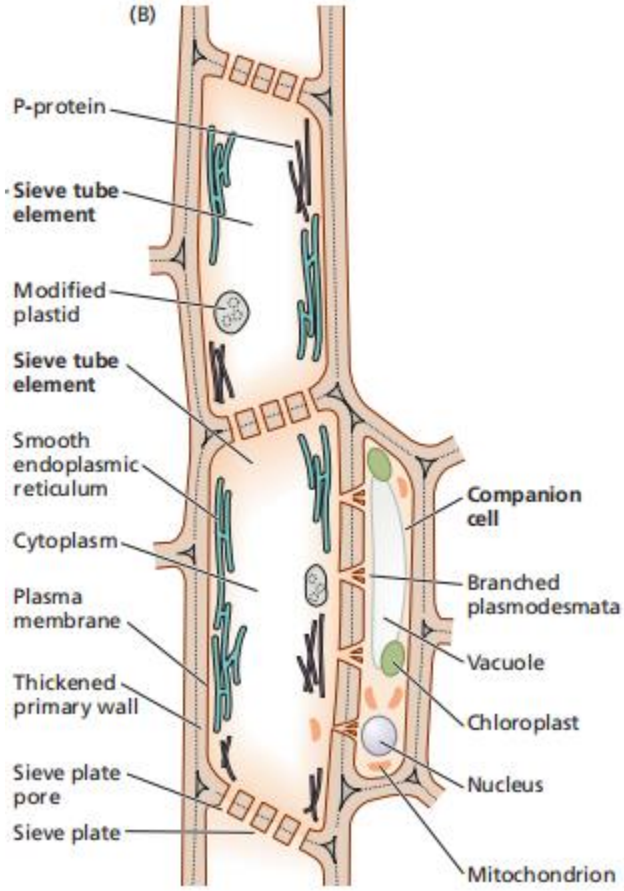
In the late 1850s Hastig began other experiments that eventually linked translocation with sieve tubes. He made a series of shallow cuts into the sap oozed from these incisions. Hastig concluded that organic solutes moved in sieve tubes. More recent studies with radioactive tracers have confirmed Hastig's conclusion: sugars and other organic substances move almost exclusively **in sieve tubes of the phloem**.

a. **Structure of Conducting Cells**

Sieve tube members are cylinders collected by sieve like areas called sieve plates, each of which has numerous sieve pores. Sieve pores may occupy more than 50% of the area of sieve plates. Sieve pores were initially thought to be clogged; but studies showed that sieve pores are open in functional sieve tubes.

Sieve tubes in most plants are short-lived; they usually function only during the season in which they are formed. In these plants, sieve tubes are eventually replaced by cells denied from the vascular cambium. During periods of dormancy, sieve pores become clogged with callose and become non-functional. When growth resumes, the callose is hydrolyzed, and the sieve tubes again transport sugars. The products of callose hydrolysis are used as substrates for the renewal of growth.

Callose and P-protein are located along the periphery of functioning sieve tube members. Callose is rapidly synthesized when sieve tubes are wounded. Callose plays the pores of wounded sieve tubes and prevents loss of assimilated nutrients through the wound. Similarly, P-protein rapidly clogs the pores of wounded sieve tubes and minimizes the loss of sugars.



Schematic drawings of mature sieve elements (sieve tube elements) joined together to form a sieve tube
Where do sugars and other organic compounds move in plants?

Self-Assessment Exercise 1

Give brief description of sieve tube

b. How Substances Move in the Phloem

Several models for phloem transport have been proposed. The validity of these models is judged by their ability to explain and accurately predict phloem transport. Such a model must also explain the rate of phloem transport.

c. Rates of Phloem Transport

Solutes move surprisingly fast in the phloem, peak rates of transport may exceed 2m/h. As much as 20litres of sugary sap can be collected per day from the several stems of sugar palm. At the cellular level, a sieve element empties and fills every two seconds.

3.3.2 Models for Phloem Transport

Hypothesis

Solutes move through the phloem via diffusion

Diffusion is too slow to account for phloem transport in plants. Consider a 10% sucrose solution connected to a pan of pure water by a 1- metre tube with a cross-sectional area of 1cm^2: The diffusion of only 1 mg of sucrose to the pan of pure water would require almost three years. Therefore, mechanisms more rapid than diffusion must be involved in solute transport in phloem.

Hypothesis 2

Solutes move through the Phloem via Cytoplasmic Streaming

Cytoplasmic streaming is too slow to account for phloem transport. Moreover, streaming apparently does not occur in mature sieve tubes. Therefore, cytoplasm streaming alone cannot account for the movement of solutes in the phloem.

Hypothesis 3

Solutes move through the Phloem via Pressure Flow

This model was proposed by German plant physiologist, **Ernst Munch** in 1926. The model states that a tugor-pressure gradient drives the uni- directional mass flow of solutes and water through sieve tubes of the phloem.
According to this model, solutes move through sieve tubes along a pressure gradient in a manner similar to the movement of water through a garden hose.

Four requirements must be satisfied for Munch's model to work:

1. There must be an osmotic gradient between the two osmometers.
2. Selectively permeable membranes must be present to establish a pressure a gradient.
3. There must be an open channel between the two osmometers to allow flow
4. The surrounding medium must have a water potential that exceeds (i.e. less negative than that of the most negative osmometers).

The pressure-flow model is attractive because it explains source-to-sink movement in plants.

Sources are the sites where sugars are made by photosyt1thesis or hydrolysis of starch, they contain large amounts of sugar, and their solute concentration is high.

Sinks are sites where sugars are used or stored in solute starch. They contain less sugar than do the sources. Their solute concentration is relatively low. Roots, active meristems and developing fruits are examples of sinks.

1. Sucrose produced at a source is loaded into a sieve tube
2. This loading decreases the water potential, which causes water to enter sieve tubes by osmosis.
3. The influx of water into sieve tube creates a pressure gradient that carries sucrose to a sink, where it is unloaded.
4. Removing sucrose at the sink increases the water potential there, causing water to movement of the sieve tube at the sink.
5. Sucrose exiting the sieve tube at the sink returns to the xylem and is recirculated.

The ability of the pressure-flow model to account for and accurately predict the characteristic of phloem transport makes it the most widely accepted model for phloem transport.
Which hypothesis best explain the transport of organic solutes in plants

Self-Assessment Exercise 2

What are sinks?

3.3.3 Loading and Unloading the Phloem

3.3.3.1 Phloem Loading

The Munch pressure-flow model accounts for the movement of solutes once they are loaded into sieve tubes. How then do solutes get from sources into sieve tubes and from sieve tubes to sinks?

Consider a chlorenchymes cell (i. e. a source) in a leaf and a cortical cell (i.e. a sink) in a root. Most chlorenchymes cells are 2-4 layers from a vein. Thus, sugars made in chlorenchymes cells must be transported across several others chlorenchyma cells before they can be loaded into a sieve tube. The movement of solutes between adjacent chlorenchyma cells is symplastic and is enhanced by the many plasmodesmas that link these cells. That is symplastic transport accounts for the movement of solutes to chlorenchyma cells boarding the vein. There are no symplastic links between chlorenchyma cells and companion and sieve cells. Sugars, therefore, move through the cell wall (i.e. the apoplast) before being loaded into the sieve tubes.

Sugars in the cell wall are loaded into sieve tubes by companion cells which many often have many plasmodesmata and include structures similar to those of transfer cells.

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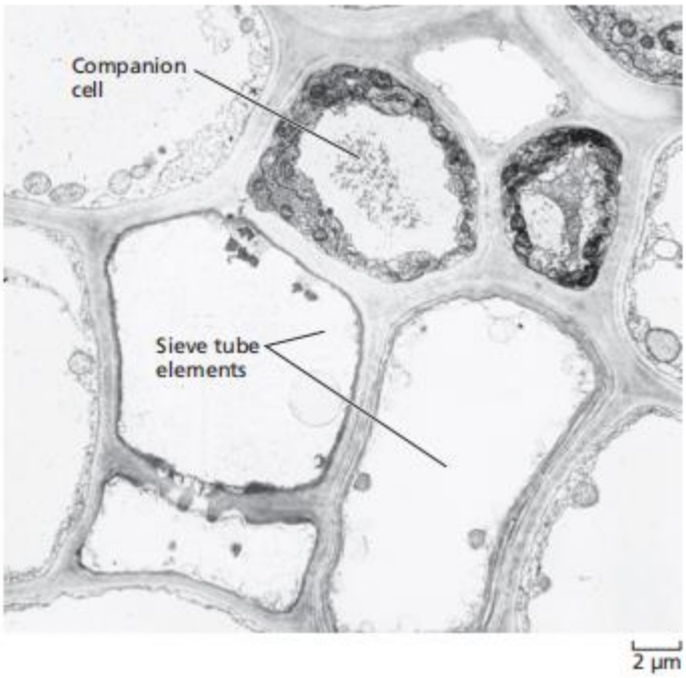

Electron micrograph of a transverse section of ordinary companion cells and mature sieve tube elements. The cellular components are distributed along the walls of the sieve tube elements, where they offer less resistance to mass flow.
(From Warmbrodt 1985.)

Cross section of a leaf vein from common grounded (Senecio eu1goris), showing sieve elements and transfer cells. The wall ingrowths of transfer cells produce large surface areas that are used to enhance loading and unloading of sieve elements.

The elaborate invaginations of the cells wall and cell membrane of transfer cells provide a large surface area for transporting sugars from the cell wall into the sieve tube. The loading of sieve tubes form the apoplast requires metabolic energy and is driven indirectly by a protein gradient generated at the expense of ATP.

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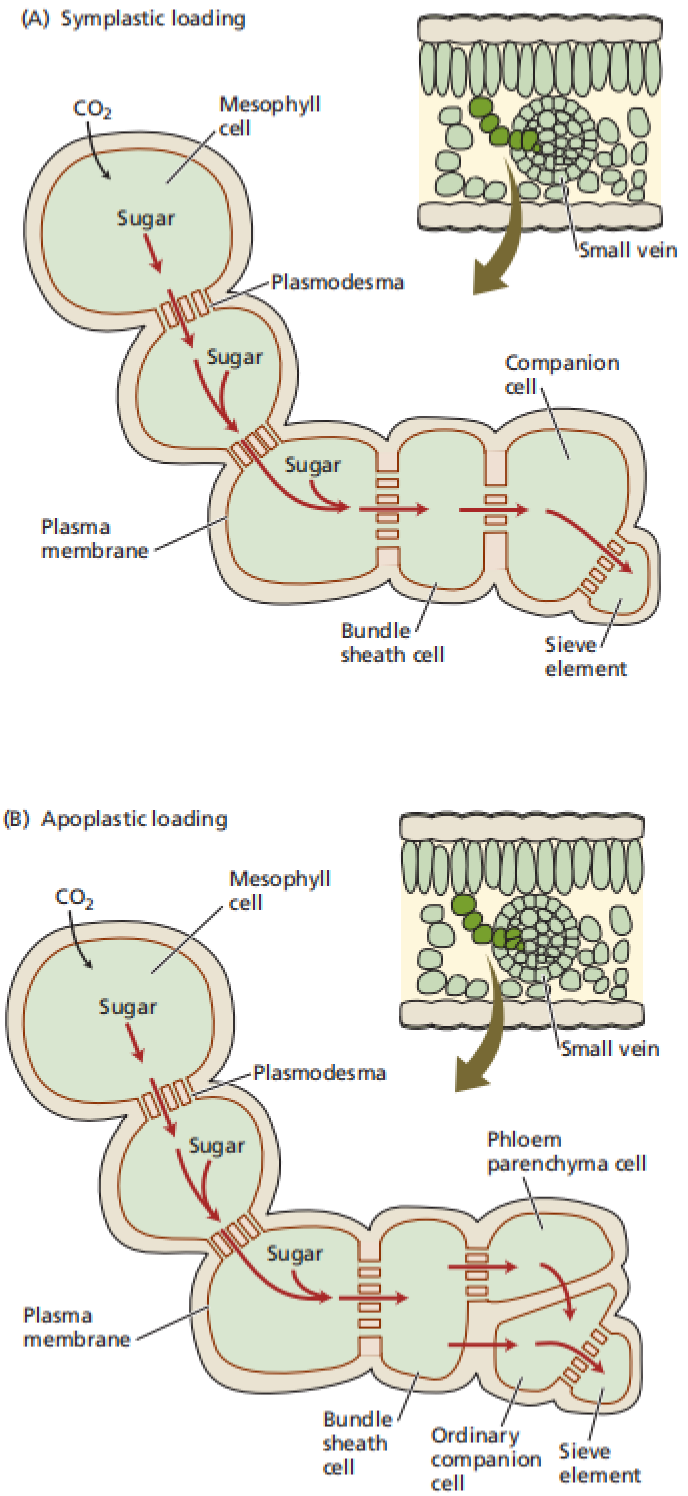

Schematic diagram of pathways of phloem loading in source leaves. (A) In the totally symplastic pathway, sugars move from one cell to another through the plasmodesmata, all the way from the mesophyll to the sieve elements. (B) In the partly apoplastic pathway, sugars initially move through the symplast, but enter the apoplast just prior
to loading into the companion cells and sieve elements. Sugars loaded into the companion cells are thought to move through plasmodesmata into the sieve elements

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Sugars and other solutes are loaded selectively into sieve tubes. Only those solutes that are transported will be loaded. For example, sucrose is always present in sieve tubes, which glucose is rarely present. If veins are bathed in a solution of sucrose and glucose, only sucrose will be loaded into sieve tubes. This selectively depends on specialized membrane carries in the cell membrane of sieve tubes and companion cells.

3.3.3.2 Phloem Unloading

Unloading of solutes from sieve tube members can occur symplastically or apoplasticatly. In vegetative sinks that are growing such as roots and young leaves, unloading is usually symplastic. In other sinks, unloading is apoplastic. The mechanism underlying phloem unloading may vary in different species.

3.3.4 Influence of the Environment on Phloem Transport

Several environmental factors affect phloem transport. One of them is **light**, which promotes photosynthesis and therefore increases the production of sucrose. As a result, increased light intensity generally promotes transport to roots. Similarly, darkness stimulates translocation from roots to shoots.

Mineral deficiencies are also important in phloem transport, which is strongly affected by the nutritional status of a plant. For example, phloem transport is slow in boron-deficient plants; transport increases dramatically when these plants are supplied with boron. Potassium deficiencies also decrease phloem transport, presumably because of the dependence of phloem loading on k^+ uptake.

3.3.5 Contents of Sieve Tubes

The most abundant compound in a sieve tube is water, which is important because as much as half of the waters in many fruits is delivered in sieve tubes. More than 90% of the solutes in sieve tubes are carbohydrates. In most plants, these carbohydrates move largely as entirely as sucrose. The concentration of sucrose may be as high as 30%, thereby giving phloem sap a syrupy thickness. However, not all plants transport only sucrose; a few plant families also transport others sugars such as raffinose, stachyose, and verbascose. These sugars are similar and consist of sucrose, attached to one or more D-galactose units. Like sucrose, they are all no reducing sugars, which are less reactive and less labile to enzymatic breakdown than are reducing sugars such as glucose and fructose.

Some plants also transport sugar alcohols in their phloem. For example, apple and cherry trees transport sosbitol, and mannitol moves in the phloem of ash (frxinus). While the Biblical manna that was miraculously supplied to the Israelites came from heaven, commercial manna (the source of mannitol) is the dried phloem-exudate of manna ash (frxinus omus) and related plants. Sieve tubes also contain ATP and nitrogen- containing compounds such as amino acids, especially during senescence of leaves and flowers. Sieve tubes also transport hormones, alkaloids, viruses, and inorganic ions, especially k^+. *What three environmental factor affect phloem transport?*

Self-Assessment Questions

1) *What is involved in pressure-flow method?*

***Answer** : According to this model, companion cells load sugars into sieve tubes at sites called sources. These sugars decrease the water potential of the sieve tube, so that water enters the cell and increases its turgor pressure.*

2) *What are sources?*

***Answer**: are the sites where sugars are made by photosyt1thesis or hydrolysis of starch, they contain large amounts of sugar, and their solute concentration is high.*

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3.4 SUMMARY

Organic solutes move through the phloem in sieve tube members, which are living cells arranged into pipe like structures called sieve tubes. Solutes move under positive pressure in sieve tubes. The primary solute transported in sieve tubes is sucrose.

Phloem transport is best explained by the pressure-flow model. According to this model, companion cells load sugars into sieve tubes at sites called sources. These sugars decrease the water potential of the sieve tube, so that water enters the cell and increases its turgor pressure.

The turgor-pressure in sieve tubes decreases a sinks, where sugars area unloaded. As a result, sugars in sieve tubes are carries along a gradient of turgor pressure generated by an osmotically driven influx of water at sources and an exit at sinks.

3.5 References/Further Readings/Web Sources

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3.6 POSSIBLE ANSWERS TO SAES

Answer to SAE 1

Sieve tube members are cylinders collected by sieve like areas called sieve plates, each of which has numerous sieve pores. Sieve pores may occupy more than 50% of the area of sieve plates. Sieve pores were initially thought to be clogged; but studies showed that t sieve pores are open in functional sieve tubes.

Answers to SAE 2

Sinks are sites where sugars are used or stored in solute starch. They contain less sugar than do the sources. Their solute concentration is relatively low. Roots, active meristems and developing fruits are examples of sinks.

Glossary

MRNA= Messenger Ribonucleic acid
IAA= Indole-3- acetic acid
ATP= Adenosine triphosphate

End of Module Questions

1) More than 90% of the solutes in sieve tubes are carbohydrate (**True or False)**

2) One of these is an example of Sinks (a) root (b) stem (c) leaf (d) flower
3) _____________ is a structural adaptation affecting transpiration (a) cuticle b) light c) wind d) temperature
4) The concentration of CO_2 in the atmosphere rarely deviates much from the O.O3%. (**True or False)**
5) This loss of water from the leaves of intact plants in a cool morning is called ______________ **(a)** photosynthesis (b) guttation (c) dew (d) transpiration