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MODULE 1

Unit 1 An Introduction to Botany
Unit 2 Structure and Function of Plant Cells: I
Unit 3 Structure and Function of Plant Cells: II
Unit 4 Structure and Function of Membranes: I
Unit 5 Functions of the Cell Membranes

UNIT 1 AN INSTRODUCTION TO BOTANY

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1.0 INTRODUCTION

This chapter describes what botany is and why you will enjoy studying it. You'll learn about the importance of plants, the lore of plants, and the concepts that unify the study of plants. This is why the entire course is titled the biology of plants, and it is only natural that you will study the biology of plants by talking about Botany which is the study of plants. You will also be introduced to the scientific method which will lead you to knowledge of the process of scientific research and how we came about most of the scientific knowledge we have. The unit will end with a study of the way Botanists view (see) life.

2.0 OBJECTIVES

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

- state at least six uses of plants that establishes our dependence on them
- list the products that are obtained from plant
- state the role that plants have played in the history of mankind
- describe the scientific method

- list and discuss the five unifying themes in botany
- explain four uses of biotechnology
- give at least three reasons why we study Botany.

3.0 MAIN CONTENT

3.1 Plants and Life

Let us open this section by examining what we had as our meals today. It is possible that you have had either breakfast, lunch or dinner or may be you have had the three meals today. Think back on the components of the meals. You will notice that our meal was more than 80% plant. This is a good introduction to our relationship with plants or put in another way, the relationship of plants and life.

For many centuries, humans have relied on plants for survival and pleasure. Asian civilizations were based on rice, middle Eastern civilizations were based on wheat and barley and American civilizations was based on corn. In Nigeria, before the advent of oil, our economy was based on palm tree (east) and groundnut (north) so we can rightly say that the Nigerian economy was also plant dependent.

Out dependence on plants is an ongoing affair. Almost everything we do is influenced directly or indirectly by plants. We use plants to make clothes, strings, ropes, furniture, medicines explosives and musical equipments among others. Yet there are so many other uses of plants. Let us look at some examples.

- Green plants and algae generate the oxygen and sugars that sustain life on earth.
- Plants supply our food and many of our drinks. For example, about 95% of our food comes from only twenty species of plants. Tea and coffee, the world's two most popular beverages are made from plants.
- Extracts from plants and plant like organisms are used to make paints, waxes, dyes, spices and drugs such as cocaine, aspirin quinine and antibiotics.
- We use flowers for decorations, perfumes and as a means of expressing our feelings.
- On the negative side, plants clog our rivers, damage our crops, cause allergies, and poison us. (I am sure you can recall incidences of people who died after a meal prepared with poisonous mushrooms, or improperly processed cassava); many children are poisoned each year from eating poisonous plants.

Plants dominate our lives and economy and we can rightly conclude that plants affect virtually everything we do.

The various needs and uses we have of plant have given rise to Botany, which is the scientific study of plants.

3.1.1 What is a Plant?

You may be one of those who have never given a though to the above question. You will not be alone in this because most of us think that we have a fairly good idea of what a plant is – quiet green organism that we eat, use for decoration, cut down when we please and plant as shades. Our notion is correct if it fits into the above, but that is not all that a plant is. It is difficult to come up with a complete definition for the word plant. The nature of plants is so varied that it will be difficult to hold unto a trait and say that it is common to all plants. For example, not all plants are green. There are plants that consume animals. Some plants do not look like or act as plants and yet they are plants. Plants have also being considered an uninteresting.

Some Plants and their Characteristics

- Giant sequoia (sequoidendron gigantum) and its taller but slimmer relative, the coastal red word (sequoia sempervirens) are the world's tallest plants. A twenty-year old tree is often more than 15 metres (50 feet) high.
- The General Sherman tree in California weighs 1,400 tons that is as much as 20 million boxes of toothpicks, 200 elephants or 10 blue whales. (The whales are the largest representative of the animal kingdom). Interestingly, these giant trees are supported by roots that seldom go deeper than 1.8 metres (6 feet) into the soil (Ask yourself, if their roots are that shallow, how come the first major wind doesn't blow them down – that is an interesting aspect of plant life).
- The oldest giant sequoia are about 3,200 years old, meaning that the trees that grow today were already 200 years old when kind David ruled the Israelites. (How come they were not destroyed when that civilization and subsequent ones were wiped out).
- Cherry tree has been used for many purposes, cherry black has been used to make a tea to ease the pains of childbirth and to cure coughs, colds and dysentery.
- Plants are used to produce the tons and tons of newsprints read in this and other countries.
- Sweet potatoes were once considered strong aphrodisiacs.
- Spinach contains little that is nutritious (expect vitamin A), Cartoons and parents try to convince their children otherwise.

Although spinach parents try to convince their children otherwise. Although spinach contains much iron, humans do not absorb it during digestion.

- Plants have been star witnesses in several criminal trails. Botanical evidence have helped convict many rapists, murderers and thieves.
- People have used fibres for more than ten thousand years. They are used to make rope, brooms, brushes, textile, linen, cigarette paper and money.

SELF ASSESSMENT EXERCISE 1

1. List four uses of plants
2. State four interesting traits found in plants (give example).

3.2 Botanists View of Life

Botanists, other scientists and non-scientists often share an almost insatiable curiously about life, and its diverse but related forms. Scientists, however, watch life in more exotic places, for e.g. while perched in a tree top of a typical rain forest or in a green house surrounded by plants bred specially for experiments. Such intense observation has generated many questions about plants. The questions can be summarized as

- How are plants constructed?
- How do plants work?
- How did plants get here?
- Why are plants important?

Botanists have answered these and other questions by using an experiment based on process called the scientific method.

The Scientific Method

This is a systematic way to describe and explain the universe based on observing, comparing, reasoning, predicting, testing, concluding and interpreting. It begins with things that we are all familiar with observation and curiosity. Such observations can happen anywhere, in a research laboratory or in a garden. For example, the observation that leaves of many plants can follow the movement of the sun, can make us ask the question. What enable the leaves of some plants to follow the movement of the sun?

This kind of causal question is at the heart of scientific method. Science is fundamentally about finding answers to such questions.

To find these answers, botanists use past experiences, ideas and observations to propose hypotheses that may produce predictions. To determine whether predictions are accurate, botanists do experiments. If experimental results match the predictions the hypothesis is rejected. In this way, some hypothesis is accepted and some are not our understanding improves by eliminating some of the explanations.

Posing hypotheses is perhaps the most creative step in the scientific method. It requires a type of reasoning called abduction, which is a process of devising explanations for observations. Abduction involves sensing ways that a new situation is somehow similar (analogous) to other known situations, and using this similarity to make hypothesis about the new situation.

Activity – Now think of situations in real life when something happens, and in an attempt to explain it, you relate it to other thing that has happened in the past. When you take conscious steps to see if the two events are really related, you are involved in a scientific method. Because you would have made guesses (hypotheses) concerning the events, and you would also try to eliminate some of them to know which is the actual cause of the event.

Science has been described as a trained and organized common sense. A conclusion that you reach makes an end to the scientific method for a particular experiment, but it seldom ends the process of scientific inquiry. Any conclusion must be placed into perspective with existing knowledge. For this reason, a conclusion is never the final answer, since there are always .more things to study; and more things to learn.

In science, as well as well as life, it is important to keep an open mind, that is, to maintain the objectivity that the scientific method requires in drawing conclusions and designing experiments and not allow biases or expectations to cloud the interpretation of result.

Although the scientific method is a powerful tool for answering some kinds of questions, it is not fool proof. For example, several studies have shown that animals that are fed larger doses of vitamin E live longer that those receiving only average amounts of the vitamin. From these studies, many concluded that vitamin E retard aging, thereby prompting all sorts of claims by skin -cream manufacturers. However, the animals fed large amounts of vitamin E also lost weight, another factor that correlates positively with increased life expectancy. The original experiment did not distinguish these possible interpretations. More experiments are therefore needed to distinguish other possible interpretations.

Science is not always are planned and organized as the scientific method suggests. Sometimes discoveries involve luck and creativity. The creative side of science involves making the mental connections to take advantages of accidental observations. For example, consider the case of Alexander Fleming. In 1928, Fleming left a culture dish of disease-causing Staphylococcus bacteria uncovered in his lab. Other organisms quickly, contaminated plate, Fleming noticed several clear areas on the plate, where the bacteria were not growing. This keen observation suggested to Fleming I that some contaminant from the air had stopped the growth of the bacteria. Efforts by other scientists later, led to the identification and purification of penicillin.

Was Fleming lucky? Perhaps -but he would not have discovered penicillin if he had not been observant and able to recognize the potential importance of what he saw. His discovery, like so many others, exemplifies a famous saying: "Lusk is when preparation meets opportunity". Most others would not even have recognized the clear areas on the plate; much les thought that those areas could be significant. Such observations are critical to science.

Discoveries are determined by our ability to observe, which often depends upon technology. To appreciate this, consider the development of the cell theory the set of postulates that holds the cell to be the fundamental unit of life. Before the middle of the seventeenth century, no one even knew that cells existed. Because most cells were too small to be seen with the naked eye, their discovery awaited the invention of microscopes. The first discovery was by Robert Hooke who in 1665 used a crude hand - built microscope to discover cells in a cork. In 1838, the study by the German Botanist Mathias Jakob Schleiden, led him to conclude that all plants "are aggregates of fully individualized, independent separate beings, namely the cells themselves" This was the first postulate of what we now call the Cell theory and was a brilliant example of inductive reasoning, which is, making a generalization based on concurring observations. The next year, German Zoologist Theodora Schwann reported that animals are made of cells and proposed a cellular basis of life.

Later in 1855, the great German Pathologist, Rudolf Virchow competed the modem cell theory when he induced that "the animal arises only from an animal and the plant only from a plant". This strong statement refuted the idea of spontaneous generation, that is, that life could arises from non-living matter, that has been suggested by Aristotle and has persisted for many centuries. Today the cell theory is tremendously important because it emphasizes the similarity of all living systems and thereby unites the many studies of different kinds of organisms.

Today, much of science is driven by new technology. Just as microscopes revolutionized our understanding of cells, so too will technology produce remarkable discoveries and new insights. That technology will overturn many of the facts you will read in this course, and in any other science book. This is why Botany concentrates on the process of science; the facts may change, but the process used to discover them remains the same.

The cycle of questioning and answering that defines the scientific method is second nature to a practising scientist; however its use is not restricted to scientists. We all observe, compare, guess, plan and do experiments, and interpret and use the results of the experimental. For example our ancestors used trial-and-error to determine which plants were edible. Parents do a similar experiment when they introduce food.

One item at a time to their children to check for allergic reactions. They also experiment, by tasting the food in question, to check its safety or taste.

SELF ASSESSMENT EXERCISE 2

1a. What method have botanists and other scientists used to find answer to issues that bother them?
b. What does this method involve?
2. Make a report of the activity you thought of a situation in real life that you used the scientific method to address.

3.3 Unifying Themes of Botany

Plant studies have revealed that plants share several important features. These features are what we want to refer to as themes in this unit. An understanding of these themes will enable you understand plants better. These themes will form the bedrock of what you will study each time you study about plants in your course. We will now take a look at these themes.

1. Plants consist of organized parts

Plants use the same building blocks to make all their parts. Imagine all the words you have been reading in this unit. They are all made from the twenty-six letters of the alphabet. The secret is in the arrangement of the building blocks. The difference we see in organs such as leaves and roots result primarily from different arrangements of similar tissue rather than the presence of unique tissues

2. Plants exchange energy with their environment

Plants absorb energy from their surroundings and in turn have an effect on their environment as they use that energy for their activities. This conversion of energy from one form to another occurs through a set of chemical reactions collectively called metabolism.

3. Plants respond and adapt to their environment

Such adaptations are inherited characteristics that help to ensure survival. These responses include the ability of plants to detect and respond to stimuli such as gravity; to convert light energy to chemical energy; to gather nutrients, to lure animals into helping pollinate, defend and disperse the plants. All of these adaptations are important because they increase a plant's chances of survival and reproduction.

4. Plants reproduce

Their reproduction can be as simple as splitting a cell, or as complex as going through the process of flower production, Mobilizing energy reserves or luring insects, birds and other Helpers. Although most plants can reproduce sexually and asexually, the greatest variation result from sexual Reproduction, in which pieces of DNA called genes move from one generation to the next. Genes combined with the influence of the environment produces the characteristic of features of plants. The diversity of plants result from their diverse environments and differences in their DNA, and is a product of evolution.

Understanding how cells read DNA and translate its instructions into metabolism and growth is a major goal of many biologists and the basis of an exciting business -biotechnology. We will talk about the ways we use biotechnology later on in their unit.

5. Plants share parts of a common ancestry

This ancestry was best explained in the most important science book ever written - the origin of species, by Charles Darwin; published in 1859. This book, which has been, described as “one long argument” for the diversity of life, used evidence, logic and analogy to explain the central role of variation in the evolution of life.

Botany discusses these themes in several contexts including the relation of structure and function, the evolution and diversity of plant, the lore, importance and uses of plants. The newest of them all is plant biotechnology. Biotechnology is a way of using organisms to make commercial products. The ability to directly manipulate a plants genome began in 1983 when botanists transferred a gene from a bacterium into a plant. Today biotechnology and molecular biology are revolutionizing biology and biology - based industries. A few uses of biotechnology are given below.

- To make vitamins and drugs. For example, plants are being transformed into industries that make drugs and oils. A promising new vaccine for Hepatitis B is made with baker's years, and plants are now used to make serum albumen, which when eaten by pets such as tomato hornworm induces paralysis and death. This protein has no effect on other organisms.

- To produce plants resistant to herbicides. Genetically engineered plants can now tolerate, glyphosate, the active ingredient in herbicide used to control weed in farms. This could increase yields significantly because weeds reduce agricultural productivity by more then 10%.

- To make food and beverages such as yogurt, cheese, bread and beer. Example, botanists at Quarter Oats are using biotechnology to increase the protein content of their oats; those at Kraft are using similar technologies to decrease the amount of saturated fat in the soybean oil used in their products.

- Other uses of biotechnology include making better - tasting food, cleaning the environment, recycling wastes, preventing tooth decay, and producing antibiotics, biodegradable plastics, and fragrances.

- We will end this section by looking at the gains of studying plant biology otherwise known as botany.

- A study of botany will show you the process of science and the doing of scientists. It will help you appreciate living organisms. Such an appreciation is the first step towards respecting and conserving life.

- Botany will help you appreciate what botanists know, what they don't know and what they do.

- You will learn the facts' and process of doing botany

- There is no reason why you can't be the next person to make a major scientific discovery.

SELF ASSESSMENT EXERCISE 3

1. Describe any 3 uses of biotechnology
2. Give two reasons why we study botany

4.0 CONCLUSION

Plants have a fascinating history and story, and our national and world economies are based on plants. Virtually everything we do is influenced by plants. We can say that plants dominate our lives. Studying plants has to be done systematically, and this is known as the scientific method. The scientific method is used to describe and reveal the universe based on observing, comparing, reasoning, predicting, testing and interpreting. This method has given us a better appreciation and understanding of plants.

5.0 SUMMARY

For many centuries, humans have relied on plant for survival and pleasure. Our dependence on plants is an ongoing affair, for example Green plant and algae generate the oxygen and sugars that sustain life on earth.

Plants are an interesting and diverse group that it is difficult to give a single definition of a plant.

Plant study has however led us to the scientific method which involves observing comparing, reasoning, predicting, testing and interpreting. This has given us a deeper understanding and appreciation of plants.

Plants consist of organized parts, exchange energy with their surroundings, respond and adapt to the environment, reproduce, and share a common ancestry.

Plant biotechnology which is a new and interesting area of plant is a multimillion-naira industry that is changing our lives and societies; example, in the production of disease and insect resistant plant varieties.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1(i) They generate oxygen and sugar that sustain life.
(ii) Plant extracts are used for paints, waxes dyes and drugs.
(iii) Flowers are used for decoration.
(iv) They clog rivers and poison us.

2(i) Giant sequoia are worlds tallest plants about 15 meters (more than 50 feet) high.
(ii) General Sherman Tree weighs 1,400 tons and yet has shallow roots.
(iii) Old sequoia about 3,200 years old.
(iv) Spinach not as nutritious as we believe, has only vit. A and iron that cannot be absorbed by humans.
(v) Cherry bark is medicinal

ANSWER TO SELF ASSESSMENT EXERCISE 2

1(a) Scientific method
(b) Observing, comparing, reasoning, predicting testing, concluding and interpreting.

2. Report of an activity - example trying to find the food source of an allergic reaction by elimination.

ANSWER TO SELF ASSESSMENT EXERCISE 3

1(i) To make vitamins and drugs
(ii) To make foods and beverages
(iii) To make better-testing food

2(i) To understand the process of science.
(ii) To appreciate living organisms and hence respect and conserve them.

6.0 TUTOR-MARKED ASSIGNMENT

List and succinctly discuss 5 unifying themes of botany.

7.0 REFERENCES/FURTHER READING

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UNIT 2 STRUCTURE AND FUNCTION OF PLANT CELLS: 1

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2.0 Objectives
3.0 Main Content
  3.1 Components of the Plant Cell
    3.1.1 Why are Cells so Small
    3.1.2 Membranes and Cell Compartments
    3.1.3 The Cytoskeleton
  3.2 The Cell Wall
    3.2.1 How the Cell Wall Grows
    3.2.2 Connections between Cells
  3.3 The Nucleus
  3.4 Ribosomes
4.0 Conclusion
5.0 Summary
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1.0 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 with that surrounds 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.

2.0 OBJECTIVES

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
- state the major functions of ribosomes
- describe how ribosomes occur in plant cells.

3.0 MAIN CONTENT

3.1 Components of the Plant Cell

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 up of:

- Plasmalemma
- Hyaloplasm
- Tonoplasm
- Microbodies
- Endoplasmic Reticulum (Er)
- Dictyosomes
- Spherosomes
- Mitochondria
- Plastids.

Some of the components of the cytoplasm has 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)

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.

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.

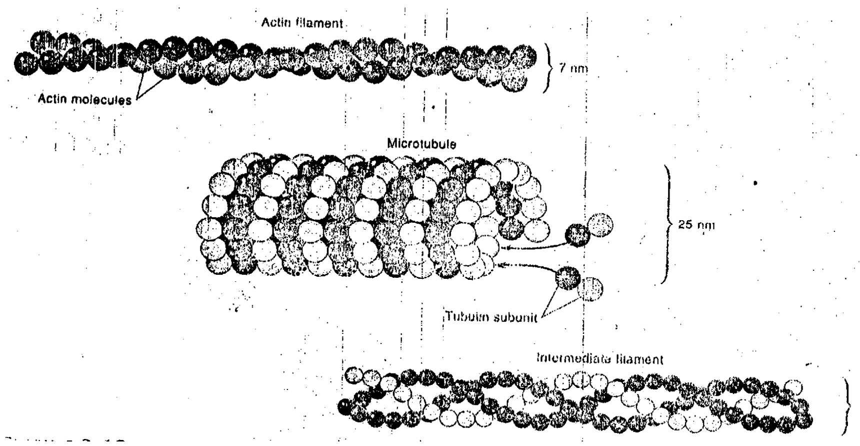
Biological membranes are usually very small and consist of mostly phospholipids and proteins. In addition to the plasma membrane, there are membranes that surround nuclei, mitochondria, chloroplasts, vacuoles and microbodies. Membranes also pervade the cell between organelle in a complex system that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

3.1.3 The Cytoskeleton

The cytoskeleton is a network of filaments that forms a mechanical support system in the cell. These filaments also help maintain organelle position, direct cell expansion, and control the movement of chromosomes during nuclear division. Groups of filaments may also form channels for transporting large molecules within the cell.

There are at least three kinds of filaments that comprise the cytoskeletons of cells in plants and animals.

(Fig. 2.1)



Structural model of the three different kinds of cytoskeletal filaments.

The largest filaments are **Microtubules** which are hollow tubules. Microtubules are made of two types of globular proteins, alpha tubulin and beta tubulin. These proteins are bound to each other as dimmers, which aggregate into microtubules.

The smallest filaments in the cytoskeleton are actin filaments which consist of two intertwined strands of globular protein actin. The proteins of microtubules and actin filaments are the same in plants and animals. This similarity suggests that these filament work the same way in both kingdoms, even though the tissues that contain them, such muscles tissue and leaf tissue, are different.

The third kind of cytoskeletal filaments are intermediate in size between microtubules and actin filaments. They are called intermediate filaments. These filaments are made of fibrous proteins wound into coils. Several kinds of proteins in intermediate filaments occur in animals, but little is known about them in plants. These proteins are usually numerous in animals and different kinds of proteins occur in different types of cells.

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. But if you recall what you learnt about cells from BIO 101 and BIO 123 you will remember that cells often change shape, and organelles and other cellular components are in constant motion. 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.

SELF ASSESSMENT EXERCISE 1

1. Give one major reason why cells are small.
2. What are the three kinds of filament in the cytoskeleton?
3. Which type of filament is the same for both plants and animals?

3.2 The Cell Wall

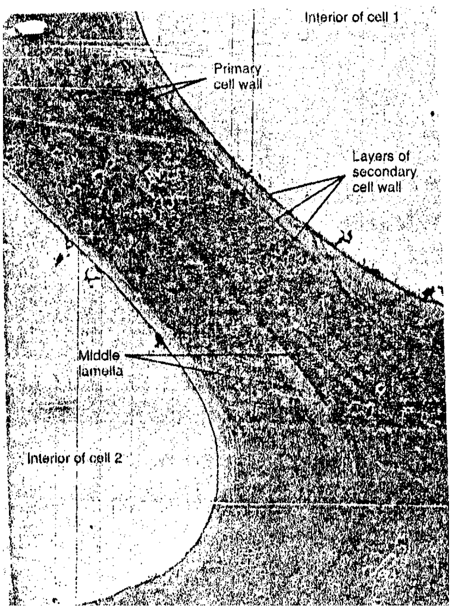
The most easily observed part of a plant cell is the cell wall. In some cells, such as the cork cell in bark, the cell wall is the only remnant of a formerly living cell. Cell walls are dynamic parts of cells that can grow and change their shape and composition.

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 (this issue has been treated extensively in BIO 124. You may need to check the unit secondary growth; xylem for more detailed information on cork cell). 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.

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.

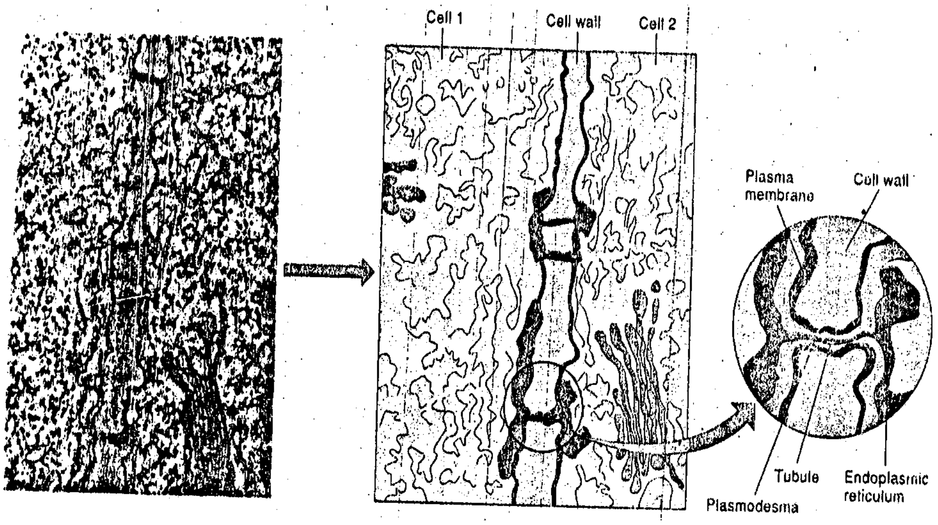
Cellular expansion requires the cell wall to stretch or deform as the cell absorbs more water. As the wall enlarges, the existing cellulose micro fibrils must separate because they cannot stretch. During expansion, new cellulose micro fibrils are deposited inside the loosened cell wall in different patterns, 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.

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 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 these 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 neighbouring cells. Despite such evidence, cells probably do not exchange all materials freely; neighbouring 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)

(Fig. 2.4)

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

Later on in unit 17 you will learn about the movement of water through plants.

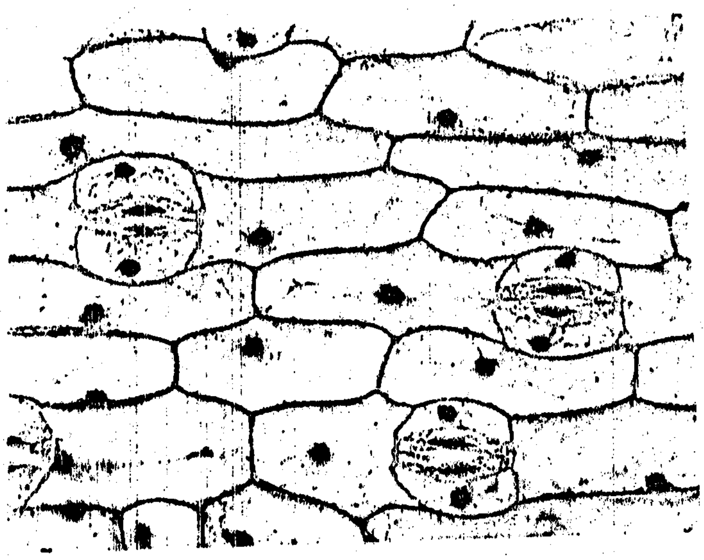
SELF ASSESSMENT EXERCISE 2

1a. What are the two types of cells walls?
b. What is the difference between them?
c. What is the area of connection between cells called.

3.3 The Nucleus

The nucleus is usually the most conspicuous organelle in a cell, when stained, it can be easily seen with a light microscope.

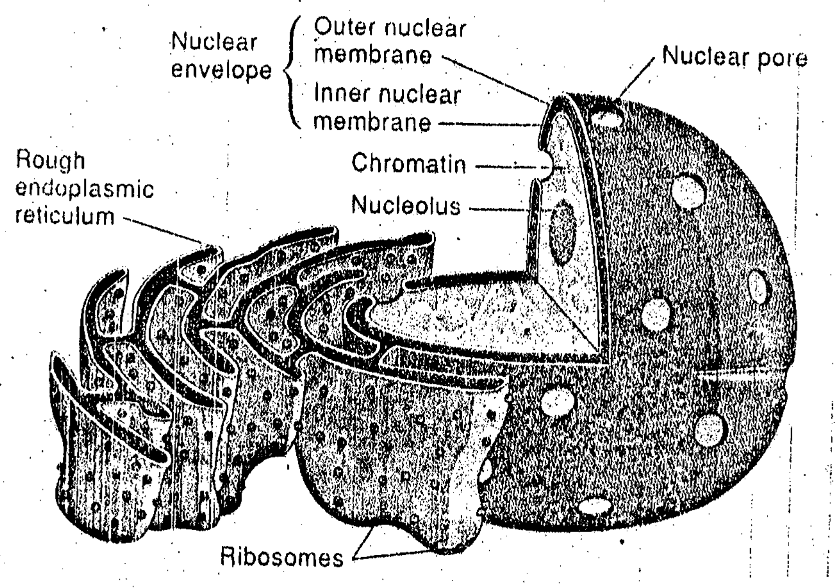
(Fig. 2.5)



(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. (you can go to BIO 101 and BIO 123 to refresh your memory on this). 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 (you will learn more about the endoplasmic reticulum in unit 3). 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. (see section 3.4). 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.

3.4 Ribosomes

Ribsomes are where proteins are made in the cell. They are usually small and consist of approximately equal amounts of protein and ribosomal RNA (RNA). Each ribosome is assembled from two subunits that are produced in the nucleus and exported to the cytosol. The two sub-units are joined when they attach to a molecule of messenger RNA (mRNA). Ribosomes usually occur in clusters called polysomes on a single molecules of mRNA

(Fig. 2.7)

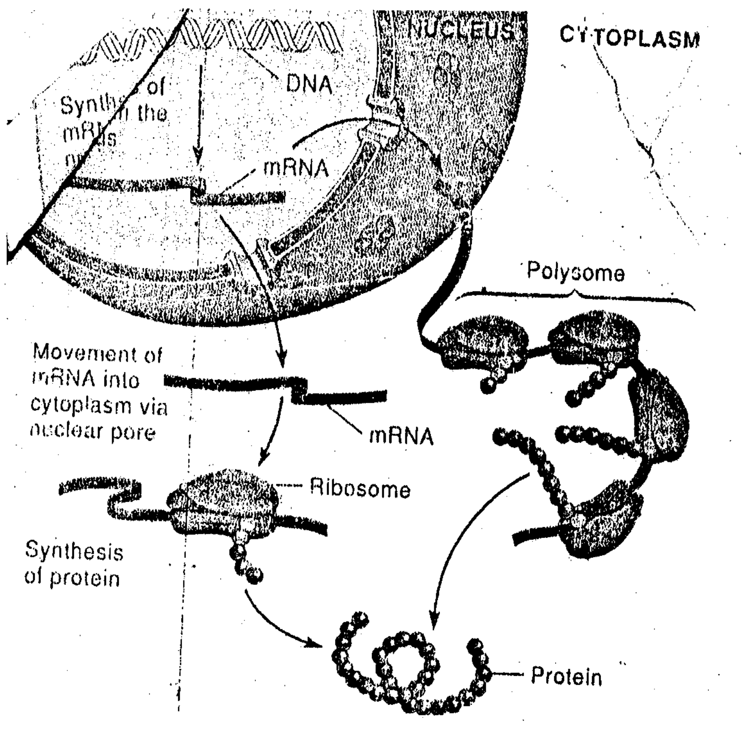


fig 2.7 Ribosomes playa central role in protein synthesis, Unlike other organelles, ribosomes do not have membranes.

Unlike the nucleus and other organelles, ribosomes are not surrounded by membranes.

Ribosomes are either attached to membranes or move freely in the Cytosol. Proteins made by cytosolic ribosomes are usually also Cytosolic; dthat is, they are not associated with membranes. These proteins include enzymes that degrade sucrose and glucose in the cytosol. Conversely, membrane bound ribosomes usually make proteins that will be attached to or embedded in membranes.
Examples of such proteins are those that control the transport of ions and other substances through the plasma membrane.

The numbers of ribosomes varies among cell types and in different stages of cell development. A growing cell can make about 10,000 ribosomes per minute. Ribosomes are especially abundant in dividing cells because these cells make large amounts of proteins.

SELF ASSESSMENT EXERCISE 3

1. Briefly describe the structure of the nucleus
2a. What is the major function of ribosomes in the plant cell
b. How do ribosomes occur? What are they called?

4.0 CONCLUSION

All plants are made of cells. Some cell components occur in all living cells, while others occur only in the cells of leaves, roots or other parts of plants. Depending on their components, cells can divide, grow, transport sugar or water, photosynthesis, secret nectar or resin, or harvest energy from organic molecules. The general components of the cell were highlighted in this chapter. The cell wall, the nucleus and the Ribosomes and their functions in plant cells were highlighted.

5.0 SUMMARY

Cells are the simplest units of a plant that can live independently. Each plant cell consists of a cell wall that surrounds a plasma membrane, which encloses the contents of the cell. The contents of a plant cell usually include a nucleus and the cytoplasm. The cytoplasm include a nucleus and the cytoplasm. The cytoplasm includes all organelles except the nucleus, plus all internal membranes and the cytosol.

Membranes divide cells into many, interconnected compartments. These compartments are connected by membranes that either move between or are attached to the nucleus and other organelles. All membranes consist of a double layer of phospholipids that has enzymes attached to or embedded in it.

The distribution and movement of membranes and other cell compartments are affected by the cytoskeleton a network of filaments that includes microtubules, acton filaments, and intermediate filaments. All three types of cytoskeletal filaments are made of different kinds of proteins.

Young cells and actively growing cells have flexible primary cell walls. As cells mature, however, they often form rigid secondary cell walls just inside the primary walls.

Plant cells are connected to one another by plasmodesmata. These connections contain cytoplasm and a plasma membrane that is continuous between cells.

The Nucleus is surrounded by a double membrane while ribosomes have no membranes.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Because cell wall is limited by the amount of plasma membrane that can service it.
2. Microtubules, acton filaments, intermediate filament.
3. acton filaments.

ANSWER TO SELF ASSESSMENT EXERCISE 2

1a. Primary cell wall and secondary cell wall
b. Secondary cell walls are formed later and are thick, rigid and lignified.
c. Plasmodesmata-primary pit-fields.

ANSWER TO SELF ASSESSMENT EXERCISE 3

1. Most conspicuous organelle in cell, contains a lot of DNA and is surrounded by 2 membranes called nuclear envelopes. These membranes may be joined by small pores or fused to form nuclear pores.
2a. Protein manufacture
b. Clusters, polysomes

6.0 TUTOR-MARKED ASSIGNMENT

See end of unit 3, since both units are continuous.

7.0 REFERENCES/FURTHER READING

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UNIT 3 STRUCTURE AND FUNCTION OF PLANT CELL: II

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1.0 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.

2.0 OBJECTIVES

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

- describe the membrane system in a plant cell
- state two major functions of the membrane system
- list the main characteristics of the plasma membrane
- describe the endoplasmic reticulum
- name the two types of endoplasmic reticulum
- describe the structure of the dictyosomes
- list the 2 major roles played by the dictyosomes in the plant cell
- list the major contents of vacuoles
- identify the two most important microbodies
- state the function of the microbodies identified
- name the two major organelles for energy conversion
- outline 3 similarities and 3 differences between the chloroplasts and the mitochondria.

3.0 MAIN CONTENT

3.1 The Membrane System

All the membranes in all cell 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.

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.

Let us now look at these individual reaction vessels to see that they look like and the functions they perform.

3.1.1 The Plasma Membrane

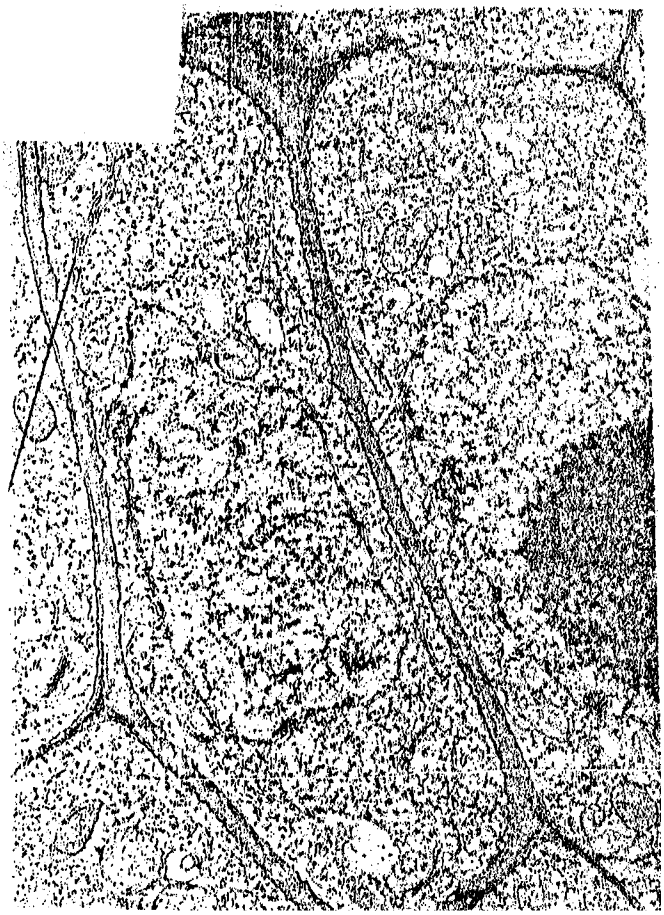
The plasma membrane is a remarkably, changeable, multipurpose membrane already mentioned, it acts as a differentially permeable barrier to substances that enter and leave the cell; some substances can pass through it, and some cannot.

Partly because of its outer position, the plasma membranes receive and translate chemical and environment signals from outside the cell. Signals translated by the plasma membrane change cellular metabolism. For example, hormones received by the plasma membrane can initiate a series of enzymatic reactions that cause the cell to enlarge. The plasma membrane also accepts packets of raw materials from other membranes inside the cell and directs the assembly of these materials into cell-wall microfibrils.

3.1.2 The Endoplasmic Reticulum

Most of the membrane surface area inside cells occurs in the endoplasmic reticulum (ER), which is an extensive network of sheet like membranes distributed throughout the cytosol. When viewed with an electron microscope, the ER appears to meander throughout the cell.

(Fig. 3.1a)

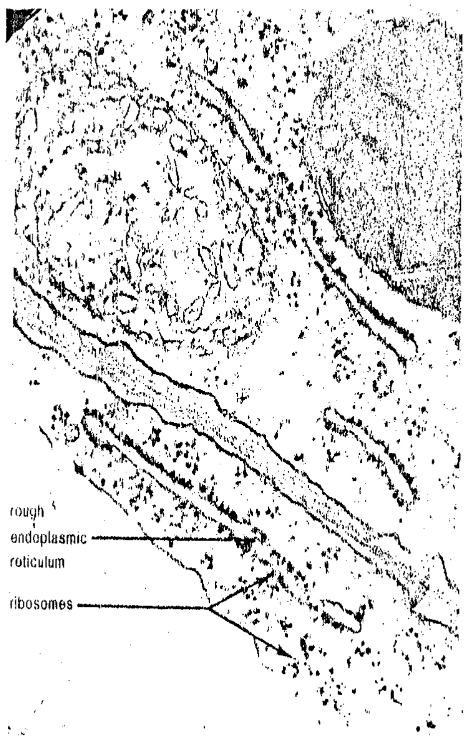


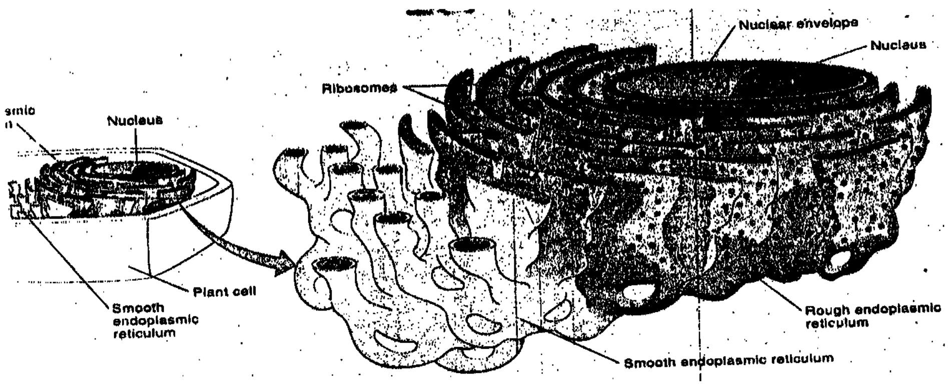
Electron micrograph of a differentiating cell in a root up of bean (phaseches vulgeb) showing dictysames (D), x 22,000, the reticulum of the cell. (b) Three-dimensionsally of the FR, as shown here, cannot be wean in the electron micrograph.

Seen in three dimensions, however, the ER is a system of flattened tubes and sacs (fig3.1b) that is continuous between the plasma membrane and the outer membrane of the nuclear envelope. Internal comportments of the ER are isolated from the rest of the eytoplasm but in contact with the space between the two membranes of the nuclear envelop. Plasmodestmata also contain portions of SER, which form a continuous in internal membrane between cells.

Two regions of ER can be distinguished in electron micrographs. One region is called the rough ER, because the many ribosomes attached to it give it a rough appearance.

(fig. 3.1b, fig. 3.2a)





In contrast, the other region is called the smooth ER because it has no ribosomes attached to it (fig. 3.2b).

Biochemical cytology and studies of isolated ER membranes have shown that the rough ER is the major region of protein synthesis in the cell. The smooth ER is involved with the synthesis of phospholipids and the assembly of new membranes both types of ER from vesicles that break away and fuse with other membranes When one of these vesicles fuse with the plasma membrane, its contents are secreted by such vesicles. Other vesicles can fuse with organellar membranes and become part of them.

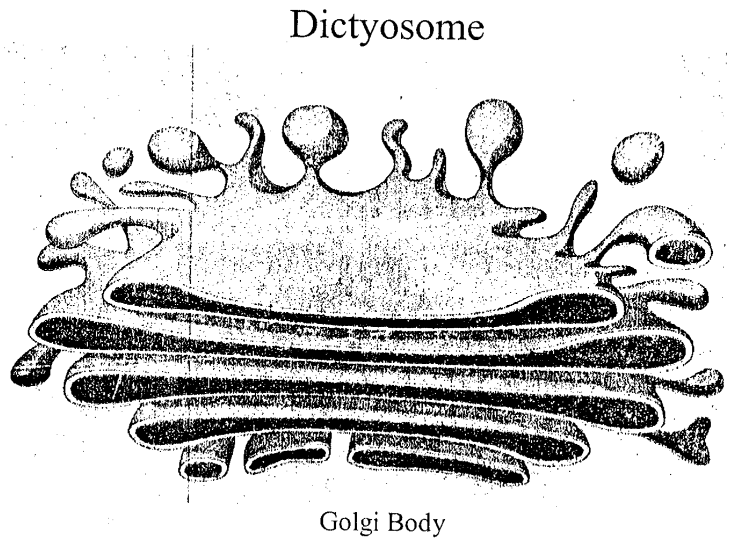
SELF ASSESSMENT EXERCISE 1

1. State any two major functions of the membrane system
2. What are the main characteristics of the plasma membrane?
3. Describe the Endoplasmic Reticule (ER).

3.1.3 Dictyosomes

Stacks of flattened, membrane vesicles are called dictyosomes, or sometimes Golgi bodies

(Fig. 3.3)



Three-dimensional representation of dictyosome (Golgi body) Verticle near nuclear membrane are considered to be part of the dictysome

Dictyosomes are usually two-sided, with one side facing the smooth ER and one side facing the plasma membrane. Membrane-bound vesicles occur near the edges of the dictyosomes and are considered to be part of them.

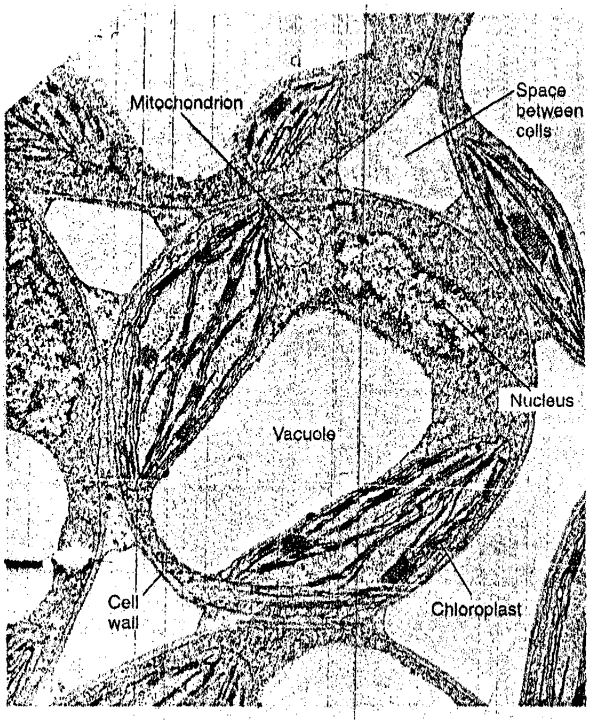
Dictyosomes receive material from the smooth ER, either through direct connections or in vesicles released by the ER. Transport vesicles from the ER fuse with the inner face of the dictyosomes and release their contents into its interior. These vesicles contain lipids, proteins, and other substances, which are often chemically modified in the dictyosome and then sorted into separate packets. For example, sugars in dictyosomes become lined to proteins, converting them into glycoproteins. Packets of glycoproteins or other materials eventually move to the edge of the dictyosome Rear the other face, where the dictyosome membrane is pinched off into another vesicle. This new vesicle moves to the plasma membrane or to other sites in the cell.

Vesicles that move to the plasma membrane are secretory vesicles because they fuse with the plasma membrane and secrete their contents to the exterior of the cell. This type of secretion is called exocytosis. Polysaccharides secreted by excocytosis become part of the cell wall. Other substances are secreted from specialized cells with the end of dictyosomes. These substances include nectar that flowers secrete as a reward for insects and other pollinators; and the oils or similar resinous chemicals secrete from the gland on leaves and stems of mints and many other highly fragrant plants.

In dividing cells, dictyosomes help build new primary walls after the nuclei has divided. Wall construction occurs when dictyosomes are guided by microtubules of a region between nuclei. Vesicles containing cell wall precursors fuse in this region to form a disk-shaped structure called a cell plate. The cell plate grows by the addition of more vesicles unit it fuses with the parent cell wall, which completes the partition between the two new cells.

3.1.4 Vacuoles

Vesicles from the ER and the dictyosomes often fuse to form larger sacs called vacuoles. Immature cells of plants and animals may contain several small vacuoles but in most plant cells, these small vacuoles fuse into larger ones as the cell matures. A mature plant cell typically has one large vacuole that occupy up to 95% of tile cell volume (fig 3.40)



The membrane of the central vacuole has its own name the tonoplast.

(Fig. 3.4b)

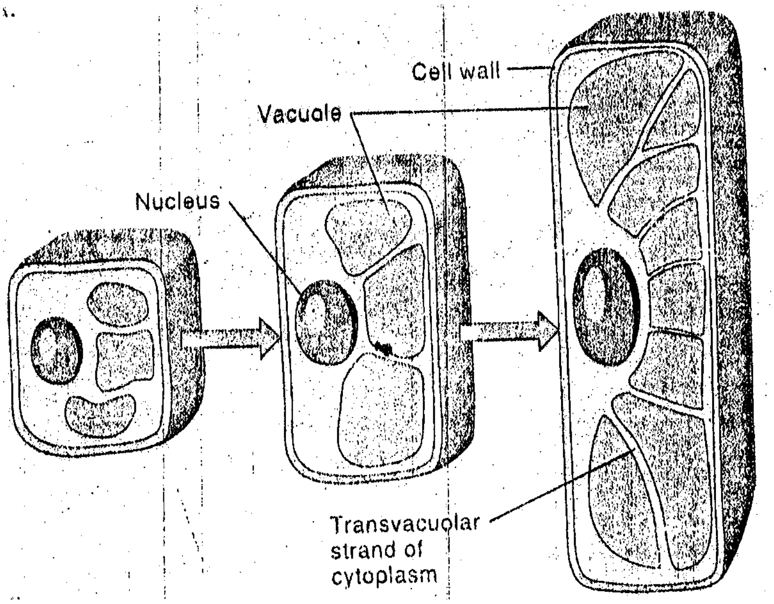


Fig* 3. 4 *Vacuoles. (a) transmission electron micrograph from a coleus leaf (Coleus blumer). The expanding central vacuole compresses the cytoplasm into a small space against the cell wall, x 20,000 (b) schematic diagram of cell growth, showing how an increase in cellular volume can occur without a 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 labour 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.

3.1.5 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.

Perioxysomes are so named because they metabolize hydrogen peroxide (H_2O_2). The enzyme that catalyses this breakdown is catalase. However perioxysomes also contain oxidases that catalyze the production H_2O_2. The important of having these oxidases and catalase in the same organelle is a mystery.

Glyoxysomes also contain enzymes that catalyze the breakdown of fatty acids into acety-CoA. This acety-CoA is used to make organic acids that can be exported from the glyoxysome and used in other metabolic pathways, such as respiration and sucrose synthesis. Unlike perioxysomes, glyoxysomes rarely occur in animals. Consequently plants can convert lipids to carbohydrates, but animals generally cannot.

SELF ASSESSMENT EXERCISE 2

1. What two major roles do the dictyosomes perform?
2. List the major contents of vacuoles.
3. What are the two most important micro bodies, and what is their function.

3.2 Organelles for Energy Conversion

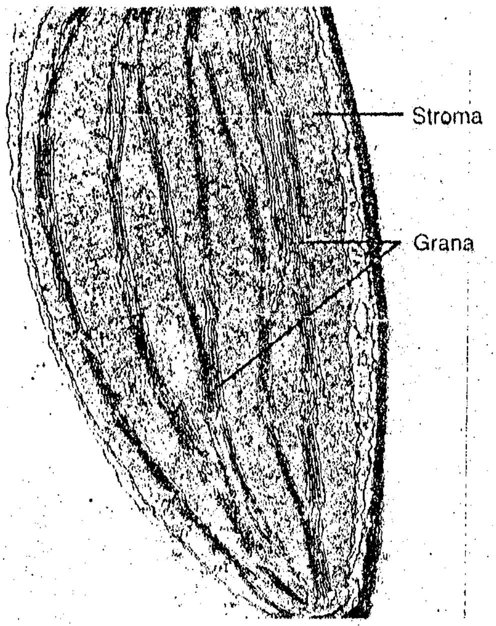
Cells thrive on the energy of ATP. (I hope you still remember what ATP means. If you are not too sieve, refer to BIO 101 and BIO 123 to refresh your memory). Two kinds of organelles, chloroplasts and mitochondria, produce most of the ATP needed for cellular metabolism. These organelles are similar in 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 phosphory late 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 respective 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 set of enzymes; Chloroplasts have many shapes and sizes, and are generally larger than mitochondria. Mitochondria are often cigar-shaped. We will now briefly look at these two organelle.

3.2.1 Chloroplasts

The fluid inside chloroplasts is called the stroma (fig 3.25a).

(Fig. 3.5a)



Chloroplast (a) Transmission electron micrograph of a chloroplast, showing strangs. Thytakoids and thytakoid stacks (grano), x 15,000 the chloroplasts in figure 18a.

Membranes occurring throughout the stroma are called thylakoids. Thylakoids are aggregated into stacks called grama, or they form connections between stacks.

(Fig. 3.5b)

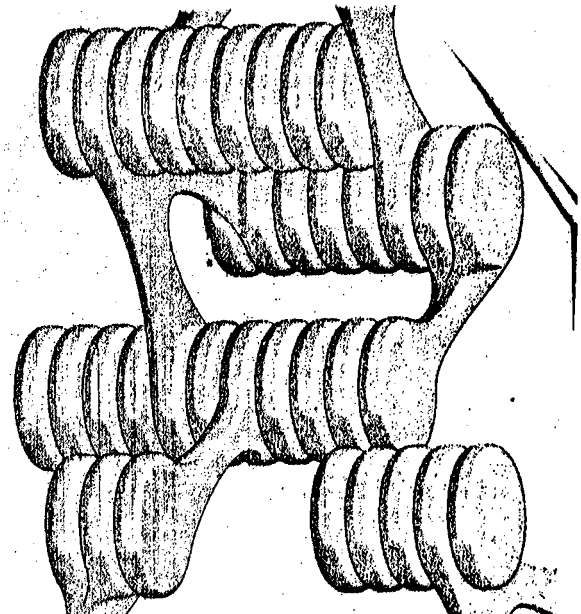


Fig. 3.5(b) three-dimensional model of chloroplast membranes drawing vessels like thytakiods in grams and between grams.

Because these connections are so common all thylakoids in a chloroplasts are probably, formed by the same, continuous membrane system. Thylakoids membranes contain a rich diversity of enzymes catalyze the reactions of photosynthesis, they are distinct from the enzymes mitochondria. Pigments in chloroplast include the chlorophylls, which create the green colour of leaves and other green organs, and the carotenoids, which are the yellow orange or red colours of some leaves, tomatoes and carrot. In addition to enzymes and pigments, chloroplasts often contain starch or oil.

The greenest cells of a leaf may each contain more than fifty chloroplasts, However chloroplasts are just one type of plastids. Other plastids are classified according to the kinds of pigments or storage products they contain; for example, amyloplasts store starch, and elaioplasts store oils. Colored, non-green plastids are chloroplasts and are usually red, orange or yellow.

3.2.2 Mitochondria

A mitochondria consist of a smooth outer membrane, and an inner membrane that is folded into tubular or vesicle-shaped cristaeb.

(Fig. 3.6)

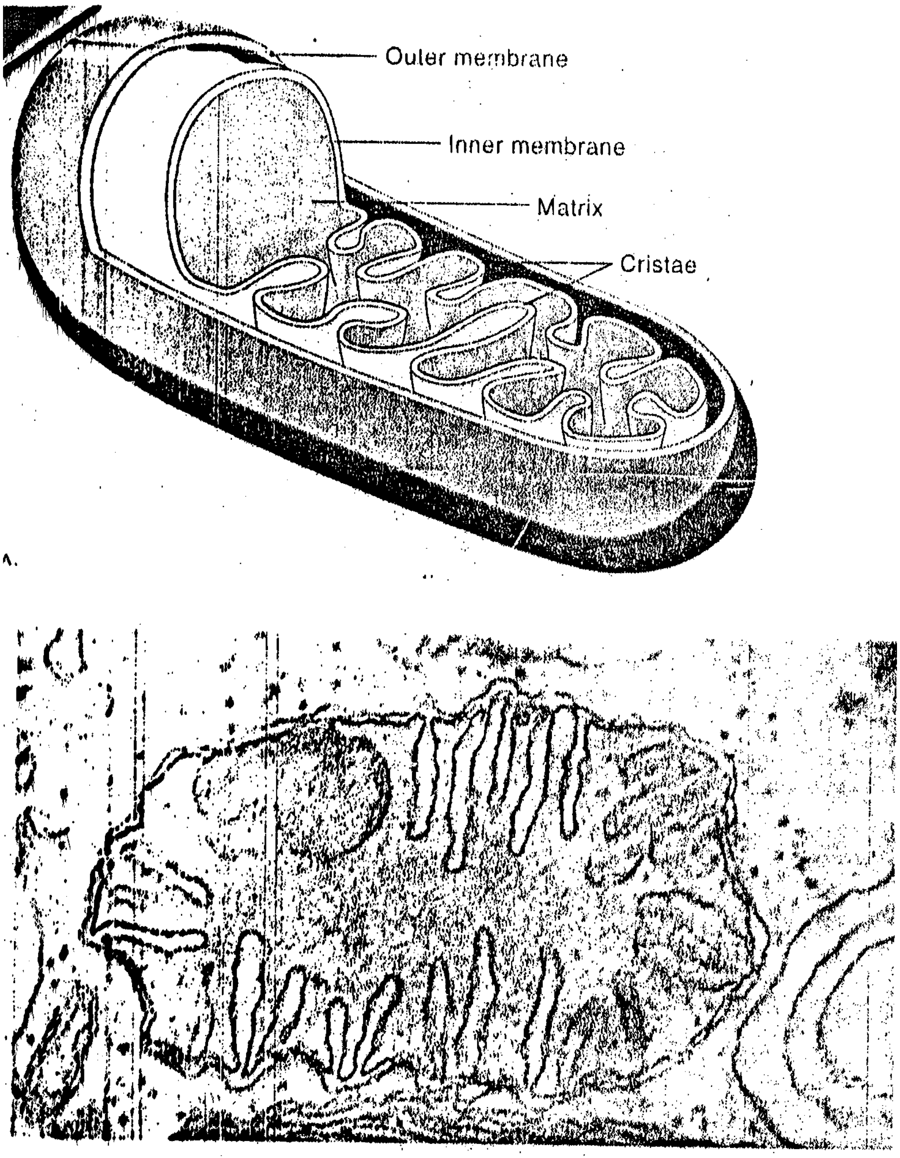


Fig* 3.6 *Mitochondria (a) Three-dimensional model of a mitochondrion (b) transmission electron micrograph of a mitochondrion, x 20,000.

The internal membrane system of mitochondria arises from the inner membrane of the mitochondria envelope, whereas, the outer membrane of the envelope is smooth. This arrangement of membranes creates two compartments within the mitochondria; one is the space between the two membranes, and the other is enclosed by the inner membrane.

Many of reactions of aerobic respiration are catalysed by enzymes bound to mitochondria membranes. Other reactions occur either in the space between the inner and outer membranes or in the matrix that is enclosed by the inner membrane. A cell may contain several hundred mitochondria, the actual number is dependent on its requirement for ATP. Dividing cells and cells that are metabolically active need large amount of ATP and usually have the largest number of TP. (you will learn more about the structure, and function of ATP when you treat respiration).

SELF ASSESSMENT EXERCISE 3

1. What are the two main organelles for energy conversion?
2. What are the major different/similarities between them?

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. In plants, only sperm cells swim and these swimming sperms are only seen in seedless plants and a few seed plants. The sperm cells of flowering plants cannot swim (Refer to BIO 124).

3.3.1 Internal Movement

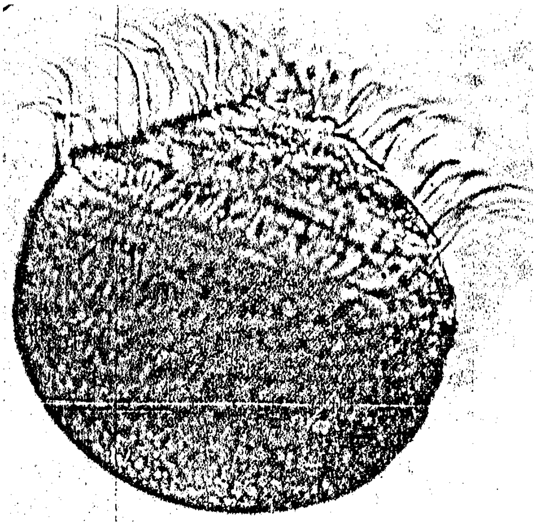
Living plant cells as seen under the light microscope have then cytoplasm in constant motion. Organelles and other particles usually move 'in a circle around the central vacuole. This streaming movement is called cyclosis.

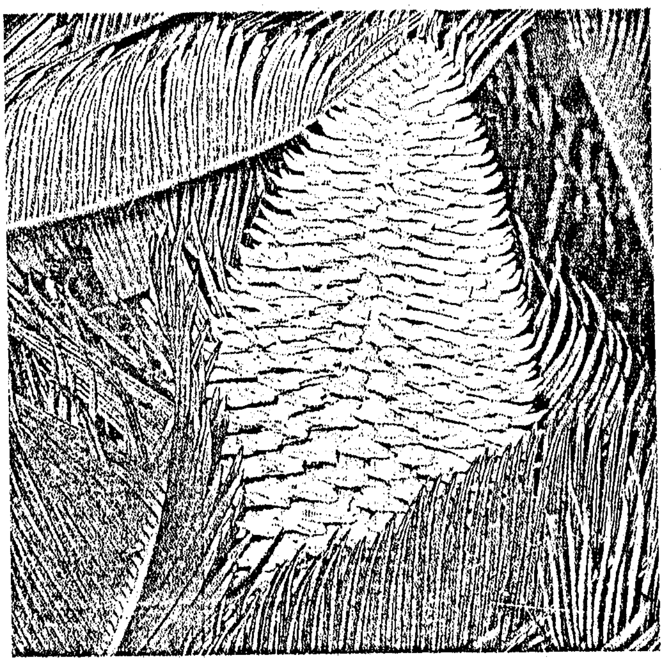
Chloroplasts and mitochondria move along definite paths that are associated with actins filaments and microtubules of the cytoskeleton. The outermost region of the cytoplasm is more anchored and relatively immobile, whereas the innermost region is more fluid. Cyclosis enhanced the exchange of materials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

(Fig. 3.7)



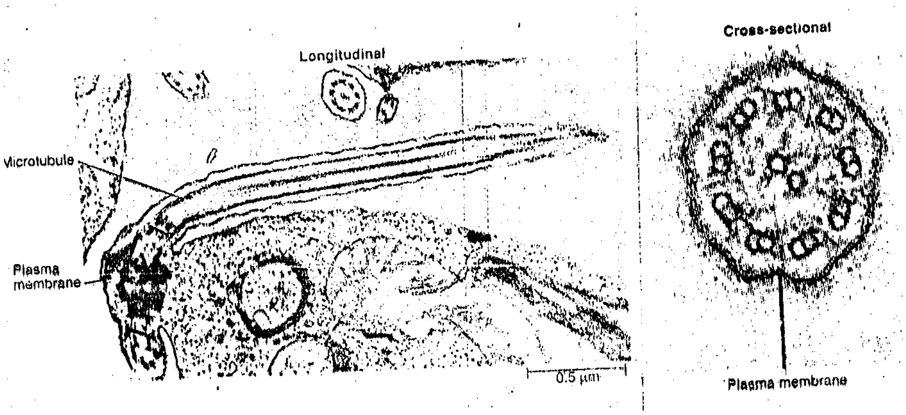


Micrograph of sperm cell from showing, x 250, (b) Photo of a that produces sperm di

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.

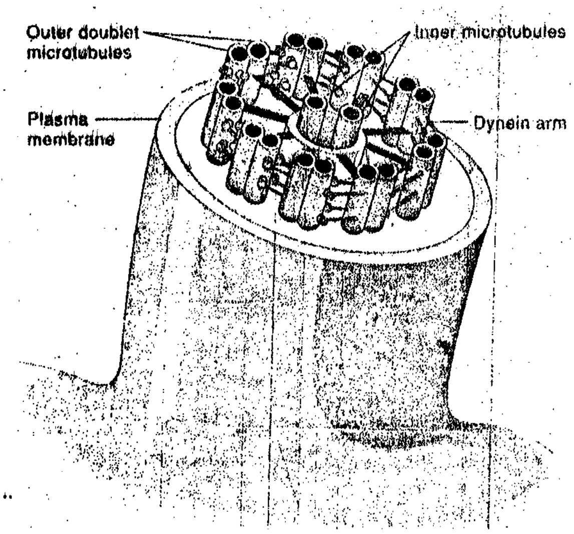
(Fig. 3.8a)



(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.

(Fig. 3.8b).



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.

4.0 CONCLUSION

This unit concludes the discussion on the structure and functions of plant cells. We had emphasized that depending on their components, cells can divide, grow, transport sugar or water, photosynthesise, secrete nectar or resin, or harvest energy from organic molecules. Most types of cells also contain genetic material that controls the activities of the cell.

Cell components vary among different cell types and among different plants. For example, components such as the plasma membrane occur in all living cells, while chloroplasts occur only in the cells of green tissue. Tissues can differ at the cellular level from one part of a plant to another.

5.0 SUMMARY

Like the nucleus, chloroplasts and mitochondria are organelles that are surrounded by double membranes. Micro bodies have single membranes. Dictyosomes and the endoplasmic reticulum are composed mostly of membranes that enclose relatively little internal fluid. Many of the chemical reactions in a cell are catalyzed by enzymes that are in or on membranes including the plasma membrane.

Sperm cells in plants and animals, as well as other kinds of cells in algae and water molds have flagella that enable them to swim. The structure and mechanism of action of the flagella identical in these organisms.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Biochemical processes e.g. photosynthesis and ATP synthesis; produce other membranes.
2. Differentially permeable; alters cell metabolism, accepts packets of raw material.
3. Extensive network of internal membranes, flattened tubules and sacs; continuous with other membranes, of 2 types-rough ER embedded with ribosomes and smooth ER.

ANSWER TO SELF ASSESSMENT EXERCISE 2

1a. Cell division-capable of forming glyioproteins and pinching off.
b. Building new primary cell walls in dividing cells
2. Water; enzymes, proteins, water-soluble pigments, growth hormones and ions.
3. Peroxisomes-metabolises hydrogen peroxide; glyoxysomes = enzymes that breakdown fatty cell.

ANSWER TO SELF ASSESSMENT EXERCISE 3

1. Chloroplasts and Mitochondria
2. **Similarities** (1) Both are bounded by 2 membranes,
   (2) Internal membranes folded
   (3) Contain enzyme
   (4) Contain DNA
   (5) Semiautonomous

   Differences (1) Have different sources of Energy chloroplasts = light Midtochondria-chemical Bonds.
   (2) Chloroplasts with chlorophyll therefore green mitochondria colourless.
   (3) Chloroplast for photosynthesimitochondria for respiration.
   (4) Chloroplasts of varied shape; mitochondria cigar-shaped.

6.0 TUTOR-MARKED ASSIGNMENT

1. List the major components of a plant cell
2. State 3 similarities and 2 differences of the chloroplast and Mitochondria

7.0 REFERENCES/FURTHER READING

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UNIT 4 STRUCTURE AND FUNCTION OF MEMBRANES: I

CONTENTS

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3.0 Main Content
    3.1 Structure of Membrane
    3.2 Functions of Membranes
    3.3 Movement of Water and Other Molecules through Membrane
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5.0 Summary
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1.0 INTRODUCTION

In unit 2 and 3, you learned that membranes have various functions in cellular metabolism. 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 listed it various functions and discussed the first one which is movement of water and solutes.

2.0 OBJECTIVES

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

3.0 MAIN CONTENT

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).

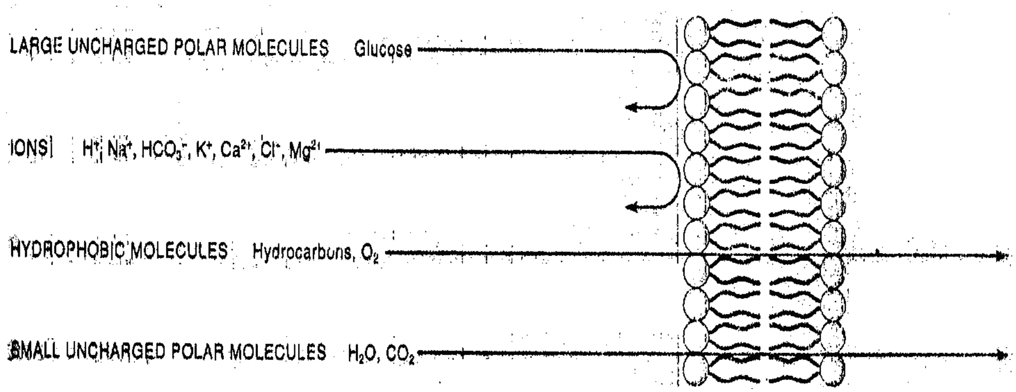


Fig. 4.1 Selective permeability of a phospholipids bilayer. The bilayer is much more permeable to hydrophobic molecules and small unchanged polar molecules than it is to and large polar molecules.

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.

(Fig 4.2)

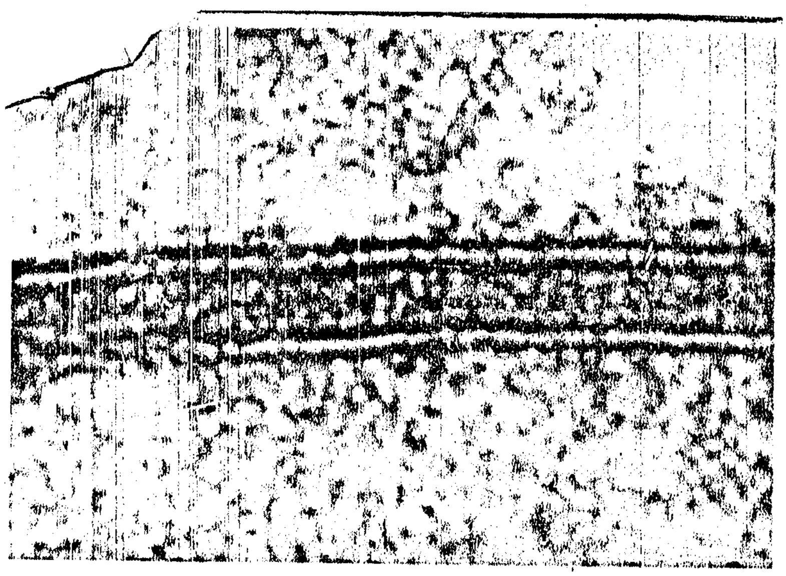


Fig. 4.2 Transmission electron micrograph of two membranes. Each membrane appears as two dark lines that are separated by a lighter region. At first, micrographs of this sort seemed to contain the Davson-Danielli model of membrane structure, but this interpretation was later found to be incorrect.

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)

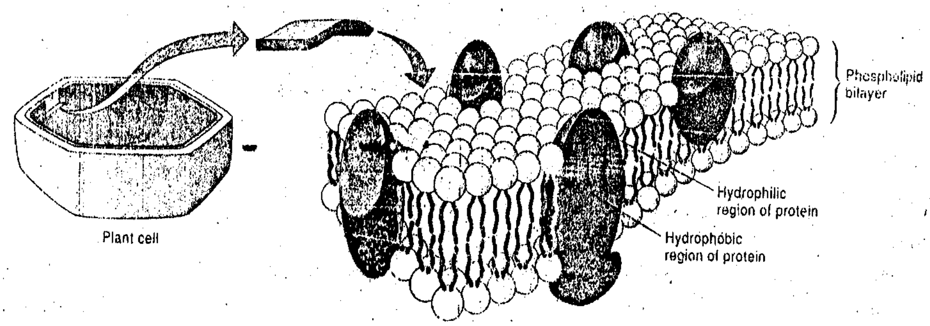


Fig. 4.3 The fluid model of membrane structure. Proteins are dispersed in the phospholipids bilayers according to the model

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.

(Fig. 4.4)

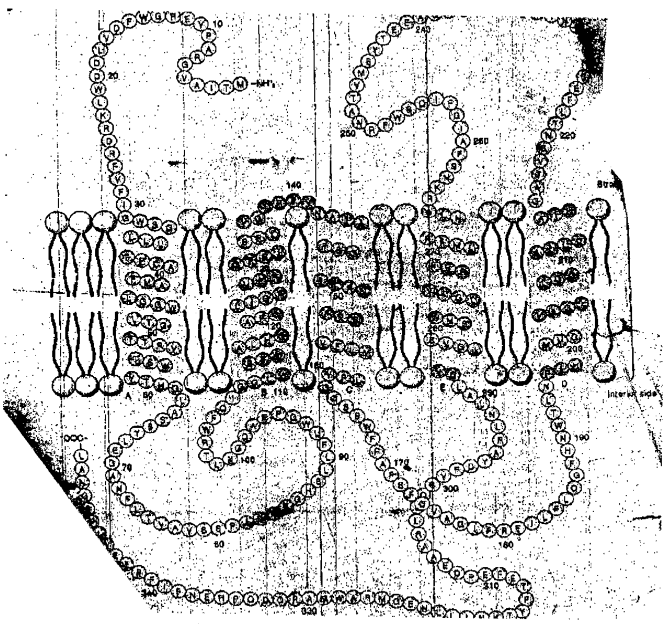


Fig 4.5 ***Primary structure of a thylakoid protein. Five regions of the protein occur in the membrane. (boxes A – E); the remaining regions provide either into the stoma or into the interior of the thylakoid. This membrane protein consists of 352 amino acids, each designated by a one-letter abbreviation (see Chapter 2, fig 2.6).***

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 (see Chapter 2, fig 2.0).

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. You will learn more about the roles of glyco-proteins in Unit 5.

3.2 Functions of Membranes

Proteins control most of the functions of membranes. These may be fifty or more different kinds of proteins in a plasma membranes and perhaps as many in the tonoplast or other organelles membranes. (Remember that once you are in doubt about any of these terms, you should fillip back to Units 2 and 3 where they were initially discussed). 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.

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.

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

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.

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.

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.

SELF ASSESSMENT EXERCISE 1

1. What is the basic structure of membranes.
2. List 4 important activities of membranes.

3.3 Movement of Water and other Molecules through Membranes

The most common kind of molecule in cells is water, Ions and other polar molecules are dissolved in this water, that is they are solutes and water is the solvent that dissolves them. Solutes include protons (H^+), mineral ions such a potassium (K^+) and magnesium (Mg^{++}). And organic compounds such as sugars and amino acids. The passage of these substances through membranes is detern1ined both by the phospholipids bilayer and by the proteins embedded in it. Non-polar molecules, such as hydrocarbons and oxygen pass easily through a membranes lipid core. Small and uncharged polar molecular, such as water and carbon dioxide, also pass through membrane lipid bilayer. The concentrations of different solutes in cells and organelles are closely regulated, despite the free passage of water and certain solutes through the plasma membranes. This inhibits substances from leaking freely into or out of the cell.

We will now take a look at some of the terms that are relates to water and solute movements. These terms are merely being introduced now. Later on in units 17 and 18 we will give a fuller treatment of them.

3.3.1 Movement of Solutes

All molecules display random thern1al motion, or kinetic energy, that is a solute molecule has a tendency to move around in a solution. One result of the random movement is that molecules diffuse outward from regions of high concentration to regions of lower concentration. Diffusion by random movement continues until the distribution of molecules becomes homogeneous throughout the solution.

Activity 1

Place a teaspoon of laundry blue into a basin of water. Let it stand for sometime and observe it from time to time. You will notice that as the "blue" ponder dissolves, the water in t6he basin gradually acquires a blue colour, that is the blue diffuses as it dissolves. The rate of diffusion depends on the size of the "blue" molecules (large molecules move slower) and the temperature of the solution (higher temperatures cause faster movement). Regardless of this rate, the "blue" concentration will eventually become uniform throughout the solution.

Because diffusion is based on random movements, each molecule has an equal change of moving toward or away from the region of high solute concentration. However, there are more high solute molecules near the crystal which means there is a greater chance of net movement away from the source. Molecular movement continues after homogeneity is reached, even though there is no longer a net change in concentration from one region of the solution to another. This means that, after such a balance is reached, for every molecule that vacates a spot, another molecules takes its place just by chance.

Diffusion is the net movement of solutes from an area of greater concentration to an area of lesser concentration, that is down a concentration gradient. We can think of solutes as marbles and the gradient as a hill, marbles rolling down a hill would be analogous to solutes diffusing down a concentration gradient. Furthermore a steeper hill would be analogous to the steeper gradient caused by a higher concentration of solutes. Thus, a steeper gradient causes a higher net rate of solute movement. Just as marbles can move up the hill if there is a force to push them, so too can solutes move from lower to higher concentrations if there is energy to punch them.

Anything that can fall, change, or flow from a higher level to a lower one has the potential to do work, which is called potential energy. When the solute is moving, it has energy of movements which is called kinetic energy.

In this unit, we will discuss these forms of energy, but later on in unit 7 we will look at energy and it uses by plants.

3.3.2 Water Potential

Like solutes, water also has potential energy to flow to where it is less concentrated, the potential energy of water has a special name. Water potential. Water tends to move down a water potential gradient, that is from a region of high water potential to a region of low water potential.

Also, like solutes, water requires energy to move up a water-potential gradient.

By general agreement the water potential of pure water is zero. This means that the water potential of a solution has a negative value because the water is less concentrated than pure water. Also, by general agreement, water potential is expressed in units of pressure instead of units of energy, because pressure is simple to measure. Thus, water potential may be expressed in bars or in megapascals (Mpa). One bar equals atmospheric pressure at sea level and room temperature, and 1 Mpa is 0.1 bar. The potential of sea water is about -25 bars, the water potential in the cells of freshly watered herbs is more than -1 bar (meaning closer to zero), and the water potential in dry seeds is about -200 bars. Later on in unit 17 we will discuss water potentials again.

SELF ASSESSMENT EXERCISE 2

What is (a) diffusion (b) potential energy (c) Water potential.

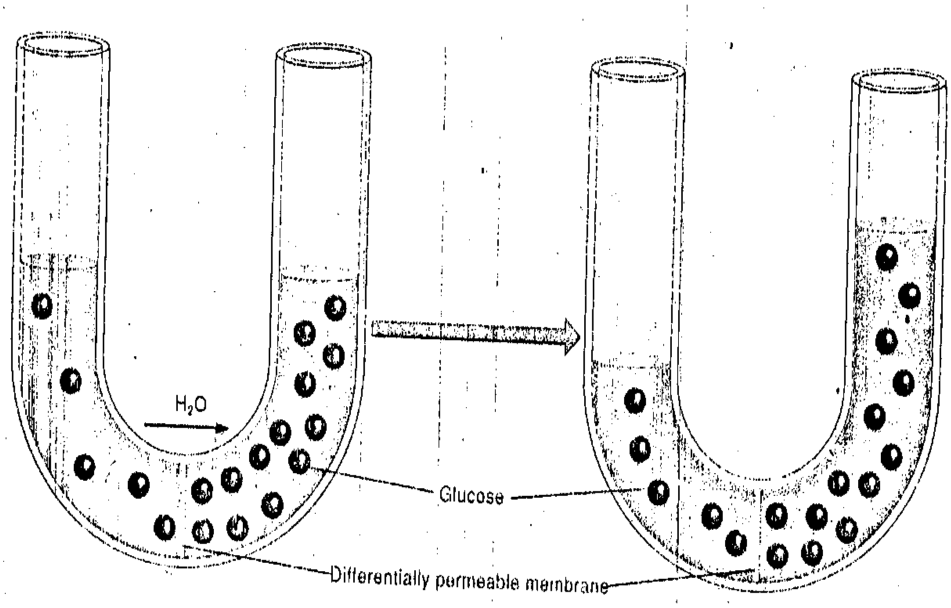
3.3.3 Osmosis

Many substances including water move through a biological membranes as freely as they move through an aqueous solution. Such unrestricted movement of a substance through a biological membrane is called passive transport. The energy for passive transport is the kinetic energy that is inherent in all molecules. That is passive transport does not require energy from cellular metabolism.

The passive transport of water influences many activities of the cell, including cell growth, structural rigidity and photosynthesis. Because of its roles in so many processes, the diffusion of water through a selectively permeable membrane has a special name; Osmosis.

Osmosis is influenced by different water potentials on either side of a membrane. Let us look at an example; consider a membrane that is permeable to water but impermeable to glucose. When such a membrane separates two halves of a container each having a different concentration of glucose, water diffuses by osmosis into the side having the higher glucose concentration (i.e. lower water potential)

(Fig 4.6)

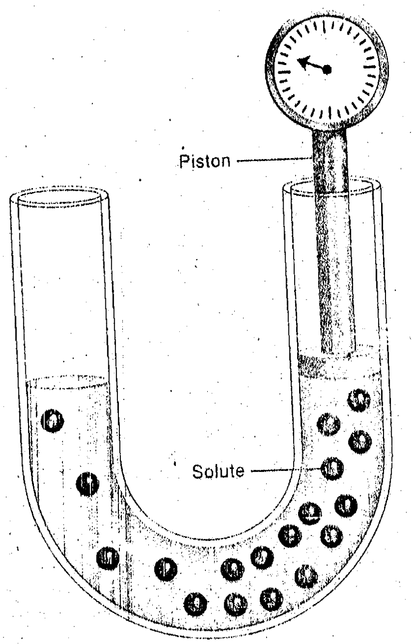


Osmosis is demonstrated by the movement of water through a differentially permeable membrane in a U-tube. Glucose, which cannot pass through the membrane, is more concentrated in the right-hand part of the tube than in the left hand part. Net movement of water into the more concentrated glucose solution causes the volume of the right-hand solution to increase.

The net movement of water will stop either when both sides of the container have the same concentration of glucose, or when the force of gravity equals the force of water movement, which ever occurs first. Note that the side that began with a higher concentration of glucose increases in volume.

The foregoing example of osmosis 'also hits at another feature of this process immediately before osmosis begins, water on the hypotonic side (low solute concentration) of the membrane has a higher water potential, which means a greater potential to move. Its movement can be prevented, however, if a piston is placed on the hypertonic side (high solute concentration), with just enough downward pressure to keep the volume constant. A pressure gauge on this piston measures the force required to maintain constant volume.

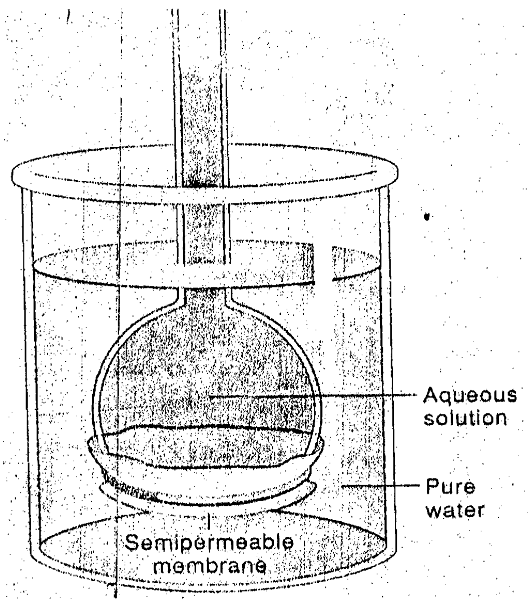
(Fig 4.7)



Higher water potential in the left-hand solution causes pressure for water to move into the right-hand solution. The amount of pressure for it is necessary to maintain constant volume on the right equals that of water movement across the membrane.

The potential of pure water to move into a solution on the other side of a membrane is called Osmotic pressure

(Fig 4.8)



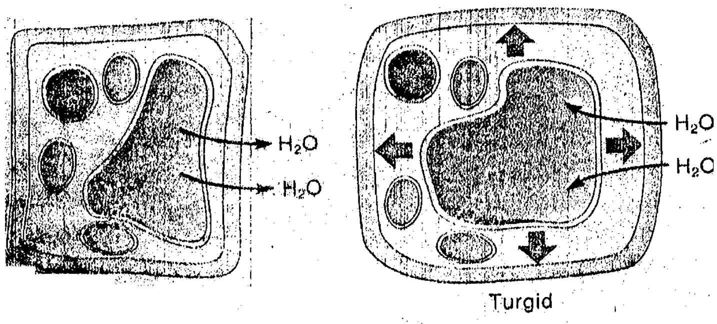
Osmotic pressure (arrows) is the pressure of pure water to move into a solution on the other side of a membrane. The osmotic potential of the solution is the potential to cause osmotic pressure.

Conversely the potential of the solution to cause osmotic pressure is called Osmotic potential. Solutions with high concentrations of solutions (i.e. more negative osmotic potential) cause high osmotic pressure Osmotic potential and water potential are expressed in the same units of measurement and may be easily confused. However, although osmotic potential occurs only across a membrane, water potential has no such limitation.

3.3.4 Turgor

Most plant cells are surrounded by a hypotonic environment. As a result, cells absorb as much water as they can hold. The outward pressure of the plasma membrane against the cell walls is called turgor pressure because it keeps the cell turgid.

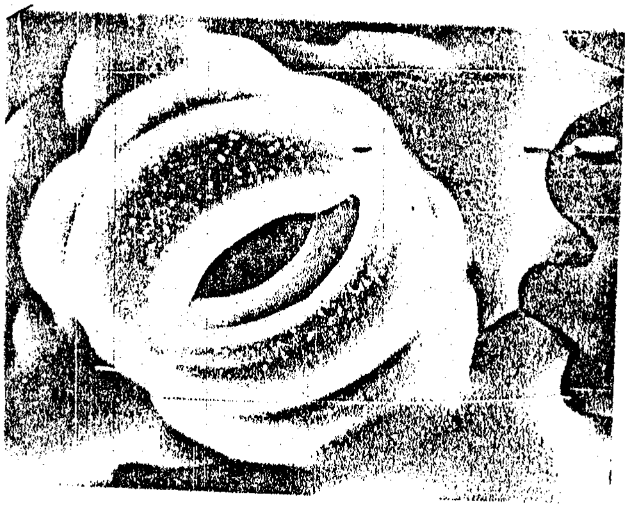
(Fig. 4.9)



Flaccid and turgid cells. The plumpness of the turgid cell is maintained by turgor pressure

Turgor pressure is vital to plants in may ways. During growth, cell expansion is caused by turgor pressure on cell walls that have become relaxed. Turgor pressure also keeps herbaceous (nonwoody) plants upright and supports the fleshy stalks and leaves of trees and shrubs, and keeps vegetables crisp when they are sprayed with water. (Think of the times you or your spouse have gone to buy vegetables and all the vegetables are dripping with water. The vegetable seller has sprinkled water on it to keep it fresh and crisp). Changes in turgor also cause movements in plants such as the opening and closing of stomata and the curling of grass leaves.

(Fig. 4.10)

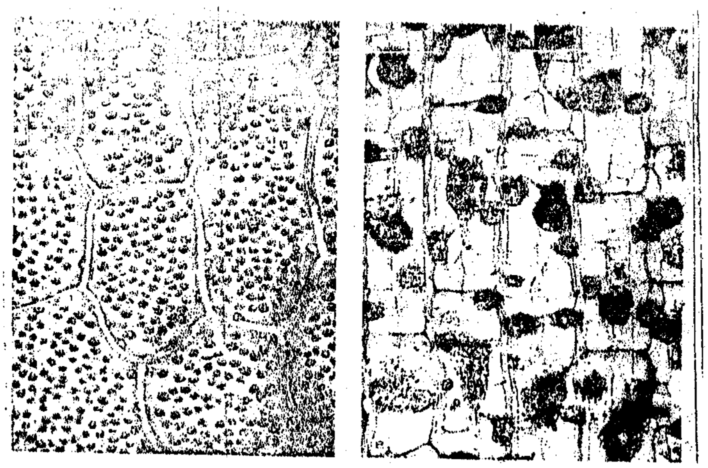


Electron micrograph of an open stoma, x 640. Stoma are when guard cells are guard they are closed when guard cell turgidly (see Chapter 21).

Some movements caused by changes in turgor are dramatic, example is the leaf movement in the sensitive plant.

Cells lose turgor when they are placed in a hypertonic solution. The continued loss of turgor causes the cytoplasm to shrink away from the cell wall.

(Fig. 4.11)



Light micrograph of (a) turgid cells, x 400, and (b) plasmolized cells, x 100, showing the effects of plasmolysis.

Osmotically induced shrinkage of the cytoplasm is called plasmolysis. This phenomenon occurs in crop and garden plant when salt accumulates in the soil from extensive use of hard (that is, mineral rich) water. It also occurs when too much fertilizer is applied. The loss of turgor in these plants cause their leaves and stems to wilt.

3.3.5 Inducing Osmosis the Control of Turgor

Although water moves freely across biological membranes, plants can control osmosis by regulating the concentrations of solutes in their cells. Loss of turgor causes the uptake of potassium ions (K^+), which are osmotically active because they change the cell's osmotic potential. As the concentration of K^+ increases, the osmotic potential increases, and move water enters the cell. Conversely, cells reduce their osmotic potential by secreting K^+ , this causes water to leave the cell.

The uptake of K^+ occurs against its concentration gradient, that is, K^+ moves from a region of low concentration outside the cell to a region of high concentration inside the cell. This process which is called active transport, requires metabolic energy (you will learn more about active transport in Unit 5).

Plants that live in high-salt environments such as salt flats, near ocean bays or inland where oceans once were, accumulate large amounts of osmotically active solutes such as the amino acid praline and the carbohydrate mannitol. These organic solutes help the plant absorb water (via osmosis) from dry, salty soil.

SELF ASSESSMENT EXERCISE 3

1. Explain the following terms:
   (a) Osmosis (b) Osmotic Pressure (c) Osmotic Potential
2. What is: (i) Turgor Pressure (ii) Plasmolysis
3. How have plants that live in high salt environments adapted to enable them get enough water.

4.0 CONCLUSION

Membranes surround cells, connect cells to one another, form complex internal networks, and divide cells into distinctive compartments. The abundance of membranes in cells underscores their importance, but it does not begin to show the density of their functions. Membranes are active and changeable participants in cellular metabolism, everything that happens in a cell is directly or indirectly or associated with a membrane. In this unit, we began our discussion of the membrane by looking at the membrane structure. We saw that all membranes have the same basic structure. We also looked at the movement of water and solutes into the plants. We identified other functions and activities that the membrane performs in the life of plant. These other ones will be discussed in Unit 5.

5.0 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.

Osmotic potential results from the potential of water to diffuse down its concentration gradient.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Membranes are a mosaic of proteins that move around in a fluid double layer of phospholipids.
2. 4 important activities of membranes
(i) Movement of water and solutes
(ii) Differential permeability
(iii) Ion pumps
(iv) Enzymes activity
(v) Cellular communication.

ANSWER TO SELF ASSESSMENT EXERCISE 2

Diffusion -movement of molecules down a concentration gradient Potential energy - potential for solutes to move down a gradient

ANSWER TO SELF ASSESSMENT EXERCISE 3

1a. Osmosis-diffusion of water across a differentially permeable membrane
b. Osmotic pressure -the pressure caused by the potential of water to continuously move into a cell from outside.
c. Osmotic potential-the counterpart of osmotic pressure from inside the cell.

2. Turgor pressure - the pressure that causes water pressure to push the plasma membrane against the cell wall.
   Plasmolysis - when turgor is lost and cytoplasm shrinks away from cell wall.
3. By accumulating large amounts of osmotically active solutes e.g. praline (amino acid) & mannitol (carbohydrate).

6.0 TUTOR-MARKED ASSIGNMENT

1. List 5 important activities in a cell that are associated with membranes.
2. Briefly discuss why plants wilt

7.0 REFERENCES/FURTHER READING

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UNIT 5 FUNCTIONS OF THE CELL MEMBRANE

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1.0 INTRODUCTION

In unit 4, you learnt about the structure of membranes, you also looked at one of the functions of membranes. Many functions of membrane relate to the general properties of phospholicpids and protein. Different membranes are made of different proteins and lipids. These have implications on their functions. In this unit you are going to learn about the other functions of membranes in relation to their structure.

2.0 OBJECTIVES

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.

3.0 MAIN CONTENT

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.

There are two types of transport proteins. One type include proteins that work by actives transport, which requires energy from ATP to move solutes up a concentration gradient, the other includes passive transport proteins, which do not require metabolic energy. In passive transport proteins merely act as channels for the diffusion of contrast to simple diffusion through the phospholipids bilayer, passive transport through protein channels is called facilitated diffusion as in simple diffusion, potential energy is also released during facilitated diffusion.

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.

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)

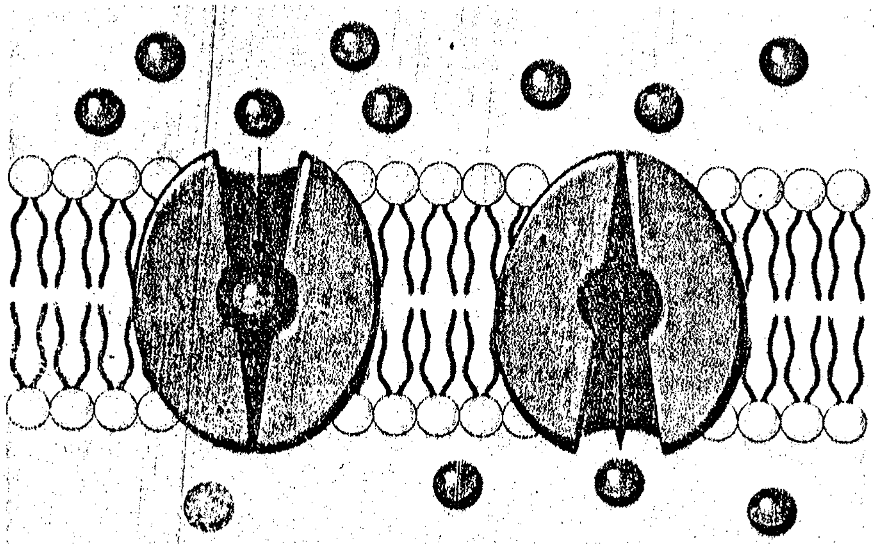


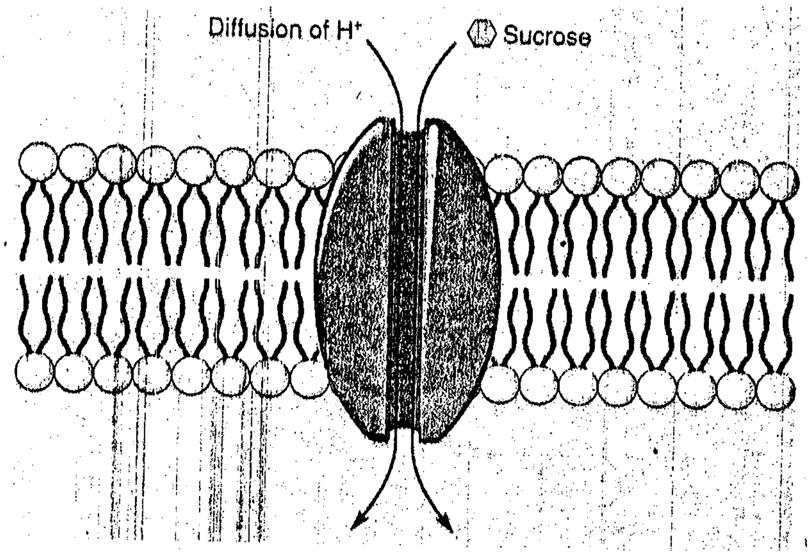
Fig. 5.1 A possible mechanism for facilitated diffusion. The transport protein (purple) accepts solute molecules (red spheres) on one side of the membrane and release them on the other side. The transport protein alternative between two forms, depending whether it is "open" to one side of the membrane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

(Fig. 5.2)



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

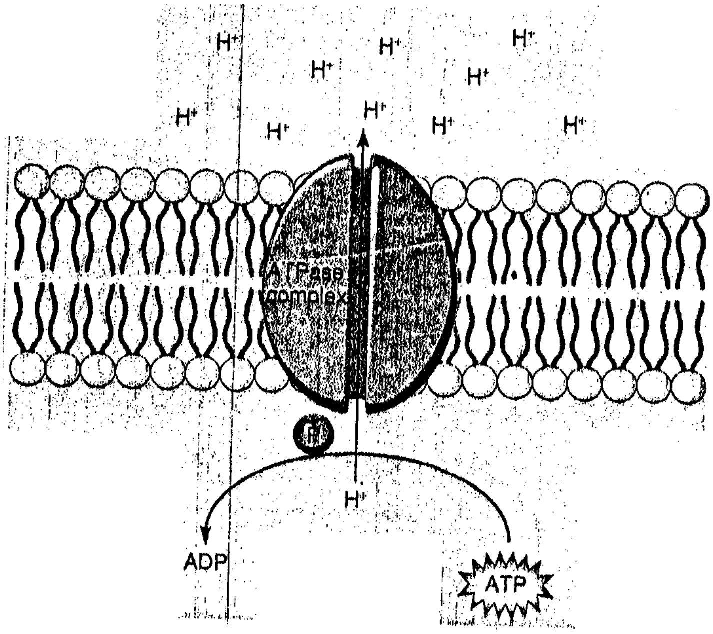
The energy for sucrose transport comes from the force of H^+ diffusion. The force of H^+ diffusion can be powerful enough to move sucrose against its own concentration gradient.

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 reactions is catalysed by membrane bound enzymes called ATP phosphohydrolases (ATPases); which are transport proteins that use the energy of ATP transport ions.

(Fig. 5.3)



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.

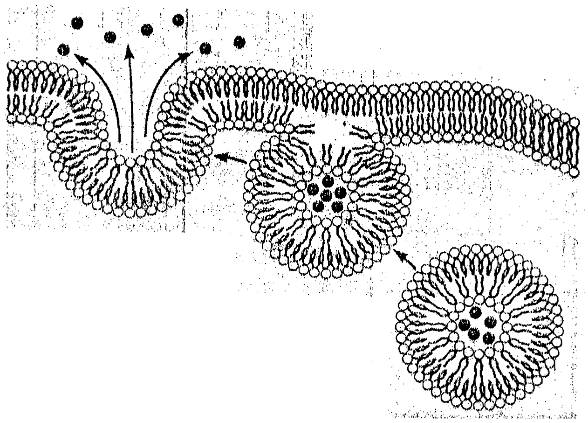
Many ATPases actively transport ions against the ion's concentration gradient, thereby creating potential energy for the passive co-transport of other solutes back across the membranes. The cotransport of sucrose with H^+, depends on a higher concentration of H^+ outside the cell. This gradient is maintained 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 cotransport 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. We will discuss the effects of electro-chemical gradients on ion transport later in this unit.

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.

Through proteins embedded in it. Nevertheless, membrane transport is often bypassed by exocytosis (fig. 5.4).

Plant cells secrete polysaccharides and proteins across the plasma membrane for assembly into cell walls. Moreover, cells of root tips secrete a polysaccharide that lubricates their passage through soil as they grow, and cells covering leaves oxide waxy substances onto their surfaces to inhibit water loss. Leaves of the Verria flytrap and other insectivororous plants.

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. (you will get more details about these from BIO 124). 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 invaginaling into the cytoplasm.

SELF ASSESSMENT EXERCISE 1

1. Differentiate between facilitated diffusion and active transport.
2. Distinguish between exocytosis and endocytosis.

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 action 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.

3.2.1 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 (fig. 5.3). 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 Chemical reactions in a cell often incorporate or release ions that affect the pH of cells, the uptake of ions fro soil also affects pH. Pumping proton our 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 auspect that auxin stimulates cellular elongation by stimulating the proton pump. You will learn more about auxins and hormones unit.

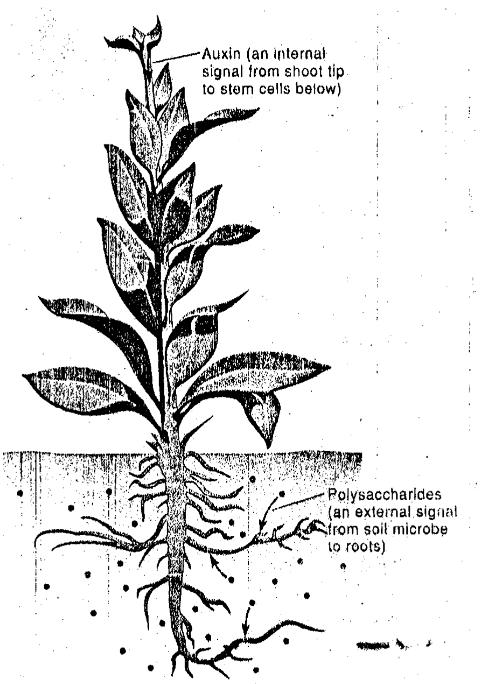
3.2.2 ATP Synthesis

These are two main types of proton pumps. One type uses ATP and occurs mainly in the plasma-membrane and in the toroplast, the other produces ATP-synthesising organelles. ATP is made from ADP and a phosphate group when the diffusion of H^+ energy (fig.5.4). 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.

3.3 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.

(Fig. 5.5)



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 transudation 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.

3.3.1 Hormone Receptors

Signal transudation 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.

3.3.2 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.

SELF ASSESSMENT EXERCISE 2

1. What is membrane potential, and what is its unit of measurement?
2. Briefly describe how cells communicate with other cells.

4.0 CONCLUSION

Membranes are active and changeable participants in cellular metabolism, everything that happens in a cell is directly or indirectly associated with a membrane. Membranes are essential to life. They are involved in the movement of water and solutes in and out of cells. They facilitate the movement of ions across cells thereby ensuring that the cells pH is maintained. They are also involved in cellular communication. Their role in cellular communication has enabled plants to acquire their own "immune system".

5.0 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.

The lipid bilayer and membrane proteins are bypassed by exocytosis the process by which proteins and other large molecules are secreted in vesicles that fuse with the plasma membrane.

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.

In the plasma membrane and tonoplast, proton pumps use the energy of ATP to move protons against an electrochemical gradient. In the membranes of mitochondria and chloroplasts, proton pump produce ATP. The ATP required to run these pumps comes from respiration (in mitochondria) or photosynthesis (in chloroplasts).

Membrane proteins are also receptors for hormones and other chemicals from other cells or organisms. As receptors these proteins signal other parts of the cell to change their metabolism. These changes contribute to cell growth, defence against disease recognition between mating cells and many aspects of plant life.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Facilitated diffusion is the movement of solutes through transport proteins. Down a concentration gradient. Active transport when solutes move against a concentration gradient with the aid of ATP.
2. Exocytosis the fusion of membrane bound vesicles to the plasma membrane and the expulsion of their content. Endocytosis-where plasma membrane invaginates to release Vesicles into the eytoplasm.

ANSWER TO SELF ASSESSMENT EXERCISE 2

1. The electrical potential produced by the different between concentration of ions on their side of a cell.
2. Cells communicate by chemical signal through receptor Proteins that are activated by binding to induce enzymes and other proteins to change metabolism of the membrane surfaces also recognize secretion or cell wall components or other-organisms.

6.0 TUTOR-MARKED ASSIGNMENT

Explain the following terms:

a. Facilitated diffusion
b. Active Transport
c. Exocytosis
d. Endocytosis
e. Membrane

7.0 REFERENCES/FURTHER READING

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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

UNIT 1 ENERGY AND ITS USES BY PLANT

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1.0 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.

2.0 OBJECTIVES

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
- using the laws of thermodynamics, explain why you always have to refill your petrol tank
- list the two primary energy transformations in plants
- give the general name for the chemical reactions that transform energy in cells.

3.0 MAIN CONTENT

3.1 Energy and How to Measure It

3.1.1 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.

3.1.2 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 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 raised 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 1,0000 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.				

SELF ASSESSMENT EXERCISE 1

1. What is Energy?
2. Distinguish between Calorie and calorie.

3.2 Energy Conversions and the Laws of the Thermodynamics

3.2.1 Energy Conversions

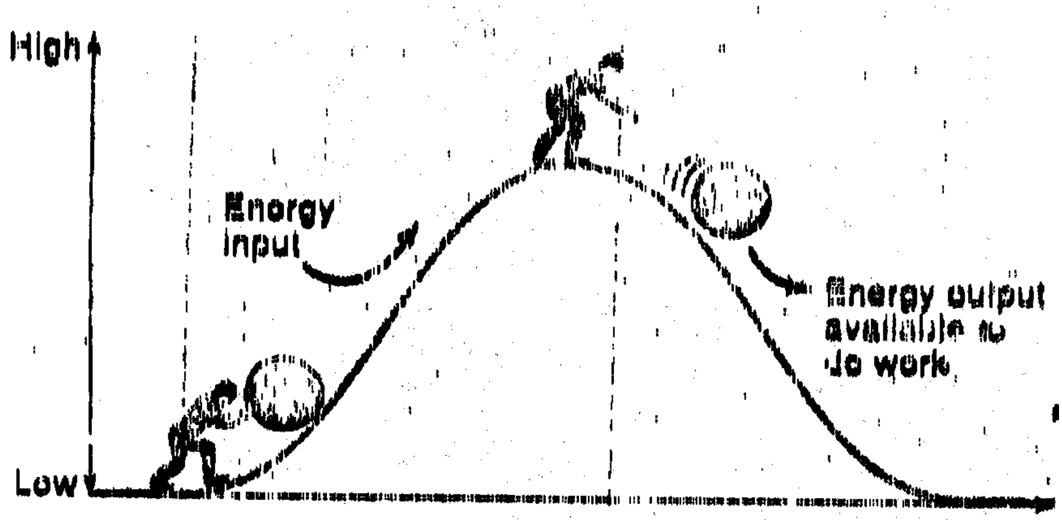
All activities of living organisms such as cellular division, heat production by flowers, moving from pace to place etc. involve the inter converting of energy from one form to another. For example, we convert the energy contained in oil electricity, and then convert the electricity to light energy to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

(Fig. 6.1)



Pushing a builder to the top of a hull requires an input of energy because it increases the potential energy of the builder. The builder stop the hull has potential energy because it can do work as it rolls down the hull as the builder roll down the hull potential energy is.

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.

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.

SELF ASSESSMENT EXERCISE 2

Differentiate between potential energy and kinetic energy.

3.2.1 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 rest9fthe 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.

Do not be out off by all these. 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.

3.2.2.1 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. **(If you think back to your secondary school science**

you will remember that you encountered this law in integrated science, chemistry or physics). 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.

There are no exceptions to this law.

3.2.2.2 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.

The restatements of the second law are based on our world which is irrelevant. For instance once the aging process starts, you cannot reverse it, neither can you unscramble an egg. You cannot convert the contents of an egusi soup to its complete parts. Irreversibility results from the message of a second law of thermodynamics, namely, the loss of usable energy as heat during an energy transformation.

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.

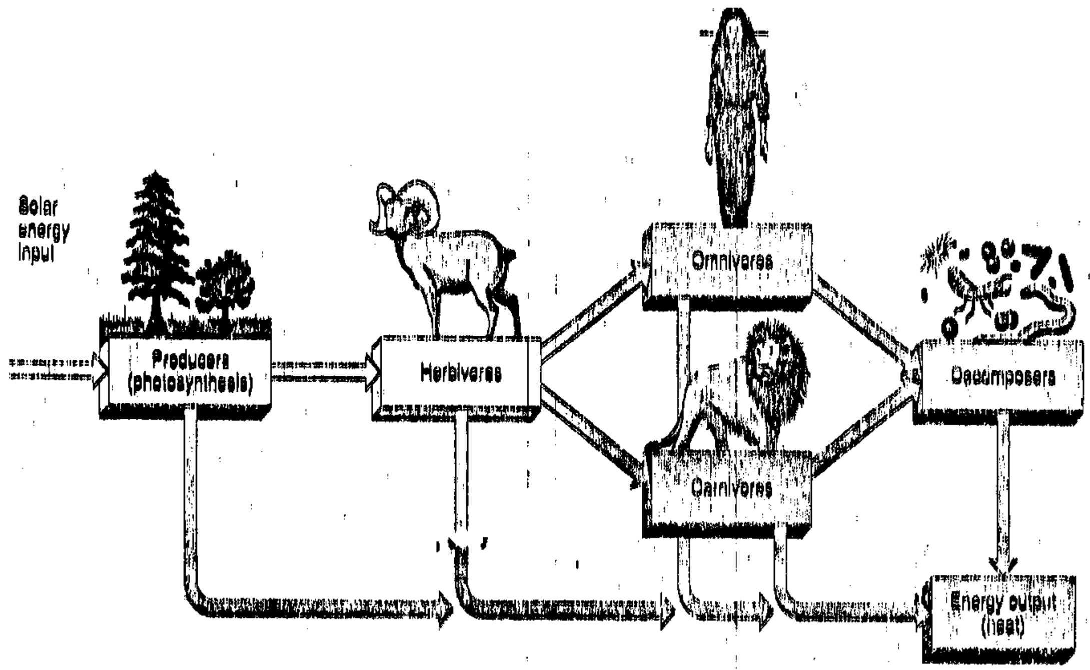
Cells derive energy from sugar and fats for growth, repair and reproduction. The chemicals reactions that free this energy are inefficient and release much heat. The cells of most organisms extract only about half of their fuel's energy for useful work (e.g. the energy used to power your brain while 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 remain 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.

(Fig 6.2)

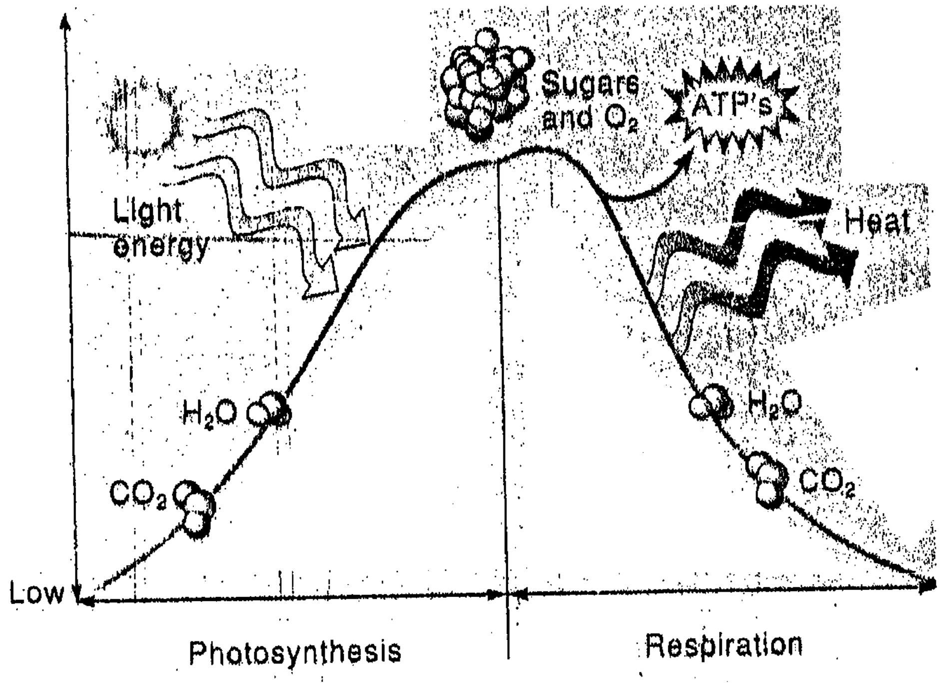


Plants are the products, that is, they transform energy in sunlight into chemical energy. This energy then frown through and to used by other

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.

(Fig. 6.3)



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.** It will form the main topic for unit 7.

SELF ASSESSMENT EXERCISE 3

1. What is the first law of thermodynamics
2. State and explain the two Primary energy transformation in plants.
3. Mention the two Primary energy transformation in plants.

4.0 CONCLUSION

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.

5.0 SUMMARY

- Energy is the ability to do work. It is measured with a variety of units, the most common of which are calories and joules. Potential energy is energy available to do work, while kinetic energy used to do work.

- 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.
- The first law of thermodynamics is the law of conservation of energy, it states that in all chemical and physical changes, matter and energy cannot be created or destroyed, only converted to other forms.

- The second law of thermodynamics states that all energy transitions are less than 100% efficient. The inefficiency results from the loss of usable energy in the form of heat. The quantitative measure of the disorder created by any spontaneous reaction is entropy. All spontaneous reactions increase entropy.

The two primary energy transformation in plant are photosynthesis are cellular respiration, while the chemical reactions that transform energy in plant and other organisms is metabolism.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Energy is the ability to do work, that is, to bring change, or move matter against an opposition force e.g. gravity of friction.
2. Calorie is the amount of energy needed to move one kilogram through one metre with an acceleration of one metre per second. It is used to measure the energy level of food, while calorie is the amount of energy required to raise the temperature of one gram of water by 1°C. 1 Cal = 1000 cal

ANSWER TO SELF ASSESSMENT EXERCISE 2

Potential energy is stored energy, that is, energy available to do work, while, kinetic energy is energy being used to do work.

ANSWER TO SELF ASSESSMENT EXERCISE 3

1. The first law of thermodynamics states that energy cannot be created or destroyed. It is the law of conserving of energy.
2. Te second law of thermodynamics is the law of empty or disorder. It states that all energy transformations are inefficient, that is, the amount, of concentrated useful energy decreases I all energy transformations. As you convert energy from one form to another, some percentage is lost as heat which is useable energy.
3. Photosynthesis and cellular respiration.

6.0 TUTOR-MARKED ASSIGNMENT

7.0 REFERENCES/FURTHER READING

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UNIT 2 ENERGY METABOLISM

CONTENTS

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1.0 INTRODUCTION

In unit 6, 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.

2.0 OBJECTIVES

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:

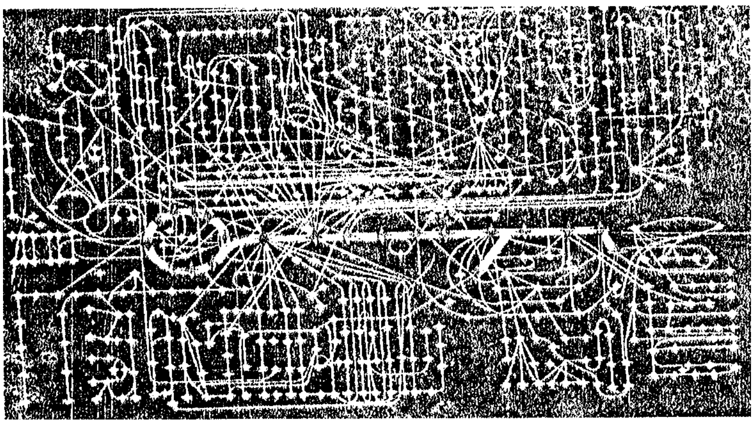
(a) Bond energy
(b) Free energy
(c) Enthalpy
(d) Endothermic reaction
(e) Exothermic reaction

- distinguish between oxidation and reduction reactions
- describe the basic structure of ATP
- state the mechanism of action of ATP
- list other compounds.

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.

(Fig. 7.l)



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.

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 ΔH (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.

3.1.1 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, such as 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).**

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

Those relationships are represented by the following formula:

$$\Delta G = \Delta H - T\Delta s$$

Where

ΔG 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.

ΔH 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

$S\Delta$ 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 ΔG 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. **(You may need to read this section over again to be able to grasp he concept embedded in it).**

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

$$\text{Glucose + Fructose} \longrightarrow \text{Sucrose} + H_2O$$

This reaction has a ΔG 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. **(What we referred to earlier on as physical or chemical assistance)**.

The free energy of a particular reaction determines many of a reaction's properties. Most important, the ΔG 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

$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$ + energy
$\Delta G = 686 kcal\ Mol^{-1}$.

Since ΔG 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.

Free Energy and Chemical Equilibrium

When a chemical reaction reaches equilibrium, a ΔG equals zero. Similarly ΔG 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.

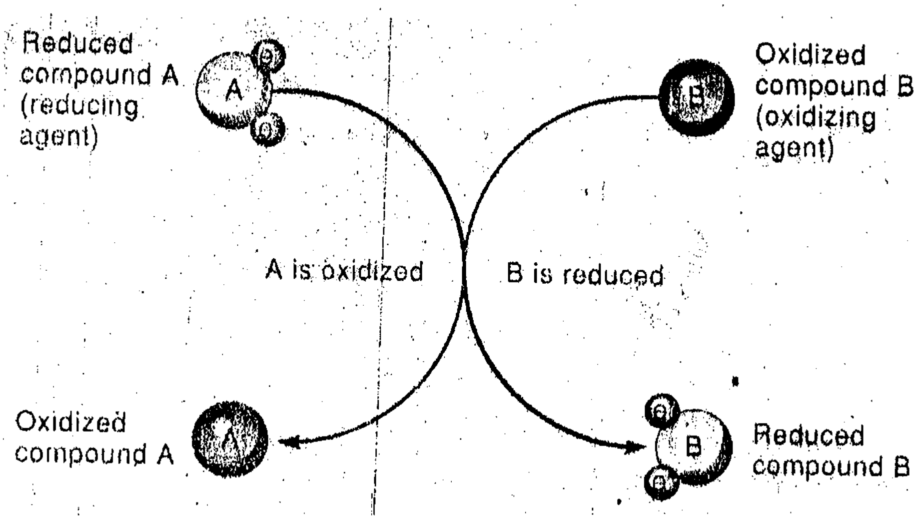
SELF ASSESSMENT EXERCISE 1

1. What is metabolism?
2. Define the following terms
(a) Bond energy
(b) Enthalpy
(c) Exothennic
(d) Free energy
(e) Endergonic
(f) Exergonic

3.1.2 Oxidation, Reduction and Energy Content

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

(Fig 7.1)



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

More reduced
More oxidized

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
Sucrose	17,000,000
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).**

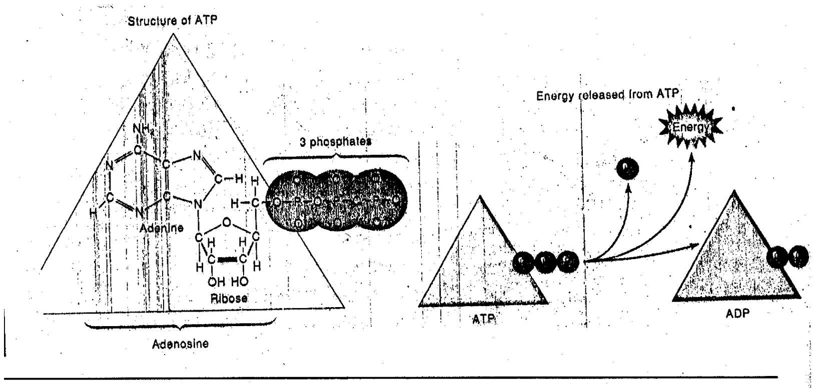
Organisms extract energy from energy-rich compounds such as sugar and fat via catabolic reactions that do work e.g. building cell walls, and replicating genetic information an important substance through which energy passes during cellular metabolism is **adenoisine triposphate,** a compound more commonly known as ATP this will be discussed in the next section.

SELF ASSESSMENT EXERCISE 2

Differentiate between oxidation and reduction reactions.

When cells need energy, they hydrolyse Adenoisine 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.

(Fig. 7.2).



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

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

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

- 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.

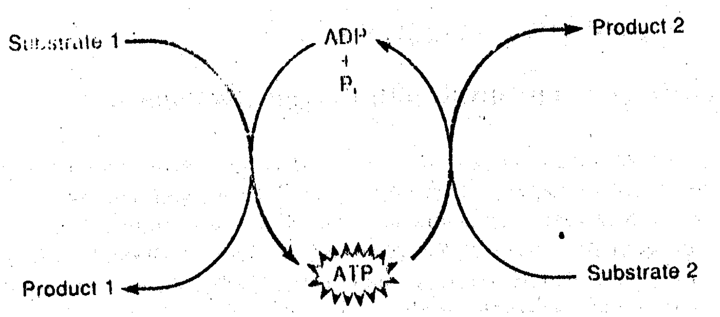
ATP is a common energy currency – All cells of all organisms use ATP for energy transformation. Like all of the different appliances that can plug into an electrical outlet and do different things, so too can different chemical reaction use cell's ATP to do different kinds of work. Organisms use ATP 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 $\Delta G = +7.3$ kcal mol^{-1}

Since the ΔG 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. (fig 7.3)

(Fig. 7.3)



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^20
ΔG = + 5.5 Kcal mol^{-l}

Because the ΔG 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 $\longrightarrow$ ADP + Pi + energy
ΔG = -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 $\Delta G = 5.5 - 14.6 = -9.1$ Kcal mol^{-l}. Thanks to the expenditure of energy by the cell (i.e. as ATP). The reaction proceeds because it's overall ΔG 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.

SELF ASSESSMENT EXERCISE 3

Describe ATP, and its mode of action.

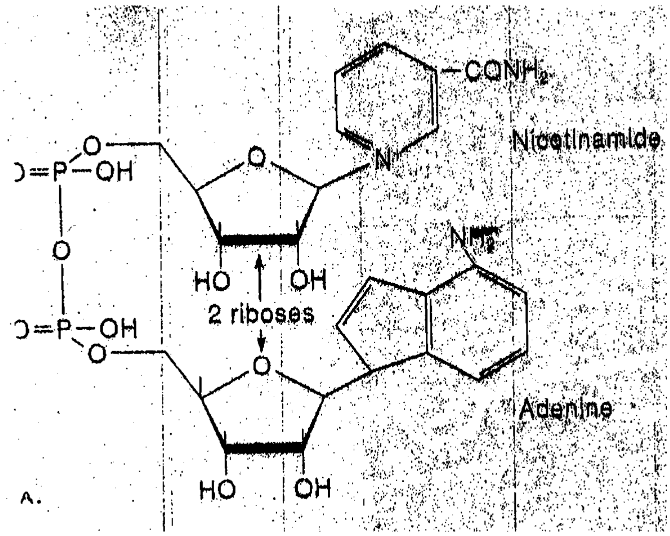
3.2.1 Other Compounds Involved in Energy Metabolism

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.

NAD^+ Nicotinamide Adenine Dinucleotide

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

(Fig. 7.4a)



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.

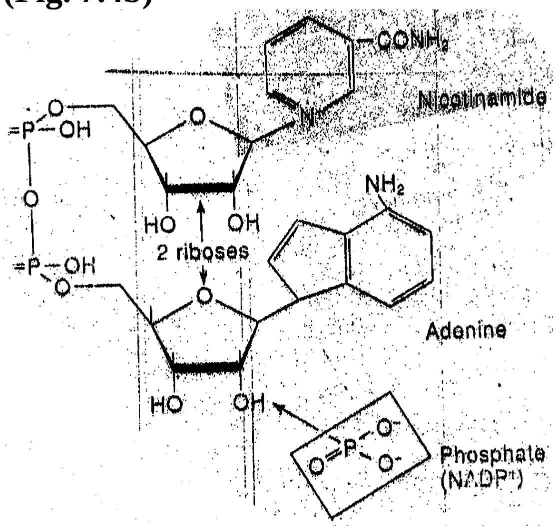
$$NAD^+ + 2h^+\ 2^{e-} \longrightarrow NADH + H^+$$

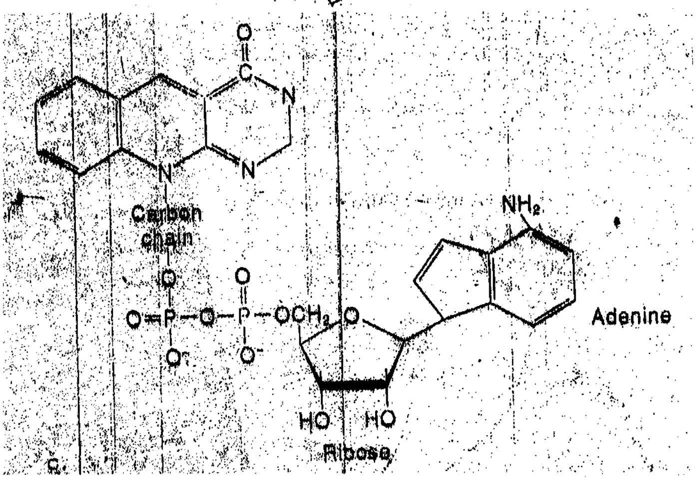
ΔG = -52.6 Kcal mol^{-1}

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

$NADP^+$: Nicotinamide Adenine Dinucleotide Phosphate
NAD^+ has a structure similar to NAD^+ with an added phosphate group

(Fig. 7.4b)



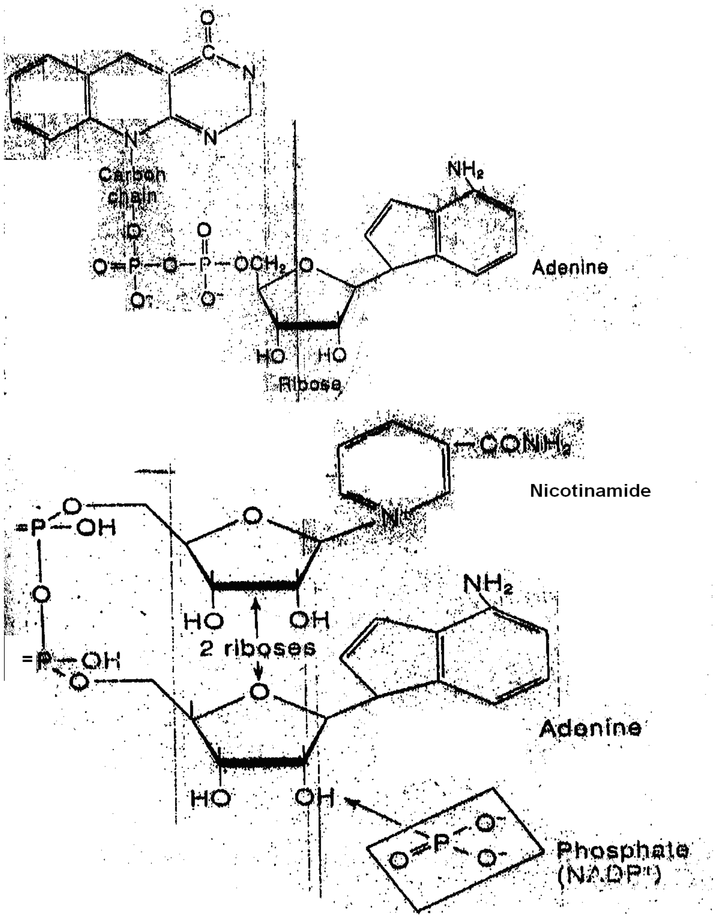


NADPH supplies the hydrogen that reduces $C0_2$ to carbohydrate during photosynthesis. NADPH also supplies the hydrogen used to reduce nitrate to ammonia.

FAD: Flavin Adenine Dinucleotide

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

(Fig. 7.4c)



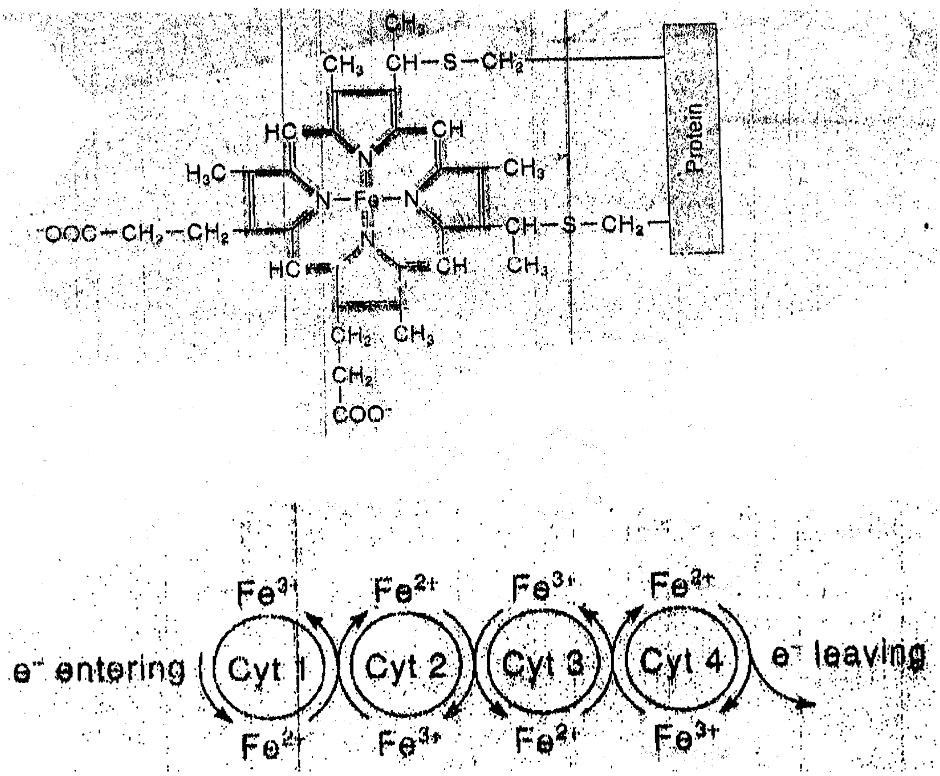
FAD, like NAD, carries two electrons, however 'FAD accepts both protons to become F ADH2 functions in cellular respiration.

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.

(Fig. 7.4 &e)



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

SELF ASSESSMENT EXERCISE 4

List other compounds involved in energy metabolism. Describe the function of any one of them.

4.0 CONCLUSION

Metabolism which represents the totality of chemical reactions that occur in an organism is a fundamental property of all life form. The total idea of metabolism involves the release or uptake of energy to transform energy into other forms. The two basic processes involved are catabolism which is a breakdown reaction that releases energy, and anabolism, a build up reaction that takes in energy. These two processes could otherwise be seen as oxidation and reduction reaction. The process of metabolism is aided by ATP as the main energy currency, while other co factors and coenzymes also assist.

5.0 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.

Adenosine triphosphate, or ATP is the energy currency of cells, which use it to do work. ATP is suited for this function because (1) most of its energy is available immediately to cells and (2) it releases about twice as much energy as is needed to drive most cellular reactions.

ATP is used by all cells for energy transformations. Many of these transformations involve coupled reaction in which the energy released by ATP is used to drive other reactions.

Other compounds involved in cellular metabolism include NAD, NADP, FAD, and cytochromes.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Metabolism is the totality of the chemical and energy transformations in a cell. It occurs in a stepwise sequence called metabolic pathways.

2(a) Bond energy - the amount of energy required to break or form particular bond.
(b) Enthalpy - the total potential energy of a molecule, designated ΔG
(c) Exothermic reaction - heat releasing reaction.
(d) Free energy - the amount of energy available to other bonds.
(e) Endergonic - reaction that absorbs energy from the surroundings and is not spontaneous (energy outwards).
(f) Excergonic reaction - usually increase the entropy and release heat to the surroun4ing outward).

ANSWER TO SELF ASSESSMENT EXERCISE 2

Oxidation reaction involves the loss of electrons either alone or with hydrogen e.g. the breakdown of glucose to water. Reduction reaction involves the addition of electrons either alone or with hydrogen. Example, the synthesis (build up) of complex molecules

ANSWER TO SELF ASSESSMENT EXERCISE 3

Adenosine triphosphate, ATP is the energy currency of cells that is, cells use ATP to do work. ATP releases about twice As much energy as is needed to drive most cellular reactions. ATP is used by cells for energy transformations which may involve coupled reaction in which the energy released by ATP is used for other reactions.

ANSWER TO SELF ASSESSMENT EXERCISE 4

Cofactors or coenzymes and include NAD^+, $NADP^+$, FAD^+ and eytochromes.

6.0 TUTOR-MARKED ASSIGNMENT

1a. What is ATP
b. What three properties of ATP makes it ideal for energy production

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UNIT 3 ENERGY METABOLISM II

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7.0 References/Further Reading

1.0 INTRODUCTION

In unit 7, you learnt about 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.

2.0 OBJECTIVES

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

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

3.0 MAIN CONTENT

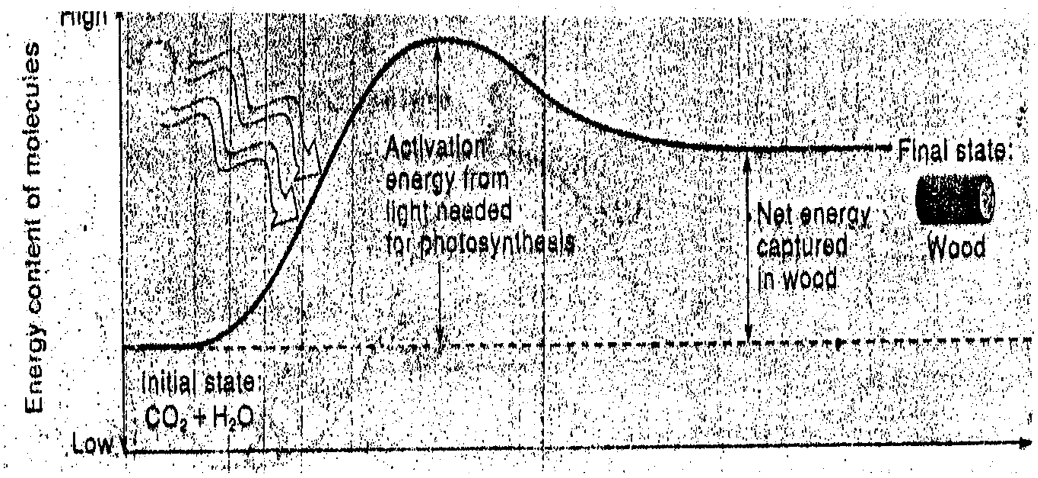
3.1 Enzymes and Energy

In unit 7, you learned that exergonic reactions (e.g. the combustion of methane) are spontaneous. I am sure you may have been wondering, if this is true, than why haven't all these reactions already occurred? You are right to wonder. The truth is that these reactions, even though they are spontaneous require an energy input to start.

To understand this, go to unit 6, and see the example of the rock on top of a hill. This rock contains potential energy, but is at rest. If given a little nudge, the rock will roll down the hill and release its kinetic energy. That little nudge is the energy input required to start the reaction. Once started the roll to the bottom of the hill spontaneously. (i.e. its own).

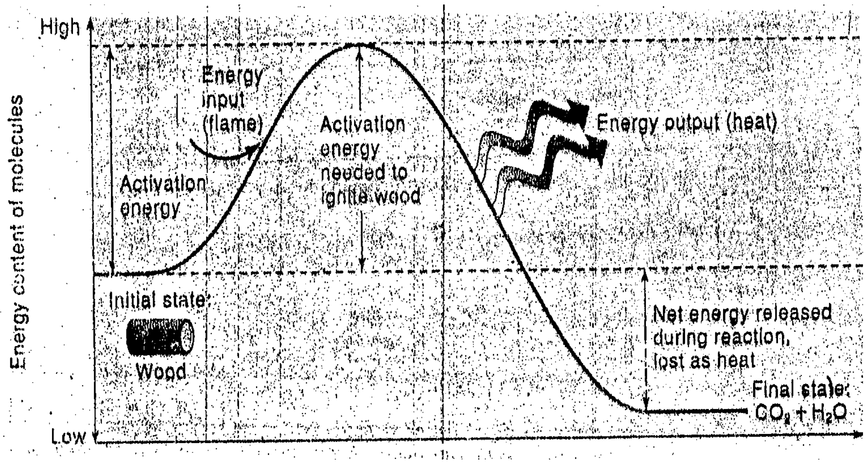
Many chemicals reactions are similar to the rock on top of the hill, they proceed only when activated by an energy input called energy of activation (E act). In photosynthesis, the energy of activation is provided by sunlight and the net gain of energy is trapped in products such a wood.

(Fig.8.la).



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

(Fig. 8.1b).



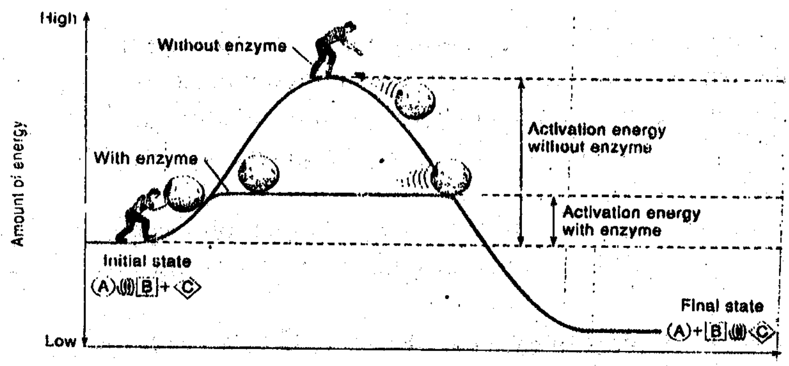
Energy of activation. (a) Plants use photosynthesis for make sugars that are, in turn, used to make products such as wood. The energy to do this that is, the activation energy for a photosynthesis – comes from sunlight. (b) The energy captured in wood is released when wood burns. To start this reaction,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

(Fig. 8.2)



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, Reproduced with permission of McC.

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 fonnu1ation of H_2CO_3 form 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 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 ($37^oC/98.6^oF$)

3.1.1 Regulating Metabolism

Enzymes regulate energy transformations by controlling metabolic reactions. If metabolism is linked to a series of interconnected roads (remember we stated this in unit 7), 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 ΔG of a reaction. (Recall that in unit 7, we identified ΔG to be the amount of energy available to form bonds, also known as free energy)

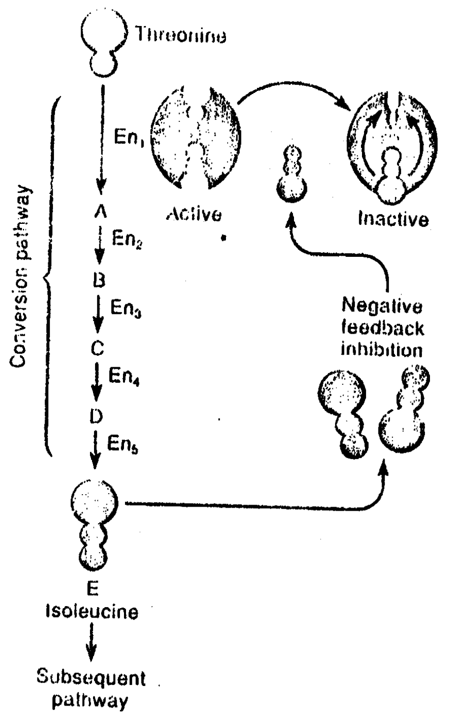
This hypothesis is not true. Enzymes do not change the ΔG of a chemical reaction.

Hypothesis 2 - Enzymes heat calls 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.

(Fig. 5.13)



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,), therchy preventing an unnecessary building of isoleucine.

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 allesterically 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 complete 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 inactive 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 as nerve gas, called non-competitive inhibitor. Although many non-competitive inhibitors bind reversible to an enzyme, many do not. For example, penicillin is noncompetitive inhibitors. Although many competitive inhibitors hat binds irreversibly to an enzyme (3) may do not for example, penicillin in a non-competitive inhibitor than 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.

SELF ASSESSMENT EXERCISE 1

1. What is energy of activation?
2. What is an enzyme and how do enzymes work?

3.2 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.
Starting from unit 9, we will treat these two topics fully. To appreciate these reactions, go to unit 6 and look at (fig. 5.5). 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 dioxide **(a low energy compound) to carbohydrate (a high energy compound).**

$$\text{Carbon dioxide + water + light} \longrightarrow \text{Carbohydrate + oxygen}$$

Carbohydrate fuels the activities of plants and other organisms.

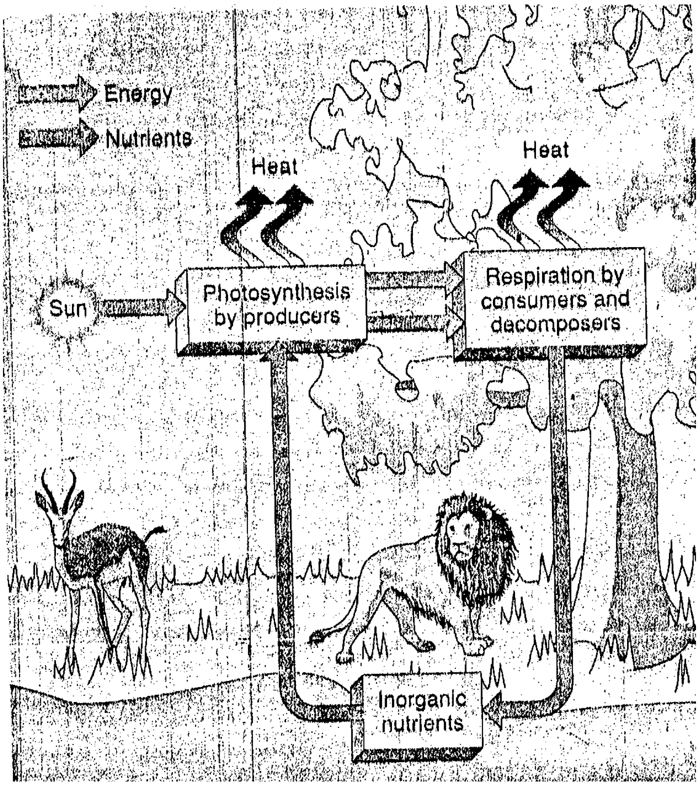
The energy-releasing (i.e. exergonic), downhill stage of the process is cellular respiration. During this process, energy -rich molecules such as sugars are oxidized to carbon dioxide and water.

$$\text{Carbohydrate} + \text{oxygen} \longrightarrow \text{Carbon dioxide} + \text{water} + \text{energy}$$

Respiration drives the cellular economy of most organisms.

3.2.1 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
(Fig. 5.14)



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.

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 energy in corn ⟶ 10 units of energy in a herbivore ⟶ 1 unit of energy 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.

Look again at (fig 5.14), notice that 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 during cellular respiration. Thus nutrients cycles in an ecosystem.

SELF ASSESSMENT EXERCISE 2

1. What are the major energy transformation activities in organisms?
2. Distinguish between photosynthesis and respiration.

4.0 CONCLUSION

Extergonic reactions are spontaneous, yet they still need a little "push" to start. This little push is known as energy of activation. In some reactions, e.g. burring of wood heat provides the energy of activation. Living cells, however derive their energy of activation from biocatalysts known as enzymes. Enzymes regulate energy transformations by controlling metabolic reaction, and they do this by lowering the energy of activation of reactions. The two major energy transformation reactions in plants are photosynthesis and respiration.

5.0 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, 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.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. It is the energy required to start up a reaction.
2. Enzymes are globular proteins that spree reactions by decreasing the energy of activation of a reaction

ANSWER TO SELF ASSESSMENT EXERCISE 2

1. Respiration and photosynthesis
2. Photosynthesis uses light energy to reduce carbon dioxide and water to carbohydrate, while respiration oxidizes carbohydrate, producing ATP in the process.

6.0 TUTOR-MARKED ASSIGNMENT

These will be given at the end of subsequent units since they are linked.

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UNIT 4 RESPIRATION

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1.0 INTRODUCTION

In units 6-8, you learned about energy and that organisms convert energy from one form to another. Plants convert stored chemical to energy by respiration. The ATP harvested from energy stored in carbohydrates and other organic molecules fuels the energy-requiring activities of the cell, including the movement of organelles and small particles within a cell, active transport across membranes, and the transport of organic compounds from one part of a plant to another. Beginning with glucose respiration harvests energy in three stages.

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.

2.0 OBJECTIVES

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

- list the sources from which sugar substrate are obtained for cellular respiration
- name the form of sugar that enters into respiration
- list the enzymes that assist in retrieving glucose from sucrose and starch
- differentiate between substrate-level phosphorylation and oxidative phosphorylation

- define chemiosmosis
- state where glycolysis occur in the plant cell.
- list the products of glycolsis
- state the link between glycolsis and Krebs cycle.
- discuss the 8-steps of the Krebs cycle
- list the end products of the Krebs cycle.

3.0 MAIN CONTENT

3.1 Retrieving Glucose from other Molecules

Most discussions of respiration focus on what happens to glucose, probably because glucose metabolism is similar in all organisms. However, glucose is usually not abundant in cells. Respiration begins by converting storage compounds vary from one organism to another, or in plant from one organ to another. For example, humans and other vertebrates, store the polysaccharide glycogen, potatoes and bananas store starch, and onions store polymers of fructose. Furthermore, sucrose is the common starter molecule for respiration in leaves, but in the same plant, respiration may begin with starch in non-green storage organs such as roots and stems.

3.1.1 Retrieval from Sucrose

Sucrose, abundant in sugarcane stems and sugar beet roots, is common in plants and is commercially important because man consume so much of it as table sugar. Besides being a common energy source in photosynthesis cells, sucrose is the carbohydrate that moves most readily through conducting cells to growing tissues.

The transfer of phosphate is catalysed by an enzyme that binds the substrate and ADP.

The energy of substrate-level phosphorylation comes from the phosphate containing substrate. Regardless of which substrate is used, the removal of a phosphate fructose must release more energy then necessary for making ATP from ADP. For example removal of a phosphate from phosphoendpyruvic acid (PEP) releases 14.8 kcal mol4 (fig 6.3) this is more than enough energy to phosphorylate ADP, which requires 7.3 kcal mol **(I hope you still remember this from unit 7?).** The remaining energy **(7.8kcal mol^4)** is lost as heat.

The second way that ATP is made involves coupling energy from an electron donor to an electrochemical gradient that spans the inner mitochondria membrane. The electron donor is usually $NADH_2$ **(a**

molecule that you learned about in Unit). (I am sure heat at this stage you would have seen the need to constantly refer to earlier units to refresh your memory about any concept you may have forgotten. This will assist you in understanding what is being discussed.) Electrons from NADH are passed through a chain of electron carriers by a series of oxidation reduction reactions. The energy from this movement of electrons is used by proton pumps to generate a proton electrochemical gradient that fuels the phosphorylation of ADP to ATP. The overall process is called **oxidative phosphorylation.**

Membranes play an important role in coupling energy between the electron transport chain and the phosphorylation of ADP. This energy-coupling is usually referred to as chemoismosis because it involves chemical reactions and transport across membranes. **Chemoismosis** is also used to make ATP in chloroplasts during photosynthesis **(This will be discussed in later units).**

Of the two ways that ATP is made during respiration, substrate-level phosphorylation is the simpler, but it accounts for only a small percentage of ATP synthesis. Most ATP is made from oxidative phosphorylation.

SELF ASSESSMENT EXERCISE 1

What is (a) Oxidation phosphorylation?
(b) Chemiosmosis

3.3 Glycolysis

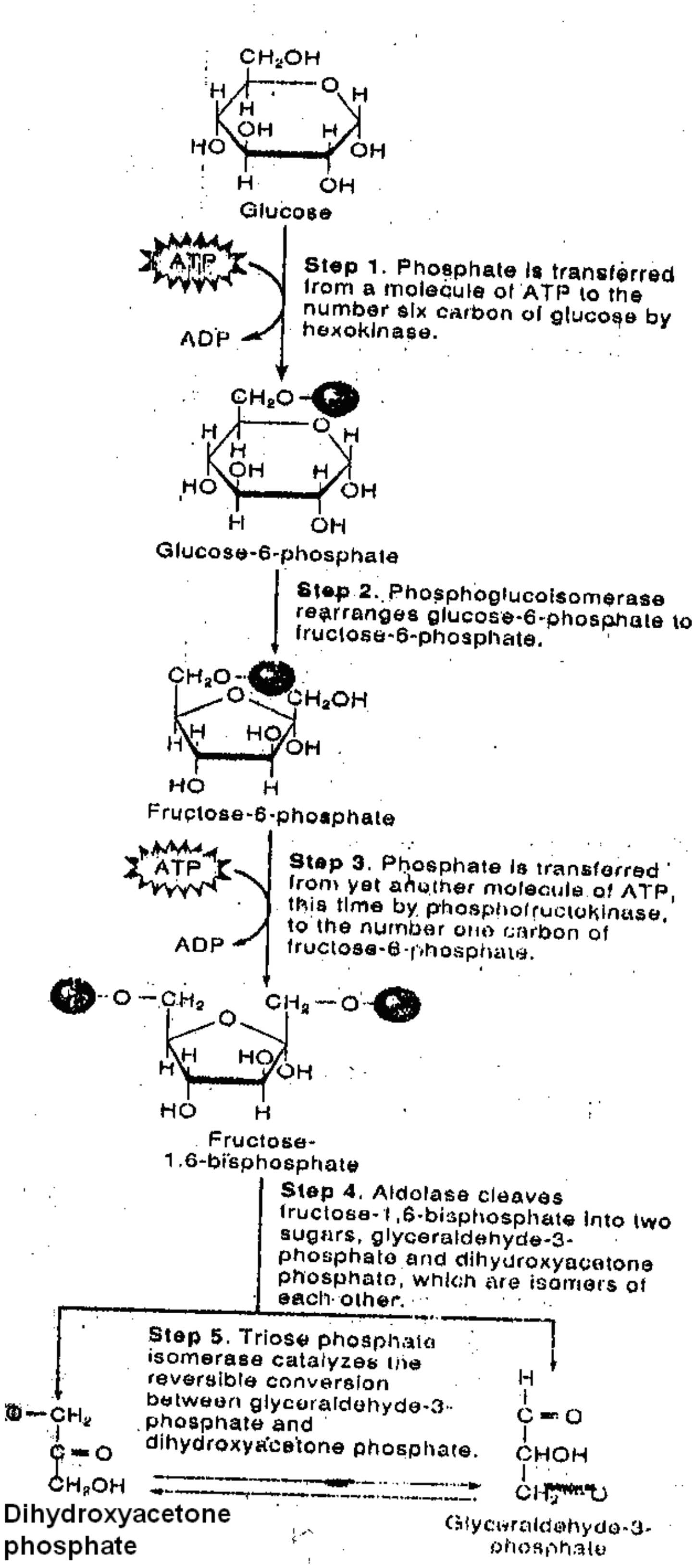
3.3.1 Potential Energy of Glucose

In unit 7, you learned that glucose contains 68^6 kcal mol^4. This means that with the addition of some heat (i.e. the energy of activation -0 Eact) to get it going one mole of glucose will yield 686,000 calories when it is completely oxidized to CO_2 and H_2O. However, all cells recover only a small amount of this energy during glycolysis, the rest is lost as heat. Because the energy is released in small increment, the excess heat does not damage the cells.

3.3.2 Breakdown of Glucose to Pyruvic Acid

During glycolysis, glucose is split into two three-carbon compounds. The entire process requires ten steps, all of which occur in the cytosol.

(Fig. 9.2)

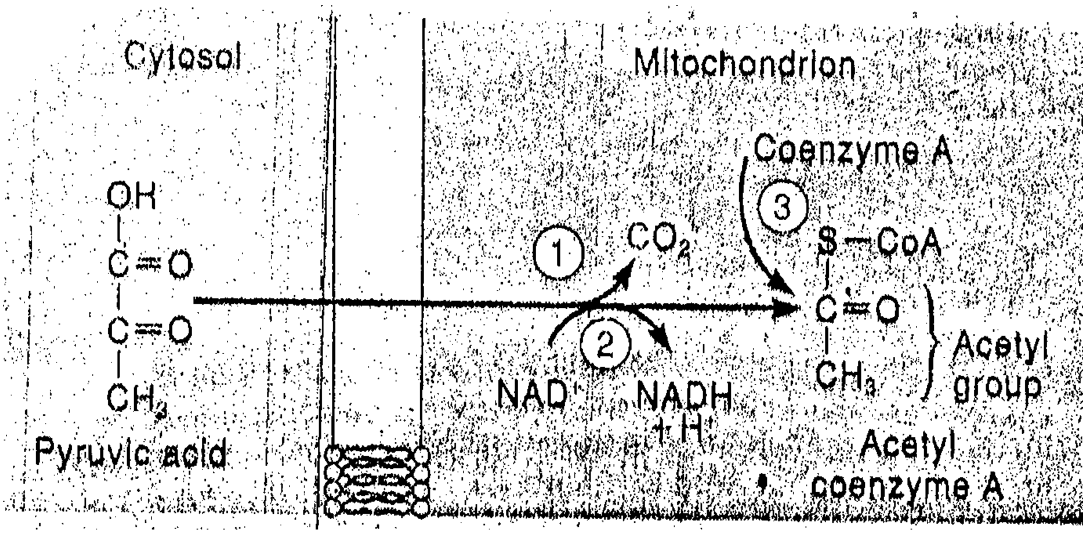


Glucose
ATP
ADP
Step 1. Phosphate is transferred from a molecule of ATP to the number six carbon of glucose by hexokinase.
Glucose-6-phosphate
Step 2. Phosphoglucoisomerase rearranges glucose-6-phosphate to fructose-6-phosphate.
Fructose-6-phosphate
ATP
ADP
Step 3. Phosphate is transferred from yet another molecule of ATP, this time by phosphofructokinase, to the number one carbon of fructose-6-phosphate.
Fructose-1,6-bisphosphate
Step 4. Aldolase cleaves fructose-1,6-bisphosphate into two sugars, glyceraldehyde-3-phosphate and dihydroxyacetone phosphate, which are isomers of each other.
Step 5. Triose phosphate isomerase catalyzes the reversible conversion between glyceraldehyde-3-phosphate and dihydroxyacetone phosphate.
Dihydroxyacetone phosphate
Glyceraldehyde-3-phosphate

3.4 The Krebs Cycle

Pyruvic acid that is transported into the mitochondrion is not used in the Krebs cycle directly. Instead, pyruvic acid first loses a molecule of carbon dioxide. The remaining acetyl group is attached to a coenzyme to form acetyl **coenzyme A (acetyl 2-CoA)** outlines the conversion of pyruvic acid to acetyl-CoA in the mitochondrion, Note that when carbon dioxide is released from pyruvic acid, NAD is reduced to NADH.

(Fig 9.3)

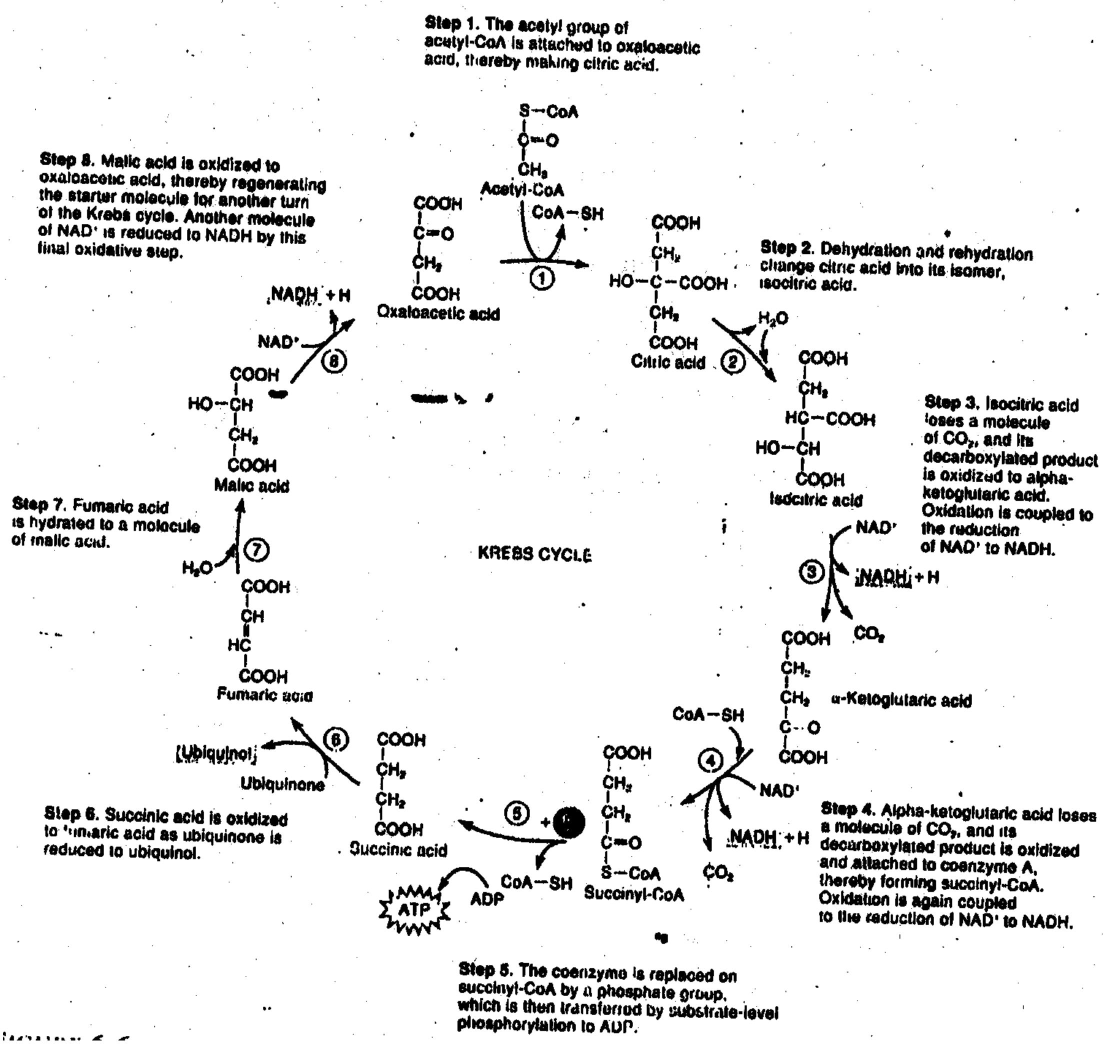


Conversion of pyruvic and to acetyl-CoA, (1) CO, is removed from pyruvic and that has been transported into the mitichiondrion. (2) the remaining two-cortion fragment is oxidized to an acetyl group, while NAIY is reduced to NADH. (3) the acetyl group is attached to the sulfur atom of enzymes A(CA).

Glycolysis and the Krebs cycle are linked by the conversion of pyruvic acid to acetyl CoA. Pyruvic acid is the final product of glycolysis, and acety-CoA is the compound that enters the Krebs cycle.

3.4.1 Step in the Krebs Cycle

The Krebs cycle named in honour of Sir Hans Krebs, is a cycle because the last segment regenerates the started chemicals for the first step.



In all, there are eight steps, seven of which occur in the mitochondria matrix. Step 6 occurs, in the mitochondria membrane.

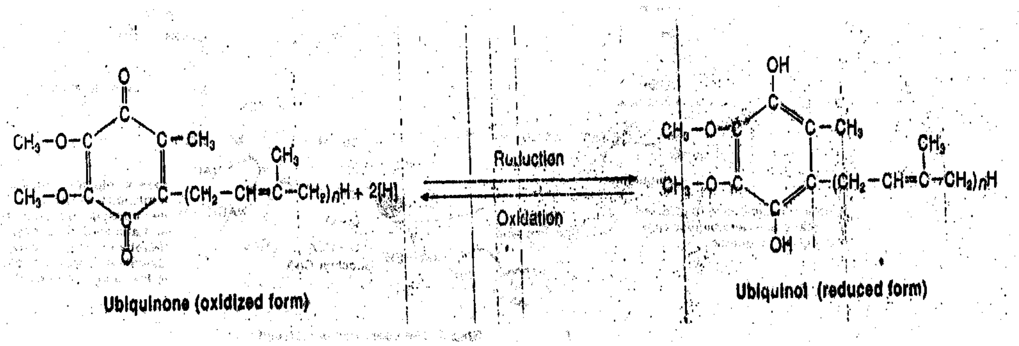
In the first step, coenzyme A is cleaved from acetyl-CoA and the acetyl group is attached to oxaloacetic acid, which has four carbons. The resulting six carbon compound is citric acid. (The Krebs cycle is also known as the citric-acid cycle because it begins with citric acid; or the tricarboxylic acid cycle because citric acid has three carboxyl groups). Citric acid is then rearranged to isocitric acid (step 2), which is the beginning substrate for two-oxidative steps that entail the removal of two molecules of carbon dioxide. These steps also reduce two molecules of NAD^+ to NADH.

In the first oxidative step, to form isocitric acid (step 3) the removal of carbon dioxide yields **alpha-keto and glutaric acid.** In the second oxidative step (step 4), carbon dioxide is removed from alphaketoglutaric acid, and the product is bound to a coenzyme A to make **succinyl -CoA**. Each step also reduces a molecule of NAD to

NADH. Coenzyme A is then cleaved from succinyl -CoA, thereby producing succinic acid and providing energy for the substrate level phosphorylation of ADP to ATP (step 5). **(As pointed out for Glycolysis, it is important that you study fig 9.4 as you read the Krebs cycle; otherwise you will be totally confused).**

Following the formation of succinic acid, three more oxidative steps occur (step 6-8) succinic acid is oxidised to **fumaric acid,** fumaric acid to **malic acid,** and malic acid to **oxaloacetic acid**. The oxidation of succinic acid also reduces the electron carrier **ubiquinone** to **ubiquinol** the oxidation of malic acid to oxaloacetic acid reduces NAD to NADH. Thus for each acetyl-CoA that enters the Krebs cycle, only one ATP is made by substrate level phosphorylation. Most of the energy derived from the oxidative steps of the Krebs cycle is stored in the high-energy derived from the oxidative steps of the Krebs cycle is stored in the high-energy electrons of NADH and ubiquinol. The energy in these molecules is harvested in the third phase of respiration, oxidative phosphorylation.

(Fig 9.5)



Reversible conversions between ubiquinose and ubiquibnol. The n in each formula stands for the number of times the 5-carbon side chain is repeated. Naturally occurring ubiquinones have 6-10 of these 5-carbon units (30-50 carbons in the side chain)

SELF ASSESSMENT EXERCISE 3

1. What is the link between glycolysis and Krebs cycle?
2. What are the end products of Kreb cycle?

4.0 CONCLUSION

All organisms including plants harvest energy from stored chemicals in much the same way. The metabolic pathways by which organisms liberate stored energy are referred to as cellular transpiration. This process breaks down complex molecule into simple chemicals and harvests the energy stored in them.

The products of the complete oxidation of glucose are the same whether the glucose is burned in the laboratory or respired in a cell. CO_2, H_2O and energy. When it is burned, a mole of glucose (180 grams) makes a small fire that lasts for several minutes. In a cell, respiration controls this process, so the heat does not destroy the tissue. Instead, some of the energy from glucose is trapped in ATP. The heat lost during respiration never causes smoke on fire because it is released slowly by many chemical reactions. The first of these is glycolysis, this is followed by Krebs cycle. At the end of Krebs cycle, respiration is not yet complete.

5.0 SUMMARY

Respiration harvests energy from organic molecules. There are several kinds of respiration, but the most common kind is aerobic respiration, which requires oxygen and produces ATP. Respiration occurs in three stages.

The first stage, glycolysis, entails the breakdown of glucose into smaller organic compounds, it occurs exclusively in the cytosol and converts some of the energy stored in glucose to ATP and NADH. During glycolysis, ATP is made by substrate level phosphorylation. The remainder of the energy from glucose is either lost as heat or remains in pyruvic acid which is shunted into the mitochondria. In the motochondria, pyruvic acid is converted to acetyl CoA in a reaction that also reduces NAD^+ to NADH.

Acetyl-CoA enters the second stage of respiration, the Krebs cycle which is a series of oxidation-reduction reactions that produce ATP, NADH, ubiquinol, and CO_2. As in glycolysis, ATP is made in the Krebs cycle by substrate - level phosphorylation.

ANSWER TO SELF ASSESSMENT EXERCISE 1

l(a) Sucrases
(b) Amylase, starch phosphorylase and debranching enzyme

ANSWER TO SELF ASSESSMENT EXERCISE 2

2(a) The process whereby electrons from NADH are passed through a chain of electron carriers by a series of oxidation-reduction reactions to generate proton electron gradient that fuels phosphorylation of ADP to ATP.

(b) The process of coupling energy between the electron transport chain and the phosphorylation of ADP. It involves chemical reactions and transport across membranes.

ANSWER TO SELF ASSESSMENT EXERCISE 3

3. During glycolysis, glucose is split into three carbon compounds, the entire process requires 10 steps. During the first half, glucose is phosphorylated twice and split into two three-carbon compounds. The first half uses ATP. The three carbon compounds are oxidised to make pyruvic acid during the second half of glycolysis, which also makes ATP and NADH.
4. The conversion of pyruvic acic to acetyl-CoA. Pyruvic acid is the final product of glycolysts and acetyl-CoA is compound that enters the Kreb cycle.
5. One mol of ATP, one mol of ubiquinol, 3mol^8 of NADH and CO_2

6.0 TUTOR-MARKED ASSIGNMENT

Briefly outline the step involved in the Krebs cycle.

7.0 REFERENCES/FURTHER READING

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UNIT 5 RESPIRATION II

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1.0 INTRODUCTION

In unit 9, we started the discussion of respiration. Respiration as you will recall is one of the energy transformation activities of plants. In unit 9, you learned that beginning with glucose, respiration harvests energy in three stages. The first stage is glycolysis, followed by Krebs cycle. In this unit, you will learn about the third stage which is the electron transport chain. This stage involves the harvesting of energy from the movement of electrons. This process like the Krebs cycle, occurs in the mitochondria. You will also learn about other types of respiration namely anaerobic respiration. Because the only storage product is not starch, you will also learn about the respiration of lipids.

2.0 OBJECTIVES

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

- describe the series of events in the electron transport chain
- explain how ATP is produced in the electron transport process
- mention two other types of respiration
- list the 2 products of pyruvic acid breakdown during anaerobic respiration
- state three economic importance of anaerobic respiration
- describe how lipids are respired.

3.0 MAIN CONTENT

3.1 Electron Transport and Oxidative Phosphorylation

When compared with glycolysis and the Krebs cycle, oxidative phosphorylation is a bonanza ATP synthesis. Energy for oxidative phosphorylation comes from NADH and ubiquinol, which are produced by j the first two phases of respiration (Refer to unit 9). The high energy electrons of NADH and ubiquinol are not used directly for ATP synthesis, instead, they start a series of oxidation reduction reaction that move electrons through several carriers. The sequence of electron carriers is known as the electron transport chain.

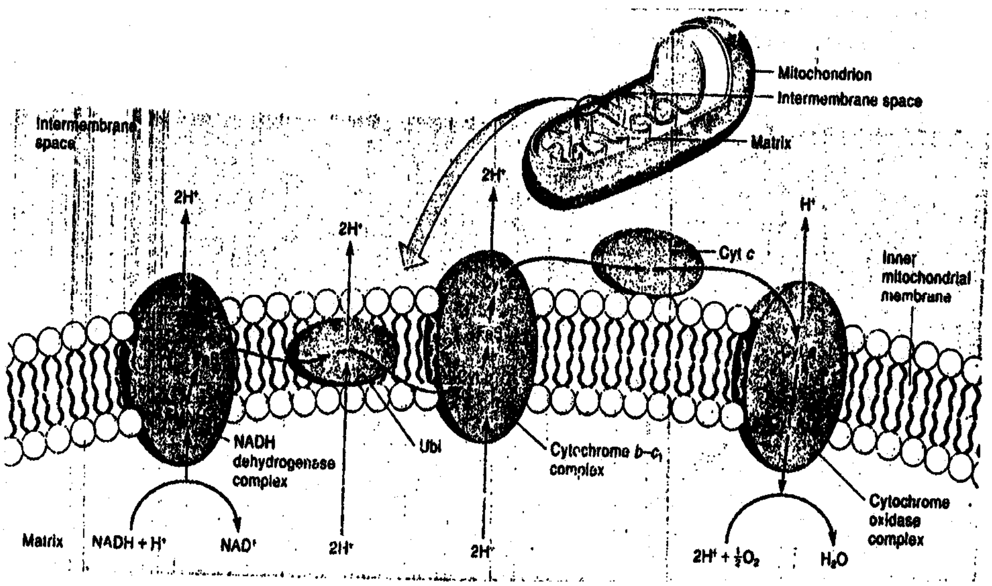
Energy from electron flow through these carriers maintains a proton gradient across the inner mitochondrial membrane, which drives the synthesis of ATP. Oxidative phosphorylation refers to the combination of the oxidative - reduction reactions of election transport that enable a cell to use the energy in NADH and ubiquinol to phosphorylate.

3.1.1 Electron Transport

The electron transport chain is like a series of tiny, successively stronger magnets, that is, each has a higher potential than its predecessor. This means that each component of the chain pulls electrons away from a weaker neighbour and gives them up to a stronger one. Thus the strongest acceptor in the chain is the terminal acceptor, oxygen, which has potentials of 0.82 volts.

There are at least nine electron carriers in the series, most of which are proteins. Some of these carriers also accept proteins and release them into the inter-membrane space. Although scientists are not quite certain how these components work together for electron and proton transport shows a widely accepted model for the sequence of steps in the chain.

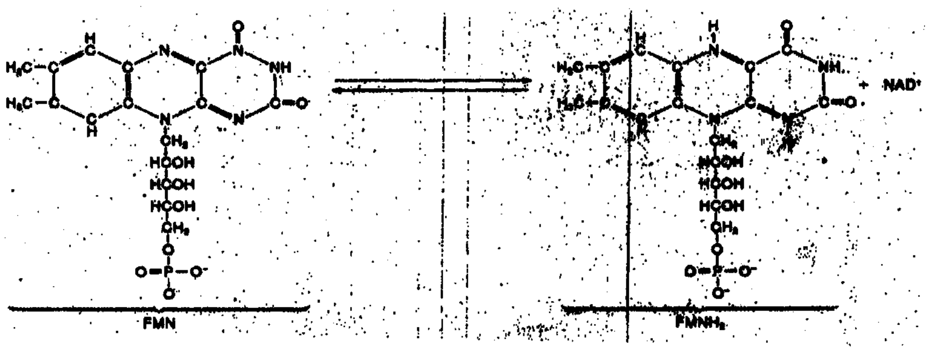
(Fig. 10.1)



Model for the sequence of steps in the electron transport chain. Two mobile electron carrier ubiquuinene (Ubt) and eytochrome (Cyt c), transfer electrons between three electrons-carrier complexes that are embedded in the membrane the NADH dehydrogenese complex, the cytochrome oxidase complex. and the cytochm uphase complex, electron flow along the chain cause protein pumping from the mitochondrial matrix into the intermembrane space. This model shows that one NADH fuels the transport of six protons, although the number of protons is arable and can be as high as eleven.

According to the model, in the first step of electron transport, **Flavin mononucleotide (FMN)** takes electrons from NADH in the mitochondrial matrix. FMN also takes 2 protons (H^4), one from NADH and one from the aqueous matrix

(Fig. 10.2)



The first step of the electron transport chain, flavin mononucleotided is reduced in a riverable reaction to FMNH$_2$ by NADH and FP the mitochondrial matrix. (FMN is also called riboflavin or vitamin B$_2$.

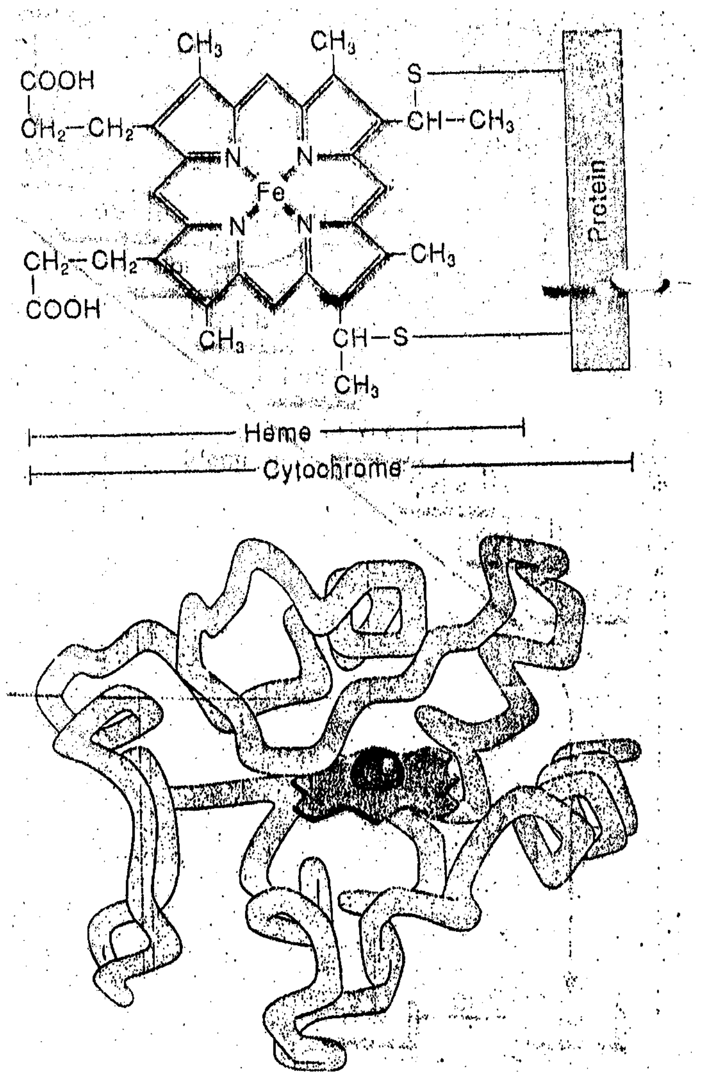
In the second step an iron and sulphur-containing protein is reduces as $FMNH_2$ is oxidized back to FMN **(i.e. the iron-sulphur protein pulls electrons from $FMNH_2$**. Meanwhile the protons from $FMNH_2$ are released into the inter-membrane space. The net result of these first two steps is that energy from oxidation reduction reactions drives the transport of protons from one side of the inner mitochondrial membrane to the other. The carriers responsible for these steps are called the **NADH dehydrogenase complex** named after the enzyme that removes hydrogen from NADH.

In the third step of electron transport, electrons are pulled from the NADH dehydrogenase complex by ubiquinone **(also called coenzyme Q),** which shuttles the electrons to a complex of two **cytochromes** and another iron sulphur protein. This complex is called the **cytochrome b-c_1 complex**. Protons are again transported from the matrix side of the inner membrane to the inter-membrane space using the energy of electron flow from ubiquinone through the cytochrome b-c_1 complex. This ubiquinone acts as a second proton pump in the electron transport system and the cytochrome b-c_1 complex acts as a third proton pump. Ubiquinone can also accept electrons directly from ubiquinone in the matrix.

Finally, electrons from the cytochrome b-c_1 complex are pulled away by a mobile cytochrome, cytochrome c_1 and shuttled to the terminal carriers complex. The terminal carrier complex consists of two more cytochromes, cytochrome a_1 and chtochrome at which form the cytochrome oxidase complex. Cytochrome a_3 donates its electrons to oxygen, which is the terminal electron acceptor in the electron transport chain. The reduced oxygen then combines with protons in the mitochondria matrix producing water.

One of the key features of the electron transport chain is that it involves iron. This element occurs not only in the iron sulphur proteins but also in cytochromes. Thus oxidation and reduction of these electron carrier entails interchanges between the reduced (Fe^{2+}) and the oxidised (Fe^{3}) forms of iron. In cytochromes, this change occurs in a complex ring group, called a **heme** that is attached to the protein.

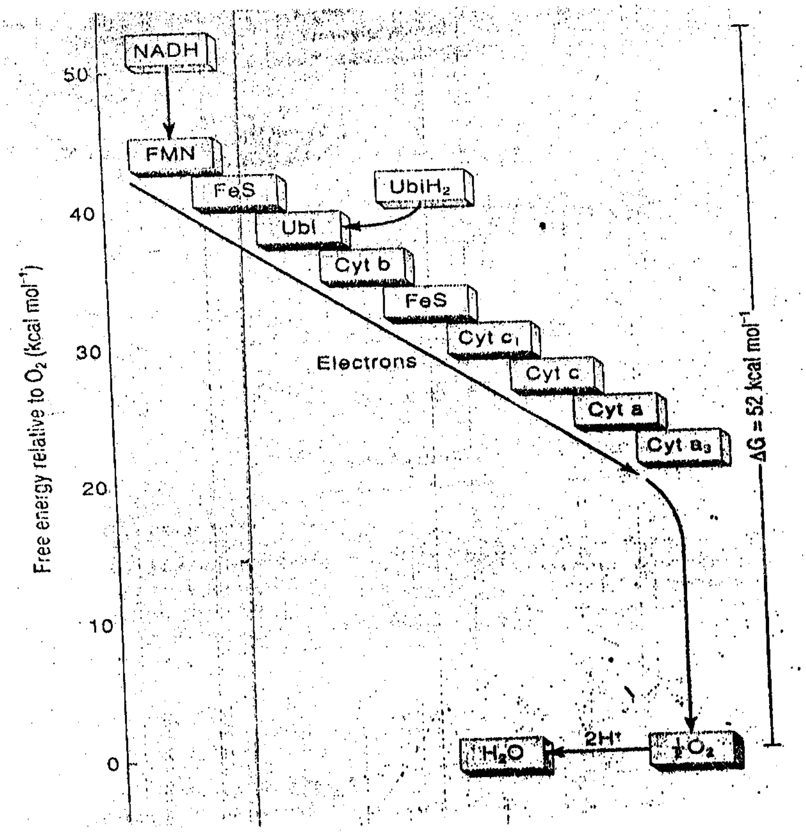
(Fig. 10.3)



Structural masks of cytochrome C_1 showing the iron-containing heme group. The heme group is blue and the iron is red. During electron transport, each iron accepts one electron and is reduced from Fe_e "to S_e"

Note that the transport of protons from one side of the inner mitochondrial membrane to the other requires energy, which is provided by the movement of electrons through the electron transport chain. Electron movement yields energy because each reduced election carrier has Jess free energy than does the donor immediately before it in the series. The lowest level of free energy in the chain occurs in the water that forms when oxygen is reduced in the last step between the NADH at the start of electron transport and the oxygen at the end, the total change in free energy is -53Kcalmol^{-l}. The energy change between ubiquinol and oxygen is about one-third less because ubiquinol enters the chain at a lower energy level.

(Fig. 10.4)



Free energy scale of the electron transport chain. The energy drop for electrons from NADH to oxygen is 53 kcal mol[3]. The energy drop from obi is about the third less.

SELF ASSESSMENT EXERCISE 1

Briefly describe the series of event in the electron transport chain.

3.1.2 Chemiosmosis and ATP Synthesis

The chemiosmosis theory of ATP synthesis was formulated by a British scientist peter Mitchel based on a series of experiments he carried out towards the understanding of ATP synthesis in the electron transport chain. His theory states that:

- Carriers of the electron transport chain are embedded in the inner mitochondrial membrane. The flow of electrons through this series of carriers is used to pump protons across the membrane. Because the membrane is not very permeable to protons, relatively few protons leak back across the membrane.

- Continued electron transport pumps more and more protons into space between the inner and outer membranes of the mitochondria. This creates a gradient of protons across the membrane.

- The proton gradient serves as a battery to work, including making ATP.

According to Mitchel's model, the interaction between electron transport and ATP synthesis is indirect electron transport produces a proton gradient, and that gradient drives the synthesis of ATP.

The inner membrane of the mitochondria is folded many times, so that much surface area is available for membrane dependent metabolism. Thousands of copiers of ATP synthase complex are embedded throughout the membrane, making the inner mitochondrial membrane a power house for making ATP.

SELF ASSESSMENT EXERCISE 2

Briefly summarize ATP synthesis in the electron transport process.

3.2 Other Types of Respiration

So far, we have limited our discussions on one type of respiration called aerobic respiration. It is the main type of respiration prevalent in many organisms. It is called aerobic respiration because it requires oxygen as the terminal electron acceptor. When oxygen is not available, other electron acceptors can be used in a process called anaerobic respiration. This is going to be the subject of discussion in the next section. Following it will be a discussion of Respiration of Lipids.

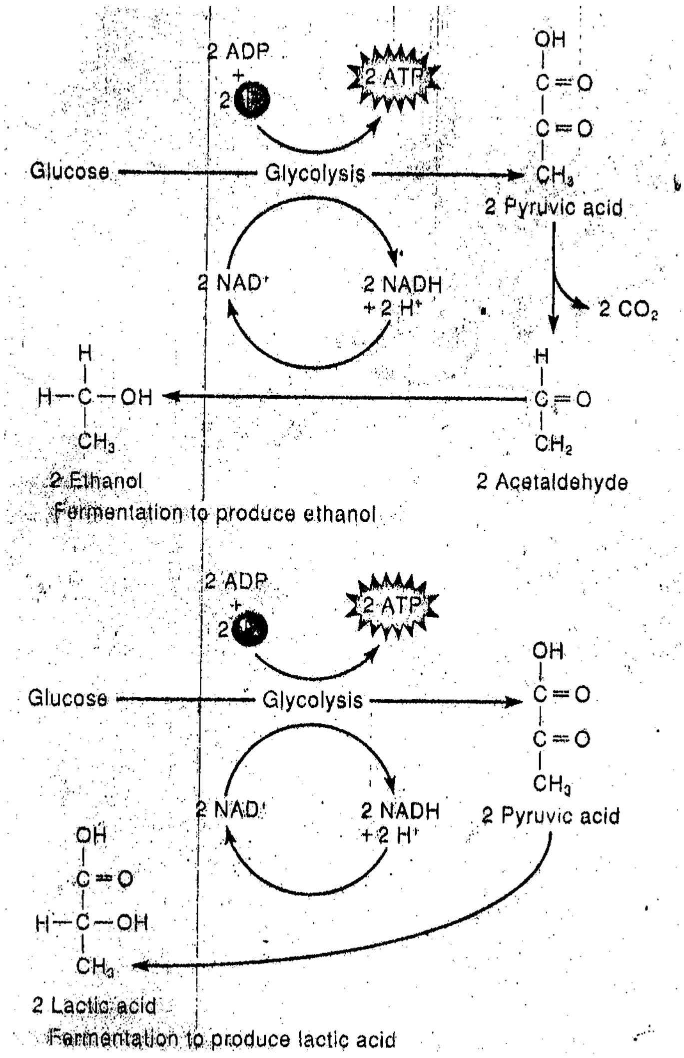
3.2.1 Anaerobic Respiration

Although oxygen is required only at the end of electron transport during aerobic respiration, electron transport and the Krebs cycle are both inhibited when oxygen is not available. Glycolysis works normally in an oxygen free environment, but energy stored in the electrons of the NADH from glycolysis can become a problem if the NADH cannot be used fast enough elsewhere in the cell, or if the supply of NAD^+ is depleted. In both cases, there would be no NAD^+ available to oxidize glyceraldehydes-3 phosphate, consequently, glycolysis would stop.

In animals, certain fungi and bacteria, pyruvic acid is reduced to lactic acid by excess NADH. In other fungi and in plants, the abundance of

NADH is relieved when pyruvic acid is converted to acetaldehyde, which is then reduced by NADH to ethanol.

(Fig. 10.5)



Anasro respiration usually produces in plants and certain fungi (a), in other fungi and in bacteria and animals it produces and (b)

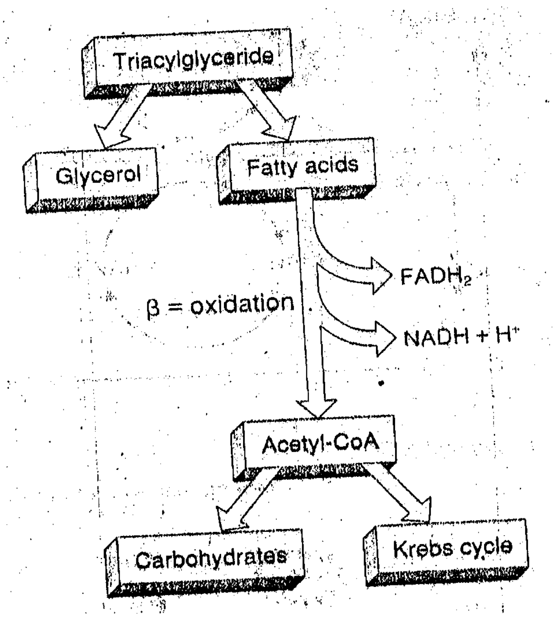
Together, these anaerobic reactions are called fermentation. Unless they have adaptations (such as aerenchyma) to facilitate diffusion of oxygen to their roots many plants ferment when they grow up in mud or in oxygen-poor water, this is why most house plants die when they are over watered. Anaerobic respiration is inefficient because it produces little or no ATP.

Anaerobic respiration is economically important. For example, fermentation by bacteria and fungi is important for flavouring cheese and yoghurt. Similarly, fermentation by yeast is important for making alcoholic beverages and bread; wine, beer and bread are made by different strains of brewer's years **(Saccharomyces cerevisiae).** This carbon dioxide produced during fermentation makes bread rise, but the alcohol from fermentation evaporates when the bread is baked. Wine is usually made by yeast that grows on grapes, although fermented honey, applies **(cider)** and other carbohydrates rich substrates are also used to make wine or wine like beverages. Likewise, although beer is usually made from barley, rice beer is common in China, and com beer is made in Mexico.

3.2.2 Respiration of Lipids

Lipids that include fatty acids are important storage compounds in oil containing seeds. When such seeds geminate their fatty acids are metabolized in glyoxysomes to recover the energy stored in them. Fatty acids are first removed from glycerol in storage triacylglycerides, and then snipped into two carbon pieces that are released as acetyl-CoA.

(Fig. 10.6)



Respiration of lipids. Triacylglycerides are hydrolysed into glycerol and carry ackiss. Forty acids are degraded by beta-oxidation into acertyl groups that are attached to coenzyme. A, which can be used in respiration or for carbohydrate synthesis. FAD and NAD are also reduced during into oxidation.

This reaction, called **beta-oxidation** is repeated for every part of carbons until all of the fatty acid is converted into acetyl-CoA molecules. Thus, a molecule of stearic acid, which has eighteen carbons,

yields nine molecules of acetyl-CoA. Beta-oxidation occurs either in the cytosol or in glyoxysomes. The release of acetyl-CoA drives the reduction of NAD^+ and FAD to NADH and $FADH_2$ respectively.
Acetyl-CoA from beta-oxidation can be used in the Krebs cycle for further recovery of the energy stored in fatty acids, or it can be routed to other metabolic pathways NADH and $FADH_2$ may be transported to mitochondria where their electrons can be used in the electron transport chain.

SELF ASSESSMENT EXERCISE 3

To what economic use can anaerobic respiration be put? 4. How are lipids respired?

4.0 CONCLUSION

Electron transport, which is the last stage of aerobic respiration is regarded as ATP bonanza. This is because a lot of ATP synthesis takes place here. The high energy electrons of NADH and ubiquinol start a series of oxidation- reduction reaction that move electrons through several carriers. This electron transport produces a proton gradient, and the gradient drives the synthesis of ATP.

Apart from aerobic respiration which occurs in the presence of oxygen, when oxygen is not present, anaerobic respiration occurs. Anaerobic is not efficient because it does not produce ATP, but it has a lot of economic uses for humans, example include flavouring cheeses and making bread.

5.0 SUMMARY

Energy rich electrons from NADH and ubiquinol fuel the electron transport chain, which is the third stage of respiration. Electronics move through a series of carriers that release energy at each step. The terminal electron acceptor is oxygen, which is reduced to form water. The energy of electron transport is used to pump protons from the mitochondrial matrix into the inter-membrane space.

As protons diffuse by chemiosmosis back into the matrix through ATP synthase complexes, their energy is coupled to the phosphorylation of ADP to ATP. This synthesis of ATP from the energy of electron transport is called oxidative phosphorylation.

There are several kinds respiration. Anaerobic respiration occurs in the absence of oxygen. It is not efficient because it does not produce ATP. Lipids are respired by beta-oxidation to yield acetyl units that enter the Krebs cycle.

ANSWER TO SELF ASSESSMENT EXERCISE 1

First, FMN takes electron and 2 protons from NADH. The FMN becomes $FMNH_2$ while NADH becomes NAD^+.
Second, FMNH is converted to FMN by NADH dehydrogenase complex.

Third, ubiquinol pulls electron from NADH dehhydrogenase to cytochrome b-c_1.
Finally, electron from cytochrome b-c_1 are pulled by cytochrome c to terminal carriers complexes which are cytochrome a, and cytochrome a_3 the cytochrome a_2 the donates then electron to oxygen which is the terminal electron acceptor.

ANSWER TO SELF ASSESSMENT EXERCISE 2

The proton gradient that is maintained by electron transport provides the energy necessary for making ATP .Protons diffuse down their electron-chemical gradient through enzyme complexes that harness the energy of proton flow for the phosphorylation of ADP.

ANSWER TO SELF ASSESSMENT EXERCISE 3

1. Flavouring cheese, making alcoholic beverages and bread.
2. By beta-oxidation to yield acetyl unit that enter the Krebs cycle

6.0 TUTOR-MARKED ASSIGNMENT

1. Briefly describe how electron transport leads to ATP synthesis
2. What are the two products of pyruvic acid breakdown in anaerobic respiration?

7.0 REFERENCES/FURTHER READING

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MODULE 3

Unit 1 Photosynthesis: Basic Issues
Unit 2 Photosynthetic Pigments
Unit 3 The Photosynthetic Process
Unit 4 Plant Hormones I
Unit 5 Plant Hormones II

UNIT 1 PHOTOSYNTHESIS: BASIC ISSUES

CONTENTS

1.0 Introduction
2.0 Objectives
3.0 Main Content
 3.1 History of the Elucidation of Photosynthesis
 3.2 The Nature of Light
4.0 Conclusion
5.0 Summary
6.0 Tutor-Marked Assignment
7.0 References/Further Reading

1.0 INTRODUCTION

Photosynthesis is a light-driven reaction that converts energy – poor compounds such as carbon dioxide and water to energy rich carbohydrates. Our knowledge of photosynthesis however started from the inquisitiveness and experimentation of early scientists. In this unit, we are going to begin a series of units that will treat the subject matter of photosynthesis. This unit will be mostly historical in nature. We will look at the early experiments carried out by pioneers, and how one thing led to the other until we got to the level we are today in the knowledge of photosynthesis.

A good understanding of photosynthesis will hinge on an understanding of the nature of light. We will also look at the pioneering efforts of Isaac Newton and Einstein that led to an understanding of the nature of light. We will reserve other issues on photosynthesis to subsequent units.

2.0 OBJECTIVES

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

- name the early scientists that pioneered efforts towards the understanding of photosynthesis
- describe the findings of Jean Senebier regarding gases (O_2 and CO_2), light and photosynthesis
- summarize the findings of the experiment of these pioneer scientists
- describe the nature of light
- name the scientist who pioneered efforts towards understanding the nature of light
- list the constituents of sunlight.

3.0 MAIN CONTENT

3.1 History of the Elucidation of Photosynthesis

Early scientists had no idea that the sun supplies the earth with virtually all its energy or that green plants trap energy and produce the invisible gases that we breathe. Ancient Greeks rather, regarded plants as "soil eater" because they noted that fertilizing the soil increases plants growth. This concept went unchallenged until 1648 when the Dutch physician – Jan Baptista van Helmont reported a simple experiment.

When van Helmont did was to plant a young willow tree weighing 5 1bs in 200 1bs of soil inside a pot. He covered the pot so that no dust can settle in it thereby increase its weigh, and left just enough opening to water it when necessary. After 5 years, he weighed the plant and found that it weighed 199 1bs. He then dried the soil and weighed it again and found that it weighed 199 1bs. It has lost about 1 1b. He noted that he did not weigh the leaves hat were shed fro the plant for 4 years.

He concluded that the 164 1bs of wood, bark and root had arisen from the water alone and that plants were not soil-eaters. Although Van Helmont conclusion would later be proved wrong, he did show that plants are not soil eaters. His careful measurements also set the stage for similar studies of how plants grow.

Near the same time, other scientists were studying combustion. One of these people, Joseph Priestly showed from his studies that combustion somehow "injured" the air. If a candle were burned in a closed container, it would go out. If a mouse were then put in the container, the mouse would die. He later reported in 1771, that he had accidentally hit upon a method of restoring air which had been injured by the burning of candles.

What he did was to put a plant under the container where the candle was burned. He found that after some time, the air got restored and candles could once again turn in them, and mouse breathes in them.

Today, we explain Priestley's results by saying that plants use CO_2 produced by combustion or exhaled by animals and that animals inhale and use the O_2 released by plants.

Priestley's experiments offered the first logical explanation of how air remained "pure" and able to support a mouse despite the burning of candles and the breathing of animals. Although he did not realize it. Priestley's experiments were the first demonstration that plants produce oxygen. Nor did Priestly realize that light was necessary for photosynthesis.

A serious problem appeared, others could not repeat Priestley's work, nor could Priestly himself repeat his experiments. **(He had probably moved the experimental apparatus to a dark part of his lab).** Seven years later, a Dutch Physician, Jean Ingenhousz confirmed Priestley's work and made an important addition by showing that light is necessary for plants to release oxygen **(although, like Priestly, he know nothing about oxygen at the time and explained it in other terms).** Ingenhousz reported that plants in the dark "contaminate the air" and make it "harmful to animals". He: also made a bold and accurate statement "The sun by itself has no power to mend air without the concurrence of plants". Based on his experiments, he published a book in which he reported that only the green parts *of* a plant could photosynthesize and that plant too "injure" air when kept in darkness. Ingenhousz must have been alarmed by his findings, because he recommended that plants be removed from houses at night to avoid poisoning the occupants.

In 1872, a Swiss preacher and part time scientist named Jean Senebier showed that photosynthesis depended on a particular kind of gas, which he called fixed air, **(and we call CO_2).** Senebier also claimed that this air (CO_2) produced by animals and plants in darkness-stimulated production of purified air (O_2) by plants in light.

Thus by the late 1700s, biologists know that at least two gases participate in photosynthesis. Work done by Lavoisier and other showed that these gases were CO_2 and O_2. Ingenhousz adapted the ideas of Lavoisier and suggested that plants do not just exchange "good air" for "bad air" rather; he suggested that plants absorb carbon from carbon dioxide. "Throwing out at the time the oxygen alone and keeping the carbon to itself as nourishment." Ingenhousz's work was extended in 1804 by the Swiss botanist and physician Nicholas de Saussure, who noted that approximately equal volumes of CO_2 and O_2 are exchanged during photosynthesis. He added the final component of the overall photosynthesis reaction when he showed that photosynthesis requires water.

$$\begin{array}{c}\text{Carbon dioxide + water + light}\\ \downarrow \\ \text{Organic material + oxygen}\end{array}$$

By this time, many botanists were studying photosynthesis. Among the most clever was T.W. Engelmann, who is 1883 designed an experiment that of water containing an oxygen requiring bacterium and used a prism to illuminate different parts of the chloroplast with different colours of light. When Engelmann viewed the **spirogyra** through a microscope, he saw that the bacteria clustered around parts of the chloroplast illuminated by red and blue light. He concluded that red and blue light are most effective for producing oxygen during photosynthesis.

Other biologists began to follow up Ingelhousz's findings that light was required for the release of O_2. Julius Sachs reported that chlorophyll, the photosynthesis pigment occurs in chloroplast and that photosynthesis forms carbohydrates only in light. This Sachs revised the overall reaction of photosynthesis as

$$\begin{array}{l}nCO_2 + nH_2O + \text{light}\\ \quad\Big\downarrow \quad \text{Chlorophyll}\\ (CH_2O)n + nO_2\end{array}$$

In this reaction CH_2O is an abbreviation for starch or other carbohydrates. Further research showed that Sachs conclusion was correct. There is no known exception to his linking of chlorophyll with oxygen production.

By the turn of the twentieth century, most biologists accepted Ingenhousz's suggestion that the oxygen released during photosynthesis came from carbon dioxide. Others however questioned this assumption. In the 1920's a Stanford University graduate student named C.B. Van Niel began a study that would resolve this question and which became a milestone in biological research. Van Niel studied a photosynthesis bacterium that uses H_2S as an electron source and deposits sulphur as a by-product. Photosynthesis in these bacteria occurred as follows:

$$CO_2 + 2H_2S \longrightarrow \text{light} \longrightarrow CH_2O + H_2O + 2S$$

Van Niel's work did not attract much attention until he made a bold extrapolation, he asserted that the oxygen released during photosynthesis came from water not carbon dioxide. His reasoning was based on analogies between the roles of H_2S and H_2O and of 0_2 and sulphur.

Sulphur bacteria

$$CO_2 + 2H_2S \text{———} \text{light} \longrightarrow CH_2O + H_2O + 2S$$

General equation

$$CO_2 + 2H_2x \text{———} \text{light} \longrightarrow H_2O \quad H_2O + 2X$$

Green Plants

$$CO_2 + 2H_2G \text{———} \text{light} \longrightarrow CH_2O + H_2O + O_2$$

Van Niel's conclusion that O_2 released by plants comes from water rather than CO_2 was tested in 1941 by Samuel Ruben and Martin Kamen, who exposed cultures of chlorella (a green algae) to H_2O labeled with $^{18}O_2$, a non-radio active isotope of oxygen hat could detect with a mass spectrometer. Ruben and Kamen reasoned that if oxygen released during photosynthesis came from water, then the oxygen would be tagged with $^{18}O_2$. Conversely, if the oxygen were derived from carbon dioxide, it would not be labeled with $^{18}O_2$. Their results were striking, the oxygen, not the carbohydrates, were labeled with $^{18}O_2$.

$$CO_2 + 2H_2\,{}^{18}O_2 \text{——} \text{light} \longrightarrow CH_2O + H_2O + {}^{18}O_2$$

These results confirmed Van Niel's claim that oxygen released during photosynthesis comes from water not carbon dioxide.

Further evidence for this conclusion was provided by Robin hill and his coworkers, who discovered that isolated chloroplast, would release O_2 in the absence of CO_2 if given a suitable election acceptor for the electrons removed from water. This light driven splitting of water in the absence of CO_2 became known as the **Hill reaction** and showed that:

1. Whole cells are unnecessary for some of the reactions of photosynthesis
2. The light-driven release of O_2 during photosynthesis is not linked directly to the fixation of CO_2.

In 1951, botanists discovered that the electron acceptor in chloroplasts is NADP, a co-enzyme that can accept electrons. Later studies showed that

NADP reduced during photosynthesis was reduced to CO_2 during photosynthesis. Similarly, the reduction of NADP is driven by light.

SELF ASSESSMENT EXERCISE 1

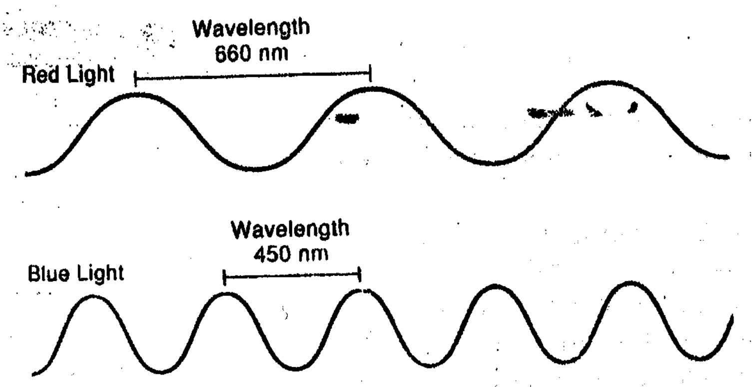
1a. Name the first scientist to carry out a study related to photosynthesis.
b. Which scientists implicated light in photosynthesis?
c. Which scientists introduced the chlorophyll factor in photosynthesis?

2. Summarize the findings of these earlier scientists as it relates to photosynthesis.

3.2 The Nature of Light

An understanding of the nature of light will enable us understand photosynthesis. It is for this reason that you will spend the next 30 minutes or more reading about light and the nature of light. Light is the part of the electromagnetic spectrum having wavelengths visible to the human eye. Virtually all life depends on light. Our understanding of light began about 300 years ago when Isaac Newton showed that White light that passed through a prism, droplet of water, or soap bubble would separate into a band of colours that if passed through another prism, could be recombined to form white light. Based on that experiment, Newton proposed that white light is actually a spectrum of colours ranging from violet to red.

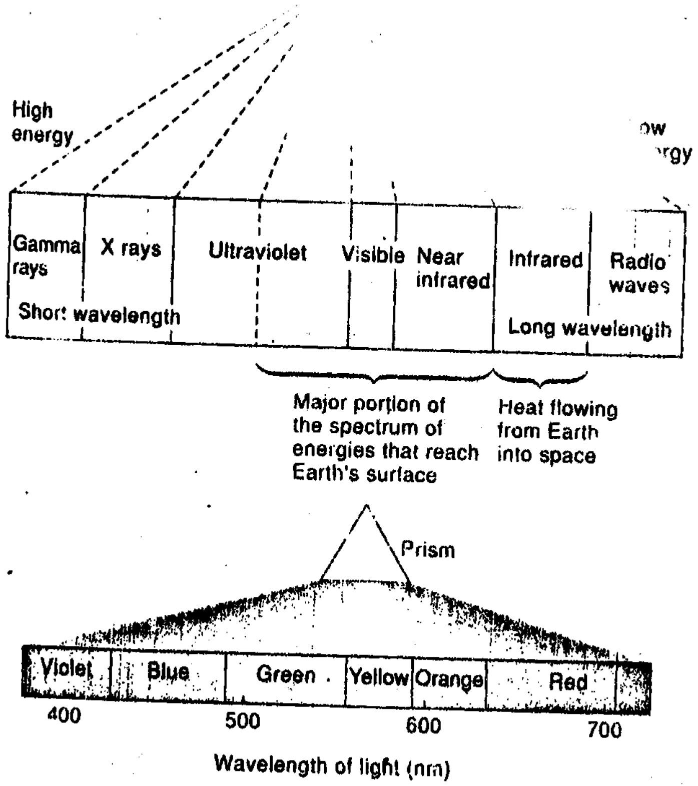
(Fig 11.1).



Properties of light (a) The wave nature of light (b) Visible light a small part of the electromagnetic spectrum. Visible light consists of a rainbow of colors ranging from violet to red light. Based on that experiment. Newton proposed that white light is actually a spectrum of colors ranging from violet to red. (fig 7.4b). two hundred years later, in the 1860s, a Scottish mathematician named James Maxwell showed that the visible light that Newton separated into a spectrum of colors is only a small part of a much larger spectrum of radiation (fig. 11.1 b)

Two hundred years later, in the 1860s, a Scottish Mathematician named James Maxwell showed that the visible light that Newton separated into a spectrum of colours is only a small part of a much larger spectrum of radiation.

(Fig 11.lb).



In 1905, Einstein linked the ideas of Newton and Maxwell by proposing that light consists of packets of energy called **photons.** The intensity **(i.e. brightness)** of light depends on the number of photons (i.e. the amount of energy) absorbed per unit of time. Each photon carries a fixed amount of energy that is determined by how the photon vibrates: the slower the vibration, the less energy carried by the photon. The distance moved by the photon during a complete vibration is referred to as the photon's **wavelength.** (fig 11.1a). Stated another way, the wavelength is the distance between vibrational crests of a photon. The wavelengths of visible light are measured in nanometers (nm) or billionth (10^{-9}) of a metre.

We perceive the different wavelength, as different colours. For example, violet light has a wavelength of about 400nm, which is about one-fortieth the thickness of the page. The energy of a photon is a **quantu**m and is inversely proportional to the wavelength of the light. The longer the wavelength (i.e. the longer the distance traveled during a vibration), the less energy per photon.

Table 11.1

Radiant Energies of Different Wavelengths of Light

Wavelength (nm)	Color	Energy (joules μmol^{-1})
100		0.399
400		0.299
450	violet	0.277
500	green	0.239
600	orange	0.199
700	red	0.171

Table 11.2

Photosynthetic Characteristics of C_3^2 C_4^2 and CAM Plants

Characteristic	**C_1**	**C_2**	**CAM**
Leaf anatomy vacuoles	Bundle wheat without dense arrangement of chloroplasts	Bundle sheath cells with dense arrangement of chloroplasts, no distinctive palisade cells	Large
Primary carboxylase carboxylating	Robulose bisphosphate carboxylase/oxygenase	PEP carboxylase	PEP at night
Grans of water required to produce 1g of dry matter	4050 to 95-	250 to 350	50 to 55
Required Sodium as micronutrient	No	Yes	Probably
Minimum atmosphere Co_2 concentration required for	0.0196-0.07%	0%-0.01%	0%-0.05%

photosynthesis			
Photorespiration detectable	Yes	Only in isolated bundle sheath cells	No
Optimum 25^0C temperature for photosynthesis	15” – 25”C	$30^0 – 40^0C$	About
Approximate fons low and of dry matter produced per hectare per year.	20 – 25	35 – 40	Usually variable

Sunlight consists of about 4% ultraviolet radiation. 52% infrared radiation and 44% visible light. Each of these kinds of light has different energy and affects organisms differently.

Ultraviolet radiation (UV) contains too much energy for most biological systems. Indeed, its light energy photons often drive electrons from molecules, this explaining why UV is also called **ionizing radiation. UV** breaks weak bonds and causes sunburn. It is absorbed by O_2, ozone (O_3), and glass. You won't get a fan by sitting in front of a glass window.

Infrared radiation (R) does not contain enough energy per photon to be a useful to living systems. Cells absorb IR radiation but this energy is insufficient to excite electrons. Consequently, most of the energy of IR is converted immediately to heat. IR is absorbed by water and carbon dioxide, but goes through glass thus, although you won't tan in front of a window, you will warm up.

Visible light contains just the right amount of energy for biological reactions such as photosynthesis. To have an effect however, light must first be absorbed. Light is absorbed by pigments.

SELF ASSESSMENT EXERCISE 2

1. Briefly describe the nature of light
2. What are the constituents of sunlight?

4.0 CONCLUSION

Scientists started many years ago to unravel the mystery of how plants obtain their food. The simple/basic experiment started by Jan-Baptista van Helmont in 1648 led to a series of experiments that discovered that plants manufacture food in their leaves by tapping from the abundant energy resident in sunlight using water and carbon dioxide, and releasing oxygen in the process. A study of sunlight also revealed that not all part of sunlight is involved in photosynthesis. It is rather the blue and red colours of light that are most effective in photosynthesis.

5.0 SUMMARY

Botanists have studied photosynthesis for several years. The pioneering efforts of Jan-Baptista van Helmont led to the understanding that plants are not soil eaters. This encouraged other scientists like Joseph Priestley, Jean Senebier, Ingenhousz and many more. The work of these scientists let to the understanding that, photosynthesis uses carbon dioxide, requires light and water and releases oxygen light for photosynthesis in plants is absorbed by chlorophyll, and that oxygen released during photosynthesis comes from water.

An understanding of the nature of light is important in trying to understand photosynthesis. Light is the part of the electromagnetic spectrum having wavelength visible to the human eye. Isaac Newton pioneered efforts towards understanding the nature of light. Later studies let to a knowledge that light consists of packets of energy called photons.

Sunlight consists of 4% ultraviolet radiation. 52% infrared radiation and 44% visible light.

Light occurs in a spectrum of colour Red and blue are the most effective for photosynthesis.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1a. Jan-Baptista van Helmont
b. Jan-Ingenhousz
c. Julius Sachs

2i. Photosynthesis uses CO_2
ii. Requires light and water and releases O_2
iii. Light for photosynthesis is absorbed by chlorophyll
iv. O_2 released during photosynthesis comes from water

ANSWER TO SELF ASSESSMENT EXERCISE 2

1. Virtually all of life depends on light which powers photosynthesis. Light moves in waves, and its energy is contained in packets called photons. The energy of a photon is inversely proportional to the wavelength of the light, the longer the wavelength, the less energy per photon. Sunlight consists of a spectrum of colours of light. Red light and blue light are the most effective for photosynthesis.

2. Sunlight consists of about 4% ultraviolet radiation, 52% infrared radiation, and 44% visible light.

6.0 TUTOR-MARKED ASSIGNMENT

These will be given at the end of the next two units, since what is discussed here are just some basic concept

7.0 REFERENCES/FURTHER READING

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UNIT 2 PHOTOSYNTHETIC PIGMENTS

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1.0 INTRODUCTION

Photosynthetic organism use light energy to make organic compounds from inorganic compounds such as water and carbon dioxide. Their ability to package light energy into chemical energy soon supported almost all other forms of life on the planet. Moreover, these autotrophs radically changed the planet and its remaining organisms by decreasing the atmospheric concentrations of carbon dioxide, diminishing the green house effect, and filling of the atmosphere with a waste product that some of the other organisms ultimately found essential for life oxygen. All of the oxygen in air that we breath has been cycled through plants via photosynthesis. But all these can only be possible if light is absorbed.

2.0 OBJECTIVES

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

- identify the pigments that are available in green plants
- discuss the properties of photosynthesis
- identify the reaction centers in chlorophyll
- distinguish between chemiosmosis in mitochondria and chloroplast.

3.0 MAIN CONTENT

3.1 Pigments

Light striking an object is either reflected, transmitted, or absorbed. Only light that is absorbed have an effect. Light that is absorbed by molecules called **pigment,** which are coloured because they transmit particular colours of light. Black pigments absorb all wavelengths of light, while white pigments absorb no wavelength of light.

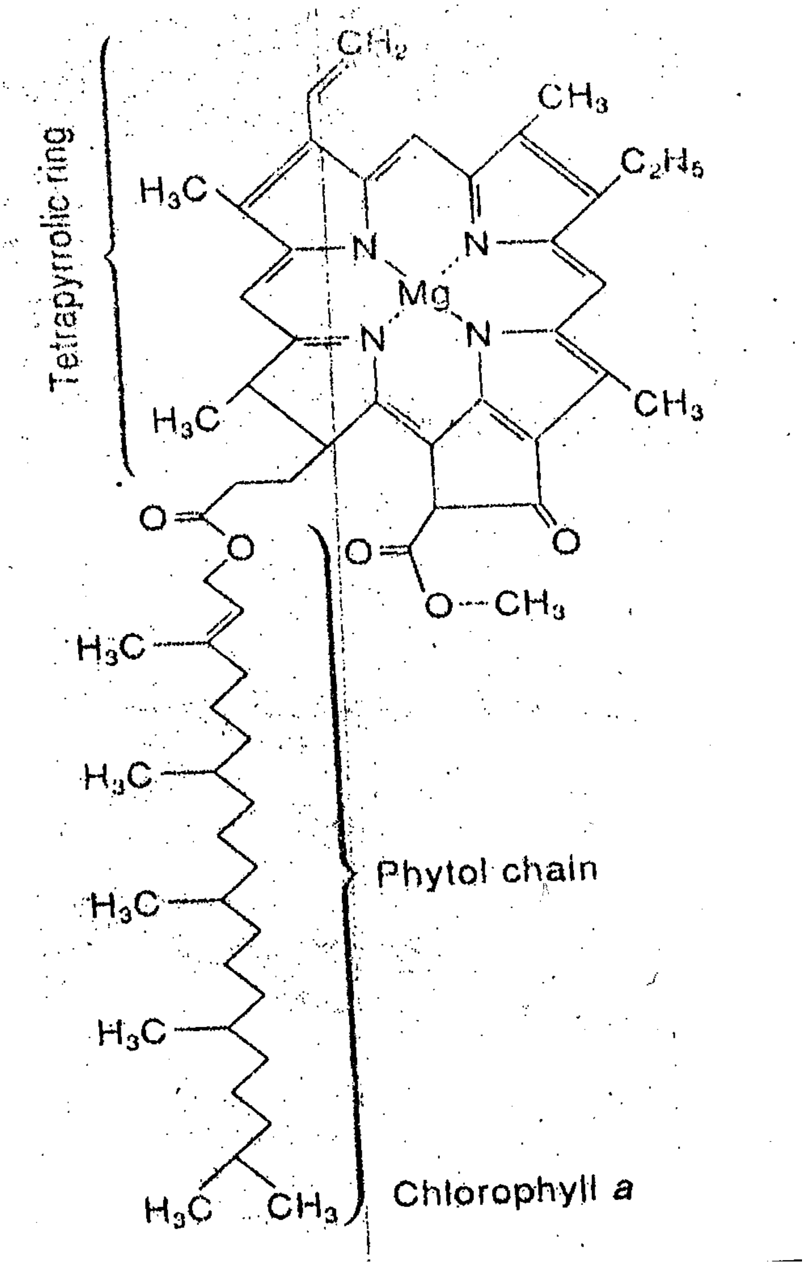
3.1.1 Pigments in Plants

Chlorophylls are fat soluble pigments that occur in plants, algae and all but one primitive group of photosynthetic bacteria. Unlike the colour or haemoglobin, which is insignificant for the molecule's function as an oxygen carrier, the colour of chlorophyll is significant, chlorophyll absorb maximally at wavelengths of 400-500nm **(Violet-blue)** and 600-700nm **(Orange red)**.
(fig. 12.2)

The synthesis of chlorophyll and of several other pigments in plants is stimulated by light, which explains why plants grown in the dark, (i.e. etiolated plants) contain no chlorophyll. Similarly, the light stimulated synthesis of anthocyanin, another plant pigment, explains why apples are always redder on the sunny side of an apple three.

There are several types of chlorophyll, the most important of which is **chlorophyll**, the primary photosynthetic pigment. Chlorophyll a **($C_{55}H_{72}O_5N_4Mg$)** is a grass-green pigment whose structure includes an atom of magnesium (Mg). (Fig. 12.1)

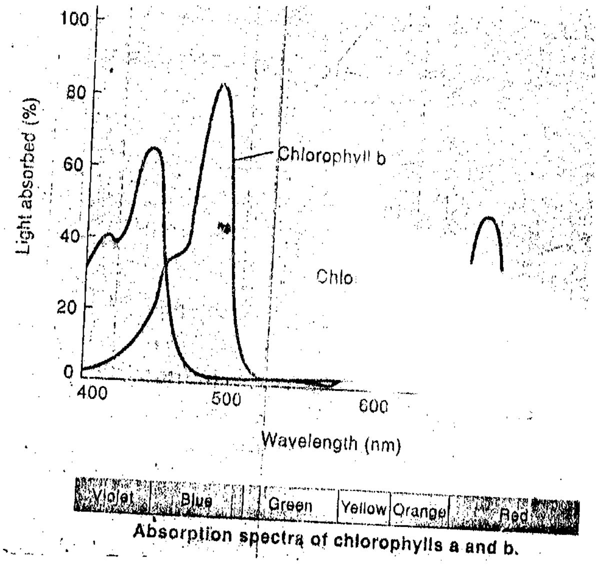
(Fig. 12.1)



Chlorophyll a, the primary pigment of photosynthesis

It occurs in all photosynthetic organism except photosynthetic bacteria, and absorbs maximally at 430 and 662nm.

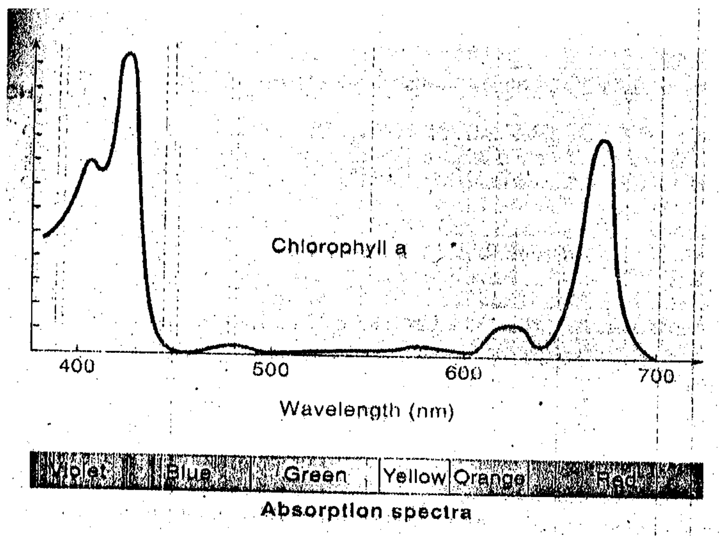
(Fig. 12.3)



The absorption of light by chlorophyll a and b. Chlorophyll absorb maximally at wavelength of 400-500nm (violet-blue) and 600-700)nm (orange-red).

The relationship of light absorption by chlorophyll a versus wavelength is shown in

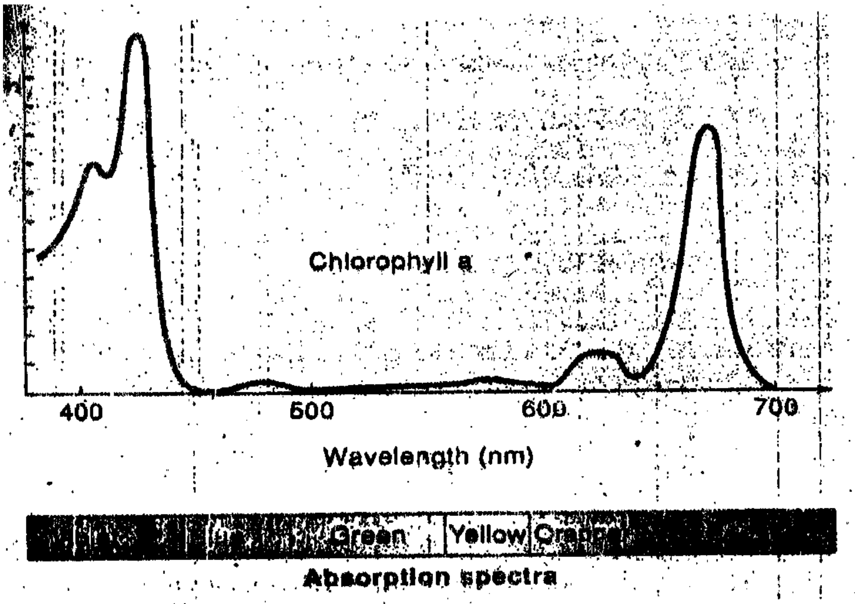
(Fig. 12.4)



The absorption spectrum of chlorophyll a vs wavelength. Chlorophyll a absorbs maximally at 410nm and 662nm and is the primary photosynthesis pigment.

This absorption spectrum shows that chlorophyll a strongly absorbs all visible light accept green light, it reflects and transmits green light, and therefore appears green. This absorption spectrum for chlorophyll a closely matches the graph showing how photosynthesis varies with different wavelength of light.

(Fig. 12.5)



The rate of photosynthesis in different wavelengths of light is similar to the ability of chlorophyll a to absorb those wavelengths. The similarity of the action and absorption spectrum of chlorophyll a suggest that light absorbed by chlorophyll a drives photosynthesis.

This so called **action spectrum** shows that the pattern of photosynthesis closely follows that of chlorophyll a suggesting that chlorophyll a is the primary pigment in photosynthesis. However, the absorptive spectrum of chlorophyll a does not perfectly match the action spectrum of photosynthesis. Therefore, we conclude that other pigments must be involved in photosynthesis. Those pigments are called accessory pigments.

3.1.2 Accessory Pigments

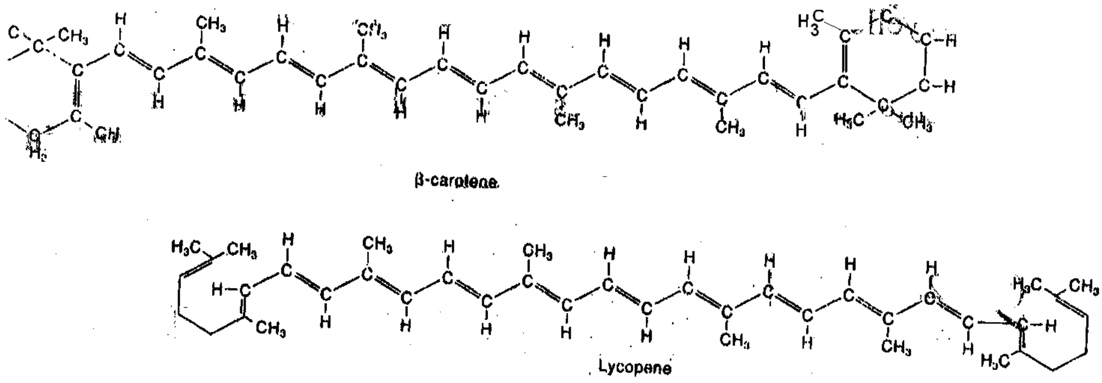
Plant also contain other pigments. Those pigments extend the range of light useful for photosynthesis by absorbing photons not absorbed by chlorophyll a.

The most common of these accessory pigments in plants are chlorophyll b and carotenoids.

Chlorophyll b ($C_{55}H_{70}O_6N_4Mg$): This is a bluish-green pigment that absorbs maximally at 453 and 642nm. It occurs in all plants, green algae, and some prokaryotes. Plants usually contain about half as much chlorophyll b as chlorophyll a.

Carotenoids: These are accessory pigments that occur in all photosynthetic organisms. They occur in all photosynthetic organisms. They contain forty carbons, are fat-soluble and often contain no oxygen.

(Fig. 12.5)



Renoids (a) Beta-carotene, a reddish-yellow carororenoid, (b) Lyeopene, a carorenoid that colors tomatoes. Beta carotene and one each have the empirical formula of $C_{40}H_{56}$

Carotenoids absorb maximally at wavelength between 460 and 550nm, therefore they are red, orange and yellow. Carotenoids are chemically unrelated to chlorophylls and consist of carbon rings linked by long carbon chains having alternating single and double bonds.

Like all accessory pigments such as chlorophyll b, carotenoids extend the range of photosynthesis by absorbing light that is not absorbed by chlorophyll a. Carotenoids also protect plants against photo-oxidation, which occurs when excited chlorophyll transforms oxygen into light energy radicals. These radicals can attract hydrogen from nearby molecules, thereby destroying the molecules and killing the cells. Mutants that lack carotenoid are susceptible to such radicals, which explains why they are bleach-white when grown in light, and soon die. Many herbicides kill plants by blocking the synthesis of carotenoids, thereby causing the plant to photo-oxidize itself.

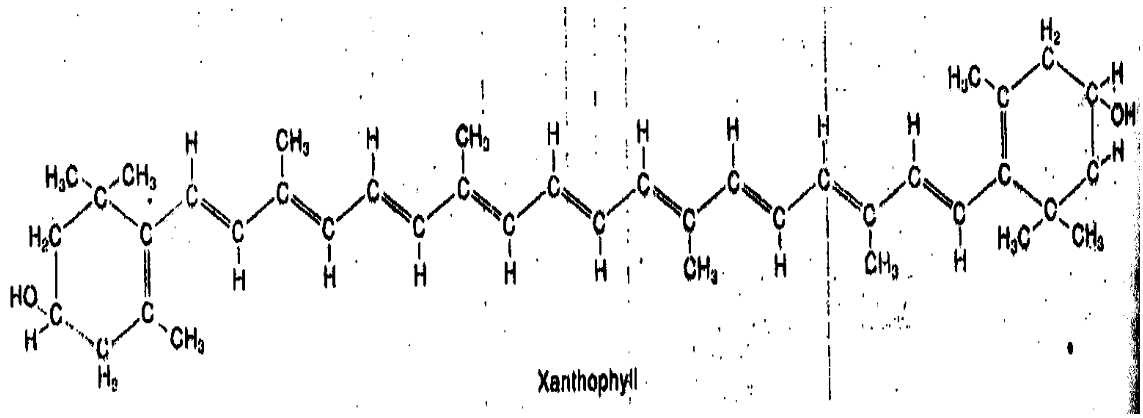
The most common carotenoid is beta-carotene a reddish-yellow pigment consisting of two six-carbon rings connected by an eighteen-carbon chain.

(Fig.12.5). Beta-carotene absorbs maximally at wavelength between 400 and 500nm. When split in half, beta-carotene becomes two molecules of vitamin A which is a precursor of retinal, a pigment essential for human vision. Carotenoids occur throughout the plant kingdom and produce the colours of tomatoes, carrots, squash, bananas, avocados and some colourful leaves.

Unlike chlorophyll, carotenoids also occur in animals. Animals cannot make carotenoids, but they can metabolize and use carotenoids from plants. For example, carotenoids colour egg-yolks, insect wings, the black ink released by squids, and the bodies of some fish and amphibians. The dazzling array of colours of carotenoids includes blue, green, red, violet, gray, chocolate and black; they result largely from proteins that are attached to the carotenoids. When heated, this protein breaks off and frees the carotenoids (this accounts for the yellow pigment released when e boil carrot.

Oxidizing carotenes produces Xanthophylls, which are red and yellow pigments in tomatoes, carrots, leaves, algae (e. g Fucoxanthin in brown algae), and photo-autotrophic bacteria.

(Fig 12.6).

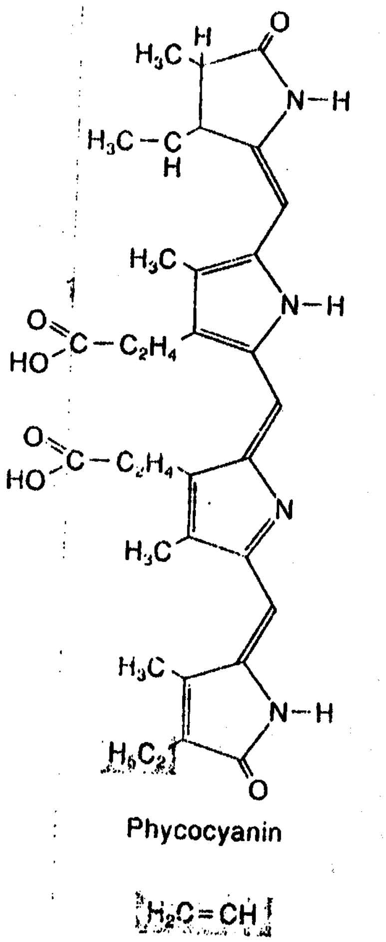


Xanthophyll. Xanthophyll are abundant in carrot, leaves and many algae.

Xanthophylls are less efficient at transferring energy during photosynthesis than beta-carotene.

Other accessory pigments include chlorophylls c and d, phycoerythrin, a red pigment and phycocyanin, a blue pigment.

(Fig. 12.7)



Phycoeyania and phycoerythrin are accessory pigments in red algae and cyanobacteria. Phycoerythrin is obtained by exchanging the highlighted group.

Different forms of phycoerythrin and phycocynin occur in red algae and cyanobacteria.

SELF ASSESSMENT EXERCISE 1

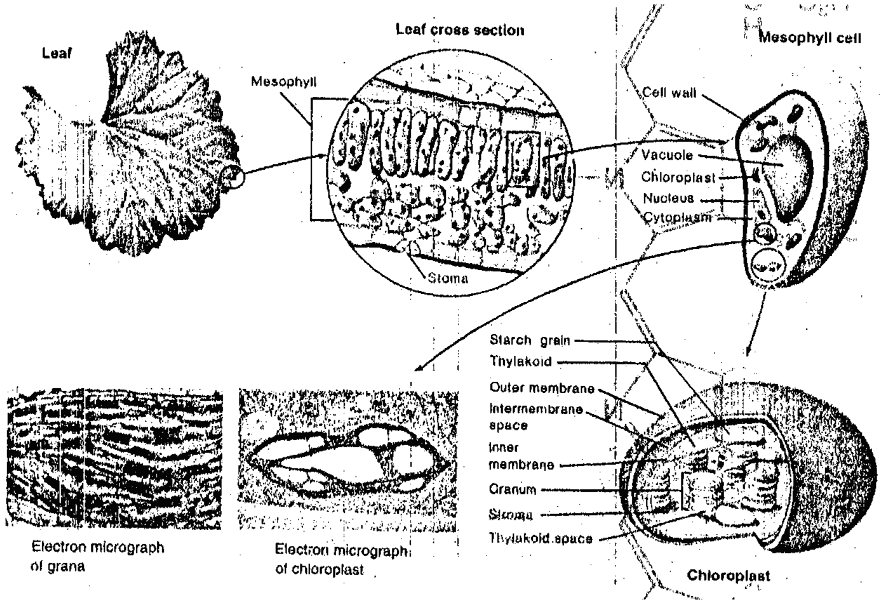
1. What absorbs light in plants?
2. What is the primary pigment for photosynthesis?
3. Name three accessory pigments?
4. What roles do accessory pigments play during photosynthesis?

3.2 Chloroplasts

The green colour of leaves is due to solar chemical factories called **Chloroplasts,** the site of photosynthesis in eukaryotes.

(Fig. 12.8)

Other accessory pigments include chlorophylls c and d, phycoerythrin, a red pigment and phycocyanin, a blue pigment



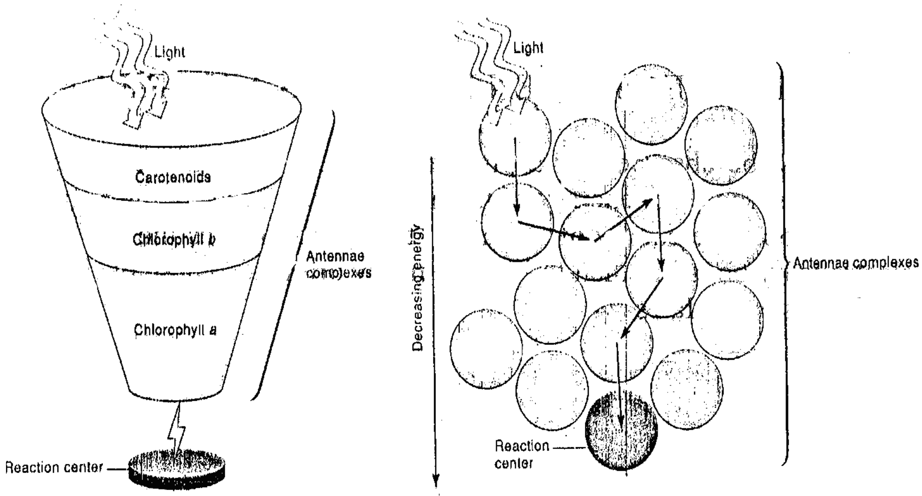
In plants, photosynthesis occurs by in chloroplasts. Light is absorbed and converted to chemical energy in thylaloid and grana; this chemical energy is then used in the stroma to make sugars.

Chloroplasts in plants are usually shaped like foot-balls. Most photosynthesic cells have 40-200 chloroplasts which amounts to about 500,000 chloroplasts per square millimeter of a leaf area. To help you put the size of a chloroplast in perspective, consider that it would take about 2,000 chloroplasts to stretch across your thumbnail.

3.2.1 Complexes of Pigments in Chloroplasts

In the early 1950s Robert Emerson at the University of Illinois made an unusual observation, he noted that red light having wavelength exceeding 690nm was ineffective for photosynthesis despite the fact that it was absorbed by chlorophyll. However, when this light was supplemented by light having a shorter wavelength photosynthesis occurred faster than it did in either light alone. This effect become known as the **Emerson enhancement effect** and it showed that plants contain two light-harvesting system.

(Fig. 12.9)



The light harvesting system in chloroplasts functions like a funnel; it collects photons and passes their energy to the reaction center.

In all but the most primitive bacteria, light is captured by a network of chloroplast pigments arranged in aggregates on thylakoids. These aggregates, called **antennae complexes** are anchored in a protein matrix and consist of proteins about three hundred molecules of chlorophyll a, and about fifty molecules of carotenoids and other accessory pigments that gather light. Energy absorbed by antennae complexes flow energetically "downhill" to a special pair of energy-collecting molecules of chlorophyll a and associated proteins called a **reaction** center fig. 12.9. Although reaction centers comprise less than 1% of the chlorophyll in plants, chlorophyll a in the **reaction center** is the electron acceptor that participates directly in photosynthesis, all other photosynthetic pigments function as antennae.

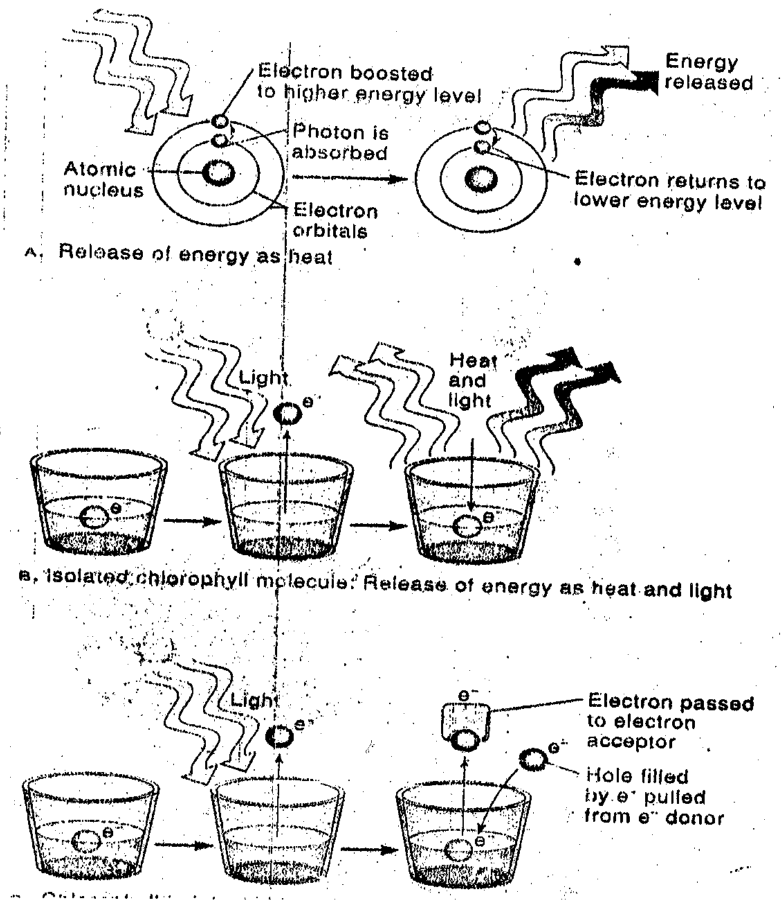
There are two kinds of reaction center chlorophylls, each having light harvesters in their antennae. One of these chlorophylls absorbs maximally at 700nm and is called p700 (for pigment 700) (fig. 7.16). The complex containing p700nm and is called **photosystem I** and consists of eleven polypeptides, six of which are coded in the nucleus, and five of which are coded in the chloroplast.

The chlorophyll a molecule in photosystem Ii resonates from energy transmitted by about one hundred molecules of chlorophyll a and b bound to nuclear-coded proteins in the antennae. Three peripheral plypeptieds bind calcium and chlorine which explain why these nutrients are essential for photosynthesis. The chlorophyll a molecule in photo system II is identical to that of photo system I, but it is associated with different proteins, in photo system I, the reaction center is bound to a large protein **(Molecular weight 110,000).** While that in photosystem II is bound to a smaller protein **(Molecular weight 47,000)**. The associated protein in photo system II shifts the maximal absorption to about 680nm. Consequently, the reaction center in photo system II is called **P680** (fig 12.11). **P680** resonates from energy transmitted by about 250 molecules of chlorophyll a and b.

3.2.2 What Happens when Pigments absorb Light?

Light must be absorbed by a pigment before it can have an effect. When light is absorbed, the energy of its photons is captured by the pigment and is used to boost the energy of electrons, that is, it changes the configuration of electrons by boosting then to higher energy orbitals. These excited electrons can have several fates.

(Fig. 12.10)



Fates of energy in energized electrons of chlorophyll.

(a) Release of energy as heat.
(b) Isolated chlorophyll: electrons that had been raised fall to original energylevel; light energy absorbed is released as heat and light (fluorescence).
(c) Intact chloroplast: energy passes to electron acceptors.

- The energy can be released as heat **(i.e. Molecular motion, fig 7.15a).** This is what is happening to the electrons in the pigment **(i.e the link)** that you are looking at now.
- That energy can be released as an after glow of light via a process called fluorescence. Light released during fluorescence has a longer wavelength (and therefore less energy) than the light that excited the pigment. Chlorophyll fluoresces deep red. Isolated chlorophyll fluoresces because no molecules are nearby to accept the energized electron.
- The energy can be passed to a neigbouring molecule. Chlorophyll in thylakoids is surrounded by other molecules that trap the energy of the excited electrons.

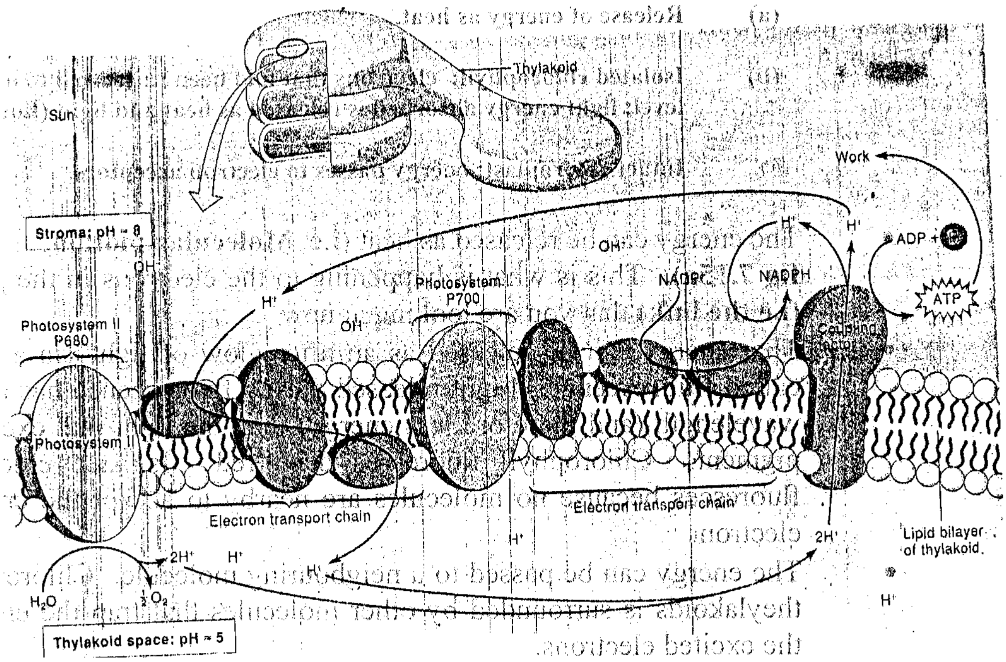
The light driven reactions of photosynthesis, which pass the energy of photons to other molecules, occur on photosynthetic membranes. In plants and algae. These photosynthetic membranes are enclosed in chloroplast. In these organisms, chlorophyll is on membranes, in vesicles, or as in cyanobacteria in parallel stacks of flattened sacs.

3.2.3 Photophosphorylation: Chemiosmosis in Chloroplasts

Photons absorbed by pigments energize electrons. Plants pass that energy through a series of molecules called an Electron Transport Chain. This transfer of electrons involves reduction and oxidation or redox, reactions. The electron donor is oxidized as the electron acceptor is reduced. For electrons to flow down this chain each receiver must attract the electrons more strongly than does the donor.

The potential energy of the electrons drops at each step of the electron transport chain plants couple this exergonic flow of electrons to an endergonic reaction that makes ATP. This light-driven production of ATP from electron transport is called phosphorylation and depends upon a proton gradient.

(Fig. 12.11)



The light-driven transport of electrons during photocynthesis creates a proton gradient across the thylakoid membrane. This proton gradient drives the formation of ATP and reduced NADP$^+$

Photons captured by pigments excite electrons, which are shuttled along carriers embedded in the thylakoid membrane. When these electrons reach transmembrane H+ - pumps, their arrival induces transport of H+ across the membrane, thereby creating the proton gradient that drives the synthesis of ATP.

Chemiosmosis in chloroplasts **(Photophossphorylation resemble chemiosmosis in mitochondria (oxidative phosphorylation). (We studied this in Unit 10)** their areas of resemblance are as follows:

1. Protons are pumped through a series of carriers that are progressively more electronegative.
2. The free energy released by electron transport generates and maintains a proton gradient across a membrane.

However, there are some difference, for example, in mitochondria energized electron moving through the electron transport chain are extracted by the oxidation for food in chloroplasts, light energizes the electrons and no food is necessary.

In mitochondria, the inner membrane pumps protons from the matrix out to the intermembrane space, this is the reservoir of protons that powers the synthesis of ATP. In chloroplasts, electron carriers in the thylakoid pump protons from the stroma into the lumen **(i.e, thylakoid space)**, which is the proton reservoir.

This light-driven pumping of protons into the lumen decreases the pH there to about 5 while the pH of the stroma increases to 8 **(i.e, a thousand fold difference in the concentration of protons)** light is required to generate this proton gradient, the difference in pH across the thylakoid membrane disappears quickly in the dark. The pH gradient is discharged during the synthesis of ATP as protons flow into the stroma across channels whose catalytic heads protrude like knobs into the stroma (fig 7.16). Coupling factor proteins in these channels include ATP-synthase, an enzyme that harnesses the flow of protons to make ATP. The ATP produced by the ATP synthase complexes is released into the stroma, where it is used to make carbohydrates.

SELF ASSESSMENT EXERCISE 2

1. Describe the structure of chloroplasts
2. How many reaction centers are in chlorophyll, what are they called?
3. What happens when pigment absorb light?
4. What can happen to the electrons
5. What process occurs both during respiration and photosynthesis, and in which organs.
6. Name one similarity between them
7. Name one difference between them

4.0 CONCLUSION

Pigments are an essential component or factor in photosynthesis. The major photosynthetic pigment is chlorophyll, which is a fat soluble pigment. The primary one being chlorophyll a. Other accessory pigments which help the photosynthetic processes are chlorophyll b and carotenoid. Other pigments present in plant cells are xanthophylls, chlorophyll c and d, phycoerythrin, and phycocyanin.

Chloroplast are the solar chemical factories in green leaf and the site of all photoshynthesis. Like in mitochondria during respiration, chemiosmosis takes place in the chloroplast. The two processes are related, but also differ in some areas.

5.0 SUMMARY

Light is absorbed by pigments that are present in plants. Only light that is absorbed can have an effect. Chlorophyll a is the primary pigment for photosynthesis and occurs in all photosynthetic organisms except photosynthetic bacteria. Accessory pigments such as carotenoids and chlorophyll b absorb light that chlorophyll cannot absorb, thereby extending the range of light used for photosynthesis.

Photosynthesis is eukaryotes occurs only in chloroplasts, which consist of a gelationous matrix called **stroma and stacks of membranes (thylakoid)** called **grana.**

Aggregates of pigments in grana absorb light and funnel its energy to special pairs of chlorophyll and proteins called **reaction centers.**

The energy of the light energies electrons which are used to pump protons from the stroma into the thylakoid space. The resulting pH gradient is discharged during the synthesis of ATP as protons flow back into the stroma.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Pigments
2. Chlorophyll
3. Carotenoid, Chlorophyll b and chlorophyll c and d.
4. They absorb light that chlorophyll a cannot absorb thereby extending the range of light useful for photosynthesis.

ANSWER TO SELF ASSESSMENT EXERCISE 2

1. Chloroplasts are football shaped, surrounded by two membranes that enclose a gelatinous matrix-stroma. The stroma contain ribosomes, DNA and sugar in stroma are thylakoids which are stacked into grana. These contain chlorophyll
2. 2 kinds - P 700 - Photosystem I
   - P 680 - Photosystem II
3. The energy of the light (photon) is captured by the pigment and is used to boost the energy of the electrons.
4. Energy in the electron can be released as heat, as an after glow of light (fluorescence), and can be passed to a neighbouring molecule.
5. Chemiosmosis in mitochondria (respiration) and chloroplast (Photosynthesis)
6. Proton are pumped through a series of carriers that are progressively more electro magnetic in both system.

7. In mitochondria, energized electrons are extracted by the oxidation of food, while in chloroplast, they are energized by light (no food is necessary).

6.0 TUTOR-MARKED ASSIGNMENT

Distinguish between chemiosmosis in mitochondria and chloroplast.

7.0 REFERENCES/FURTHER READING

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UNIT 3 THE PHOTOSYNTHETIC PROCESS

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1.0 INTRODUCTION

Photosynthesis packages light into chemical bonds. It is estimated that each year, photosynthesis produces about 1.4 x 10^{14}kg of carbohydrates. **(This estimate means that enough sugar to fill trucks that will go from here to the moon and back fifty times is being produced** every **year).** Packaging light into carbohydrates involves two major reactions – Photochemical reactions and biochemical reactions.

The Photochemical reactions are the processes that convert light energy into chemical energy from where photosynthesis takes off. The biochemical reactions now use the products of the photochemical reactions to go into biosynthesis. In this Unit, you are going to learn how plants use the light energy they have attracted to produce carbohydrate. You will also learn that plants do this in two ways leading to the classification of plants as C_3 and C_4 plants.

2.0 OBJECTIVES

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

- name the two types of reactions involved in photosynthesis
- summaries the sequence of events at the photochemical reaction of photosynthesis
- explain the biochemical reaction
- name the product(s) of the photochemical and biochemical reactions of photosynthesis
- distinguish between C_3 and C_4 plants.

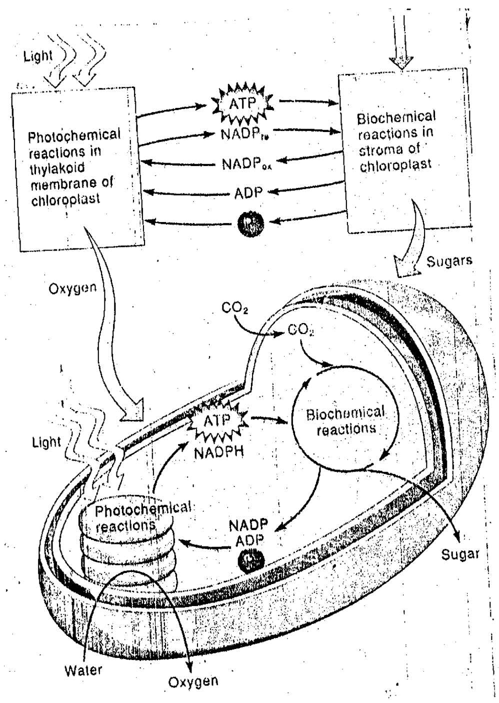
3.0 MAIN CONTENT

3.1 The Photochemical and Biochemical Reactions of Photosynthesis

Having studied some basic issues relating to photosynthesis namely it history and the nature of light; and having studied the pigments involved in photosynthesis, it is now time to study the interesting but complex subject. As you study this unit, you should remember to always refer to Units 11 and 12 to clear any doubts about any concepts.

In 1905, F. F. Blackman reported an interesting set of experiments showing that photosynthesis was more complex than most botanists' had realized. Blackman reported that in dim light, increasing the intensity of light increased the rate of photosynthesis, but temperature did not. Thus, these reactions were light-dependent but temperature-independent. However, in bright light, increasing the temperature increased the rate of photosynthesis, while further increase in light intensity did not. Thus, these reactions were temperature-dependent and light-independent.

(Fig. 13.1)



Photosynthesis consist of photochemical and biochemical reactions. The photochemical reactions convert light-energy to chemical energy ATP and NADPH. The biochemical reactions use the ATP and NADPH produced by the photochemical reactions to reduce CO2 to sugars. The photochemical reactions occurs on thylakoid membranes, whereas the biochemical reactions occur in the stroma.

Blackman's experiment provided the first evidence that photosynthesis is a two-stage process the light dependent photosynthesis reactions become known as the **photochemical or (Light) reactions** of photosynthesis; these reactions are insensitive to changes in temperature. The temperature – dependent reactions become known as the **biochemical (or dark) reactions** of photosynthesis because of their insensitive to light. However, these enzymatic reactions occur only in light – dark only means that light is not directly involved in the reactions **(It is important that you understand this now – these reactions do not occur at night).** Further studies showed that the photochemical reactions oxidize water, release oxygen, produce ATP and reduced $NADO^+$ that are used in the biochemical reactions, which reduce carbon dioxide to carbohydrate.

3.1.1 The Photochemical Reactions

Cycle Electron Flow

Photosynthetic prokaryotes use only cyclic photophosphorylation, a process geared to energy production rather than to biosynthesis. Photophosphorylation is relatively simple and involves only photo system I. **(Refer to Unit 12).** Electrons energized by light are recycled through the electron transport chain and return to the same reaction centre from which they originated. Electron carriers move the electrons only in the company of hydrogen ions. Which are transported across the membrane as the elections move to the next member of the chain. In the process the energy-releasing flow of electrons is coupled from ADP and Pi.

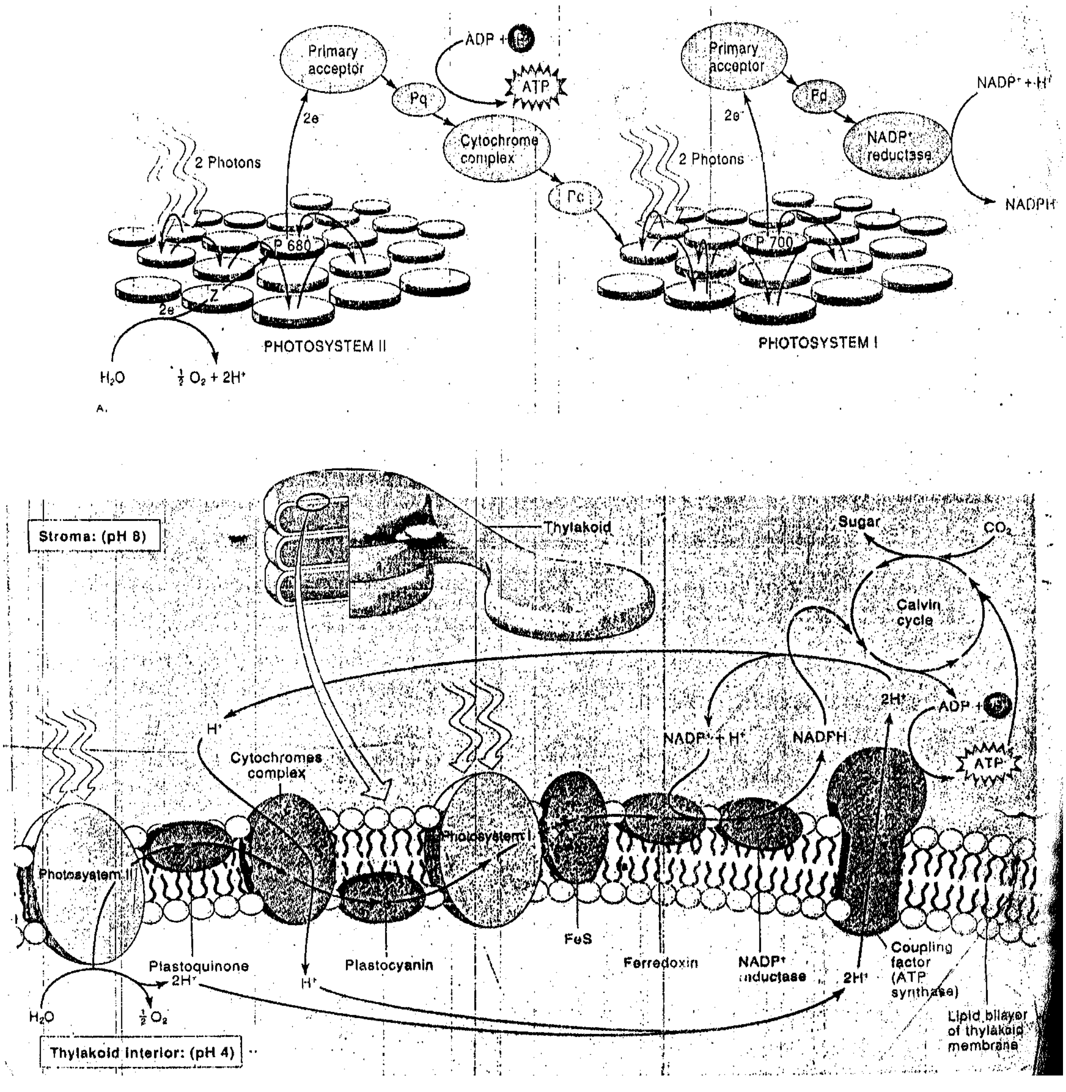
The coupling mechanism is chemiosmosis, as in mitochondria. At each step of the electron transport chain, electrons lose potential energy, finally returning to their ground-state energy in P700. Absorption of more light excites the reaction centre again, restarting the cycle. Electrons that return to P700 have only about half of the energy they had when they left the remainder of the energy is the photosynthesis pay-off.

Cyclic phosphorylation short-circuits -production reduced $NADP^+$ by shuttling the energized electrons from P700 to ferrodoxin and then to plastoguinone. As the electron again moves down the electron transport chain, ATP forms. These processes generate no oxygen or reduce $NADP^+$.

Noncyclic Electron Flow

Cyclic photophosphorylaton alone occurred for more than a billion years and is geared to energy production, not biosynthesis. It suffices for prokaryoler that use molecules such as H_2S as an electron source. However, plants strip electrons from water. This requires a huge change in biochemistry, because the voltage from one light-energized reaction centre of P700 doesn't have enough energy to strip electrons from water and give them to carbon dioxide. Plants overcome this problem by grafting onto tile bacterial system a second, more powerful photo system that enabled a linear noncyclic electron flow.

(Fig. 13.2)



(a) ***Summary of noncyclic flow of electrons. When photosystems I and II are illuminated, electrons flow from water to NADP' electrons ejected from P680 are replaced by electrons from water, and a by-product of this process is O2. The energized electrons from P680 flow through an electron transport chain to P700, generating an ATP in the process. Illumination of P700 energised the electrons actions: these electrons are used to reduce NADP'***

(b) ***Photosystems I and II are linked in series in the thylakoid membrane. Noncyclic flow of electrons produces ATP, reduced NADP' and O_2.***

These two pumps are connected in series, much as we use two batteries to increase the voltage in a flashlight. The second pump is photo system II, whose unique arrangement of pigments allow it to harvest shorter wavelength light. This new photo system acts first in what is now called the **Z** scheme, model for noncyclic flow of electrons (and energy) during the photochemical reactions of photosynthesis (See fig. 13.2). Noncyclic photophosphorylation occurs in green plants, algae, and photosynthetic bacteria, and involves two photosystem that:

1. Make ATP in the electron transport chain linking photo system I and II: and
2. Reduce NADP

Summary of the Photochemical Reactions

- The photochemical reactions of photosynthesis start at P680 and end at NADP these reactions are linear rather than cyclic, and produce ATP and NADPH. (While you are reading this summary, look at fig 7.19 and try to follow each stage for better understanding of how they occur).

- A photon hits the end of the reaction centre nearest the inner surface of the membrane, exciting an electron. This electron carries it energy to the other end of the reaction centre **(the end nearest the other surface of the membrane).**

- Three more photons cause other electrons to do the same thing. Thus, four photons strike P680 of photosystem II, which functions like a tiny capacitor by creating a separation of charge. Although the reaction centre captures 98% -99% of the photons that it absorbs, only about half of their energy is stored in the change separation, thus, photo system II is only about half as efficient as a battery.

- Like all energy rich substances, the excited electrons are unstable and release much of their energy as heat. The electrons ejected from P680 leave "holes" that are filled by electrons from Z protein, a manganese -containing protein that get it electron from water, release oxygen, and uses the electrons to replace those ejected by photons absorbed *by* the reaction centre. All these occur in less than one billionth (10^{-9}) of a second.

- Splitting two molecules of water releases a molecule of O_2 and few electrons, all that one. However, only one electron at a time can be accepted by P680. The electrons stripped from water are managed by manganese, whose stable oxidation states, ranging from $+^2$ to $+^7$ suit it ideally for its function as a charge accumulator. At saturating intensities of light, one molecule of oxygen is released per about 2,500 molecules of chlorophyll.

- Within a few trillionth of a second, the electrons ejected from P680 of photo system II reduce phaeophyton, a pigment that accepts electrons from chlorophyll. The resulting separation of charge widen as the electron moves across the thylakoid membrane and are accepted by plastoquinone (Pq), which is embedded on the outer, stromal side of the membrane.

- The electrons then descend an electron tral1Sport chain of molecule (such as cytochromes) in thylakoids linking photo system II and photosytem I, which are connected in series in thylakoids membranes. As the electrons move down this chain, they form a proton gradient that generates ATP.

- The final electron acceptor in the electron transport chain is P700, the reaction centre of photo system I. There, the electrons have a higher energy than when they left P680 in split second earlier. At P700, four more photons absorbed by antennae transfer their energy to the reaction centre, where the energy is used to eject electrons from P700, electron donor, located on the thylakoid space side of the membrane. These energized electrons cross the membrane and reduce ferrodoxin. A small, iron-Containing protein that is the electron acceptor of photo system I. Ferrodoxin then reduce $NADP^+$ to NADPH.

- Because the ferrodoxin is on the outer, stromal side of the membrane, $NADP^+$ forms on the stroma, where it is used in biochemical reactions t to reduce carbon to carbohydrates.

- The light protons used in the photochemical reactions make three molecules of ATP and reduce two molecules of $NADP^+$.

$$2H_2O + 2NADP^+ + 3ADP + 3Pi \xrightarrow{\text{8 photons}} O_2 + 2NADPH + 3ATP + 4e + 2H^+.$$

- These ATPs and NADPs are used to reduce CO_2 in the biochemical reactions of photosynthesis.

The evolution of photosystem I changed life on earth: it made photosynthetic organisms independent of H2S from decaying organic compounds as sources of electrons. It liberated oxygen into the atmosphere, thereby allowing the evolution of aerobic respiration.

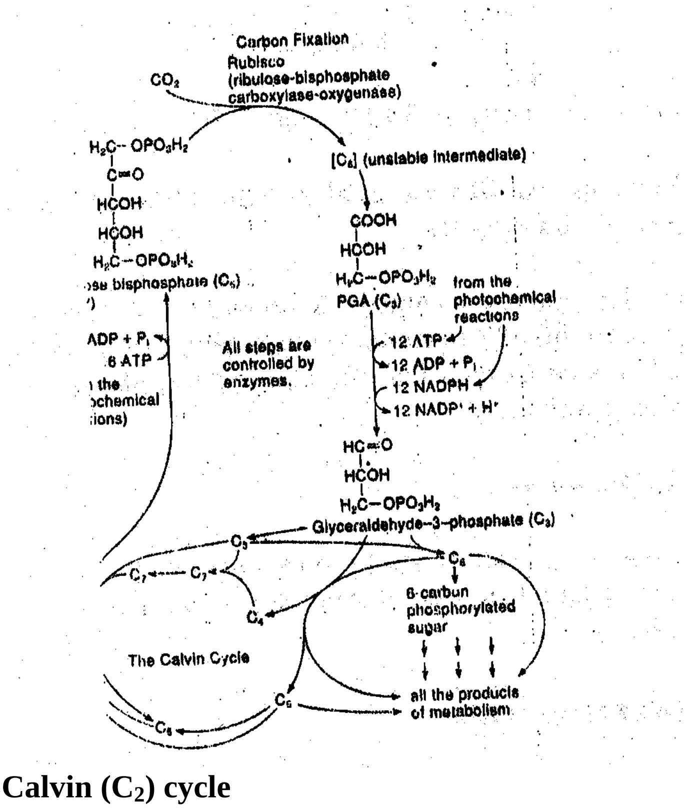
SELF ASSESSMENT EXERCISE 1

1. What are the two phases of reactions involved in photosynthesis?
2. Summarize what happens during the photochemical phase of photosynthesis.

3.1.2 The Biochemical Reactions

The biochemical reactions of photosynthesis reduce carbon dioxide to carbohydrate, a storage depot of chemical energy the summary of what happens during this stage is summarized below. Read it as you look at it, to understand how they occur.

(Fig. 13.3)



Calvin (C_2) cycle

- CO_2 diffuses into the chloroplast stroma and is fixed; that is it is incorporated into an organic compound. This occurs by the covalent bonding of CO_2 to RuBP ribolose 1.5-phosphate aided by the enzyme RUBP carboxylase/Oxygenase **(Also called rubisco)**.

- Rubisco occurs in all autotrophs except a few species of bacterial, and is the most abundant protein on earth.

- The reaction of CO_2 and RuBP produces an unstable six-carbon compound that immediately breaks into two molecules of 3-phosphoglyceric and (3-PGA) fig 13.4. This 3-carbon molecules is the first stable product of photosynthesis, which explains why botanists refer to this series of reactions as the C_3 cycle or Calvin cycle.

- Plants that use only the Calvin cycles to fix carbon dioxide are called C_3 plants. About 85% of plants belong to this category e.g oaks, barley, rice, peanuts, cotton, tobacco, soyabeans and most trees.

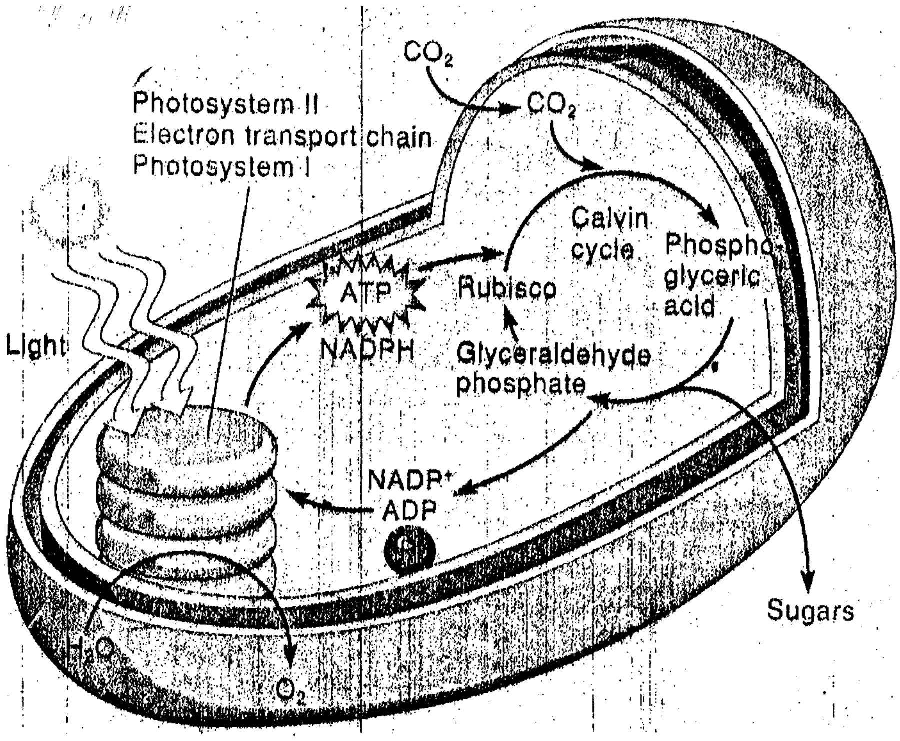
- A phosphate group is cleaved from each molecule of 3-PGA, and ATP and electrons from NADPH (produced by the photochemical reactions) are then used to reduce diphosphoglycerate (DPGA) to glyceraldehydes-3-phosphate (G-3-P), a three-carbon sugar. The sugar, not glucose, is the carbohydrate produced by the Calvin cycle and is the starting point for many other metabolic pathways in the plant.

- Some of the G-3-P is used to reform RuBP. This can occur in' the dark and requires ATP made in the photoche1nical reactions. The rest of the G-3-P moves through a series of chemical reactions to form fructose diphosphate which is used to make glucose, sucrose, starch and other compounds needed by the plant.

Summary of the Biochemical Reactions

The first step of the Calvin cycle makes precursors for glucose and other carbohydrates, while the later steps generate RuBP. Since the Calvin cycle takes in only one carbon (as CO_2) at a time, it takes six turns to produce a net gain of six carbons (i.e the two molecules of glyceraldehydes-3-photosphate, a three-carbon sugar). These six turns require eighteen ATPs (three per carbon) and twelve NADPHs (two per carbon). All of which come from the photochemical reactions of photosynthesis.

(Fig. 13.4)



A summary of photosynthesis. The photochemical reactions, which occur in thylakoids and grana, produce O2 ATP, and reduced NADP. The Calvin cycle (i.e., biochemical reactions), which occurs in the stroma uses the ATP and reduced NADP, to reduce CP2 to carbohydrate (three key intermediates are shown here). The by-products ADP_1P and NADP' are returned from the Calvin cycle to the photochemical reactions.

$$6CO_2 + 18ATP + 12\ NADP + 12H_2O$$

$$\downarrow$$

$$C_6H_{12}O_6 + 18Pi + 18ADP + 12NADP^+ + 6H_2O + 6O_2$$

Although this summary equation is convenient for understanding the basis of photosynthesis, it is imperfect, some of the intermediates of the Calvin cycle are siphoned off to make other compounds (e.g. amino acid).

SELF ASSESSMENT EXERCISE 2

1. Briefly explain the biochemical reaction of photosynthesis.
2. What is the product of the reaction?

3.2 C4 Photosynthesis

In some groups of tropical grasser e.g sugar cane, CO_2 is still fixed via the Calvin cycle but only after fixing it through another set of reactions that take place before the Calvin cycle. An explanation of what happens in these plants is presented below:

- Carbon dioxide diffuses into the leaf through stomata and is fixed in mesophyll cells. These cells lack rubisco;

- Carbon dioxide in mesophyll cells combines with a 3-carbon compound called phosphonenolphyruvic acid (PEP), a respiratory intermediate.

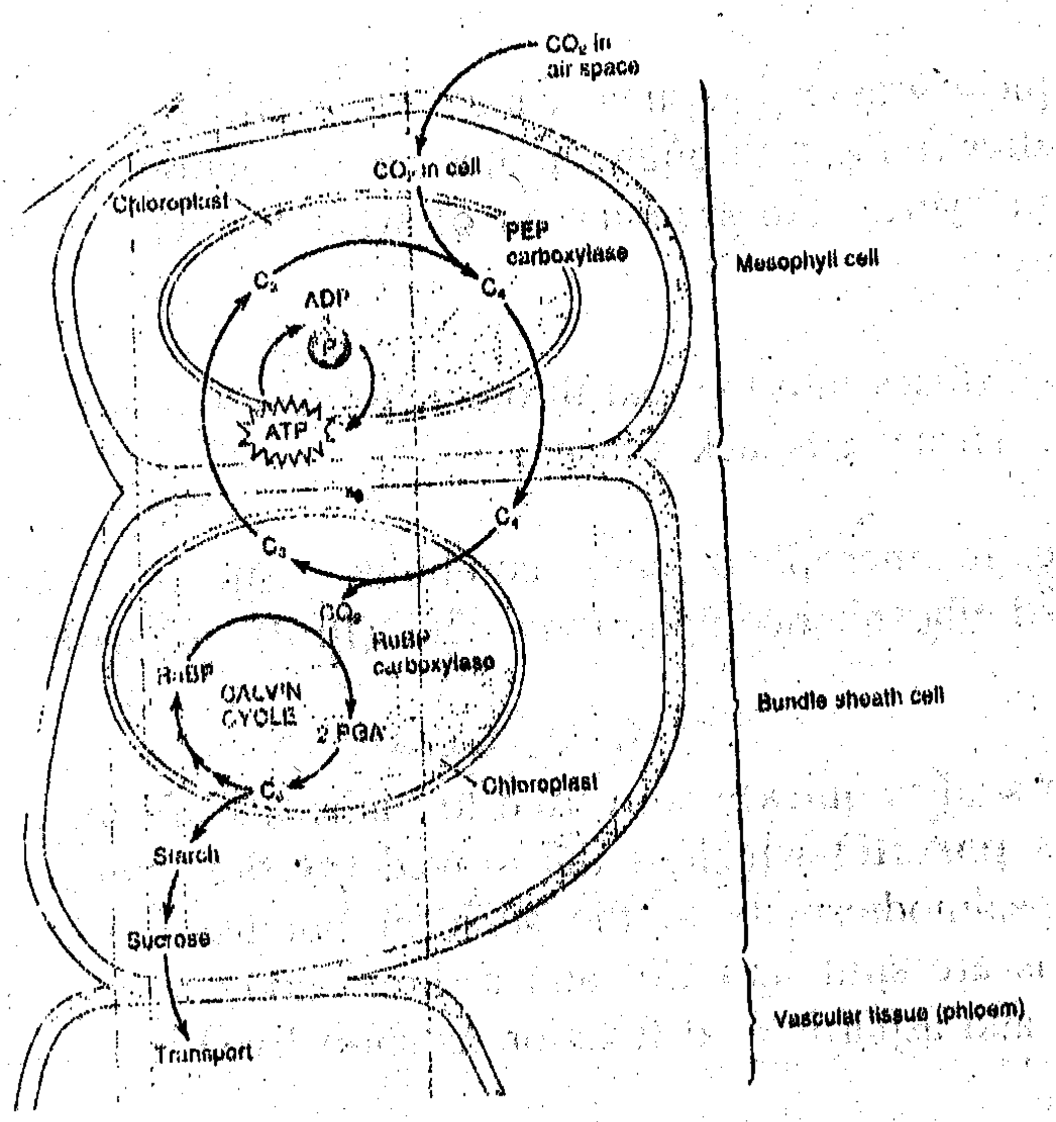
- The four-carbon acid is quickly converted to malic acid (Malate) or aspartic acid **(as partate)** which is the moved **(at the expense of ATP)** through psalmodiesmate to the adjacent bundle-sheath cell. There these acids are split into CO_2 and a three-carbon compound. Thus malic acid and aspartic acid function as short-lived reserviours of CO_2.

- The pumping by C_4 plants of CO_2 into bundle sheath cells keeps the internal concentration of CO_2 in bundle sheath cells 20-120 times greater than normal. This high concentration of CO_2 allows rubisco to fix CO_2 at maximal rates. This enables C_4 plants to fix CO_2 more efficiently than C_3 plants do.

- The CO_2 released in the bundle-sheath cells is fixed by the Calvin cycle. Meanwhile the 3-carbon compound is shuttled back to the mesophyll cell (again at the expense of ATP), where it is converted to PEP, and the initial CO_2 acceptor in C_4 photosynthesis.

Plants such as sugar cane are called C_4 plants because a four-carbon acid is the first stable product of their photosynthesis. Although none of the photosynthesis reactions of C_4 plant are unique, they produce dramatic differences in plant growth. The advantage of the added set of reactions to C_4 photosynthesis is that PEP carboxylase scarvenges CO_2 and does not react with oxygen. This combined with the pumping of CO_2 by surrounding mesophyll cells into bundle-sheath cells, enable C_4 plants to fix CO_2 with rubisco that is insulated from high concentrations of oxygen.

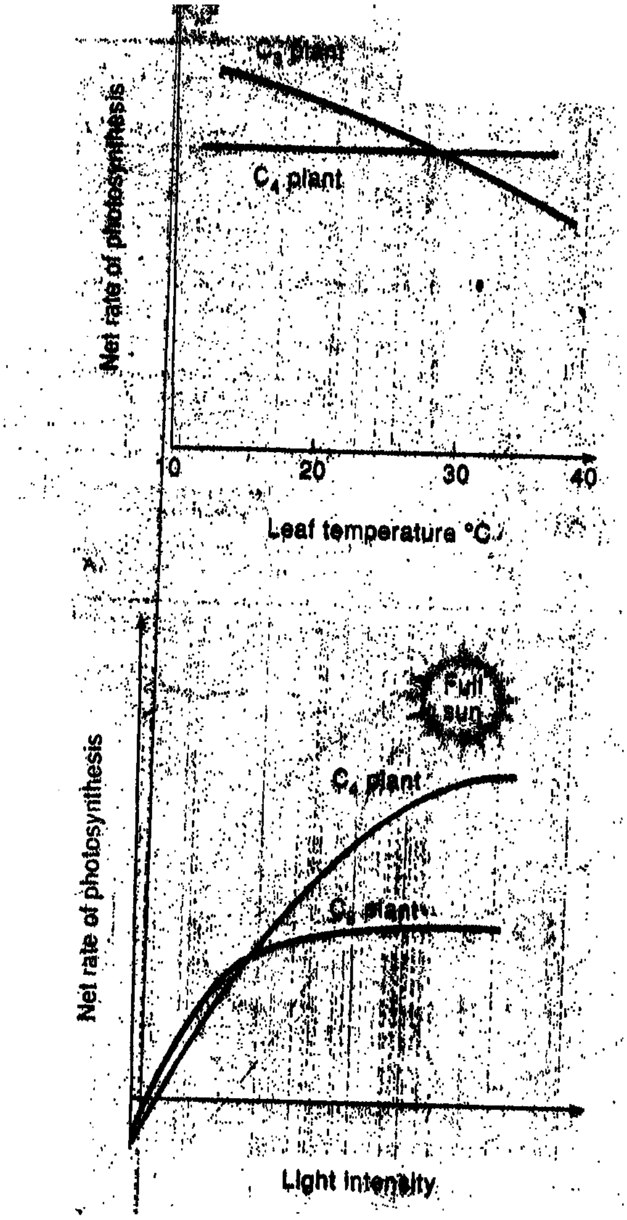
(Fig. 12.5)



Summary of C_4 photosynthesis. Mesophyll cells fix CO_2 into four-carbon acids that move into bundle-sheath cells. There, the acids are decarboxylated; the CO_2 released by this decarboxylation is fixed via the calvin cycle in the bundle-sheath cell. The three carbon compound move back to the mesophyll cell, where it is converted to PEP/the CO_2 acceptor.

C_4 plants can fix CO_2 until the internal concentration of CO_2 reaches zero. This allows them to continue to fix CO_2 even in hot, dry weather when stomata begin to close.

(Fig. 7.26)



C_4 plants are photo synthetically more efficient than C plants only in dry night conditions. Their increased efficiency in these condition is due to the absent of photorespiration in C_4 plants.

As a result, they need only about half as much water as C_3 plants for photosynthesis.

C_4 plants use nitrogen more efficiently than do C_3 plants, largely because they saturate their rubisco with CO_2, thereby maximizing its efficiently.

It is almost impossible to light-saturate C_4 plants, (Fig. 13.6b) consequently, they usually out-compete C_3 plants in hot, dry weather.

C_4 photosynthesis evolved in the hot conditions of the tropics. Today C_4 plants are all angiospemIs that are most common in hot, open ecosystem. They occur in at least seventeen families none of which includes only C_4 plants. The families are diverse, distantly related and have no common C_4 ancestors. Most are monocosts; with some dicots. Examples include, com sugarcane, sorghum, millet and piginveed (Amarathus). There are no algae. Table 7.2 summaries the characteristics of C_4 plants and compares them with C_3 plant.

SELF ASSESSMENT EXERCISE 3

1. In which group of plants do C_4 photosynthesis occurs?
2. Why are C_4 plants said to be more efficient than C_3 plants?

4.0 CONCLUSION

The photosynthesis process involves two clear and distinct phases- the photochemical and biochemical reactions. The photochemical react are light dependent. They oxidize water, release oxygen, produce, ATP and reduced $NADP^+$ that are used in the biochemical reaction, which reduce carbon dioxide to carbohydrate. The biochemical reactions reveal that plants fix carbon in two form one form is through the Calvin cycle and produces a 3-carbon molecule as the first stable product of photosynthesis. These plants are referred to as C_3 plant. Another group of plants first produces a 4-carbon molecule, before the 3-carbon molecule. Such plants are regarded as C_4 plants and are believed to be more efficient than the C_3 plants.

5.0 SUMMARY

The photochemical reactions in photosynthesis convert light-energy into chemical energy I n plants, the photochemical reactions oxidize water, produce ATP, reduce NADP, and involve two photo systems connected in series. The ATP and reduced NADP made in the photochemical reactions are used in the biochemical reactions of photosynthesis to reduce carbon dioxide to carbohydrate.

The biochemical reactions are collectively referred to as the Calvin, or C_3, cycle and begin with the fixation of carbon dioxide by an enzyme called ribulose bisphosphate carboxylase/oxygenase (Rubisio). The product of the biochemical reactions is glyceradehyde-3-phosphate, a sugar that is the starting point for several metabolic pathways, fixing each molecule of carbon dioxide requires three ATP and two reduced $NADP^+$ s.

Plants that use only the Calvin cycle are called C_3 plants. C_4 photosynthesis occurs in tropical grasses and involves fixation of carbon dioxide into a four-carbon acid in mesophyll cells. The acids then move to bundle sheath cells, where they are broken down to carbon dioxide and a 3-carbon molecule. C_4 plants are more efficient during hot conditions.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Photochemical reaction and Biochemical reaction.
2. The photochemical reactions of photosynthesis convert light-energy into chemical energy. In plants, the photochemical reactions oxidize water, produce ATP, reduce NADP, and involve two photosystems connected in series.

ANSWER TO SELF ASSESSMENT EXERCISE 2

1. The biochemical reactions of photosynthesis used ATP and reduced NADP made in the photochemical reactions to reduce carbon dioxide to carbohydrate Glyceraldehyde-3-phosphate.
2. Tropical grasses.

ANSWER TO SELF ASSESSMENT EXERCISE 3

1. Fix CO_2 with rubisco that is insulated in high concentration of oxygen
   Fix CO_2 until internal concentration of CO_2 reaches zero
   Fix even in hot dry weather when stomata begin to close.
2. Need only about half the water of C_3 plants.
   Use nitrogen more efficiently.

6.0 TUTOR-MARKED ASSIGNMENT

In what ways is C_4 plants more efficient in respiration than C_3 plants.

7.0 REFERENCES/FURTHER READING

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UNIT 4 PLANT HORMONES I

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1.0 INTRODUCTION

Plant growth and development result from complex highly organized events. The involve more than forming masses of new cells or the increase in size of an organism we do know that plant growth and development are controlled by internal signals. The leaves of a corn plant for example, always have the same basic shape and seeds germinate in specific and predictable ways.

Plant growth is also influenced by external signals from the environment. The external and internal signals that regulate plant growth are mediated, at least in parts, by plant growth regulating substances, or hormones. Plant hormones are organic compounds that are made in small amounts in one part of the plant and transported to another part where they initiate physiological responses. However, these responses are not always an "excitation" or stimulation, the regulation of bud dormancy, for example, results from the inhibition of growth.

Five major classes of plants hormones have been identified and they are auxins gibberellins, cytokinins, abscisic acid and ethylene. These hormones have several characteristic 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 discuss two of the hormones; auxins and gibberellins.

2.0 OBJECTIVES

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

- state how auxins and gibberellins were discovered
- name the scientists that pioneered research effort in this direction
- describe how auxins and gibberellins are transported
- list the effect of auxins and gibberellins
- compare the mode of action of auxins and gibberellins on growth.

3.0 MAIN CONTENT

3.1 Auxins

3.1.1 Discovery

The first inkling that there may be a "something" that affects growth cam from the work of Charles Darwin and his son in late 1870s. From a series of manipulations of the coleoptiles of canary grass and oat, they concluded that the growth of coleoptiles toward light was somehow controlled by the tip of the coleoptiles. In 1881, the Dawins published their findings, in a book where they suggested that **phototropism** (that is, the movement of plant toward light), was due to an "influence" produced in the tip of a coleoptiles that move to the growing region where it caused the coleoptiles to grow toward light.

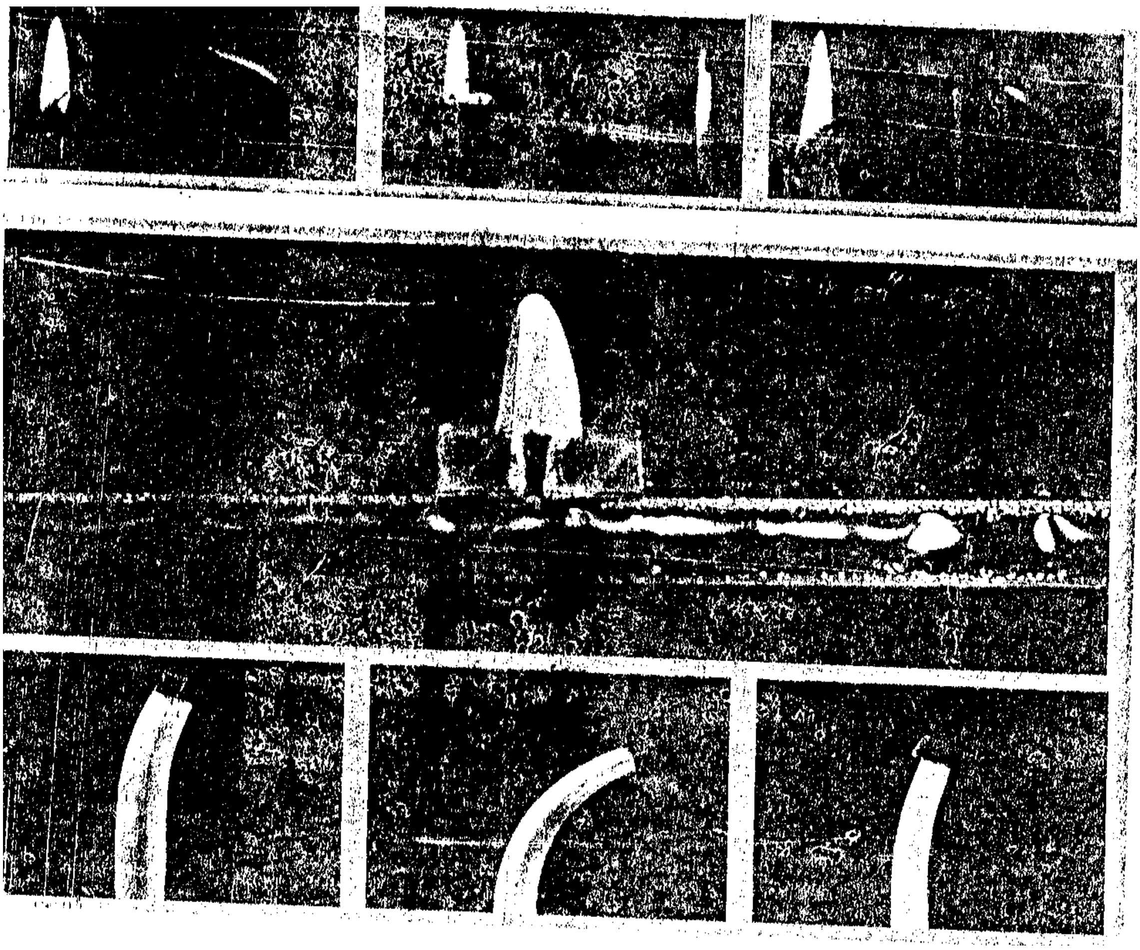
In 1913, another Danish plant physiologist, Peter Boysen-Jensen took up the study after cutting of the tip of the coleoptiles, replacing it alone, replacing it on agar, and replacing it on butter, he concluded that the tips ofcoleoptiles do not have to be in their normal position to affect growth, and the "influence" that controls phototropism can move through agar. **(I am sure you must have learned about agar from your practical biology and class. Agar is a gelatinous substance that keeps water in a semisolid state at room temperature)**

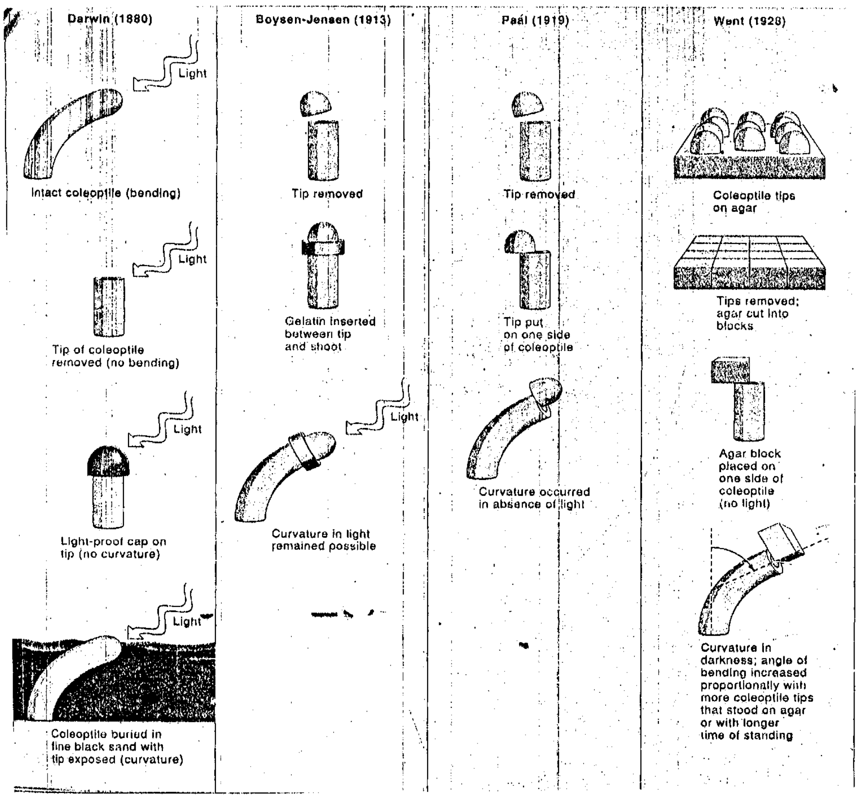
Boysen-Jensen reasoned that this "influence" was probably water soluble chemical since it could move through agar. Later he tested it with butter and it did not work, he also tested it with pieces of platinum foil to see if it has any electrical signal, and again it did not work.

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 to him 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.

It was in 1926, that the puzzle was finally unraveled through the studies of Frits Went. Went separated the "influence" for phototropism from the plant that produced it. He first cut off the tips of oat coleoptiles and placed them onto agar so that their cut surfaces touched the agar. After about an hour, the tips were discarded, and pieces of the agar that they had touched were placed on the cuts lips of decapitated coleoptiles grown in the dark. His results were convincing

(Fig. 14.1).





(a) ***Darwin's study of phototropism. In the left photograph, the celoptile is curving toward the light of a candle. On the celoptile shown in the middle photograph, the top 2mn of the plant has been covered by light proof foil. The shoot does not bend even though the growing zone of the celeoptile toward the light shows that a signal must move from the light-sensitive tip to the growing zone which is farther down.***

(b) ***Went's study of phototropism. These experiments were the first demonstration of a hormone in plants. Went gave the name auxin to the hormone involved in photo tropism of celeoptiles.***

(c) ***A diagrammatic summary of some of the important experiments that demonstrated the existence of auxins. The Paal and Went experiments were done in the dark***

- 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 hat 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).**

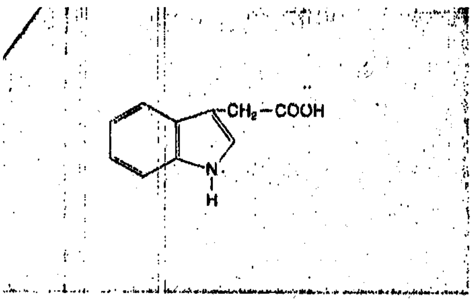
SELF ASSESSMENT EXERCISE 1

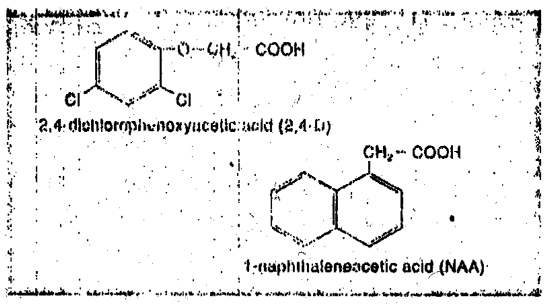
1. Who pioneered the efforts that led to the discovery of auxin
2. Whose study concluded what is known today about auxins

Synthesis:

The most active naturally occurring auxin in plants is **Indole-3-acetic acid,** or **IAA**

(Fig. 14.2)





Structure of indole-3-acetic acid (IAA).

IAA is the most active naturally occurring auxin. Severl synthetic compounds have auxinlike effects. Synthetic auxins such as 2,4-D and NAA have chemical structures similar to that of 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.

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 (fig 14.4).

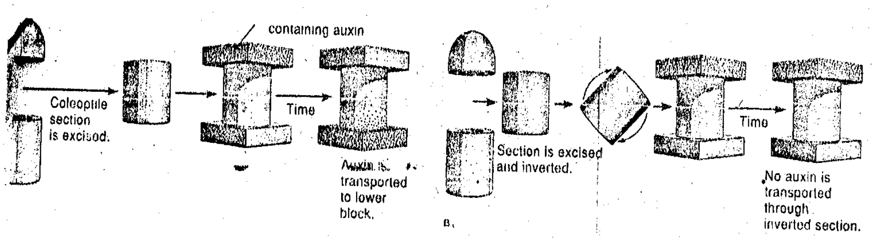
Synthetic auxins such as 2,4-D are used extensively as herbicides because they are inexpensive, relatively non-toxic to humans and have a elective effect, they kill broadleaf dicots but not monocots. The exact mechanism for this electivity is unknown. Synthetic auxins are also used to prevent preharvest 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.

3.1.2 Transport

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

(Fig 14.3).



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 continues even 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.

3.1.3 Effects of Auxin

Auxins affect plants in many ways, we will now look at some of them.

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 (if you have not studied this in BIO 124, you will. You may look it up)

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: (Please refer to BIO 124)

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 Cytokinins will be discussed in unit 15.

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 favour differentiation of phloem.

Theseobservations 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 auxin 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

Nureries 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.

SELF ASSESSMENT EXERCISE 2

1a. List the 3 naturally occurring auxins
b. Which is the most active
2. To what most common use is synthetic auxin put.
3. How is auxin transported in (a) shoot (b) root
4. List 6 effect of auxins.

3.1.4 Auxins and Calcium

The Responses elicited by IAA depend on presence of another non-hormonal factor calcium ion (Ca^{2+}). For example, Ca^{2+} -is required for the polar transport of IAA, and Ca^{2+} - deficient plants are usually not responsive to IAA. The most recent model accounting for the interaction of IAA and Ca^{2+} is as follows:

i. IAA stimulates release of Ca^{2+} from the vacuole and endoplasmic reticulum of a cell.
ii. This release of Ca^{2+} increases the concentration of Ca^{2+} in the cytoplasm

iii. This increase in internal Ca^{2+} activates Calmodulin a Ca^{2+} -activated protein that regulates many processes in plants, animals and microbes.
iv. H^+ pumps, and thereby produce the physiological response.

3.2 Gibberellins

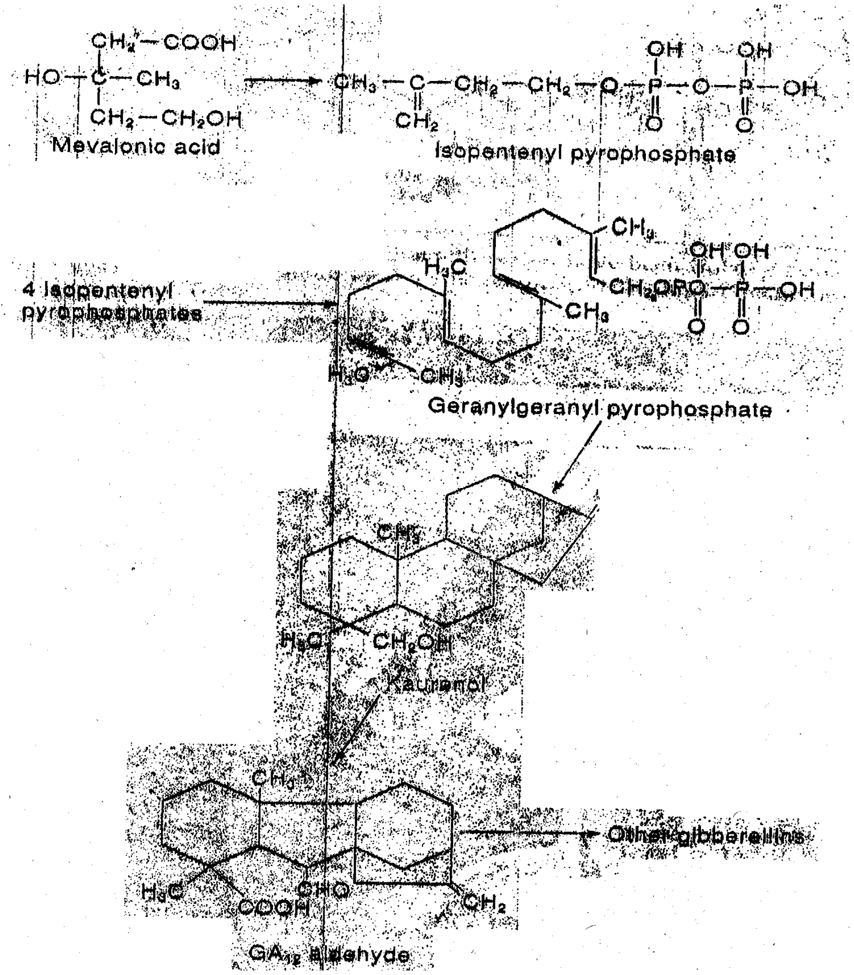
3.2.1 Discovery

Ewiti Kurosawa, a Japanese, scientist pioneered efforts in this regard when he isolated the hormone gibberllins from rice plant infected with the "Foolish seedling" disease - Gibberella fujikuroi.

3.2.2 Synthesis and Transport

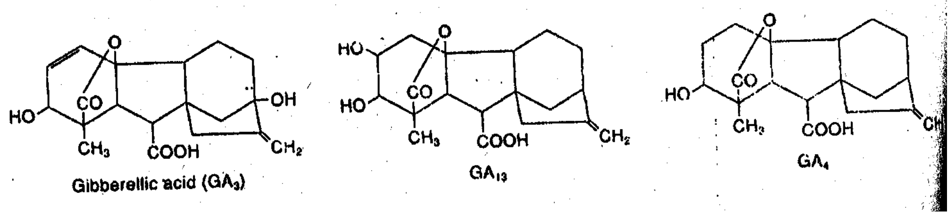
Gibberelin is made through the mevalonic acid pathway

(Fig 14.4).



Gibberellin is made via the mevalonic acid pathway

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.

SELF ASSESSMENT EXERCISE 3

1. Who pioneered the effort that led to the discovery of giberellin.
2. How is gibberellin transported.

3.2.3 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

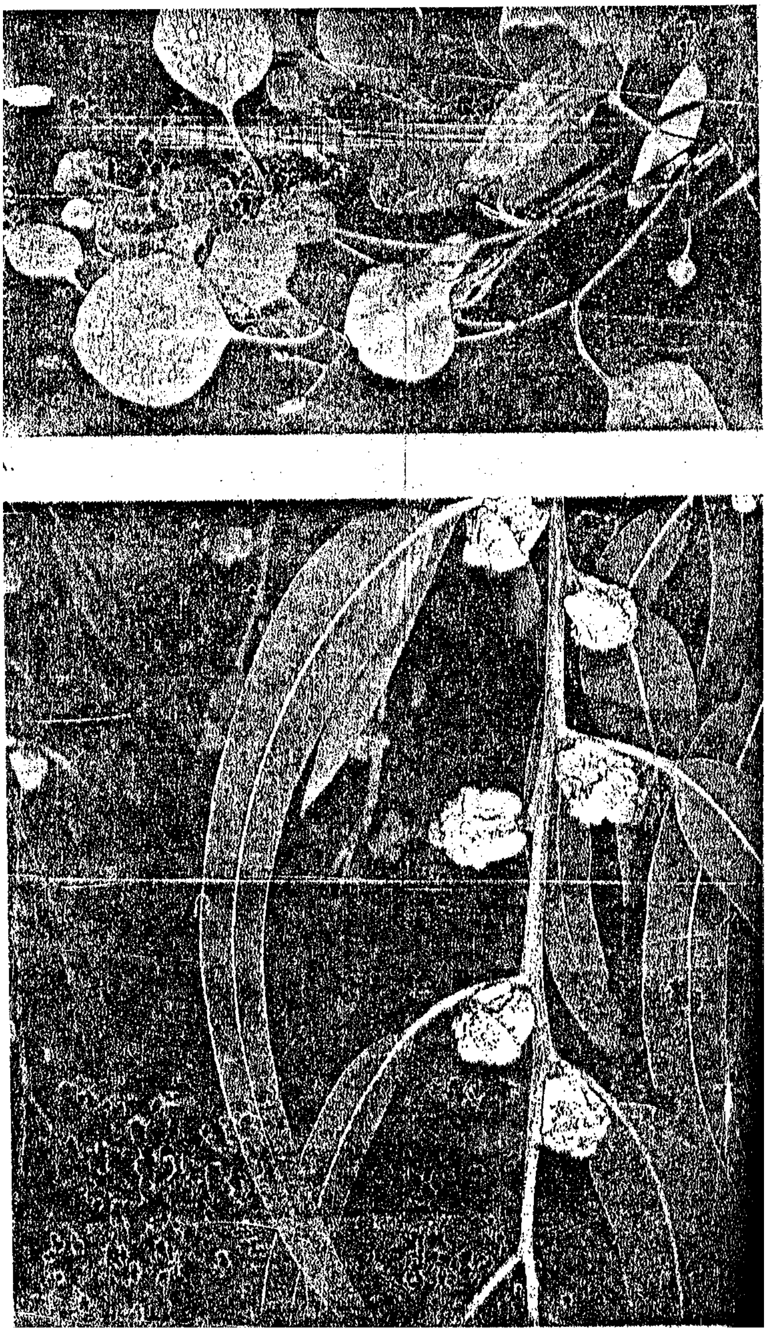
GAS play a critical role in seed germination in cereal grasses such as barley in this way.

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 juvenite stage and an adult stage of growth. For example juvenile stages of eucalyptus have leaves that are shaped differently then those of adult stages.

(Fig. 14.6)



(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 plat 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.

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 I size almost three fold and are more loosely paced making them less susceptible to fungal infections.

SELF ASSESSMENT EXERCISE 4

1. List 5 effects of Giberellins
2. Distinguish between the mode of action of GA and IAA on growth.

4.0 CONCLUSION

Plant growth and development are strongly influenced by plant-growth regulating substances, which are organic compounds made in one part of a plant and transported to another part, where they elicit a response. These growth regulating substances have been traditionally referred to as hormones. There are five major classes of plant hormones. The two treated here are auxins and gibberellins. These hormones may elicit many responses and interact in complex ways to stimulate or inhibit growth.

5.0 SUMMARY

Plant hormones are organic compound made in one part of a plant and transported to another part of the plant where they elicit a response. Plant hormones are active at small concentrations. Plant hormones and the responses they elicit have the following characteristics.

- Although a hormone may have some characteristic effects, it may also has many other effects. That is, a single hormone can elicit many different responses.

- The responses elicited by an 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.

- Hormonal responses change under different conditions and in different plants.

The five major classes of hormones are auxin, gibberellins, cytokinins, ethylene and abscisic acid.

Auxins stimulate cellular elongation, differentiation of vascular tissue, fruit development, formation of adventitious roots and production of ethylene. The most active naturally occurring auxin is indoleacetic acid (IAA), which is transported polarly in root and stems. Synthetic auxins are used extensively in modem agriculture.

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.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Charles Darwin
2. Frits Went

ANSWER TO SELF ASSESSMENT EXERCISE 2

1i. IAA
ii. 4-chloro-IAA
iii. Phenylacetic acid
1b. IAA

2. Herbicides
3(a) Shoot -basipetally
(b) Root-acropetally

4i. Cellular elongation
ii. Apical dominance
iii. Abscission
iv. Differentiation of vascular bindles
v. Fruit formation
vi. Formation of adventitious root

ANSWER TO SELF ASSESSMENT EXERCISE 3

1. Ewiti Kurosawa
2. Non-polar

ANSWER TO SELF ASSESSMENT EXERCISE 4

1(a) Extensive growth of intact plats.
(b) Seed Germination
(c) Flowering
(d) Juvenility
(e) Fruit formation.
2.

- GA controls internodes elongation, while IAA control elongation in seedlings and herbs.
- GA controls cellular elongation and division while IAA controls cellular elongation only.
- GA leads to non acidification of cell wall while IAA leads to cell wall acidification.

6.0 TUTOR-MARKED ASSIGNMENT

(This will come at the end of unit 15, since it is a continuation of this unit)

7.0 REFERENCES/FURTHER READING

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UNIT 5 PLANT HORMONES II

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1.0 INTRODUCTION

Plant hormones as discussed in the last unit 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. At the end we will come across oligosaccharins that effect plants growth but do not fit into the general characteristics of hormones.

2.0 OBJECTIVES

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

- state how cytokinins, ethylene and ABA were discovered
- name and scientists that pioneered research effort in this direction
- 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
- state how ABA counteracts the effects of other hormones
- explain why calcium is regarded as a messenger in hormone transport?
- explain why botanists find it difficult to accept oligosaccharins as plant hormone
- illustrate the statement that many hormones work harmoniously together to produce a single effect
- list other less known plant hormones.

3.0 MAIN CONTENT

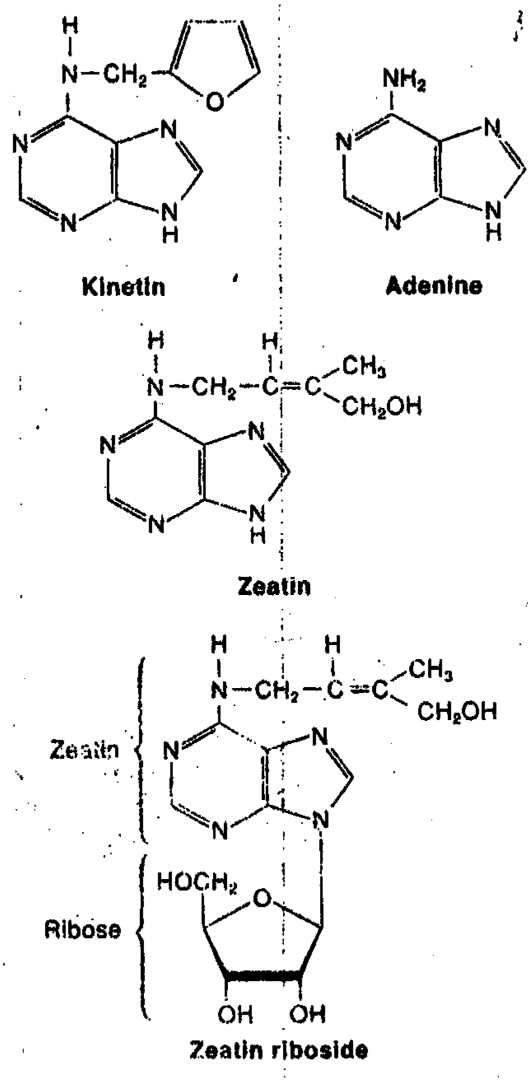
3.1 Cytokinins

3.1.1 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, botanists 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 cytoinins 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.

(Fig 15.1)



Cytokines. All cytokines are structurally related to the prune adenine

Soon thereafter, the influence of coconut milk on cellular division was explained when it was shown to contain zeatin and zeatin riboside, another cytoinins. Since then, botanists have isolated other naturally occurring cytoinns (e.g. kinetina and 6-benzylamino purine). All of these cytoinins 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.

3.1.2 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.

3.1.3 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. (Refer to Bio 123). 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.

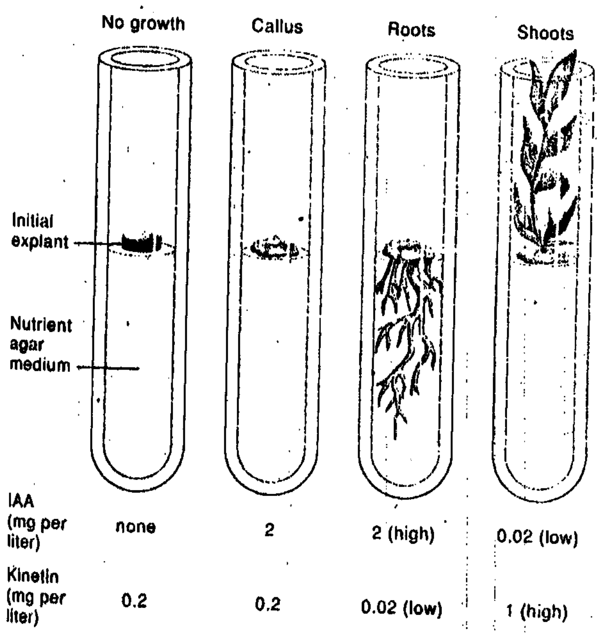
ii. Effect on Cotyledons

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.

(Fig 15.2)



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.

SELF ASSESSMENT EXERCISE 1

1(a) Which scientist pioneered research effect in chytokinins discovery
(b) Who eventually led a breakthrough?

2. How is cytokinins transported
3. What are the effects of cytokinins (Name/List them)

3.1.4 Cytokinins and Calcium

Small amounts of cytokines do not stimulate cellular division in cultured cells. Which merely enlarge due to the presence of auxin. However, addition calcium switches the growth pattern from cellular enlargement to cellular division. Therefore, the presence of calcium increases a cell's sensitivity to cytokinin. Cytokinins also stimulate bud formation in mosses; substance that increase cells permeability to Ca^{2+} mimic the effect of cytokinins, and cytokinin-induced formation of buds can be inhibited by applying inhibitors of clamodulin. Similarly, the addition of calcium enhances the cytokinin- induced delay of leaf senescence. These effects may be mediated by cytokinin-induced changes in the concentration of Ca^{2+}

3.2 Ethylene

3.2.1 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?

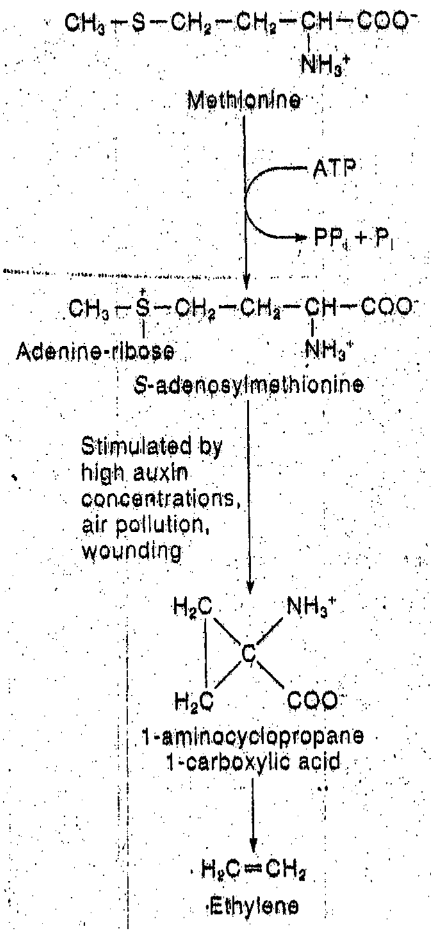
This question was answered in 1901 when Soviet plant physiologist Dimitry Neljubow identified ethylene as the combustion product of "illumination gas" that was responsible for defoliating and inhibiting the elongation of plants growing near the lamps.

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.

3.2.2 Synthesis and Transport

Enthylene is made from methionine, and amino acid

(Fig. 15.3)



Photosynthesis of ethylene from Methronm e, 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.

3.2.3 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 insensive 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. Fruits such as, thereby allowing growers to harvest their crops in shorter periods of time.

iv. Sex Expression

The sex of flowers on monoecious plant (i.e 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.**

3.2.4 Ethylene and Auxin

IAA as stated in unit 14 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.

SELF ASSESSMENT EXERCISE 2

1. When was ethylene identified as an agent of fruit ripening? And by who?
2. What are the effects of ethylene?
3. Ethylene and IAA are related but do not necessary act together. Discuss this statement.

3.3 Abscisic Acid

3.3.1 Discovery

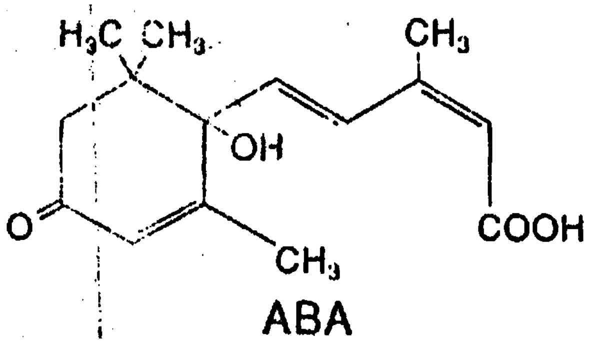
By the 1940s botanists suspected that some aspects of plant growth and development resulted from inhibition rather than stimulation of growth. Near the end of that century, Torsten Hemberg of Sweden confirmed that dormant buds of ash and potato contained inhibitors that blocked the effects of IAA. When the binds 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. Addicott discovered a compound that stimulated abscission of cotton fruit. He named this substance **abscisin**. Botanists later were surprised to discover that domin and abscisin was the same compound. This compound was natured **abscisic acid or ABA** and unfortunately name, because subsequent research has shown that ethylene rather than ABA controls abscission.

3.3.2 Synthesis and Transport

ABA (Fig 15.4) 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, phaloem and parenthyma. Like grbberel1ims and cytokinin ABA moves non polarly. There are no synthetic abscisis acid.

(Fig. 15.4)



The structure of abscisic (ABA)

ABA fig. 15.4 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.

3.3.3 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, for example.

- Affect 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 plans, 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.

SELF ASSESSMENT EXERCISE 3

1. How is ABA transported?
2. In what areas do ABA counteracts the effects of other hormones? How does it do this?

3.4 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 botanist 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.

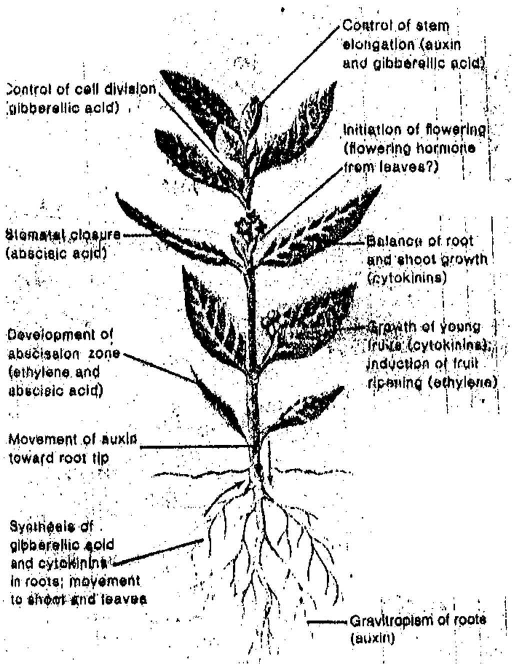
(c) Brassosteroids

Are plant hormones in tea, bean and rice plants that stimulate growth of stems.

3.5 Hormonal Interactions

Hormones seldom, if ever, function alone, rather, plant growth and development usually result from interactions of plant hormones.

(Fig. 15.5)



Numerous hormonal interactions influence plant growth and development.

But what controls the amounts of hormones, and thereby their ratios and resulting interactions? These are controlled in two ways.

i. Regulation of the rate of synthesis several factors influence the rate of hormone production. For example, daylight can trigger the synthesis of IAA and the synthesis of gibberellins in biennials is stimulated by cold temperatures.

ii. Regulation of the rate of breakdown or inactivation. Inactivation of hormones usually Occurs either by oxidizing the hormone or by conjugating (i.e. combining) it with another compound. Coordinated synthesis and inactivation could control the amount of hormone present and therefore control the growth response.

SELF ASSESSMENT EXERCISE 4

1. What are the less known plant hormones? Or hormone-like substances.
2. Discuss any 3 effects where hormones interact.

4.0 CONCLUSION

The other 3 major hormones that regulate plant growth and development cytokinins. Ethylene and abscisic acid. Each of these hormones is made in several parts of the plant and has several effects. The effects of hormones are governed by many factors including the presence of other hormones, non-hormonal factors such as calcium ions and the varying sensitivity of different tissues to hormones.

Oligosaccharins are hormone like substances whose mode of action is different. They elicit specific effects. Oligosaccharins that inhibit flowering in one specie will always inhibit flowering in one specie in other species. This is very much unlike the way other plant hormones work. Other compounds that function like hormones include batasins and brssosteriods.

5.0 SUMMARY

This unit concludes the series on plant hormones. In unit 14, we summarized three characteristics of hormones. We will repeat them her and add more for emphasis.
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:

- Although a hormone may have some characteristic effects, it also has many other effects. That is, a single hormone can elicit many responses.
- 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.

- Hormonal responses change under different conditions and in different plants

- A single aspect of growth and development can be influenced several hormones.

- Response elicited by plant hormones probably result from changing ratios of hormones rather than from the presence or absence of any one hormone.

The five major classes of plant hormones are auxin, gibberellins, cytokinins, ethylene and absicsic acid: Auxins and gibberellins were treated in Unit 14.

- Cytokinins stimulate cellular division, expansion of cotyledons and growth of lateral buds. Cytoinins also delay senescence of detached leaves and is combination with IAA, may influence formation of roots and shoots.

- Ethylene is a gaseous hormone that influence fruit ripening, abscission, sex expression and the radial expansion of cells.

- Abscisic Acid (ABA) is an inhibitor that cause stomata to close, affects dormancy of some seeds, and in general, counteracts the stimulatory effects of other hormones. These effects may occur because ABA is a calcium antagonist.

Oligosaccharins are fragments of cell wall that regulate plant growth and development. Unlike other plant hormones, Oligosaccharins have specific effects.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1(a) Gottlieb Haberland
(b) Miller, Skoog & Associates

2. Non polarly in xylem, phloem and parenchyma cell

3a. Cellular division
b. Effects on cotyledon
c. Organogenesis
d. Senescence

ANSWER TO SELF ASSESSMENT EXERCISE 2

1. 1934 by R. Gane

2a. Fruit ripening
b. Flowering
c. Abscission
d. Sex expression
e. Stem elongation

3. IAA stimulates ethylene production but each acts independently e.g IAA stimulated cellular elongation and production of lateral buds. While ethylene decreases elongation of shoot and roots with the aid of IAA.

ANSWER TO SELF ASSESSMENT EXERCISE 3

1. Non polarly through xylem, phloem and parenchyma cells.

i. Inhibtis amylase produced by seeds created with gibberellin.
ii. Promotes chlorosis that is inhibited by cytokinins.
iii. Inhibits wall elasticity and well growth promoted by IAA.

ANSWER TO SELF ASSESSMENT EXERCISE 4

1. ABA is a Ca^{2+} antagonist it interferes with Ca^{2+} antagonist. It interferes with Ca^{2+} metabolism.

i. Oligosaccharins
ii. Batasin
iii. Brassosteriods.

2i. Development of abscission zone: ethylene and ABA.
ii. Control of stem: auxin and gibberellins.
iii. Fruit growth and ripening: Cytokinin and ethylene.

6.0 TUTOR-MARKED ASSIGNMENT

1. Many hormones work together to produce a single effect. Give three examples of areas where more than one hormone works for a single effect.
2. How is the transport of IAA different from that of other hormone.

7.0 REFERENCES/FURTHER READING

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MODULE 4

Unit 1 Plants Responsive to Environmental Stimuli
Unit 2 Movement of Water and Minerals
Unit 3 Transportation of Food Substances in Plants

UNIT 1 PLANTS RESPONSIVE TO ENVIRONMENTAL STIMULI

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1.0 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 behaviours are short-term responses e.g. the closing of the leaf of Mimoso puechica when touched takes about a second or less, and curvature of a stem towards light is usually completed within a few hours. Other behaviour 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 the unit.

2.0 OBJECTIVES

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

- state what tropism is
- distinguish between phototropism, gravitropis, hydrotropism and thymotropism
- describe naetic movements
- differentiate between seismonasty and nyctinasty.
- describe what photoperiodism is
- mention one of the responses controlled by photoperiodism

3.0 MAIN CONTENT

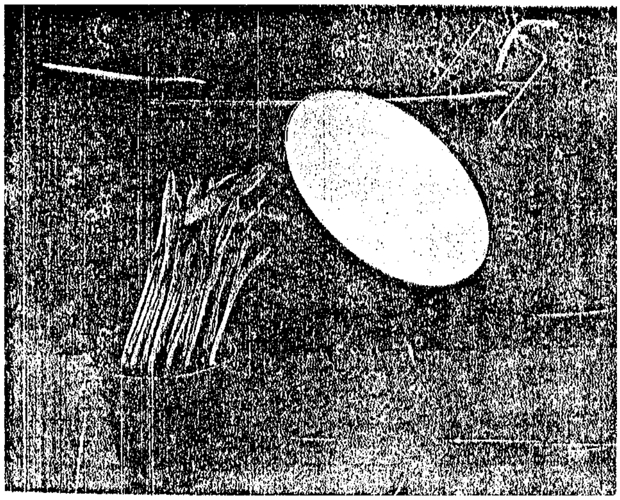
3.1 Tropism

Plant growth toward or away from a stimulus such as light or gravity is called tropism. There are several kinds of tropisms, each of which is named for the stimulus that causes the response. For example, phototropism is the growth of a stem or coleoptile toward light, and gravitropism is growth towards or away from gravity. Tropisms result from differential growth. Meaning that one side of the responding organ elongates faster than the other side. This causes curative of the organ toward or away from the stimulus. Growth of an organ toward a stimulus is called positive tropism. Thus, stems that grow toward light are positively phototropic. Conversely, growth of an organ away from a stimulus is called a negative tropism. Roots, which grow away from light, are negatively phototropic.

3.1.1 Phototropism

Phototropisim is a tropic response to uni-directional light (light coming from one direction, see (fig. 16.7)

(Fig 16.1)



Phototropic curvature of corn shoots toward light. Unilateral light causes IAA to move the shaded side of the stem. This IAA stimulates growth on the shaded side, causing the shoot to curve toward the light.

From Unit 14, you learnt Frits Went, He determined that during phototropism, the rapid elongation of cells along the shaded side of coleoptiles is controlled by IAA coming from the apex. Went formulated his hypothesis jointly with Russian plant physiologist Nicolai Cholodny, and this work became known as the Cholodny-Went hypothesis. Although this hypothesis was a major step in our understanding of phototropism, the mechanism by which IAA controlled phototropism remained a mystery. Either of two hypothesis could have accounted for the increased activity of IAA on the shade side of the coleoptile.

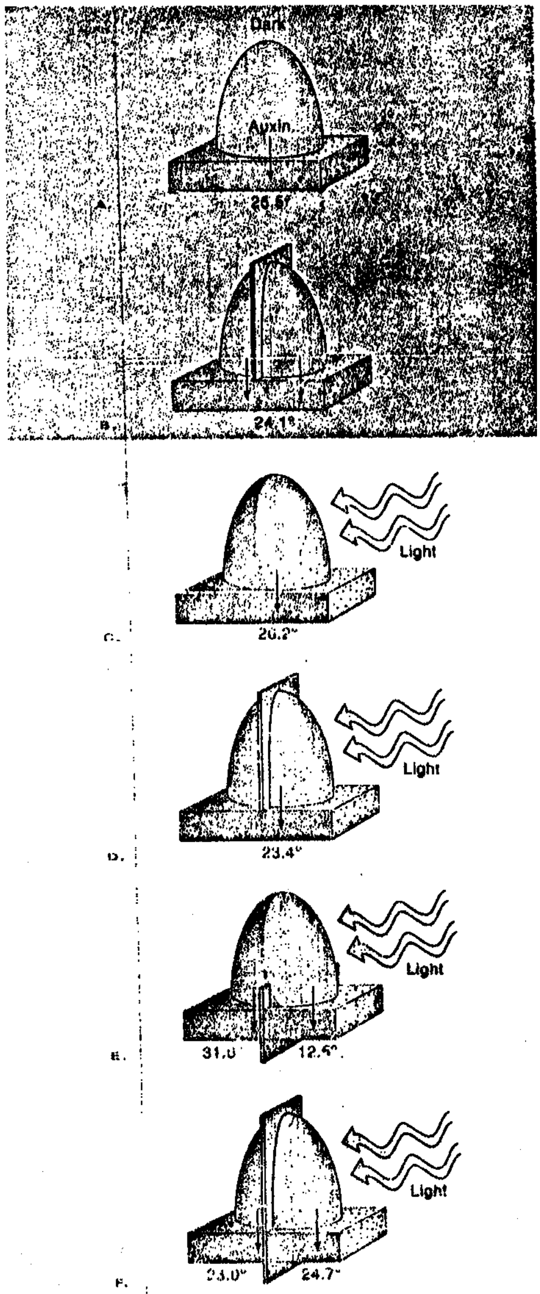
Hypothesis I

Light destroys IAA along the lighted side of the coleoptile.

Such a mechanism could result in more IAA along the shaded side of the coleoptile, which would account for the phototropic curvative.

The Evidence: In the 1950s Winelow Briggs and his colleagues determined that the amount of IAA produced by coleoptiles grown in light is the same as that made by coleoptiles grown in the dark.

(Fig. 16.2)



Brigg's experiment. A and B (done in the dark) showed that splitting the tip celeoptile did not significantly affect the total amount of auxin that was diffusing from the tip into the agar block. The degree curvature produced when the agar block is applied to the side at a decapitated celeoptiile is directly related to amount of auxin produced, and is shown by the numbers below the agar blocks. Comparing A and B with C and D shows that auxin production is non-dependent on light. If a barrier is partially into the tip auxin is displaced from the lighted (a) to the dark (b) side as shown in E experiment shows that it was displacement that had occurred and the results in light E do not reflect different rate of auxin production on the lighted and dark sides.

Thus, light does not destroy IAA.

Hypothesis 2

Light causes IAA to move t the shaded side of the coleoptile. According to this hypothesis, the difference in IAA concentration between the lighted and shaded sides of the coleoptile would result from the movement of IA rather than its destruction.

The Evidence: Briggs and his colleagues collected more IAA from the shaded side of coleoptiles than from the lighted sides, suggesting that light causes IAA to move to shaded side of the stem. This conclusion was confirmed by inserting impermeable barriers between the split tips of coleoptiles. These barriers blocked the movement of IAA to the shaded side of the coleoptiles (fig 19.2). As a result, the coleoptiles did not curve towards the light. More recent experiments using IAA labeled with radioactive carbon (14C) have confirmed that unidirectional light causes IAA to move to the shaded side of coleoptiles, where its increased concentration causes cells there to elongate more rapidly than cells on the lighted side of the coleoptiles. As a result, the coleoptile curves toward the light.

Although the Cholodny-Went hypothesis adequately explains phototropism in coleoptiles, it often fails to account for phototropism by stems, which contain more chlorophyll than do coleoptiles. In stems, unidirectional light triggers production of an inhibitor that shows cellular elongation on the illuminated side of the stem. Because cellular elongation does not change on the shaded side of the stem, the stem curves toward the light.

SELF ASSESSMENT EXERCISE 1

What is phototropism; and what drives it.

3.1.2 Gravistropism

This was foffi1erly referred to as <u>geotropism</u>. This kind of tropism causes stems to grow upward and roots down-wards. Both of these responses are of adaptive significance. Stems that grow upward are apt to receive more light than those that do not roots that grows down-ward are more likely to encounter a favourable environment than those roots that do not.

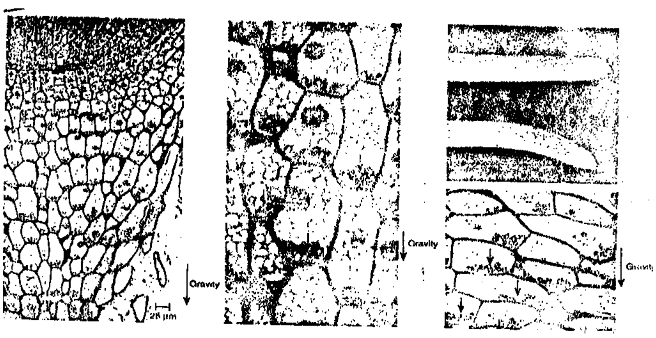
The phenomena is now called gravitropism because it is clearly a response to gravity and not to the earth (prefix "geo") as such.

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 roots, such gradiention hoffi1one concentration have not been as well documented. Nevertheless, in some -what horizontally growing roots, the upper sides grow more rapidly then 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 Darwine. 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 Darwine 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.

(Fig. 16.3)



(a) ***Longitudinal section of a root cap of corn cells in the center of the cap contain numerous starch-laden amyloplasts located in the lower part of the cells.***

(b) ***Magnified view of (a) arrows indicate amyyloplast that have sedimented to the bottom of the cell.***

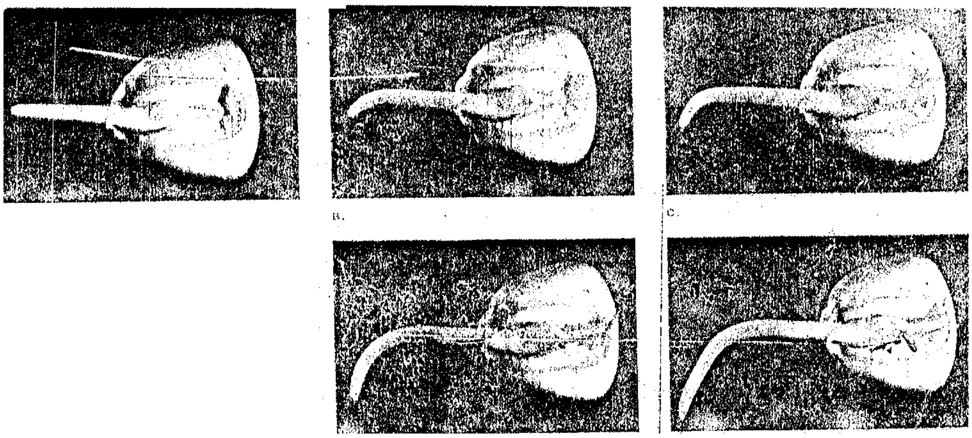
(c) ***These atinyloplasts (arrows in lower photo) quickly sediment to the sides of cells when roots are oriented horizontally. This sedimentation of amyloplasts has long been thought to be the basis for how roots perceive gravity (upper photo).***

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 inhibite cellular elongation in roots, the lower side of roots grow lower than the upper side of the root and the roots curve down-ward.

(Fig. 16.4)



Gravitropism by horizontally oriented roots of corn. Downward curvature begins within 30 minutes and is completed within a few hours curvature results from faster elongation of the upper side of the root than of the lower sides.

When the root reaches a vertical position, the lateral asymmetries of Ca2+ and IAA disappear, and straight growth resumes.

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. Concumently, 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.

(Fig. 16.5)

Negative gravitropism, by a stem of this plant was placed on inside 24 hours before this picture was taken.

SELF ASSESSMENT EXERCISE 2

1. What is gravitropism, how is it controlled?
2. And what is its mechanism of action.

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.

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.

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 thighmotropism of desk-stimulated tendrils. Various degrees of thigmotropism are exhibited not only by tendrils, but also by leaves, stems, petioles and roots.

SELF ASSESSMENT EXERCISE 3

What is (a) Hydrotropism?
(b) Thigmotropism?

3.2 Nastic Movements

These are movements that also occur in response to environmental stimuli. Unlike tropisms, nestic movements are independent of the direction of the stimulus. They occur in an atomically predetermined direction, rather than toward r away from the stimulus. Nastic movements include some of the most unusual plant kingdom.

3.2.1 Seismonasty

This is a nestic 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 pindica) touching a leaf causes the leaflets to fold and the petiole to drop.

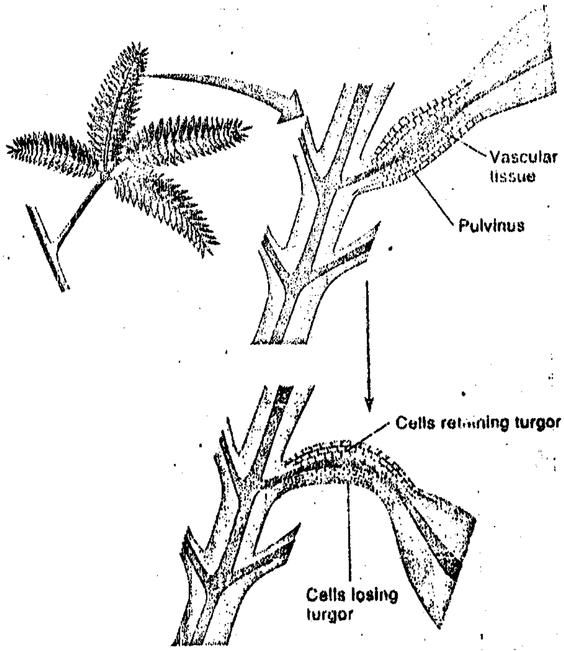
(Fig. 16.6)

Seismstic movement of leaves and leaflets of the sensitive plant (Mimosal). In undisturbed plants

(a) Leaves are erect. Touching a leaf
(b) causes leaflets to fold and the petiole to drop
(c) The response occur in the following ways:

i. Touching a leaf generates an electrical signal that moves along the petiols
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 petiols.

(Fig 16.7).



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.

3.2.2 Nyctinasty

This is a naetic 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, these 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.

SELF ASSESSMENT EXERCISE 4

Distinguish between Seismonesty and nyctinasty.

3.3 Photoperiodism

All eulcaryotic 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.

3.3.1 Flowering Responses

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.

SELF ASSESSMENT EXERCISE 5

1. What is photoperiodism?
2. What event in plants is most affected by it?

4.0 CONCLUSION

Plant growth and development are strongly influenced by the environment. Some responses of plants to stimuli such as light, gravity, and touch are rapid. Most responses of plants to environmental signals are due to growth and are controlled partly by hormones. These hormones stimulate or inhibit growth in response to environmental cues such as light, day length, temperature touch, and gravity and thus allow plants to respond efficiently is environmental demands by growing ins specific directions, producing flowers, and displaying other responses appropriate to their survival in a particular habitat.

5.0 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 plants 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.

Gravitropism, a growth response to gravity results from the accumulation of IAA along the lower side of roots and stems. In stems, the accumulation of IAA stimulates cellular elongation, which causes the stems to curve up.

Thigmotropism is a growth response to touch. It is common in tendrils, which coil around objects that they touch. It is controlled by IAA and ethylene.

Naetic movements occur in an anatomically predetermined direction. Seismonaety is a nastic movement resulting from contact or mechanical disturbances, while nyctinaety is a naetic response result from daily rythms of light and dark.

Photoperiodism is the ability of plant to sense changes in the relative length of night and day. One of the responses controlled by photoperiodism is flowering.

ANSWER TO SELF ASSESSMENT EXERCISE 1

Phototropisms are growth responses of plants to uni-directional light. They are mostly if not entirely, mediated by auxin and are very important in determining the form of a plant.

ANSWER TO SELF ASSESSMENT EXERCISE 2

1. Gravitropism is a growth response to gravity. It is controlled by calcium and IAA, and results in stems growing up and roots growing down.
2. Gravitropism is important because it increased the probability that

i. Roots will encounter water and minerals and
ii. That stems and leaves intercept light for photosynthesis.

ANSWER TO SELF ASSESSMENT EXERCISE 3

1a. Hydrotropism is the growth of roots towards soil moisture
b. Thigmotropism is a growth response to touch

ANSWER TO SELF ASSESSMENT EXERCISE 4

Seismonasty is a nastic response resulting from contact or mechanical disturbance, while nyctinasty is a naetic response resulting from daily rythms of light and dark.

ANSWER TO SELF ASSESSMENT EXERCISE 5

1a. Photopenodism is a response to changes in the relative lengths of night and day.
b. Flowering

6.0 TUTOR-MARKED ASSIGNMENT

1. What is Photoperiodism
2. Distinguish between phototropism, gravitropism hydrotropism and thigmotropism.

7.0 REFERENCES/FURTHER READING

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UNIT 2 MOVEMENT OF WATER AND MINERALS

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1.0 INTRODUCTION

The survival of all plants depends on their ability to transport a variety of substances into, through and out of their bodies. At the cellular levels, diffusion is usually adequate for this movement. The evolution of multicellularity rendered diffusion inadequate for moving substances throughout a plant because the time required for diffusion is inversely proportional to the square distance covered. Also plants colonizing the land were in a race to intercept light for photosynthesis. This means growing taller and exposing large leaves to the dry, hostile environment. The algae-like photosynthetic cells in leaves could only function in a highly humid environment, which was far from the soil's water. In ferns and other small plants, roots and root hairs were enough to absorb the water. Because leaves are located far from the leaves merely absorbing water was not enough. Plants require a system for transporting water from the soil to the leaves. This led to the evolution of the xylem system for long distance water transport.

The mechanism of action for the long distance water transport and the factors affecting it are discussed in this unit.

2.0 OBJECTIVES

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.

3.0 MAIN CONTENT

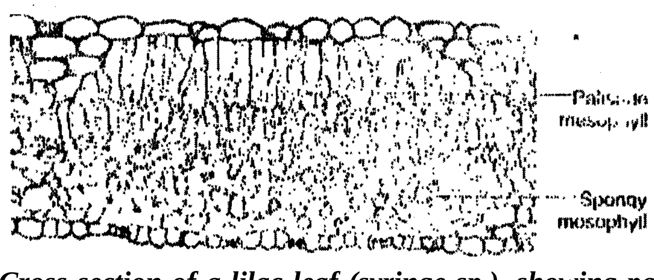
3.1 Moving Water and Mineral in the Xylem

Water is the most abundant compound in plant cells; it accounts for 85% - 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.

3.1.1 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.

(Fig. 17.1)



Cross section of a lilac leaf (syringe sp.), showing palisade and spongy regions of mesophyll. The loose arrangement of mesophyll cells exposes large amount of surface area.

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 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.

3.1.2 Structure of the Conducting Cells

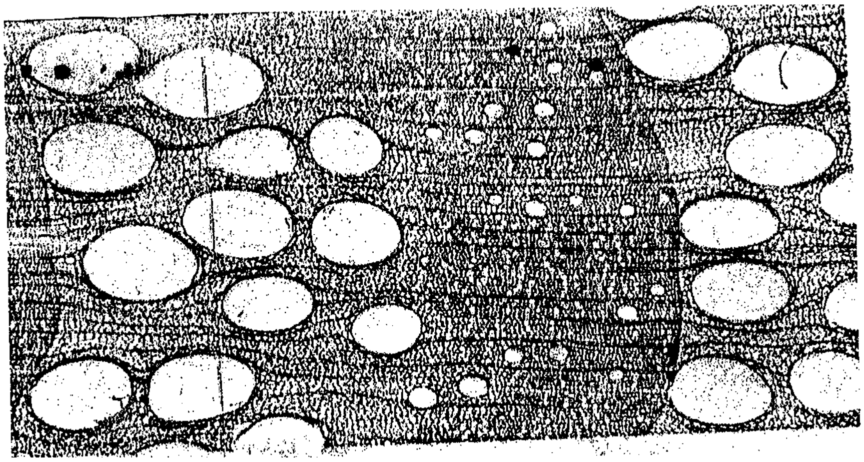
Water must move rapidly though plants to replace the water lost by transpiration. Through what tissues does water move? To answer this question, consider the result of two simple experiments:

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 xylary elements.

In BIO 124, you learnt that there are two kinds of xylary elements in plants: tracheids and vessel elements.

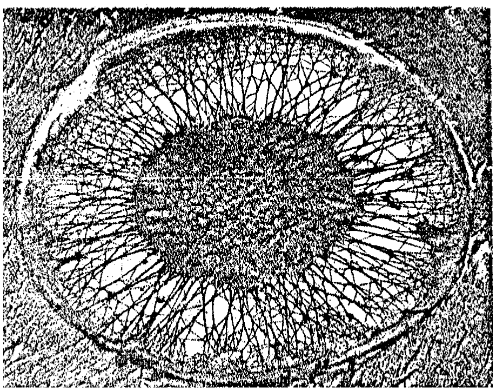
(Fig. 17.2)



Cross section of wood, showing vessels and tracheids-vessels and tracheids transport water and dissolved minerals from roots to shoots.

You may also wish to refer to your note in BIO 124 to refresh your memory. 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 (10-15µm 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.

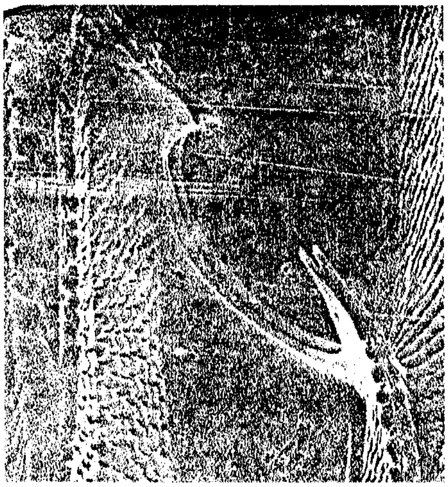
(Fig. 17.3)



Bordered pits are valvelike structures that are abundant in walls where tracheids overlap one another-pits link tracheids into long, water-conducting chains and allows water to flow through xylem. X3, 050

Vessel elements are shorter and wider than tracheids ; their diameter are usually between 40 and 80μm, and may be as large as 5000μm. 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.

(Fig 17.4)



Scanning electrons micrographs of part of a vessel. Vessel elements are stacked end to end; the walls separating adjacent vessel element are often either wholly or partially or dissolved.

SELF ASSESSMENT EXERCISE 1

1(a) How does water move from roots to leaves
(b) What is transpiration

3.1.2 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, **ψ**. 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

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 leaves like those shown in fig 2.1.6 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 apoplant 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 favouring 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.

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 summarized in fig 2.1.7 and describes the process 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.

SELF ASSESSMENT EXERCISE 2

Which hypothesis best explains water movement in xylem. Describe it.

3.2 Factors Affecting Transpiration

3.2.1 Environmental Factors

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 shows in humid air.

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.

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.

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.

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.

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.

SELF ASSESSMENT EXERCISE 3

List the factors that affect transpiration.

3.2.1 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: les 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 their.

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.

SELF ASSESSMENT EXERCISE 4

List four (4) structural factors that affect transpiration. What is their mode of action?

4.0 CONCLUSION

The biggest challenges that plants faced are they invaded land were obtaining and transporting water in the dry terrestrial environment. These challenges to survival led to the evolution of roots and a specialized vascular system to gather and transport the water, and an epidermis and stomata to conserve it. The xylay elements of the vascular twine became highly adapted to moving water up the plants. The transpiration-cohesion hypothesis i.e. the beat explanation for water movement. The transpiration is affected by certain environmental and structural factors.

5.0 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.

The movement of water through the xylem is best explained by the transpiration-cohesion hypothesis. 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. The water potential gradient that lifts water through the xylem extends the length of the plant and into the soil, thereby pulling water in plants is also promoted by the strong cohesion of water molecules. The adhesion of water to the cell walls of trachaids and vessels helps to prevent gravity from draining the water columns.

Environmental factors that affect transpiration include atmospheric humidity, internal concentration of Co_2 in the leaf, air movement, air temperature, availability of water in the soil, and light.

Structural adaptations that reduce transpiration include the presence of a cuticle, trichomes, sunken stomata, and decreased leaf area.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Water and dissolved mineral move from roots to leaves in dead conducting cells of the xylem
2. Transpiration is the evaporation of water from the shoot of a plant.

ANSWER TO SELF ASSESSMENT EXERCISE 2

1. The transpiration-cohesion hypothesis best explain how water moves in xylem. The driving force for the movement of water is a water- potential gradient generated by transpiration. Transpiration from leaves lifts water up plants. Cohesion of water from

breaking, and adhesion of water molecules to cell walls prevent gravity from draining the water column.

ANSWER TO SELF ASSESSMENT EXERCISE 3

Factors that affect transpiration are humidity, temperature, light, soil, wind and the internal concentration of CO_2 in leaves.

ANSWER TO SELF ASSESSMENT EXERCISE 4

Four structural factors that affect transpirations are cuticles, trichomes, sunken stomata, and reduced leaf Area. Their mode of action is by reducing transpiration.

6.0 TUTOR-MARKED ASSIGNMENT

1a. Discuss three {3} environmental factors that affect transpiration
b. What two structural factors affect transpiration.

7.0 REFERENCES/FURTHER READING

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UNIT 3 TRANSPORTATION OF FOOD SUBSTANCES IN PLANTS

CONTENTS

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1.0 INTRODUCTION

The evolution of multicellularity, in plants rendered diffusion inadequate for moving substances throughout a plant, is discussed in Unit 17. Apart from requiring a system for transporting water from the soil to that leaves; multicellularity also require a system for transporting the sugars made in leaves to distant sites for storage and use. The phloem was thus evolved as the long distance transport systems for moving sugars and other solutes.

The mechanism of action of phloem in moving sugars and solutes and the factors affecting this movement are discussed in this unit.

2.0 OBJECTIVES

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

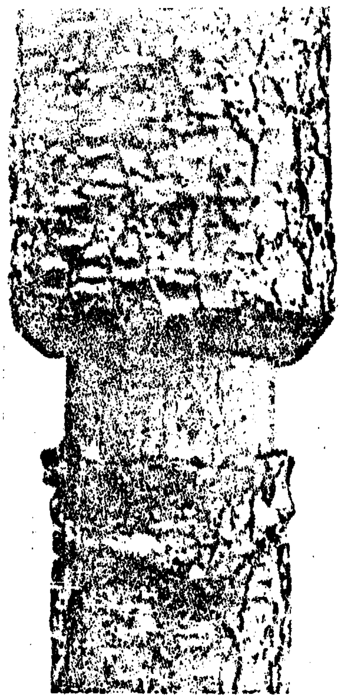
- describe the system of phloem loading and unloading
- list the environmental factors affecting phloem transport
- list the contents of sieve tubes.

3.0 MAIN CONTENT

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, 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.

(Fig. 18.1)



This girdle on a black cherry tree (Prunus serotina) blocked the flow of nutrients through phloem from above, stopping growth below

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.

3.1.1 Structure of Conducting Cells

Sieve tube members are cylinders conI1ected 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 plates should 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.

SELF ASSESSMENT EXERCISE 1

1. Where do sugars and other organic compounds move in plants?
2. What is the nature of the phloem’s sieve tube members?

3.1.2 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.

Rates of Phloem Transport

Solutes move surprisingly fact in the phloem peak rates of transport may exceed 2mh-1. As much as 20litres of sugary sapcan be collected per day from the several stems of sugar palm. At the cellular level, a sieve element empties and fills every two seconds.

Models for Phloem Transport

Hypothesis

Solutes move through the phloem via diffusion

Diffusion is much 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 are 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.

SELF ASSESSMENT EXERCISE 2

1. Which hypothesis best explain the transport of organic solutes in plants
2. What are its basis postulates.

3.2 Loading and Unloading the Phloem

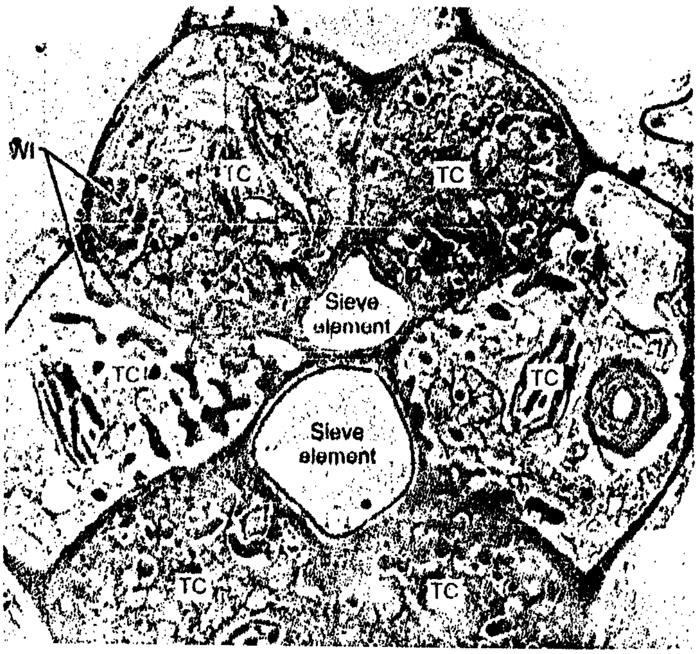
3.2.1 Phloem Loading

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.

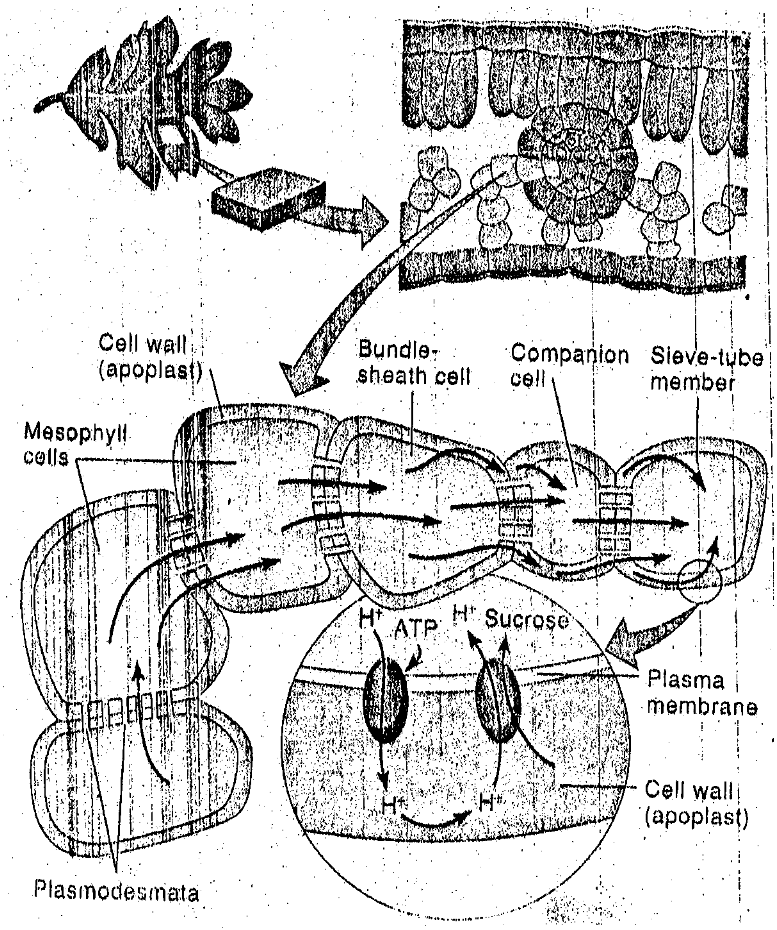
(Fig 18:2)



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 A TP.

(Fig. 18.3)



Model of sucrose loading into phloem. According to the model, IP is pumped out of the sieve tube, using energy from ATP sucrose to transport into the sieve tube.

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.

3.2.2 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.

3.2.3 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.

3.2.4 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^+.

SELF ASSESSMENT EXERCISE 3

1. Discuss how solutes are loaded in the phloem.
2. What three environmental factor affect phloem transport?
3. List the contents of sieve tubes.

3.3 Exchange between the Phloem and the Xylem

The contents of xylem and phloem are in aqueous equilibrium; that is, they have a similar water potential. For example, water entering loaded sieve tubes comes from the xylem and water leaving unloaded sieve tubes returns to the xylem and is recirculated. The movement of water between xylem and phloem is occasionally accompanied by an exchange of the solutes of these tissues.

4.0 CONCLUSION

In Unit 17, we concluded that the challenge of inhabiting lands by plants led to the evolution of roots and a specialized vascular system to gather and transport water, and an epidemic and stomata to conserve it. The evolution of multicellularity and tissue specialization also produced a system to move the products of photosynthesis to distant sites of use and storage. The companion cells and the sieve tubes of phloem are the structures responsible for this movement. The pressure-flow model proposed by Ernst Munch is the best possible explanation for this transport. This model explains that solutes move through the phloem via turgors-pressure. This movement is affected by some environmental factors which include light, temperature and mineral deficiencies.

5.0 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 turgors 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.

Phloem transport is affected by temperature, light and mineral deficiencies.

ANSWER TO SELF ASSESSMENT EXERCISE 1

1. Sugars and other organic compounds move in the phloem
2. Sieve tube members are cylinders connected by sieve-like areas called sieve plates each of which has numerous sieve pores.

ANSWER TO SELF ASSESSMENT EXERCISE 2

1. Pressure-flow model
2. Sugars are carried by water along a gradient of turgor pressure generated by an osmotically driven influx of water at sources and an exit at sinks.

ANSWER TO SELF ASSESSMENT EXERCISE 3

1. Solutes are loaded in phloem cells symplasticlly and apoplastically. Symplasticlly, they are moved through the plamodesmates between an chlorenchyma cell and another. They are then moved from the lest chlorenchyma to the veins through the cell walls (apoplastic)

2a. Light
b. Temperature
c. Mineral deficiencies

3i. Water
ii. Carbohydrates and sucrose
iii. Other sugars e.g. raffinose, stachyose and verbascose
iv. Sugar alcohols e.g. sorbitol and mennitol
v. ATP
vi. Nitrogen containing compounds e.g. amino acids.

6.0 TUTOR-MARKED ASSIGNMENT

a. Which model best describes the movement of solutes in plants.
b. Describe this model

7.0 REFERENCES/FURTHER READING

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