

**A FOUNDATION TEXT  
IN  
CELL BIOLOGY**

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# FOREWORD

This Book is intended for students who wish to understand the Basic Cell Physiology in relations to Cell structures, Processes, Functions and Development. The study of Cell Biology is essential for this purpose, but it would be almost impossible for a student to survey on his own the massive body of existing knowledge, constantly augmented by a remarkable torrent of brilliant discoveries and findings by scientists. The purpose of the Book “**A Foundation text in Cell Biology**”, then, is to update and organize our knowledge into something that can be comprehended in a relatively short time and still convey a reasonably complete picture of the Basic Physiology, structure and functions of living cells, tissues, organs and organs systems.

A Foundation Text in Cell Biology encompasses basic cell structures and cellular functions including: Cell composition, Cell growth, Cell division, Cell cycle and Cell transport. Elaboration of Cell structure has significantly aided understanding the structure of organisms in relation to functions. The book also contains guidelines for Students' Practical Activities and Tutor Marked Assessment Questions. Therefore, it is designed not only to give instruction in Tutorial form but also to provide a ready means of Self-assessment. It is intended primarily for students of Biology, Botany, Biochemistry, Developmental Biology, Agriculture, Genetics, Microbiology, and Biotechnology at higher levels of education, but it should also prove useful to foundation students of Medical and Laboratory Sciences as well as candidates for Diploma and College Examinations.

The contents follow the conventional arrangement of most courses and have been divided into Fifteen Chapters for ease of reference. Chapters One and Two are essentially introductory, covering aspects of (i) Chemical Constituents of Cell and Organic Molecules; (ii) Cell Discovery, Development and Levels of Organization. While, Chapters Three to Five outline the (iii) Prokaryotic and Eukaryotic Cells, (iv) Protozoa, Algae and Fungi Cells; and (v) Viruses: Discovery, Structure and General Properties. The focus in Chapters Six to Eight is on (vi) Ultrastructure in Eukaryotic Plant and Animal Cells; (vii) Enzyme Activities and Reactions in Cells; and (viii) The Nucleic Acids, Proteins and Storage of Genetic Information in Cells. Whereas, Chapters Nine to Twelve deliberates on (ix) Cell Cycle and Cell Division; (x) Diversity in Plant and Animal Cells; (xi) Movement of Materials across Cell; (xii) Cell Growth, Differentiation and Specialization. While Chapters Thirteen to Fifteen considers (xiii) Photosynthesis; (xiv) Respiration in Living Organisms; and (xv) Cell Microscopy, Cytological Techniques and Reporting of Laboratory experiments.

Keeping the subject within bounds has involved some sacrifices. The subject is paramount, and the authors' interest is secondary. I hope the “**A Foundation text in Cell Biology**” serves its purpose well, but it clearly would have had much less chance of doing so without the intensive collaboration of Dr Samuel R. Osu, Dr Godwin Evans Udofia, Dr Aniefon Alphonsus Ibuot, Dr Aniefiokmkpong Okokon Okon, Dr Christiana Ofonime Edet-Umoh, Dr Inemesit Ndarake Basse, Dr Samuel Eguom Osim, Dr Joseph Etim Okon, Dr Ofonmbuk Samuel Aderi, Dr Esther Etop Ekon, Dr Nsimeneabasi Michael Udoh, Dr Emem Okon Mbong and Mayen Godwin Ben, all skilled biologists and great Teachers with the desire to share their joy upon learning new things. I commend them for their steadfastness and guts. This publication has been produced as part of the authors' long-term research plan and desire to promote the study of Cell Biology and related courses.

They have brought together their varied experiences in research and teaching to produce this textbook to assist the user or academic community. And so, I do hereby unreservedly recommend the textbook to many colleagues and students around the world.

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# PREFACE

The purpose of writing this book titled “A Foundation Text in Cell Biology” is to introduce students in Polytechnics, Colleges of Education and Universities to the study of Basic Cell Physiology in relations to Cell Structures, Processes, Functions and Development.

We have taught this course at NCE, HND and BSc levels for more than twenty (20) years. This is where we got the motivations to put our lecture notes together which finally resulted in the present text. It is sequentially and clearly written in simple and straight forward English. This is an attempt to satisfy the desire of students of Biology, Agriculture, Microbiology, Biochemistry, Developmental Biology, Genetics, and Biotechnology at higher levels of education in Nigeria.

This text will go a long way in assisting Lecturers teaching Introductory Developmental/Cell Biology, Molecular Biology, General Physiology, Biochemistry and other related courses in Tertiary Institutions in Nigeria, as it covers the Core Curriculum and Minimum Academic Standard of the National University Commission (NUC), National Board for Technical Education (NBTE) and National Commission for Colleges of Education (NCCE). More so, the availability of this text would bring relief to students and others, since foreign texts are not readily available.

The book is comprehensive and up-to-date in contents with ways of performing practicals and reporting experiments. Each chapter of this text is supported with summary, students' practical activities, and thought provoking Tutor Marked Assessment Questions to aid stimulate an enquiry into the subject matter. The meaning of terms used in each chapter is explained as Chapter Glossary to aid effective revision. The authors shall be satisfied if students gain knowledge from this Book in order to further expand their understanding of the fundamental concept of the topics included in this book.

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# Chapter One

## CHEMICAL CONSTITUENTS OF CELL AND ORGANIC MOLECULES

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### 1.1 INTRODUCTION

Cells are largely composed of compounds that contain carbon. The study of how carbon atoms interact in chemistry plays a large role in understanding the basic function of cell. This is because carbon atoms can form stable bonds with four other atoms, which are uniquely suited for the construction of complex molecules. These complex molecules are typically made up of chains and rings that contain hydrogen, oxygen and nitrogen atoms, as well as carbon atoms. These molecules may consist of 10 to millions of atoms linked together in specific arrays. Most *biomolecules* in cells are built up from members of one of four different families of small organic molecules: sugars, amino acids, *vitamins*, and *fatty acids*. Each of these families contains a group of molecules that resemble one another in both structure and function. *Monosaccharides* for example are single sugar molecules which act as the building blocks of *disaccharides* and *polysaccharides*. *Monosaccharides* are the simplest forms of *carbohydrates*. In addition to other important functions, these molecules are used to build large *macromolecules* (organic molecules). For example, sugars can be linked to form the DNA and RNA of chromosomes, and *fatty acids* can be linked to form the *lipids* of all cell membranes.

### 1.2 LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- (i) State the chemical constituents of life.
- (ii) Discuss water and its composition.
- (iii) List three physical properties of pure water.
- (iv) Describe constituent of salt and inorganic ions.
- (v) List the functions and roles of salts and inorganic ions in cells.
- (vi) Explain organic molecules.
- (vii) Explain the importance of cell organic molecules.
- (viii) Describe carbohydrate and its chemical structure.
- (ix) Compare monosaccharides, disaccharides and polysaccharides.
- (x) State the constitution of nucleic acid.
- (xi) Describe the basic unit of protein, its structure and functions.
- (xii) Describe glyceride and fatty acid groups as the two major building blocks of fats.
- (xiii) Explain the term enzymes.
- (xiv) State the properties of enzymes.

### 1.3 CHEMICAL CONSTITUENTS OF CELL

#### (a) Chemicals of Life

In order for living organisms to grow, multiply, and reproduce, they must draw from the environment all the chemicals which they require for the synthesis of cell materials and the generation of energy. These substances, in general, are referred to as nutrients. The chemical composition of a typical cell indicates the major chemical elements as required: Carbon (C), Hydrogen (H), Oxygen (O), Nitrogen (N), Phosphorus (P) and Sulphur (S). The physiological functions of these principal elements found in the cells of living organisms are highlighted in Table 1.1.

Water accounts for about 80–90% of the total weight of a living cell and is always the major essential nutrient in quantitative terms. The solid matter of cells contains, in addition to H<sub>2</sub> and O<sub>2</sub> (derived metabolically from water), carbon, nitrogen, phosphorus, and sulphur. These six elements account for about 95% of the cellular dry weight. Many other elements included in the residual fractions are potassium, magnesium, calcium, iron, zinc, boron and molybdenum.

**Table 1.1:** Physiological functions of principal elements

Element	Physiological Functions
Hydrogen (H <sub>2</sub> )	Constituents of cellular water and organic cell materials
Oxygen (O <sub>2</sub> )	Constituent of cell water, organic cell materials. As molecular oxygen, acts as an electron acceptor during aerobic respiration.
Carbon (C)	Components of organic cell materials
Nitrogen (N <sub>2</sub> )	Components of Protein, nucleic acid and co-enzymes
<b>Sulphur</b> (S)	Constituents of protein and some co-enzymes
Phosphorus (P)	Components of nucleic acid, phosphorus and co-enzymes.
Magnesium (M)	<b>Cofactor</b> for many enzymatic reaction involving functions in binding substrate to enzymes and important component of chlorophyll
Calcium (Ca)	Co-factor for many enzymes
Iron (Fe)	Constituent of Cytochrome and co-factor for many enzymes

**Source:** (Irwin et al. 1985)

#### (i) Growth Factors

Any organic substance that a living organism requires as a precursor of constituent of its organic cell material but which it cannot synthesize from a simple carbon source but must be provided as a **nutrient** is referred to as a "**growth factor**." There are three types of **growth factors in organisms, such as:** vitamins, amino acids, purine & pyrimidine bases.

These substances fulfill specific needs in **biosynthesis** and are therefore required in small amounts relative to the principal cellular Carbon and other sources.

#### (ii) Importance of Carbon

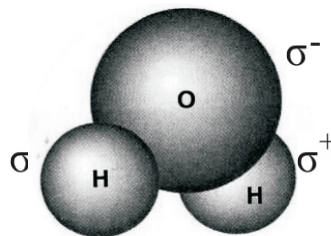
Of the six principal elements required by organisms, only carbon has four covalent single bonds spaced in a **tetrahedral configuration** with an angle of 109.5° between any two bonds. Following this unique property of carbon, organic compounds and **organic molecules** formed can have different kinds of three-dimensional structure.

Except carbon, other elements cannot form molecules of varied shapes and sizes. Thus, the number of carbon-containing compounds is enormous. Certain properties of the element carbon account for the occurrence of so many organic compounds (carbon-containing substances) in nature. These reasons are: First, carbon can establish stable covalent bonds with other carbon atoms to form allotropes, i.e., forms of an element having the same physical state but different properties, for example, graphite, diamond, and *buckminsterfullerene*.

The second reason is that carbon atoms can form stable bonds with other elements. For example, several groups of organic compounds such as alcohols, esters, ketones, aldehydes, and *fatty acids* contain oxygen atoms bonded to carbon. Other carbon bonds may be with hydrogen, nitrogen, sulphur, and halogens. Carbon, in combination with these elements, establishes a great variety of new physical and chemical attributes in organic molecules. Thirdly, carbon atoms can form double or triple bonds with other carbons and with atoms of other elements such as nitrogen to produce different organic molecules with different properties. The key to the chemical characteristics of carbon atoms is in their electron configuration. It has four valence electrons with a little **propensity** to either lose or gain electrons to form ionic bonding. Carbon atoms, instead, complete the octet state by sharing electrons with other carbon atoms or atoms of other elements in four covalent bonds. Each carbon atom acts as a central point from which a molecule can diverge in four directions. This **tetravalence** is behind *carbon's versatility*, which results in the formation of diverse, large, and complex organic molecules. Carbon chains constitute the backbone or skeleton of most organic molecules, and variations in the skeleton are the main source of molecular complexity and diversity that characterize living matter.

#### (b) Water/Composition of Water

Water is the most abundant substance in living systems, making up 70% or more of the weight of most organisms. This important liquid in existence is made up of hydrogen and oxygen covalently bonded together. Water is one of the few compounds that are liquid at the temperatures found over much of the Earth's surface. Unlike most substances, water expands as it freezes. Thus, ice is less dense than liquid water, which explains why ice is formed on the surface of lakes and rivers. Naturally, water occurs as rain, sea water, river water, lake water, and underground water. Pure water can be obtained by the process of distillation. Water molecules are polar because there is an uneven distribution of electrons between the oxygen and hydrogen atoms (see Figure 1.1). The negative pole is near the oxygen atom and the positive pole is between the hydrogen atoms.



**Figure 1.1:** The unequal sharing of electrons causes the water molecule to be polar.

**Source:** Miller and Levine (2006).

*Note:* The hydrogen end of the molecule is slightly positive and the oxygen end is slightly negative.

**(c) Abundance of Water**

Water is one of the most important requirements for life. This is so because life forms are only encountered where there is an abundance of water. The forms in which water exists are quite diverse, as they occur as solid ice, liquid, moisture, mist, and vapour. Living cells either grow in water or are bathed by water. Those that use water as a habitat are known as aquatic organisms, such as fish and other water creatures. Aqueous media are carried by animals and plants as fluids, while in soils they occur as interstitial water or on surfaces as adsorbed water films.

Most of the earth's water is contained in the ocean (97.1-97.6%), whereas much smaller quantities are maintained in polar ice and glaciers (2.1%), ground water (0.3-0.8%), and inland freshwater such as lakes (0.009%) and rivers/streams 0.00009%.

Aquatic systems are unusual in that they resist extreme environmental fluctuations better than either terrestrial systems or the atmosphere. These are due to the unique *properties of water* and include the great solvent power, large *heat capacity*, high *surface tension*, electrical *polarity* with separation of positive (+ve) and negative (-ve) charges and is a permanent *dipole*. The strength of the *polarity* is expressed as the *dipole* moment. The value of the *dipole* moment for water is quite high, approximating  $1.8 \times 10^{-8}$  electrostatic units. Water molecules are polar. Hence, water is an excellent solvent for other polar substances.

**(d) Properties of Water**

**(i) Polarity**

When a water molecule is referred to as polar, it means that the distribution of electric charges (i.e. positive and negative charges) is permanent, with the centres of the charges being separated by a short distance. In a water molecule, instead of being linear (in a straight line), the hydrogen and oxygen atoms are situated asymmetrically. Thus, water is a bent molecule with a  $104.5^\circ$  bond angle. This angular configuration results from the effect of the two lone pairs of electrons around the oxygen atom (the oxygen part of the molecule is negative and the hydrogen part positive) and is responsible for the *polarity* of water. Due to the high *polarity*, water is a good solvent, i.e., it dissolves other polar substances with ease. Most matter on earth are polar and therefore soluble in water. Hence, water is described as a *universal solvent*. This is of high biological importance because all chemical reactions in cells occur in aqueous media.

**(ii) Cohesion**

The strong *polarity* of water molecules ensures that they interact with surrounding water molecules by forming fluctuating hydrogen bonds. *Cohesion* is the attraction between molecules of the same substance, mainly because of hydrogen bonding. *The cohesion* of water causes capillary attraction, which is the ability of water to move upward in a narrow tube. *Cohesion* makes it possible for water to move up the fibers of a plant as water molecules are held together to form a column of water. The surface of water in a graduated cylinder always curves inward at the center because *adhesion* between the water molecules and glass molecules is stronger than the *cohesion* between water molecules.

**(iii) Surface Tension**

The forces that cause the surface of liquid to contract so as to occupy a least space is called **surface tension**. This action results from inward actions of cohesive forces between individual molecules at the surface of the liquid. In water, due to its high **polarity**, these forces are very strong. It pulls down the molecules at the surface and this is of great biological importance. **Surface tension** and strong cohesive forces are associated with the movement of solution in vessels and tracheid plant stems, and allows water insects to walk on the surface of water. Water surface acts like an “elastic skin” that resists deformation when a small weight is placed on it. The water striders take advantage of this property of water. This is because at the water surface, there are only downward and sideways forces whose combined effect stretches the surface of water and makes it behaves like an elastic skin, thereby creating the stretched-membrane effect. However, below the surface of water, upward forces will balance downward force and sideways force will balance out and hence, the resultant becomes zero.

**(iv) High Specific Heat Capacity**

One of the most important **properties of water** from an ecological standpoint is its high specific heat (its capacity to absorb energy in relation to a given temperature change while at a constant volume). This allows water masses to absorb or lose a relatively high amount of heat energy with a corresponding small change in temperature. Hence, water can act as a buffer against extreme temperature fluctuations, which often occur in the surrounding terrestrial environment. Aquatic organisms are subjected to much narrower changes in temperature than land organisms.

**(v) Density – Temperature Relationship in Water**

Unlike most liquids, water is not densest at its freezing point but instead at  $-4^{\circ}\text{C}$ .

This is mainly due to two factors: The tendency (shared by all liquids and gases) for molecules to increase their distances between one another as the temperature increases; The tendency for water molecules to form a highly ordered lattice structure through intermolecular hydrogen bonding as their freezing points are approached. The ice lattice is a somewhat open structure, and molecules are less closely packed than those in liquid water. Therefore, ice at  $0^{\circ}\text{C}$  has a density of approximately  $0.915\text{g/cc}$  and the density of liquid water at the same temperature is  $0.99987\text{g/cc}$ . These results in the **anomalous expansion of water** and the unusual density properties mean that as water cools, it tends to sink as it nears  $4^{\circ}\text{C}$ , whereas ice floats. Therefore, lakes and large bodies of water freeze from the surface downward and very rarely freeze solid.

**(vi) Viscosity**

Water has a high **viscosity** due to interactions between molecules via hydrogen bonding. This has an impact on both water flow and energy expenditure in biological systems. The **viscosity** of a fluid, on the other hand, is a measure of its resistance to deformation at a particular rate. It relates to the colloquial idea of “thickness” in liquids. Syrup, for example, has a greater **viscosity** than water.

**Physical Properties of Water**

Pure water exhibits some physical attributes such as being odourless, tasteless, and colourless. It has a neutral pH at 7.0 and turns white anhydrous Copper Sulphate blue

## 1.4 WATER AS A UNIVERSAL SOLVENT

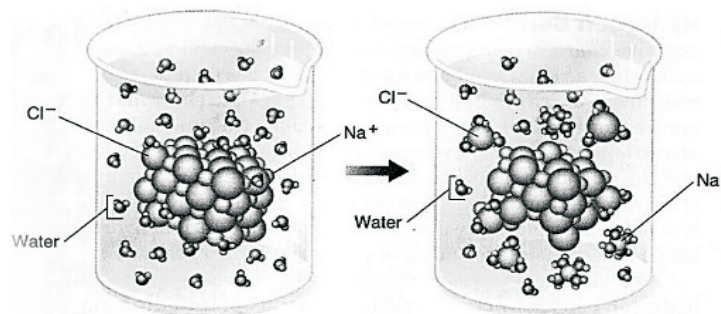
Water is called a **universal solvent** because more substances dissolve in it. However, it is also an efficient solvent because it dissolves a wide variety of substances like ammonia, nitrates, phosphorus, sugars, alcohol, and various organic substances. Water is also covered in the sections on the context of mixtures, solutions, and suspensions.

### (a) Mixture

Natural water is not always pure; it is often found as part of a mixture. A mixture is a material composed of two or more elements or compounds that are physically mixed together but not chemically combined. Salt and pepper stirred together constitute a mixture. So do sugar and sand. The Earth's atmosphere is a gas mixture, and living things are partly made up of gas mixtures.

### (b) Solutions

If crystals of table salt are placed in a glass of warm water, sodium and chloride ions are attracted to the polar water molecules. Those ions break away from the crystal and are surrounded by water molecules, as illustrated in Figure 1.2. The ions gradually become dispersed in the water, forming a type of mixture called a solution, in which all the components are evenly distributed throughout the solution. In a saltwater solution, table salt is the solute (the substance that is dissolved). While water is the solvent (the substance in which the solute dissolves), Water's polarity gives it the ability to dissolve both ionic compounds and other polar molecules, such as sugar.



**Figure 1.2:** Sodium Chloride dissociating in water.

**Source:** Miller and Levine (2006).

*Note:* When ionic compound such as sodium chloride is placed in water, water molecule surround and separate the positive and negative ions.

### (c) Suspension

Some materials do not dissolve when placed in water but separate into pieces so small that they do not settle out. The movement of water molecules keeps the small particles suspended. Such mixtures of water and non-dissolved material are known as suspensions. Some of the most important biological fluids are both solutions and suspensions. The blood that circulates through the body is mostly water, which contains many dissolved compounds. However, blood also contains cells and other undissolved particles that remain in suspension as the blood moves through the body.

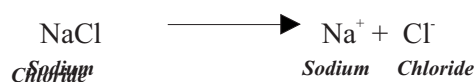
### 1.5 IMPORTANCE OF WATER TO LIFE FUNCTIONS

Water (H<sub>2</sub>O) is vital not only for human beings but also for all living organisms to survive. The importance of water relates to its properties, and the most noticeable of its physical properties is that it is a liquid at room temperature; this is unusual for compounds with molecules of similar atomic composition for example hydrogen sulphide (H<sub>2</sub>S) do not behave like water. Some of the importance of water are discussed below.

- (i). Being liquid at room temperature, water provides an environment for organisms to live in. Water also provides a liquid environment inside cells, where significant metabolic reactions that are key to life take place in solution.
- (ii). Due to their polar nature, water molecules dissolve a wide range of solutes and keep such substances in solution. Water is known to dissolve many more substances than common solvents and is regarded as a **universal solvent**. It is the solvent that transports many essential molecules and other particles around the body. These include nutrients and waste products from the body's metabolic process.
- (iii). The thermal properties are well suited to supporting life. Water helps the body to cope with environmental temperature changes and maintains the body's temperature within a safe and comfortable range. For example, its high specific **heat capacity** (4.2 kJ/g/°C) implies that a lot of energy needs to be gained or lost in order to change the temperature of water, and since an organism is made of 60–70% water, the internal environment inside organisms resists temperature changes that could cause damage. The heat of fusion of water prevents the liquid environment of the cell (protoplasm) from freezing and tearing the cells apart.
- (iv). The adhesive property of water makes water adhere to other substances. Due to this property, water from the soil is able to stick to the root hairs. Also, water molecules are cohesive, making it possible for water to move upward through the very narrow xylem of tall plants, such as trees, against gravity. Due to the cohesive property, a continuous column of water can be pulled up to the top of the trees. These columns of water do not break easily.
- (v). Water is an essential condition for the **germination** of seeds, as it is known to help activate some enzymatic reactions responsible for **germination**.
- (vi). Water is an essential material needed during photosynthesis.
- (vii). Plant turgidity is made possible due to the **turgor pressure** as a result of water build up in plant cells.

### 1.6 SALTS AND INORGANIC IONS

In the body, some of the most common solutes found dissolved in water are mineral **salts**, compounds of metals, and non-metallic **radicals**. It is a fact that when a **salt** dissolves in water, it **dissociates** into its constituent ions. For example:



**Salts** are ionic compounds, and when decomposed by electricity, their free ions enable the passage of electric currents. The important cations are sodium (Na<sup>+</sup>), potassium (K<sup>+</sup>), calcium (Ca<sup>2+</sup>), magnesium (Mg<sup>2+</sup>), copper (Cu<sup>2+</sup>), and iron (Fe<sup>2+</sup> or Fe<sup>3+</sup>). Important anions include chloride (Cl<sup>-</sup>), carbonate (HCO<sub>3</sub><sup>-</sup>), sulphate (SO<sub>4</sub><sup>2-</sup>) and iodide (I<sup>-</sup>). In addition to these major mineral elements, other elements may be present in minute amounts. These trace elements include molybdenum (MO<sub>4</sub><sup>-</sup>) and cobalt (CO<sup>2+</sup>). Some are required by animals, some by plants, while a few by both. Though needed in the smallest quantities, their absence can cause diseases and death.

The important *properties of water* mentioned earlier apply to natural or pure water. However, these properties are somewhat modified by the presence of dissolved salts. This is particularly apparent with sea water, which contains approximately 35 ppt of dissolved salts. Due to the additional dissolved salts in sea water, the specific *heat capacity* is somewhat lowered, *viscosity* is increased and the initial freezing point lowered. The presence of sea salt prevents volume expansion obtained with pure water as it approaches its freezing point. Thus, typical sea water (salinity 35 ppt) increases in density as the temperature decreases until it begins to freeze.

### 1.7 FUNCTIONS OF SALTS AND INORGANIC IONS IN CELLS

The functions of these mineral salts and their derivatives are varied and can be summed up as thus:

- (i) **As constituents of various chemicals:** Nitrogen and sulphur are obtained by plants as nitrates and sulfates. Phosphorus is found in adenosine triphosphate (ATP), and iodine occurs in thyroxine, the thyroid hormone in animals.
- (ii) **As constituents of structures:** Many proteins form structural materials such as connective tissues and fibres in which nitrogen and sulphur are important elements. Nitrogen and phosphorus, as constituents of nucleic acids, are found in the chromosomes; phosphorus in the cell membrane; calcium in the plant cell wall; and calcium and phosphorus in bones.
- (iii) **As constituents of enzymes:** Enzymes are proteins, all of which contain nitrogen. In addition, certain enzymes contain metal ions such as copper or iron.
- (iv) **As metabolic activators:** Certain ions activate enzymes, e.g. magnesium activates enzymes in phosphate metabolism.
- (v) **As constituents of certain pigments:** The two well-known biological pigments are haemoglobin and chlorophyll, which contain iron and magnesium, respectively. Iron is also found in the *cytochromes*, which is of great importance in energy released.
- (vi) **As determinant of electrical impulse:** Cation balance in cells. sodium, potassium and chloride ions are particularly important especially in nerves, muscles and sensory cells where they are involved in the transmission of nerve impulses.
- (vii) **As determinant of Osmotic pressure:** Mineral salts, together with the solutes, determine the osmotic pressure of cells and body fluids. In human, the pressure must not be allowed to fluctuate beyond narrow limits, and much of human's physiology are directed towards preventing this.

### 1.8 CELL ORGANIC MOLECULES

*Organic molecules*, also called biological molecules, or *biomolecules* are the numerous substances produced by cells and living organisms. *Organic molecules* have a wide range of sizes and structures and perform a vast array of functions. The four major types of organic molecules are carbohydrates, *lipids*, nucleic acids, and proteins.

#### (a) Carbohydrate and its Chemical Structure

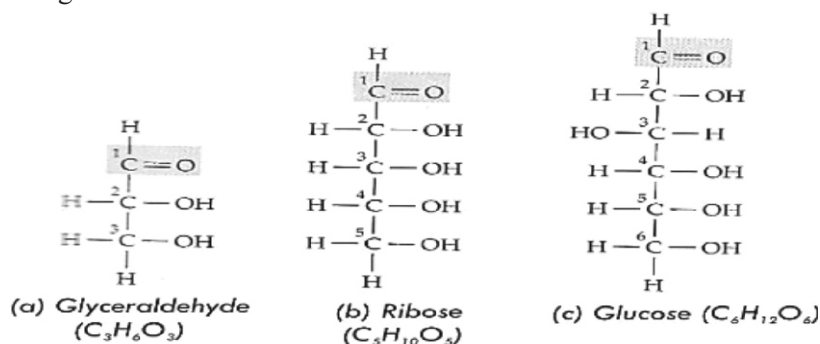
*Carbohydrates* are compounds containing carbon, hydrogen, and oxygen atoms, usually in a ratio of 1:2:1. They are produced primarily in plant cells during photosynthesis and function in both plant and animal cells as a source of energy. When *carbohydrates* react with oxygen, carbon dioxide, water and energy, energy is released. This reaction takes place slowly inside cells. Thus, living things use *carbohydrates* as their main source of energy as well as a major component that makes up their structures. The energy is released through a process called *cellular respiration* in a controlled manner; it is used by the cells for all their activities.

Examples of *carbohydrate* are outlined below:

### Sugars

There are three major groups of sugars: *monosaccharides*, *disaccharides* and *polysaccharides*.

- (I) **Monosaccharides:** These are the simplest *carbohydrates*, which are the basic building block (monomers) of all the more complex carbohydrates. *Monosaccharides* include pentoses (5 carbon atoms, e.g. arabinose and ribose), hexoses (6 carbon atoms, e.g. **glucose**, **fructose**, and **galactose**). Among *monosaccharides*, glucose (corn or blood sugar) and fructose (fruit sugar) are the most common and sweet-tasting sugars. They both have the same chemical formula ( $C_6H_{12}O_6$ ), but their structural arrangements are somewhat different. Glucose is particularly important as it is the main source of energy in living things, and the basic structural units of most complex *carbohydrates* are shown in Figure 1.3. Galactose is commonly found in milk. *Monosaccharides* are mostly reducing sugars.

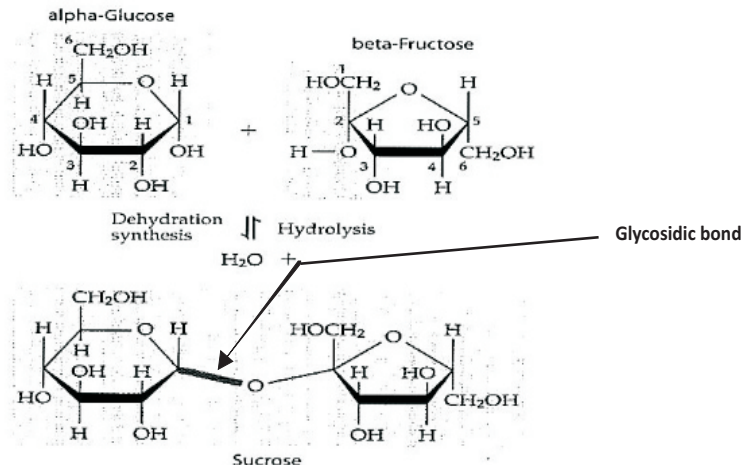


**Figure 1.3:** The Structure of Monosaccharides.

*Source:* Adapted from Ginsburg (1981).

**Note:** Examples of biologically important monosaccharides. (a) Glyceraldehyde, a three-carbon sugar, is an important energy source and provides the basic carbon skeleton for numerous organic molecules. (b) Ribose, a five-carbon sugar, is found in the nucleic acids DNA and RNA and in the energy-carrier molecule ATP. (c) The six-carbon sugar glucose serves important structural and transport roles in the cell. The terminal carbon atom 1.

- (ii) **Disaccharides:** These are composed of two monosaccharides that are bonded together. *Disaccharides* are those carbohydrates that, on hydrolysis with acids or enzymes, give two molecules of monosaccharides which can either be the same or different. *Disaccharides* act as an energy source for the body, just like any other carbohydrate. When we eat foods that contain *disaccharides*, our bodies break them down into simple sugars (monosaccharides) for absorption in the small intestine. The three major *disaccharides* are sucrose, lactose, and maltose. As shown in Figure 1.4, sucrose (table sugar) is formed when glucose and fructose molecules are bound together; maltose (malt sugar) is formed when a molecule of glucose combine with a molecule of galactose. Each molecule of a disaccharide contains two sugar rings.

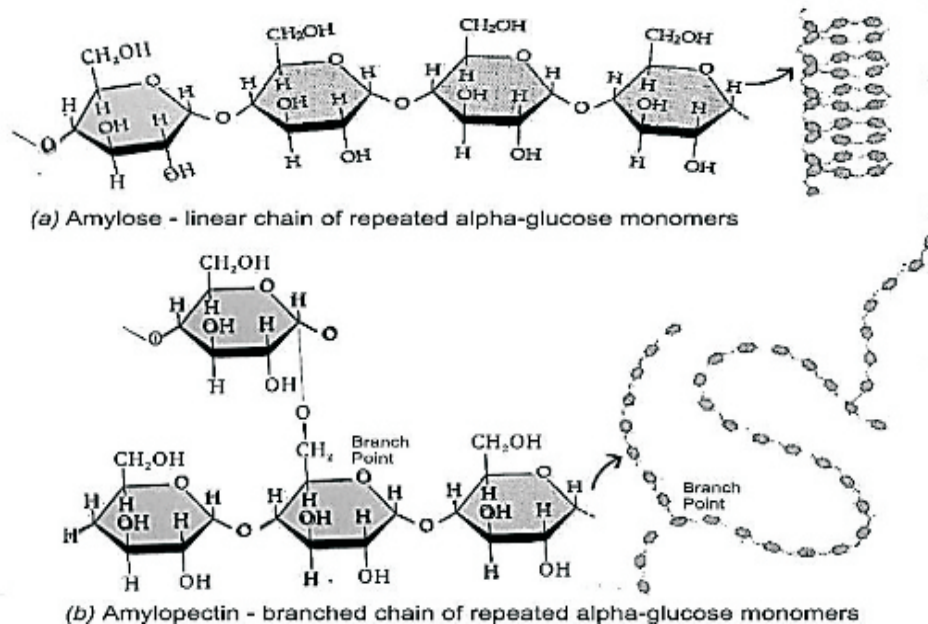


**Figure 1.4:** The Structure of Disaccharide.

**Source:** Adapted from Ginsburg (1981).

***Note:** Sugar is generally transported in plants as the disaccharide sucrose. Sucrose is made up of two monosaccharide subunits, one alpha-glucose and one beta-fructose, bonded in a 1,2 linkage (the carbon 1 of glucose is linked to the carbon 2 of fructose). The formation of sucrose involves the removal of a molecule of water (dehydration synthesis). The new chemical bond formed in the course of this reaction is shown in Figure 1.4 as glycosidic bond. In cells, the formation of this bond, **glycosidic bond**, always involves an activated monomer (such as uridine diphosphate glucose, or UDP-glucose) and is therefore a more complicated, multistep process than is implied here. The reverse reaction – splitting sucrose into its constituent monosaccharides – requires the addition of a water molecule (hydrolysis). Formation of sucrose from glucose and fructose requires an energy input of 5.5 kcal per mole.*

- (iii) **Polysaccharides:** When many monosaccharides combine to form a very long chain of macromolecules, polysaccharides are said to be formed. **Polysaccharides** are the **condensation** products of simple sugars. Examples of polysaccharides are starch, cellulose, glycogen, dextrin, and insulin. **They** are very complex carbohydrates. They act as energy storage molecules in plants (as starch) and in animals (as glycogen) (see Figure 1.5). They also provide support structure in plant cells (cellulose found in cell walls) and insect skeletons (chitin). Each polysaccharide molecule contains hundreds of sugar rings.



**Figure 1.5:** The Structure of Polysaccharide.

**Source:** Raven, Evert and Eichhorn (1999).

**Note:** In most plants, accumulated sugars are stored in the form of starch. Starch occurs in two forms: unbranched amylose and branched amylopectin (a) A single molecule of amylose may contain 1000 or more alpha -glucose monomers with carbon 4 of the next (known as a 1 – 4 glycosidic linkage) in a long, unbranched chain that winds to form a uniform coil. (b) A molecule of amylopectin may contain 1000 to 6000 alpha -glucose monomers or more; short chains of 8 to 12 alpha -glucose monomers branch off the main chain at intervals of 12 to 25 alpha glucose monomers.

## 1.9 COMPARISON OF MONOSACCHARIDES, DISACCHARIDES AND POLYSACCHARIDES

Table 1.2: Comparison of Monosaccharides, Disaccharides and Polysaccharides

	Monosaccharides	Disaccharides	Polysaccharides
i	Monosaccharides are single molecules which act as the building block of disaccharides and polysaccharides	Disaccharides are sugar molecules composed of two monosaccharides	Polysaccharides are carbohydrates made out of many monosaccharides
ii	Water soluble	Water soluble	Insoluble in water
iii	Taste sweet	Taste sweet	No sweet taste
iv	Reducing sugars	Some are reducing sugars	Non-reducing carbohydrates
v	Have a single monomer	Composed of two monomers	Composed of a large number of monomers
vi	Have simple, linear, unbranched structures	Have simple, linear, unbranched or branched structures	Have complex, branched structures
vii	Have a single ring structure	Have two ring structures	Have a number of ring structures

Similarities between *Monosaccharides*, *Disaccharides* and *Polysaccharides* are as follows:

- (i). All three are carbohydrates.
- (ii). All are composed of Carbon, Hydrogen and Oxygen (C, H and O) atoms.

### 1.10 PHYSICAL AND CHEMICAL PROPERTIES OF MONOSACCHARIDES

#### (a) Physical Properties of Monosaccharides

##### (i) Colour and Shape

Monosaccharides are colourless and crystalline compounds.

##### (ii) Solubility

They are readily soluble in water.

##### (iii) Taste

They have sweet taste.

##### (iv) Stereo isomerism

D-glucose and L-glucose are mirror images of each other.

The presence of asymmetric carbon atoms in a compound gives rise to the formation of isomers of that compound. Such compounds, which are identical in composition and differ only in spatial configuration, are called "stereo isomers."

**(v) Optical Isomerism**

A beam of ordinary light may be regarded as a bundle of electromagnetic waves vibrating in all directions perpendicular to the axis of the beam. When such a beam of light is made to pass through a nicol prism, all vibrations except those in one plane are eliminated. This is called plane polarised light. When such a beam of plane polarised light is passed through a solution of an optical isomer, and the plane polarised light is found to rotate to the left, it is described as levorotation, but if the plane polarised light rotates an equal number of degrees to the right, it is described as dextrorotation. This phenomenon, exhibited by asymmetric compounds, is called optical isomerism.

**(vi) Mutarotation**

When an aldohexose is first dissolved in water and the solution is kept in an optical path and plane polarised light is passed, the initial optical rotation shown by the sugar gradually changes until a constant fixed rotation characteristic of the sugar is reached. This phenomenon of change of rotation is called "mutarotation".

**(b) Chemical Properties of Monosaccharide**

Below are chemical properties of Monosaccharides:

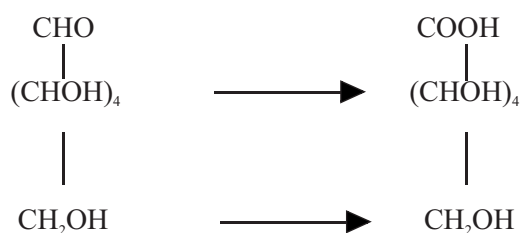
**(i) Glucoside Formation**

**Glucose reacts with methanol in the presence of HCl and gives  $\alpha$  and  $\beta$  glucoside.**

Glucoside formation is due to the reaction of alcohol with glucoside -OH group of Glucose.

**(ii) Oxidation**

Glucose when treated with bromine water, forms gluconic acid. The aldehyde group is oxidised to carboxylic group.

**(iii) Reduction**

Monosaccharides can be reduced by various reducing agents such as sodium-amalgam or by hydrogen under high pressure in the presence of catalysts. The reduction is due to the presence of aldehyde or ketone group. On reduction they yield alcohols.

**(iv) Reaction with concentrated  $\text{H}_2\text{SO}_4$** 

Glucose is treated with concentrated  $\text{H}_2\text{SO}_4$  or HCl, and forms 5, hydroxymethyl furfural which on further heating yields levulinic acid and formic acid.

This reaction is the basis of the colour test, known as **Molish test** for sugars. When pentoses are treated with mineral acids furfural is obtained on heating.

**(v) Ester formation**

They can form esters with carboxylic acids due to the presence of hydroxyl(OH) groups. For example glucose reacts with five molecules of acetic anhydride to form penta acetate derivative. It obviously indicates that the glucose contain five OH groups.

**(vi) Reducing property**

Monosaccharides act as the best reducing agents. They readily reduce oxidizing agents such as ferric cyanide,  $H_2O_2$  and cupric ion. In such reactions, the sugar is oxidized at the carbonyl group and the oxidising agent becomes reduced. Glucose and other sugar capable of reducing certain compounds are called reducing sugars. Glucose reduces Tollen's reagent, Fehling's reagent, Benedict's reagent etc. At the same time glucose is oxidized to gluconic acid.

**(vii) Reaction with alanine**

The aldehyde group of glucose condenses with the amino group of alanine to form **Schiff's base**. Fructose also gives Schiff's base with alanine.

The browning reaction occurs during baking of bread and other mixtures of carbohydrates and proteins is believed to be due to the formation of Schiff's base between the amino groups of proteins and the aldehyde groups of carbohydrates.

**(viii) Fermentation**

Fermentation is the process of converting a larger complex molecule into simple molecules by means of **enzymes** in an anaerobic condition. The products of the reaction are alcohol and  $CO_2$ .

**1.11 GLYCERIDE AND FATTY ACID GROUPS AS THE MAJOR BUILDING BLOCKS OF FATS****Lipids**

**Lipids** are biological molecules that are generally insoluble in water. They are made up of carbon, hydrogen and oxygen atoms, but unlike carbohydrates, have a much higher ratio of carbon: hydrogen: oxygen atoms to hydrogen atoms and oxygen atoms. One particular **lipid** has the formula  $C_5H_{11}O_6$ . Due to large quantities of carbon, **lipids** contain more stored (potential) chemical energy than sugars or other molecules, but this energy is more difficult to liberate for cell use. **Lipids** that are solid at room temperature are called fat; while those that are liquid are called oils. Many lipids are formed when a glycerol molecule combines with fatty acids. Thus, a lipid molecule is made up of **fatty acid** and glycerol. If each carbon atom in the fatty acid component of a **lipid** is joined to another carbon atom by a single bond, the lipid is said to be saturated. The term 'saturated' implies that the **fatty acid** contains the maximum possible number of hydrogen atoms. However, if there is at least one carbon-carbon double bond (i.e.  $C=C$ ) in a fatty acid, the fatty acid is said to be unsaturated. Lipids whose fatty acids contain more than one double bond are termed **polyunsaturated**. **Lipids** such as olive oil which contains unsaturated fatty acids tend to be liquid at room temperature. Cooking oils such as corn oil, sesame oil, canola oil and peanut oil contain polyunsaturated **lipids**.

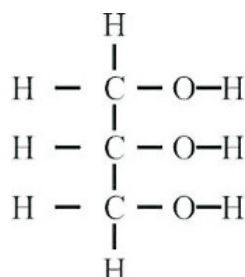
**(a) Importance of Fats and Oils**

- (i) **Sources of energy:** Fats and oils are stores of energy. In cellular respiration, lipids provide about twice as much energy per gram as carbohydrate.
- (ii) **Insulation:** Mammal has a layer of fat under skin. This layer helps to keep the animals warm. Whales and seals which live in Antarctica waters have especially thick layer of fat, called blubber, to protect them from extreme cold.
- (iii) **Protection:** Delicate organs, such as the kidneys are protected by a layer of hard fat.
- (iv) Food, vitamins A, D and E are soluble in fats and oils. Foods containing lipids provide animals with these essential vitamins.

**(b) Saturated and Unsaturated Fats and Oils**

The fats which contain glycerol combined with saturated fatty acids are called saturated fats. Fat which contain glycerol combined with unsaturated fatty acids are called mono unsaturated fats or polyunsaturated fats, depending on the number of double bond, in a molecule. Animal fats contain a large proportion of saturated compounds and are solid, while plant fats contain a large proportion of *unsaturated* compounds and have lower melting points. Many scientists believe that eating a lot of saturated fat increases the risk of heart disease.

**Note that:** Lipids (fats and oils) are mixture of compounds of *glycerol* with *fatty acids* (Figure 1.6). These compound can be saturated (with only single bonds between carbon atoms) or *mono unsaturated* (with a double bond between carbon atoms) or *polyunsaturated* (with more than one carbon-carbon double bond per molecule).

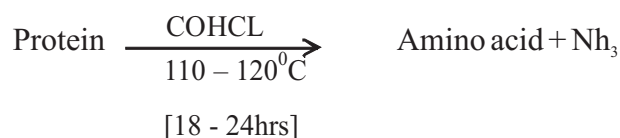


**Figure 1.6:** Structure of Glycerol.

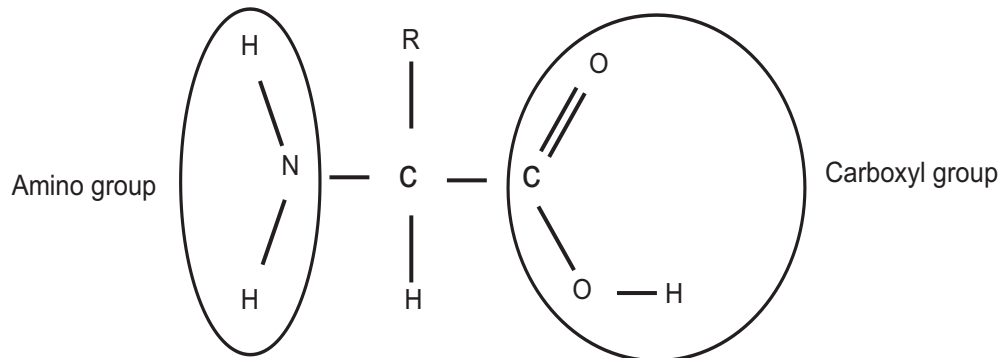
**Source:** Adapted from David (1997).

### 1.12 BASIC UNIT OF PROTEIN (AMINO ACID), ITS STRUCTURE AND FUNCTIONS

- (a) *Amino acids* is an organic molecule that is made up of a basic amino group ( $-\text{NH}_2$ ), an acidic carboxyl group ( $-\text{COOH}$ ); and an organic R group (or side chain) that is unique to each amino acid. Proteins are complex molecules composed of carbon, hydrogen, oxygen, nitrogen and sometimes sulphur and phosphorus atoms. Like carbohydrates and lipids, proteins are composed of simpler units or building blocks which are call *amino acids*. There are more than 20 different kinds of amino acids that bond together covalently in chain like structures to form thousands of different kinds of proteins. The kind of protein formed and the way it will behave depends on its sequence of instructions from the DNA. When protein is hydrolyzed, the products are amino acid and ammonia.




Amino acids consist of two important components: the amino group ( $-\text{NH}_2$ ) found at one end and a carboxyl group ( $-\text{COOH}$ ) found on the other end. The general structure of amino acid showing the R group in the structure is represented in Figure 1.7.



**Figure 1.7:** General formular of Amino acid  
**Source:** Adapted from David (1997)

The R group in the structure determines the type of amino acid  
 If R = H it is Glycine

R = CH<sub>3</sub> it is Alanine

R =  - CH<sub>3</sub> it is phenylalanine

R =  CH<sub>2</sub> it is tyrosine

R =  CH<sub>2</sub> it is tryptophane

Amino acids contain a carboxyl group (-COOH) and amino group (-NH<sub>2</sub>). About 20 different amino acids are found in living things. These differ from each other in only one part of the molecule, shown by the letter “R” in this formula. The common amino acids and their abbreviation are presented below:

**(I) Common Amino Acids**

- Alanine (Ala)
- Arginine (Arg)
- Asparagine (Asn)
- Aspartic acid (Asp)
- Cysteine (Cys)
- Glutamic acid (Glu)
- Glutamine (Gin)
- Glycine (Gly)
- Histidine (His)
- Isoleucine (Ile)
- Proline (Pro)
- Serine (Sen)
- Threonine (Thr)
- Tryptophane (Trp)l)
- Tyrosine (Tyr)
- Valine (Va)

**(ii) Classification of Amino Acid**

- When the compound has one amino and one carboxylic group it is called mono amino and mono carboxylic and if two they are diamino or dicarboxylic amino acid. For example Aspartic acid (Asp) and Glutamic acid (Gluc) are dicarboxylic amino acid whereas lysine (Lys) is a diamino amino acid.
- Attached side chain could be aliphatic or aromatic configuration. For example Tryptophan (Tryp), Tyrosine (Try) and Phenylalanine (Phe) are aromatic amino acids while others are aliphatic, amino acid.
- When in solution some may be basic, acidic or neutral. For example, Histidine (His) is a basic amino acid, Glutamic acid (Gluc), is an acidic amino acid and Glycine (Gly) is a neutral amino acid.
- Sulphur and non-sulphur containing amino acid: Examples of Sulphur containing amino acids are Cysteine (Cys) and Methionine (Met).
- Essential and non-essential amino acid: All essential amino acids are those that cannot be formed by the body, while the non-essentials are those that the body can easily synthesize from available substrates. The numbers of essential amino acids in nature are ten (10) and include Aromatics.
  - Phenylalanine (Phe)
  - Tryptophan (Tryp) – Sulphur containing
  - Methionine (Met) – Branch chain amino acid
  - Valine (Val)
  - Leucine (Leu)
  - Isoleucine (Ile)
  - Lysine (Lys)
  - Histidine (His)
  - Arginine (Arg) – Acid amino acid
  - Threonine (Thr)
- Protein amino acids and Non-protein amino acids  
If an amino acid is present in the body but not present in a protein molecule, it is called non protein amino acid. Example includes ornithine and citrulline.
- Imino acids  
Imino acids are those that contain secondary amino group in their structure. Examples are Proline and Hydroxyproline.

**(iii) Physical Properties of Amino Acids**

**(a) Solubility**

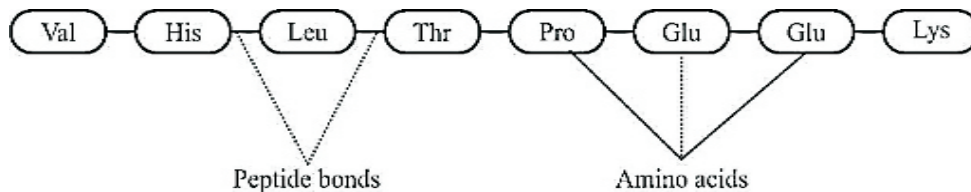
In general, amino acid is readily soluble in water, insoluble or slightly soluble in alcohol and insoluble in diethyl ether. Tyrosine is only slightly soluble in cold water but more soluble in hot water. Cysteine dissolves only with difficulty in both cold and hot water. Proline and hydroxyproline are soluble in alcohol and in ether

**(b) Melting point**

All amino acids are characterized by high melting points usually above 200°C and sometimes 300°C. The high melting point and high solubility suggests that amino acids have highly charged polar groups.

### 1.13 PROTEINS

Proteins consist of very long chains of amino acids that joined to each other. Here is what one section of an important human blood protein looks like (see Figure 1.8).



**Figure 1.8:** Structure of Protein as long chain Amino acids

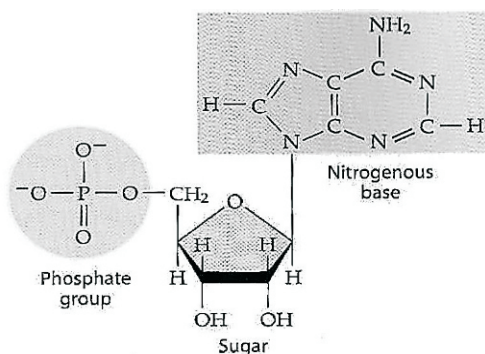
**Source:** Adapted from David (1997).

There is not enough room to show the end of the protein. The chemical bonds by which Amino acids are joined in a protein are called **peptide bonds**. Proteins are compounds which contain carbon, hydrogen, oxygen, nitrogen and sometimes sulphur. Proteins are vital because:

- (i) Proteins are materials from which new tissues are made. If organisms are to grow and if they need to repair damaged tissue;
- (ii) **Enzymes** are proteins. None of the reactions which take place in living things would take place rapidly enough without **enzymes**.
- (iii) Hormones are proteins which control the activities of organisms.
- (iv) Protein can be oxidized during respiration to provide energy and every protein molecule is made from a large number of molecules of amino acids.

### 1.14 NUCLEIC ACIDS

Nucleic acids are naturally occurring chemical compounds that are capable of being broken down to yield phosphoric acid, sugars, and a mixture of organic bases (purines and pyrimidines). Nucleic acids are the main information – carrying molecules of the cell, and by directing the process of protein synthesis, they determine the inherited characteristics of every living thing as shown in Figure 1.9. The two main classes of nucleic acids are **deoxyribonucleic acid (DNA)** and **ribonucleic acid (RNA)**. DNA (deoxyribonucleic acid) is the master blueprint for life and constitutes the genetic material in all free-living organisms and most viruses. RNA is the genetic material of certain viruses, but it is also found in all living cells, where it plays an important role in certain processes such as the making of proteins.

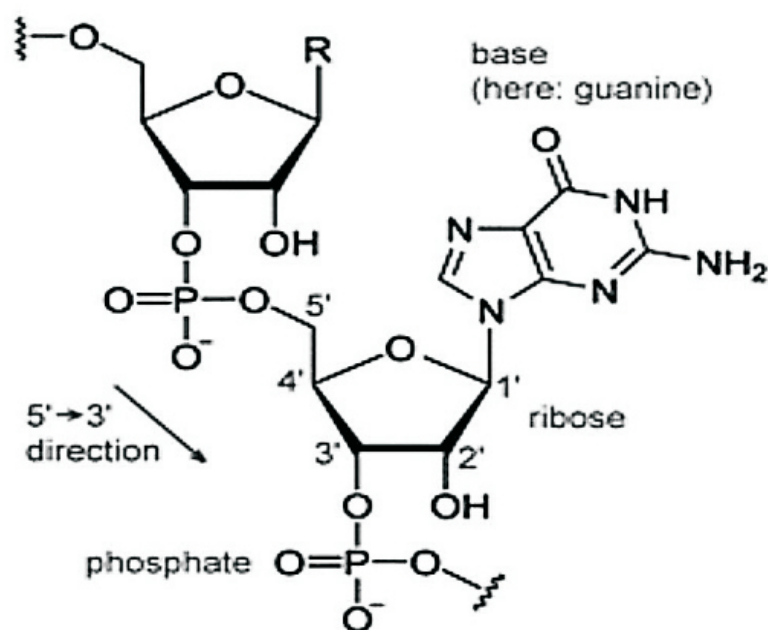


**Note:** A nucleotide is made up of three different subunits: a phosphate group, a five-carbon sugar, and a nitrogenous base. The nitrogenous base in this nucleotide is adenine, and the sugar is ribose. Because there is a single phosphate group, this nucleotide is called adenosine monophosphate, abbreviated AMP.

**Figure 1.9:** A Schematic representation of Nucleotide.

**Source:** Raven, Evert and Eichhorn (1999).

Structurally, nucleic acids are polynucleotides – that is, long chain-like molecules composed of series of nearly identical building blocks called nucleotides. Each **nucleotide** consists of nitrogen – containing aromatic base attached to a pentose (five-carbon) sugar, which is in turn attached to a phosphate group. Each nucleic acid contains four of five possible nitrogen – containing bases: Adenine (A), Guanine (G), Cytosine (C), Thymine (T), and Uracil (U). A and G are categorized as purines, and C, T and U are collectively called pyrimidines. All nucleic acids which contain the bases A, C, and G, T, however, are found only in DNA, while U is found in RNA (Figure 1.10 [a]). The pentose sugar in DNA (2<sup>1</sup> – deoxyribose) differs from the sugar in RNA (ribose) by the absence of a hydroxyl group (OH) on the 2<sup>1</sup> carbon of the sugar ring. Without an attached phosphate group, the sugar attached to one of the bases is known as a **nucleoside**. The phosphate group connects successive sugar residues by bridging the 5<sup>1</sup> hydroxyl group on one sugar to the 3<sup>1</sup> – hydroxyl group of the next sugar in the chain. These nucleoside linkages are called **phosphodiester bonds** and are the same in RNA and DNA (see Figure 1.10 [b]).



**Figure 1.10: (a)** Structure of RNA.

**Source:** Miller and Levine (2006).

**Note:** Just like DNA, RNA is made of monomer called nucleotides. Each nucleotide is made up of three components: a nitrogenous base, a pentose (5c) sugar called ribose and a phosphate group. Each nitrogenous group is a nucleotide attached to a sugar molecule, which is attached to one or more phosphate groups. RNA is a one stranded polymeric molecule that is vital to genetic coding, decoding and regulation. Its primary role is to convert the information stored in DNA into protein.

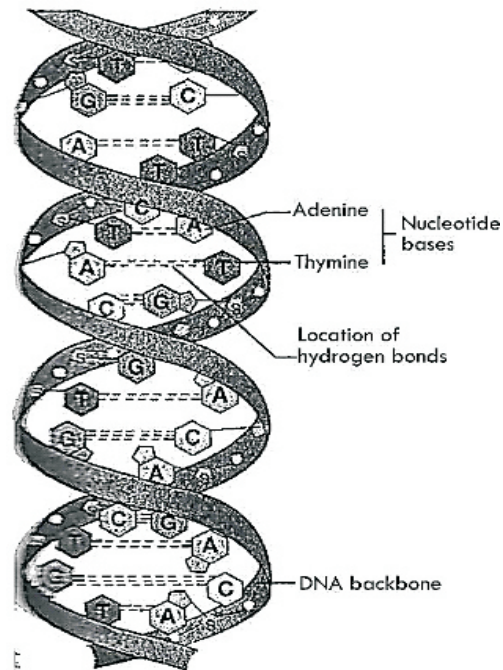


Figure 1.10: (b) Structure of DNA molecules.

Source: Stern (2000).

*Note:* In this enlargement of a small portion of a DNA molecule, the rings of the twisted ladder formed by the two entwined spiraling strands consist of nitrogen-containing bases supported by alternating units of sugar (S) and phosphate (P) molecules. The purines adenine or guanine (A or G) occur opposite the pyrimidines thymine or cytosine (T or C). The purines and the pyrimidines opposite each other are held together by hydrogen bonds linking the nitrogenous bases of the paired molecules. The double helix is 2 nanometers wide.

## 1.15 ENZYMES

**Enzymes** are *biological catalysts* of very high *specificity*. They are proteins that speed up chemical reactions and remain unchanged in the process. They are destroyed by agents that destroy protein and are influenced by changes in pH and temperature. **Enzymes** speed up biochemical reactions by lowering the *activation energy* which is the energy barrier that must be overcome before biochemical reactions take place.

### Why Enzymes are Studied

#### (i) Provision of Energy

The potential chemical energies stored in food substances have to be converted to kinetic energy in cells by the activities of the enzyme. It is the activities of enzymes that help release the stored energy in food.

#### (ii) Biochemical Reactions

**Enzymes** are responsible for bringing about biochemical reactions in cells and tissues of living organisms. These reactions are important in growth and development of the organism.

#### (iii) Regulations and Maintenance

The study of enzymes and the reactions they catalyze enable man to understand the functions of the body and by so doing become able to maintain, regulate and control the functioning of the organism.

#### (iv) Use of Drugs and Chemicals

Through the study of enzymes, man is able to use drugs, toxic substances or pesticides as these substances exert their effects on enzymes and their reactions.

(v) **Fertilizers and Vitamins use**

The study of enzyme enables man to understand application and use of vitamins. These substances assist in enzyme reactions when provided in correct amounts. Enzyme reaction becomes enhanced in the presence of these substances thereby resulting in accelerated growth, good health and higher productivity. On the contrary, if these substances are not provided to the enzymes, the result will be retarded performance and maybe death.

(vi) **Industries**

Many industries such as brewery; processing and storage industries; food production, distilleries, baking and many more have been successful by the actions and knowledge of enzymes and their reactions.

(vii) **Medicine**

In medical practices, man uses drugs and other physical means to regulate and control enzyme reactions for a healthy living.

(viii) **Extraction and Purification of Organic Substances**

Understanding enzymes and their reactions have enabled man to extract and purify many organic substances and make them readily available, for example starch, sugar, protein, vitamin etc.

(ix) **Biochemical Techniques and Procedures**

The extraction and *purification of enzymes* and their substrates have evolved such biochemical techniques as precipitation, filtration, chromatography (paper column, thin layer, ion exchange and gas chromatography), electrophoresis, centrifugation, spectrophotometry and other sophisticated analyzers.

(x) **Studies of isoenzymes** are applied in the identification of closely related species of organisms and in diagnostic medicine.

(xi) **Enzyme and Regulation of Metabolism**

Enzyme reactions regulate and control various biochemical reactions in cells of organisms that bring about harmonious functioning of the whole organism.

(xii) **Disease symptoms and expression of genetic coding** causes of many disease symptoms were understood by the study of enzymes and their reactions. If the coding of amino acid in an enzyme is not properly done by the gene, the expression of effects could be dramatic, for example if the coding of amino acid in tyrosinase by the gene is defective, the structural expression is albinism.

**Properties of Enzymes:**

- (i) Enzymes are not used up at the end of the reaction.
- (ii) They lower the *activation energy* of biochemical reaction.
- (iii) They are thermolabile i.e. destroyed by heat.
- (iv) Their activities are affected by pH of the reaction.
- (v) Enzymes bring about biochemical reaction by forming enzyme substrate-complex.
- (vi) Enzymes are specific in their reaction.
- (vii) Most enzyme reactions are reversible.
- (x) Enzymes are protein in nature.

- (viii) Enzyme speed up biochemical reactions.
- (ix) They are required in small amounts as compared with the amount of substrate.

### 1.16 CO-ENZYMES, COFACTORS AND PROSTHETIC GROUPS

#### (a) Co-enzyme

These are non-protein organic molecules which function as carrier of atoms or groups of atoms during enzyme reactions. They are loosely bound to the enzyme and can be readily separated from enzyme. Many vitamins functions as *coenzymes*, and can be divided into two groups:

- (i). **Those needed for the transfer of hydrogen include:** Nicotinamide Adenine Dinucleotide (NAD), Nicotinamide Adenine Dinucleotide Phosphate (NADP), Flavin Mononucleotide (FMN), Flavin Adenine Dinucleotide (FAD).  
NAD, NADP – the B<sub>3</sub> Vitamins.  
FMN, FAD - The B<sub>2</sub> Vitamins (riboflavin).  
Lipoic acid.  
*Coenzyme Q* (Ubiquinoids).
- (ii). **Those needed for transfer of groups of atoms other than hydrogen, ATP and its derivatives include:** Sugar phosphate, Pantothenic acid – vitamin B<sub>5</sub>, Thymine pyrophosphate – Vitamin B<sub>1</sub>, Pyridoxine – Vitamin B<sub>6</sub>, Folate co-enzyme, Biotin – Vitamin H (also called Vitamin B<sub>7</sub>), Cobalamin – Vitamin B<sub>12</sub>.

#### (b) Cofactors

Are non-protein organic chemical compound that is required by enzyme as catalyst. They are considered as helper molecules for enzymes. Activators metal which assist enzyme in their reactions for example Sodium (Na<sup>+</sup>), (Potassium) K<sup>+</sup>, (Calcium) Ca<sup>+</sup>, (Rubidium) Rb<sup>+</sup>. These are non-protein, helper molecules that are metal ions.

#### (c) Prosthetic Groups

These are non-protein parts of an enzyme molecule which are tightly bonded to the enzyme. Prosthetic groups are integral part of an enzyme and cannot be detached from the enzyme without denaturing the enzymes. Examples include:

- (i) Heme – that binds to *cytochrome* oxidase enzyme.
- (ii) FAD (Flavin Adenine Dinucleotide) – that binds with the enzyme nitrate reductase and *hyponitrite reductase*.
- (iii) Iron that binds to catalase and peroxidase.
- (iv) Cu<sup>2+</sup> that binds with diphenol oxidase.
- (v) FMN (Flavin Mononucleotide)

### 1.17 CHAPTER SUMMARY

- Living organisms draw from the environment all the chemicals which they require for the generation of energy.
- The major chemical elements include carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur.
- Plants also use growth factors in small amounts as organic nutrients.
- Carbon chains constitute the backbone or skeleton of most organic

molecules.

- Water is the most abundant substance in living systems, making up 70% or more of the weight of most organisms.
- It is liquid at the temperatures found over much of the earth's surface, and expands as it freezes.
- Water molecules are polar with surface tension and have a high specific heat capacity.
- In the body, some of the most common solutes found dissolved in water are mineral salts, compounds of metals and non-metallic radicals.
- Water provides a liquid environment inside cells where significant metabolic reactions that is key to life takes place.
- Organic or biological molecules are produced by cells and living organisms, and they include carbohydrates, lipids, nucleic acids, and proteins.
- The main difference between monosaccharides, disaccharides and polysaccharides is that monosaccharides are monomers of sugars and disaccharides are composed of two monomers, whereas, polysaccharides are composed of a large number of monomers.
- Enzymes are proteins that speed up biochemical reactions and are influenced by changes in pH and temperature.
- They are not used up at the end of the reactions and are destroyed by heat.
- Prosthetic groups are non-protein parts of an enzyme molecule, and co-enzymes are non-protein organic molecules that function as carriers of atoms or groups of atoms during enzyme reactions.
- Metal activators which assist enzymes in their reactions are referred to as cofactors.

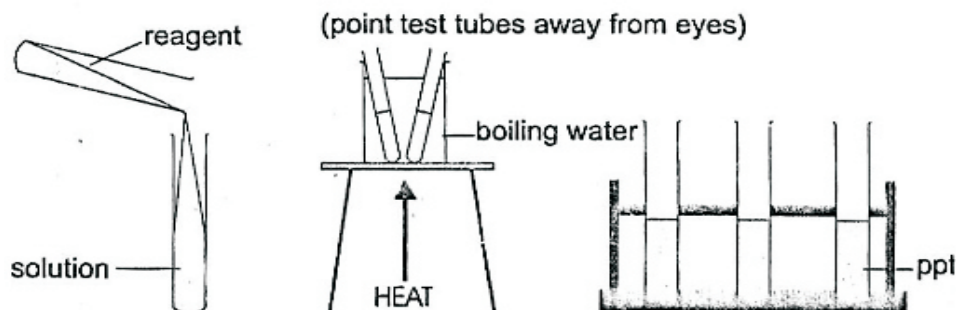
## 1.18 STUDENTS' PRACTICAL ACTIVITIES

### ACTIVITY 1: Food Test

**AIM:** To test for reducing sugar (Figure 1.11).

#### MATERIALS

- (i) Food sample (Banana)
- (ii) Test tube racks
- (iii) Bunsen burner
- (iv) Beakers (500cm<sup>3</sup>)
- (v) Pestle and Mortar
- (vi) Test tubes
- (vii) Benedict's solution OR Fehling's solution(reagent)
- (viii) 1% starch solution
- (ix) 10% glucose solution
- (x) 1% starch solution
- (xi) 10% glucose solution
- (xii) 1% sucrose solution



**Figure 1.11:** Testing for Reducing Sugar.

**Source:** [Adapted from SRC Biology (2006): Philip Harris/itec].

### PROCEDURE

- (i) Half fill a beaker with tap water and place it on a tripod and gauze. Heat the water using a Bunsen burner.
- (ii) Label five test tubes 1-5.
- (iii) Use a pestle and mortar to mash the food sample, add a little water and filter.
- (iv) Put  $1\text{cm}^3$  of solution as indicated in the table on the next page into the labelled test tubes.
- (v) To each tube add  $2\text{cm}^3$  Benedict's or Fehling's solution.
- (vi) Place the test tubes in the beaker of boiling water and heat them for about five minutes.
- (vii) Place the test tubes in a test rack and compare the colours.

### DISCUSSION

- a) What colour changes took place when the reagent (Benedict's or Fehling's) was added to each liquid?
- b) With which of these food materials did the reagent give a decisive colour change on heating?
- c) Outline a method for testing a reducing sugar in a given food sample e.g. Yoghurt.

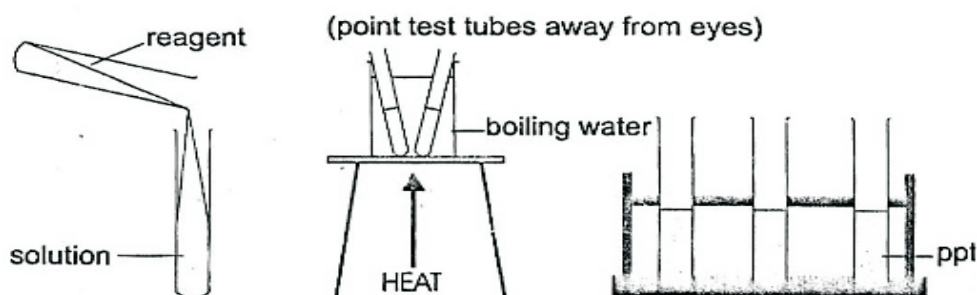
### ACTIVITY 2: Food Test

**AIM:** To test for non-reducing sugar (Figure 1.12).

### MATERIALS

- (i) Spatula
- (ii) Bunsen burner
- (iii) Beaker
- (iv) Beakers ( $500\text{cm}^3$ )
- (v) Test tube racks
- (vi) Test tubes
- (vii) Benedict's solution
- (viii) Fehling's solution
- (ix) 10% sucrose solution
- (x) Hydrochloric acid
- (xi)  $\text{Na}_2\text{CO}_3$  powder

Test tube No.	Solution	Colour change on heating with Benedict's/Fehling's reagent	Inference
1	1% starch		
2	10% glucose		
3	Banana		
4	1% sucrose		
5	Water		



**Figure 1.12:** Testing for Non-Reducing sugar.

**Source:** [Adapted from SRC Biology (2006): Philip Harris/itec].

### PROCEDURE

- (i) Prepare a water bath by half filling a 500cm<sup>3</sup> beaker with water, placing it on a tripod and gauze and heating it to boiling.
- (ii) Next label three test tubes 1-3 near the rim
- (iii) To tube 1 add 2cm<sup>3</sup> of 10% sucrose solution followed by two drops of dilute hydrochloric acid;
- (iv) In tube 2 place 2cm<sup>3</sup> of 10% sucrose solution
- (v) In tube 3 place 2cm<sup>3</sup> of water and two drops only of dilute hydrochloric acid;
- (vi) Put the test tubes in the water bath for two minutes;
- (vii) Remove the tubes from the water bath and allow to cool;
- (viii) With a spatula add Na<sub>2</sub>CO<sub>3</sub> powder to the solutions in test tubes 1 and 3 until effervescence stops (Care!);
- (ix) Add 2cm<sup>3</sup> of Benedict's (Fehling's) solution to each test tube;
- (x) Place all the three test tubes in the water bath for two minutes
- (xi) Record the results in your notebook as follows.

Treatment	Colour Change	Inference
1. 10% sucrose + HCl + Na <sub>2</sub> CO <sub>3</sub> and tested with Benedict's or Fehling's solution		
2. 10% sucrose tested with Benedict's or Fehling's solution		
2. Water + HCl + Na <sub>2</sub> CO <sub>3</sub> + Benedict's or Fehling's solution		

### DISCUSSION

- a) Why was the sucrose solution heated with a dilute acid before it would react with the reagent?

### ACTIVITY 3: Food Test

**AIM:** To test for fats and oil in food substances

### MATERIALS

- (i) Measuring cylinder
- (ii) Test tube rack
- (iii) Vegetable oil
- (iv) Propan-2-ol
- (v) Test tubes
- (vi) Dropping pipette (dry)

### PROCEDURE

#### A. Solubility Test

- (i) Label two test tubes 1 and 2;
- (ii) Pour 2cm<sup>3</sup> of alcohol (propan-2-ol) into each of test tubes 1 and 2;
- (iii) To test tube 1 add one drop of vegetable oil using the dry dropping pipette;
- (iv) Shake the tube sideways until the oil dissolves in the alcohol;
- (v) Add 2cm<sup>3</sup> of water to each of test tubes 1 and 2;
- (vi) Record your results as below.

Test Tubes		Results
1.	Oil dissolved in alcohol + water	
2.	Alcohol + water	

**Cleaning the Tubes:** Keep the oily tubes separate from the others and clean them with hot water and liquid detergent.

**B. Translucent Test**

- (i) Label three pieces of filter paper A-C and treat them as follows:
  - (a) With a dropping pipette place a drop of vegetable oil on it
  - (b) Crush groundnut on it  
Crush a freshly cut piece of yam on it
- (ii) Immediately hold each piece of filter paper up to the light and record your observations;
- (iii) Leave each in the air for 10 minutes to dry and observe as in 2 above. Record your observations and comment on your results.

**DISCUSSION**

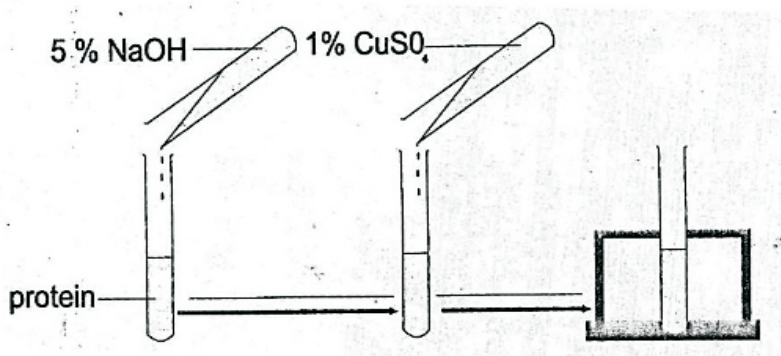
- a) Highlight the differences between the contents of tubes 1 and 2 in experiment A?
- b) Which of the food substances in experiment B (yam, groundnuts) contained oil? Give reasons for your answer.

**ACTIVITY 4: Food Test**

**AIM:** To test for protein using Biuret test (Figure 1.13).

**MATERIALS**

- (i) Pestle and mortar
- (ii) Test tubes
- (iii) Dropping (iv) Pipette (dry)
- (v) Food substances i.e. egg, milk, onion, smoked herring, beans
- (vi) 1%  $\text{CuSO}_4$  solution
- (vii) 5% NaOH solution



**Figure 1.13:** Testing food for proteins using the Biuret test.

**Source:** [Adapted from SRC Biology (2006): Philip

**PROCEDURE**

(i) In your notebook draw up a table like one below

Food	Result on adding NaOH and CuSO	Inference
Egg white		
Milk		
Onions		
Smoked Herring		
Beans		

- (i) Label five test tubes (1-5);
- (ii) Using the pestle and mortar crush the solid food in small quantity of water and pour 2cm<sup>3</sup> of the solution into a test tube. If the food is a liquid pour 2cm<sup>3</sup> of it into test tube
- (iii) Add 5cm<sup>3</sup> of 5% sodium hydroxide solution
- (iv) Add 5cm<sup>3</sup> 1% copper(II) tetraoxosulphate (VI) solution (Biuret solution) and shake the tube gently sideways to mix the contents
- (v) Return to the rack and wait for a few seconds.
- (vi) Record the results in the table in your notebook

**DISCUSSION**

- a) In which of your samples do you think protein is fairly abundant?
- b) If a food sample gives a violet colour with the Biuret test does this mean that it contains only proteins?

**1.11 TUTOR MARKED ASSESSMENT QUESTIONS**

HAVING READ THROUGH CHAPTER ONE, ANSWER THE FOLLOWING QUESTIONS IN THE SPACES PROVIDED.

1. Give the Physiological Functions of the following Elements found in the Cell of Living Organisms.
  - (a) Calcium (Ca)
 

.....
  - (b) Phosphorus (P)
 

.....
  - (c) Carbon (C)
 

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  - (d) Nitrogen (N)

4 ×  $\frac{1}{2}$  = 2Marks

2. (a) List **Four** forms in which Water occur naturally on Earth.

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$4 \times \frac{1}{2} = 2$  Marks

(b) Why are Water Molecules Polar? and give the value of Dipole Moment.

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(c) Give a good reason why Water is a Universal Solvent.

$2 \times \frac{1}{2} = 1$  Marks

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$2 \times \frac{1}{2} = 1$  Marks

(d) State **Four** functions of Mineral Salts as Inorganic ion in Cells.

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$4 \times \frac{1}{2} = 2$  Marks

3. (a) What is an Organic Molecule?

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(b) Mention **Four** Major Organic Molecules Produce by Cell of Living Organism.

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$4 \times \frac{1}{2} = 2$  Marks

- (c) State Two Similarities between Monosaccharide, Disaccharide and Polysaccharide.

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$2 \times \frac{1}{2} = 1$  marks

- (d) List **Six** Physical Properties of Monosaccharides.

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$6 \times \frac{1}{3} = 2$  Marks

4. . Explain **Two** Chemical Properties of Monosaccharides under:

- (a) Ester Formation

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$2 \times \frac{1}{2} = 1$  Marks

- (b) Fermentation

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$2 \times \frac{1}{2} = 1$  Marks

- ) Draw and label the chemical structure of a Nucleotide to show the **Three** different sub units.

Drawing  $3 \times \frac{1}{3} = 1$  Marks  
Labeling  $4 \times \frac{1}{2} = 2$  Marks

(d) Explain briefly the term Nucleotide.

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**$4 \times \frac{1}{2} = 2$  Marks**

(a) What are Amino acids?

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**$2 \times \frac{1}{2} = 1$  Marks**

(b) List **Ten** Essential Amino acids in Nature.

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**$10 \times \frac{1}{2} = 5$  Marks**

(c) What are Enzymes?

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**$2 \times \frac{1}{2} = 1$  Marks**

(d) State **Four** Properties of Enzymes.

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**$4 \times \frac{1}{2} = 2$  Marks**

6. (a) What are Lipids?

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**$2 \times \frac{1}{2} = 1$  Marks**

(b) State **Six** Importances of Fat and Oil.

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**$6 \times \frac{1}{2} = 3$  Marks**

(c) Draw and Describe briefly the structure of RNA molecule.

**Drawing -  $4 \times \frac{1}{2} = 2$  Marks**

**Labeling -  $4 \times \frac{1}{2} = 2$  Marks**

(d) Distinguish Co-enzymes into two main groups:

(i) Those needed for transfer of hydrogen.

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$3 \times \frac{1}{2} = 1\frac{1}{2}$  Marks

(ii) Those needed for transfer of groups of atoms other than hydrogen, ATP and its derivatives.

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$3 \times \frac{1}{2} = 1\frac{1}{2}$  Marks

## Chapter Two

# CELL DISCOVERY, DEVELOPMENT AND LEVELS OF ORGANIZATION

Dr. Christiana O. Edet Umoh & Dr. Ubong E. Harrison

### 2.1 INTRODUCTION

**B**oth living and non-living things are composed of molecules made from chemical elements such as carbon, hydrogen, oxygen, and nitrogen. The organization of these molecules into cells is one feature that distinguishes living things from all other matter. The cell is the smallest unit of matter that can carry on all the processes of life. Every living thing, from the tiniest bacterium to the largest whale, is made of one or more cells. Prior to the 17th century, no one knew that cells existed since they were too small to be seen with the naked eye. The invention of the microscope allowed Robert Hooke (1665) and Antonie Van Leuwenhoek (1674) to see and draw the first "cell," a term coined by Hooke to describe the cells in a thin slice of cork that reminded him of the rooms where monks lived. The idea that all living things are made of cells was put forward in about 1840 and 1855. The "Cell Theory," i.e., "cells only come from other cells," contradicts the earlier theory of "*Spontaneous Generation.*" All living organisms are composed of cells. And all including humans, also begin life as a single cell. This single cell divides repeatedly until it develops into an organism, often consisting of billions of cells. During the first few hours of any organism's development, the cells all look alike, but changes soon take place, not only in the appearance of the cells but also in their function. Some modifications, for example, equip cells to transport food and water, while other cells become modified for the secretion of various fluids such as resin or nectar, and also give strength to tissues such as wood. Some cells may live and function for many years, while others mature and degenerate in a few days. This chapter examines the definition of cell, the two basic types of cells, the cell as a living unit, common *features of cells*, cell size and shape, cell organization, viruses as a bridge between living and non-living things, and the characteristics of living things that clearly demonstrate that the cell is a living unit. Organization is one of the defining features of living things. Organisms are organized according to a hierarchy of structural cell levels as shown below, with each level building on the one below it. Atoms are organized into complex molecules such as proteins. These form the components of cells. Some organisms consist of single cells, but others are collections of many cells of different types, organized together into tissues and organs. This type of hierarchical organization allows the grouping of particular specialized cells together to perform a particular function.

### 2.2 LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- (i) Review the background of cell biology.
- (ii) State important historical events in cell biology.
- (iii) Discuss the history of cell discovery.
- (iv) State modern and exception of the cell theory.
- (v) Define cell and list all the cell types.
- (vi) Examine cell as a living unit.
- (vii) Highlight common features of cells.
- (viii) Explain the level of organization in organism.
- (ix) Enumerate the advantages of complexity in cellular organization.
- (x) Highlight the advantages of simple cellular organization.
- (xi) List characteristics of living things which clearly demonstrates that cell is a living unit.

### 2.3 CYTOLOGY: A STUDY OF CELL BIOLOGY

**Cytology** is a branch of biology that deals with the different structures and functions of the cell. It focuses mainly on the idea of the cell as the basic unit of life. Cell biology received a boost from the discovery of cell appearances, multiplication and how their various components perform and integrate varieties of functions.

The knowledge explains the structure, organization of the **organelles** they contain, their physiological properties, metabolic processes, signaling pathways, life cycle, and interactions with their environment.

The mid-20th century development of **electron microscopes** further spurred cell research and led to a vast new insight into cells and new forms of cell research that continues to the present. Consequently, all the **metabolic reactions** of living cells are controlled by biological catalysts called enzymes, which are globular protein molecules. Knowledge on the properties and functioning of enzymes is necessary in order to understand how these **metabolic reactions** proceed. In multicellular organisms, cells are aggregated into tissues, tissues form organs, organs form part of organ-system and an organism consists of a number of co-ordinated organ-systems.

Knowing the components of cells and how cells work is fundamental to all biological sciences. It is also essential for research in bio-medical fields such as cancer and other diseases. Research in cell biology is closely related to genetics, biochemistry, molecular biology, immunology and developmental biology.

### 2.4 CELL DISCOVERY: HISTORICAL PERSPECTIVES

A Dutchman named Zacharias Jeussen whose expertise was making spectacles produced the first compound microscope in 1590. This microscope and others manufactured at that time had lenses of poor quality. **Single-lens microscopes** came into existence around 1630 and the oldest literature in English alluding to microscopic examination is that of Nathaniel Highmore in 1651. The first English book devoted to microscopy was published in 1664. A year after, 1665, Robert Hooke curator of instruments for the Royal society of London published his celebrated Micrographia. In the book, Hooke described various discoveries made with both his compound microscope and magnifying glasses. His discoveries included the presence of “cells” in cork, describing eukaryotic microorganisms such as fungi growing on leather and rust fungi growing on the surface of leaf.

The first person to publish accurate observations using the microscope was another Dutchman, from Deft, called Antonie Van Leeuwenhoek (1632-1723). He earned a living as a draper, but uses his spare time to construct simple microscopes made up of double convex glass lenses held between metal plates. The **magnification** of his lenses ranged from 50 - 500 times. Leeuwenhoek succeeded largely due to his skill as an instrument maker and the quality of lens; his ability to handle instruments; his way of mounting and illuminating specimens (at 45° angle to provide a form of dark-field microscopy in which specimens appeared as bright objects against a dark background); his curiosity and the fact that he was wealthy and had the time for research; the constant communication of his findings with members of the Royal Society of London.

When Hooke examined a slice of cork, he observed a network of tiny box-like compartments “cellulae”, a Latin word meaning little rooms. What Hooke observed were not cells though, but empty cell wall of dead plant tissues. The works of Hooke and Leeuwenhoek in association with the Royal Society of London laid the foundation for the development of the concept of cell.

In the intervening years of the 17th century, much was not achieved in the study of cells largely because of the limited **resolution of microscopes** of those days and essentially also; the descriptive nature of the biology of that time was based on observations without explaining the complicated details.

By the 1830s improved lenses were introduced and led to higher resolutions and better *magnifications*. About that year, the English botanist, Robert Brown discovered that every plant cell he observed possessed a rounded structure, which he referred to as nucleus. In 1838, Mathias Schleiden came to the conclusion that all plant tissues were made up of cells. A year later, Theodore Schwann reported fundamental similarity between plant and animal cells. Brown and Schleiden inferences provided the basis for the understanding of the importance of cells and cell biology in a single unified theory of cellular organization. Schwann postulated that:

- (i) All organisms consist of one or more cells;
- (ii) Cell is the basic unit of structure for all organisms;  
In 1855, Rudolf Virchow concluded that cells arose in only one pattern i.e. by division of pre-existing cells. Virchow then encapsulated this in the third tenet of Schwann postulate.
- (iii) All cells arise only from pre-existing cells.

The three tenets above formed what was called the cell theory. However, further researches revealed more attributes of the cells thus the list of tenets in what is referred to as the *modern cell theory*.

As with the rapid growth of molecular biology in the mid-20<sup>th</sup> century, cell biology research exploded in the 1950's. It became possible to maintain, grow and manipulate cells outside of living organisms. The following historical events are important in discussing cells and cell theory.

## 2.5 SOME HISTORICALLY IMPORTANT EVENTS IN CELL BIOLOGY

1590	<b>Jansen</b> invented the compound microscope, which combines two lenses for greater magnification.
1665	<b>Robert Hooke</b> , using an improved compound microscope, examined cork and used the term 'cell' to describe its basic units. He thought the cells were empty and the walls were the living material.
1632-1723	<b>Antonie van Leeuwenhoek</b> , using a good quality simple lens (Mag. X 200), observed nuclei and unicellular organisms, including bacteria. In 1676, bacteria were described for the first time as 'animalcules'.
1700-1800	Further descriptions and drawings published, mainly of plant tissues, although the microscope was generally used as a toy.
1827	<b>Dolland</b> dramatically improved the quality of lenses. This was followed by a rapid spread of interest in microscopy.
1831-3*	<b>Robert Brown</b> described the nucleus as a characteristic spherical body in plant cells.
1838-9*	<b>Schleiden</b> (a botanist) and <b>Schwann</b> (a zoologist) produced the 'cell theory' which unified the ideas of the time by stating that the basic unit of structure and function in living organisms is the cell.
1840*	<b>Purkyne</b> gave the name <i>protoplasm</i> to the contents of cells, realizing that the latter were the living material, not the cell walls. Later the term cytoplasm was introduced (cytoplasm + nucleus = <i>protoplasm</i> ).
1855*	<b>Rudolf Virchow</b> showed that all cells arise from pre-existing cells by cell division.
1866	<b>Haeckel</b> established that the nucleus was responsible for storing and transmitting hereditary characters.
1866-1888	Cell division studied in detail and chromosomes described by <b>Flemming</b> .
1883	<b>Andreas Franz Wilhem</b> named discrete bodies within the green plant as Chloroplasts.

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1890	A German scientist <b>Richard Aitman</b> discovered Mitochondria.
1898	<b>Golgi</b> first sees and describes the Golgi apparatus by staining cells with silver nitrate.
1887-1990	Improvement in microscopes, fixatives, stains and sectioning. The beginning of experimental Cytology started to become experimental. <b>Cytogenetics</b> , with its emphasis on the functioning of the nucleus in heredity, became a branch of cytology.
1900	<b>Mendel's</b> work, forgotten since 1865, was rediscovered giving an impetus to cytogenetics. Light microscopy had almost reached the theoretical limits of resolution, thus slowing down the rate of progress.
1930s	Electron microscope developed, enabling much improved resolution.
1946 to present	Electron microscope became widely used in biology, revealing much more detailed fine structure in cells called ultrastructure.
1965	<b>Christian de Duve</b> and his colleagues use a cell-fractionation technique to separate peroxisomes, mitochondria, and lysosomes from a preparation of rat liver.

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*\*Significant events in the development of the cell concept. \*cytology - the study of cells, especially by microscopy.*

*\*cytogenetics- the linking of cytology with genetics, mainly relating structure and behavior of chromosomes during cell division to results from breeding experiments.*

*Source:(Taylor et al,1997).*

## 2.6 MODERN CELL THEORY

The cell theory is very important in biology because it points out the basic similarities among the diverse forms of living things. It can be seen from the cell theory that all organisms are related in structures and function, because they are made of cells with similar structures and functions. The cell theory allows us to compare and to make predictions about organisms.

Let's examine the following statements that represent the Modern cell theory:

- (i) All known living things are made up of cells;
- (ii) The cell is the structural functional unit of all living things;
- (iii) All cells arise from pre-existing cell's division (Spontaneous generation does not occur);
- (iv) Cells contain hereditary information which is passed from cell to cell during cell division;
- (v) All cells are basically the same in chemical composition;
- (vi) All energy flow (metabolism and biochemistry) of life occurs within cells;
- (vii) All cells are capable of self-regulation;
- (viii) All cells are able to respond to stimuli.

## 2.7 EXCEPTIONS IN MODERN CELL THEORY

- (i) Difficulty exists when the concept of cell theory is applied to viruses.
- (ii) Viruses are defined as infectious sub cellular and ultra-microscopic particles.
- (iii) Viruses cannot be visible without the aid of **electron microscope**.
- (iv) Viruses lack the internal organization which is the characteristics of a cell
- (v) Due to these properties viruses do not easily fit in the definition of a cell and are described as "**Primitive organism**" that has not reached a cellular state.

- (vi) Other organisms which do not fit in the definition of cell theory are: Protozoan, fungus and algae.

## 2.8 CELL AND CELL TYPES

A cell is defined as a unit of *protoplasm* bounded by a plasma or cell membrane and possessing a nucleus. *Protoplasm* is the life giving substance and includes the cytoplasm and nucleus. The cytoplasm contains *organelles* such as ribosomes, mitochondria, Golgi bodies, plastids, lysosomes and endoplasmic reticulum. Plant cells have in their cytoplasm large vacuoles containing non-living inclusions like crystals and pigments. Bacteria have neither *organelles* nor a well formed nucleus.

Every cell has three major components: i.e. Plasma membrane, cytoplasm and DNA (naked in bacteria and covered by a membrane in all other organisms). All living things can be grouped according to the types of building blocks they are made up of. Most organisms are made up of one or more cells. Cells can be divided into two basic sorts; the *prokaryotes*, which are simple cells and the *eukaryotes*, which are complex in their structure. The eukaryotes can be further divided into the following cell types belonging to protists, fungi, plants and animals.

Viruses are non-cellular and have no *cellular machinery* of their own. They are considered by some scientists to be non-living and by others to be capable of life (inert rather than non-living). All cells must secure a source of energy, if they are to survive and carry out their metabolic processes. Some called *autotrophs* are able to obtain energy from a source that is from the physical environment, by using light or chemical energy. Other types of cells, called *heterotrophs*, need to obtain energy from other living organisms or their dead remains.

### (a) Two Basic Types of Cells

The *Cytologists* recognize two basic types of cells. Organisms which do not possess a well formed nucleus are *prokaryotes* such as bacteria. Other organisms possess a well-defined nucleus, covered by a nuclear membrane and they are called *eukaryotes*.

### (b) Cell as a Living Unit

The cell is the unit of life that make-up living organisms e.g man and every other living thing. The cell level of an organism is where the metabolic process occurs that keep the organism alive. That is why the cells are called the fundamental unit of life. Cells are capable of converting fuel (food) to usable energy. Therefore, cells do not only make-up living things; they are living things themselves.

### (c) Common Features of Cells

All cells have been found to show some characteristic features in common.

- (i). They utilize extraneous energy to organize atoms and molecules from the external environment and synthesize *macromolecules* typical of their own structure. This is called synthetic activity.
- (ii). The information for their synthetic activities is perpetuated through repeated cycles of multiplication.

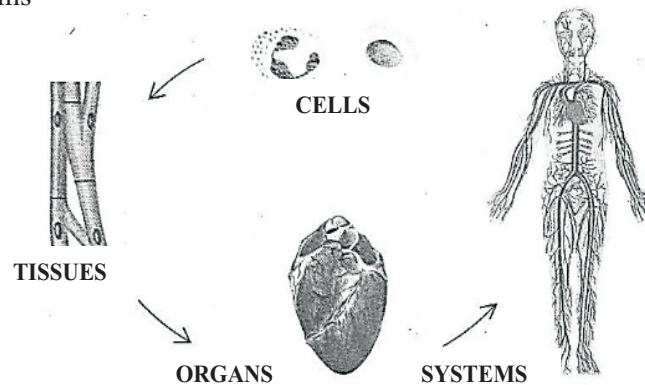
- (iii). Cells control their internal environment in such a way as to create the most suitable conditions for their metabolism.
- (iv). They regulate their component reactions so that these work in harmony. It should be noted that in multi-cellular organisms, cells operate in groups in a harmonious manner.

Cells vary in Size and Shape. The largest single cells such as, ostrich eggs, single cell organism like *Acetabularia* and nerve cells may be ten or more centimeters in length. The smallest micro-organisms such as Mycoplasma are less than  $10^{-3}$  or 1/1000 m.m.

## 2.9 LEVELS OF ORGANIZATION IN ORGANISMS

Biologists have identified levels of organization that make it easier to describe the cells within a multi-cellular organism(see Figure 2.1). The levels of organization in multi-cellular organisms are:

- (i). Cells
- (ii). Tissues
- (iii). Organs
- (iv). Organ-systems



**Figure 2.1:** The organization of a human system.

**Source:** Ramalingam (2005).

### 2.9.1 Cells

Organisms are grouped on the basis of their levels of organization. The cell as one of the levels of organization is the simplest among these categories. Organisms which exist at **cellular level** could exist as a single (one cell) cell, **colonial cells**, **filamentous cells** and complex multi-cellular cells. Most single cell organisms are free living and these include *Chlamydomonas*, *Amoeba*, *Paramecium*, *Plasmodium* and *Entamoeba* (parasitic) and Yeast. **Colonial cells** are cells that associate to form colonies. Usually individual cells aggregate together and secrete a gelatinous matrix into which they are embedded to carry out life processes. Examples of such cells are *Volvox*, *Pandorina* and *Eudorina* (all algae) and the Slime Mould *Dictyostelium* (a fungus). **Filamentous cells** are cells that join end to end to form filament as found in *Spirogyra*, *ulvothrix* (non branching filamentous green algae), *Zygnema*, *Oedogonium* etc.

Complex multi-cellular cells are common among higher plants and animals cells. These cells are thus part of the living organism, examples of such cells include: cheek cells, onion root tip, and epidermal cells. The study of the microscopic appearance of cells, especially for the diagnosis of abnormalities and malignancies is called **cytology**.

### 2.9.2 Tissues

A tissue is made up of structurally similar cells performing the same functions. It is a group or layer of similar specialized cells which together perform certain special function. The study of the structure and arrangement of tissues is known as Histology. In multicellular organisms tissues are classified into Plant tissue and Animal tissue.

#### (a) Plant Tissues:

Multicellular plant tissues can be divided into two major groups

- (i) The meristematic tissue
- (ii) The permanent tissue

#### Meristematic Tissue

The **meristematic tissues** are made up of mature cells and constitute the region of active cell division which means they are made up of embryonic undifferentiated cells capable of cell division. As the plant develops many regions become specialized for functions and cease the reproduction of new cells. The cell division is then confined to undifferentiated tissues called meristem. The characteristics of **meristematic tissues** are:

- (i) The cells appear very small;
- (ii) They have thin walls;
- (iii) They are rich in cytoplasm, thus, have small vacuole;
- (iv) They lack intercellular spaces.

The **meristematic tissues** are found in the growing tips of roots and stems and thus, are called **apical meristems** responsible for increase in length of the plant body. Meristematic cells are also found in the **periphery** of the roots and stems and are responsible for increase in girth.

**Permanent Tissue:** This is classified as: (Surface Tissue, Fundamental tissue and **Vascular tissue**)

#### (i) Surface Tissue

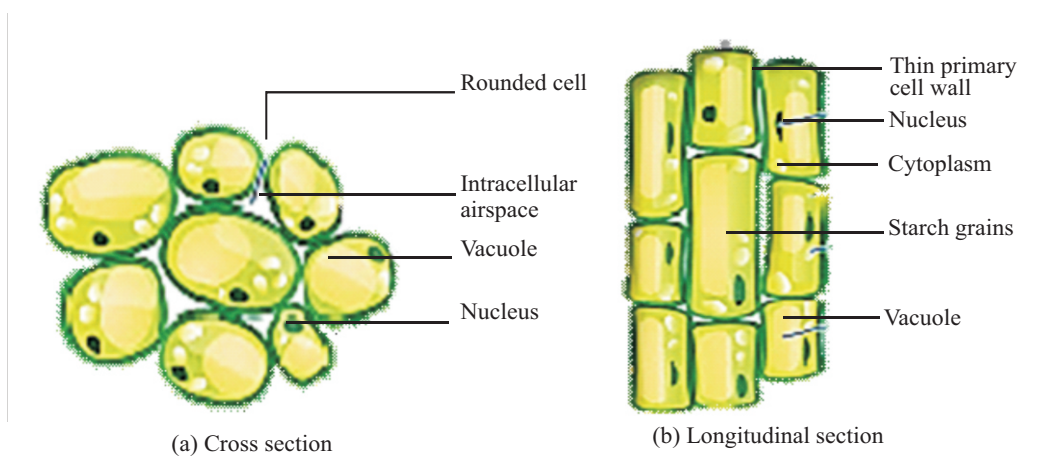
Surface tissue forms the protective outer covering of the plant body and is comprise of epidermis which forms (i) the principal surface tissue of roots, fruits and stems of both young and **herbaceous** adult plants, and (ii) surface of leaves which is often one cell thick and flat or thick in some plants found in dry habitat.

#### (ii) Fundamental tissue

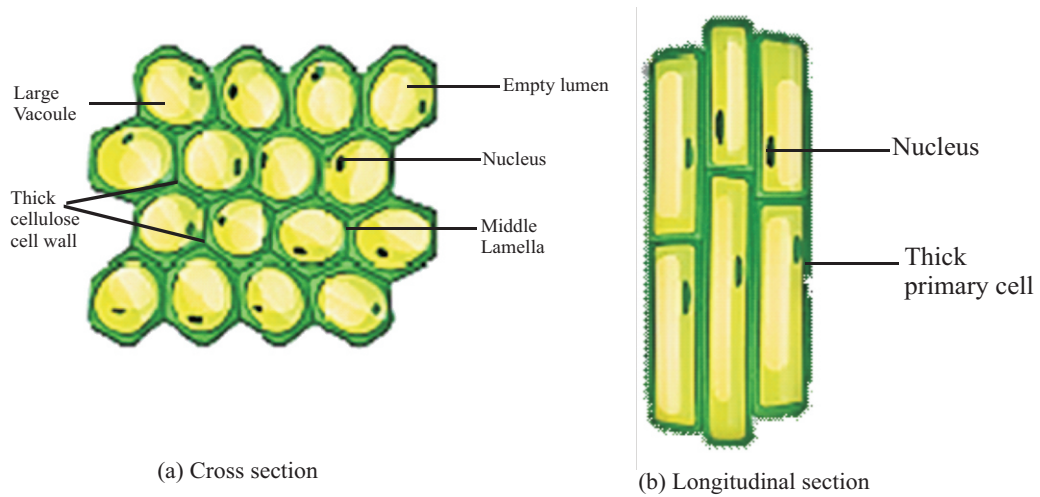
Fundamental tissues are those tissues that are neither surface tissue nor **vascular tissue**. They are made up of parenchyma tissue cells, collenchyma tissue cells, sclerenchyma tissue cells and endodermis tissue cells.

**Parenchyma** is a packing tissue in plants with large vacuoles; cylindrical roundish cells with flattened surfaces found in the root, stem and leaf (see Figure 2.2). The parenchyma tissue cells frequently contain chloroplast and carry out photosynthesis. Non-green parenchyma tissue cells are usually for storing food and water. Collenchyma tissues have cells that possess reinforcing thickening in their corners and are found in stems of herbaceous plants (see Figure 2.3).

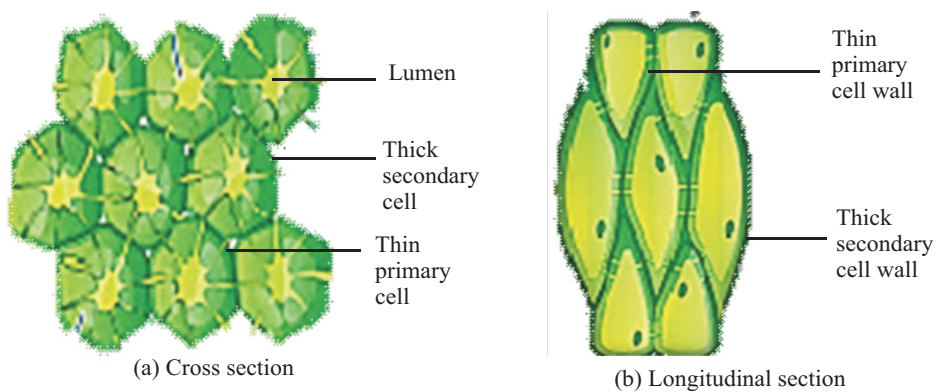
The sclerenchyma tissue cells have thick wall cells and are found in the stems (see Figure 2.4) while the endodermis tissue cells are found around and surrounding the vascular tissue core of roots.



**Figure 2.2** Structure of Parenchyma cells from herbaceous plant in cross and longitudinal sections



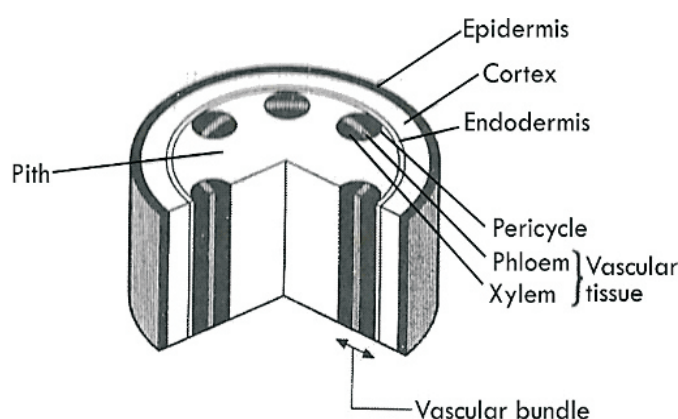
**Figure 2.3** Structure of Collenchyma cells from herbaceous plant in cross and longitudinal sections



**Figure 2.4** Structure of Sclerenchyma cells from herbaceous plant in cross and longitudinal sections  
**Source:** Taylor, Green and Stout (1997).

**(iii) Vascular Tissue**

The *vascular tissue* is also known as conductive tissue. Cells of this tissue function as tube or duct within which water and other soluble substances are conducted about plant body. There are two main types of *vascular tissue* i.e. the *xylem* and phloem. The *xylem* transports water and dissolved substances upward from soil and provides support particularly to the aerial parts of plants. The *xylem* comprises of *tracheids* and *vessel elements*. Phloem transports organic materials including manufactured carbohydrate and amino acids from the leaves to the roots, stems and fruits for storage or the growing point of plants for use. Cells that are unique to the phloem are the sieve cells and the companion cells (see Figure 2.5).



**Figure 2.5:** Cross section of a young Dicot Root showing vascular bundle.

**Source:** Taylor, Green and Stout (1997).

**(b) Animal Tissue**

Cells of multicellular animals may be discussed under the following groups of tissues:

- (i). Connective tissue (cartilage and bone)
- (ii). Epithelial tissues
- (iii). Muscular tissues
- (iv). Nervous tissues
- (v). Blood tissues

**(i) Connective Tissue**

This tissue connects and binds together other tissues and organs and all have the three common characteristics namely:

- Development from embryonic mesoderm.
- Have large amount of intercellular matrix (non-living materials).
- The matrix may be liquid, semi liquid or solid and determines the nature and function of every connective tissue as it does the actual connecting and supporting functions.

**There are four main types of connective tissues.**

- (i). The blood and lymph;
- (ii). Connective tissue proper;

(iii). The cartilage;

(iv). The bone.

The connective *tissue* proper, the cartilage and bone are sometime described as the supporting tissues, while the blood and *lymph* form the vascular tissues in animals.

#### **Connective tissue proper**

In connective *tissue* proper, the intercellular matrix contains numerous fibres which are grouped into:

**Collagenous fibre** or **white fibre** which is composed of numerous fine fibrils of proteins known as collagen. The collagens are flexible and resist stretching and thus confer considerable strength on the tissue that possesses them.

Elastic fibre or yellow fibre which is composed of proteins known as elastin that is thin and easily stretched.

**Reticular fibres** which are branched and interlaced to form a complex network. These are formed at the point where connective tissue and other tissues joined.

#### **Cells that make up the connective tissue include:**

The fibroblasts secrete proteins from which the fibres are formed.

**Macrophages** which are found near blood vessels and move by *amoeboid motion* to engulf dead red cells, bacteria and other foreign particles in the body.

Most cells produce substances that prevent clotting during blood circulation.

Fat cells form fat storage and constitute the *adipose tissue*.

#### **Functions of Connective tissue proper**

- (i) Bind muscle fibres together.
- (ii) Attach skin to the underlying *tissue*.
- (iii) Form membranes that line the heart and abdominal cavity.
- (iv) Form mesenteries that bind various organs.
- (v) Function as packing materials.
- (vi) Form a thin sheet around blood vessels.

#### **(a) The Cartilage**

These are specialized form of dense fibrous connective tissues, made up of firm but elastic matrix secreted by cartilage cells located in cavities within the matrix. Cartilage is found in the mammalian body in areas such as the pinna of the ear, the tip of the nose, the lining of the trachea, surfaces of the skeletal joints and end of the ribs (see Figure 2.6).

#### **Types of Cartilage include:**

**Hyaline cartilage** is found at end of long bones, lower ends of ribs, and hyoid apparatus of trachea.

**Fibrous cartilage** is found as the inter-vertebral discs of the backbone of mammals.

**White fibro cartilage** consists of a mixture of white fibrous tissues and cartilaginous tissues in various proportions.

**Elastic or yellow cartilage** gives shape to the pinnae of the ear.

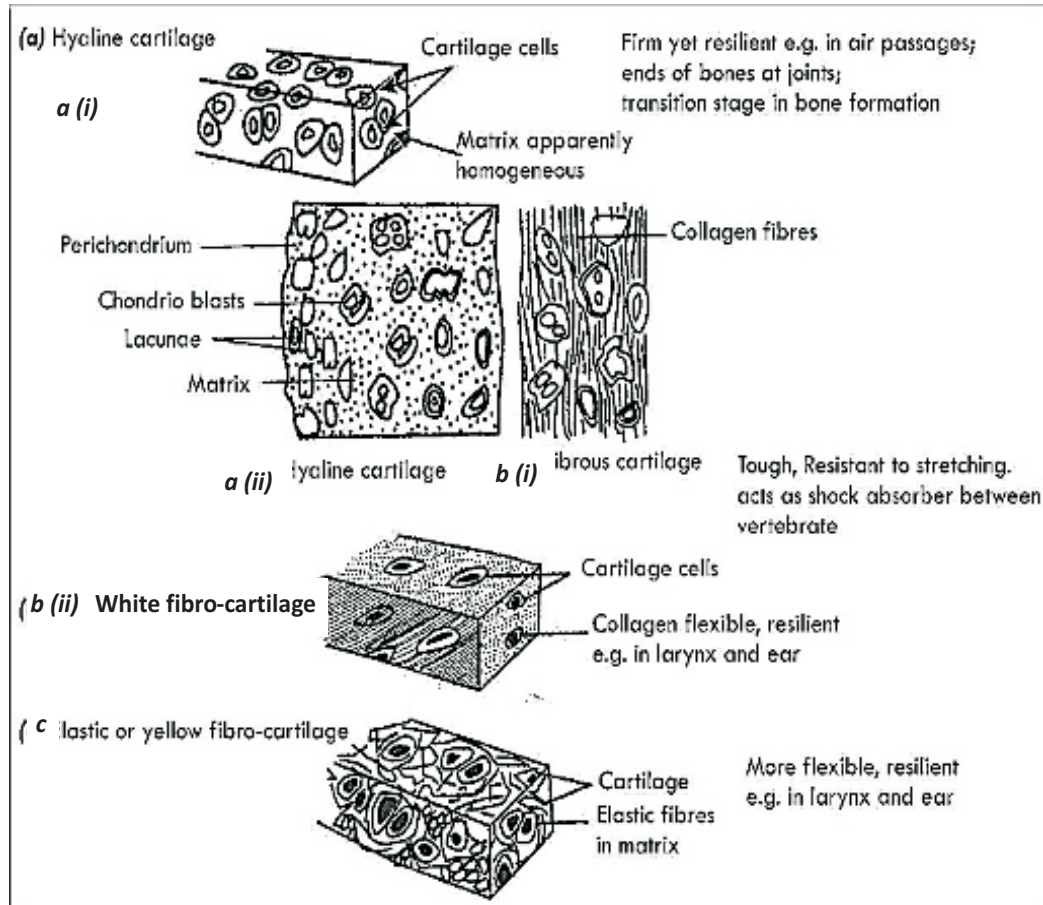
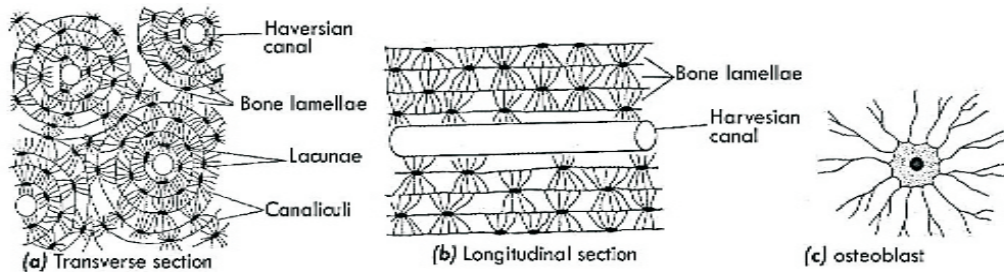


Figure 2.6: Cartilage ('Biscuit bone').

Source: (Okoi et al,2005).

**(b) The Bone**

Bones consist of dense matrix made up of proteins and calcium salt. About 65% of the bone is mineral salt including calcium phosphate, calcium carbonate and magnesium chloride. Bone cells are known as *osteocytes* and these secrete both the protein and calcium throughout life (see Figure 2.7). The protein-mineral complex contributes hardness to the bone. Bone formation and destruction are regulated by the availability of calcium, phosphate, vitamins D and the hormones *thyrocalcitonin* and *parathyrin* secreted by the thyroid and *parathyroid glands*.



**Figure 2.7:** Diagram showing structure of compact bone in transverse, longitudinal section and osteoblast

**Source:** Robert (1976).

*Note:* In development, osteoblasts arrange themselves in concentric rings around a series of Haversian canals, each of which contains artery and vein. The osteoblasts secrete an organic matrix which later becomes greatly hardened by impregnation with mineral salts.

#### **Functions of Bones and Cartilages**

- Provide sites for attachment of muscles and tendons.
- Provide support to the body.
- Provide system of leverage at the joints.
- Provide locomotion in conjunction with muscle.
- Enclose red blood manufacturing cells.

#### (ii). **Epithelial Tissues**

These are composed of cells which form a continuous layer or sheet covering the surface of the body and lining the cavities within the body. Examples are; the linings of the outer portion of the skin the linings of the digestive tract, the linings of the lungs, blood vessels, kidney tubules and urinary bladder. Epithelial tissue cells are packed tightly together such that there are only small amounts of cement materials with almost no intercellular spaces.

#### **Functions of Epithelial tissue cell**

- Protection of the underlying cells from mechanical, chemical and physical injury, bacteria and desiccation.
- Those lining the digestive tracts are known to absorb water and nutrients.
- Linings of the digestive tracts and a variety of other epithelial tissues secrete a wide range of substances including mucus, waxes, milk saliva and sweats.
- They play major role in sensory reception as the entire body is covered by the epithelium.
- Epithelial tissue cells can be grouped based on structural consideration i.e. the shape of the cells or the cilia the cells may bear.

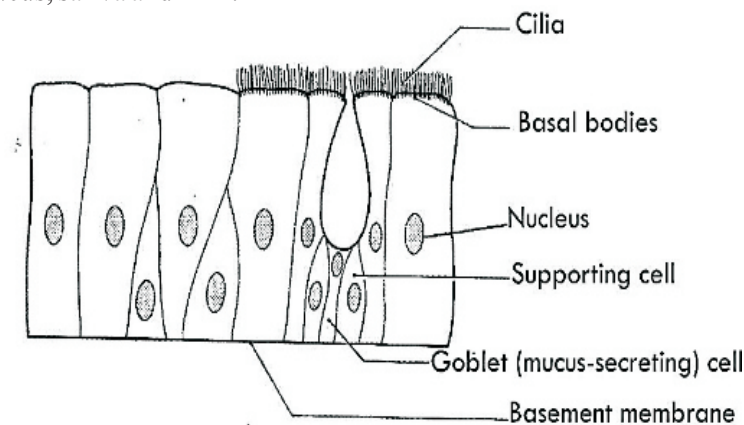
The groupings include:

- **Squamous epithelial tissue cells:** made up of thin flattened cells found on the surface of mammalian skin, the lining of the mouth and Oesophagus, the endothelium lining of the cavity of the blood vessels and vagina.
- **Cuboidal epithelial tissue cells:** that is elongated pillar-like cells lining the stomach and the intestine. Cuboidal and columnar epithelial tissue cells may have cilia on their free surfaces.

- **Ciliated cuboidal epithelial tissue cells:** may be found in the sperm ducts of earthworms and other animals while the ciliated columnar epithelial tissue cells may be found lining the ducts of the respiratory system of man and other air breathing vertebrates (see Figure 2.8).

**Function**

- (i) **Columnar cells** play a part in stimuli reception.
- (ii) Columnar and **cuboidal** cells specialize in secreting substance such as waxes, mucus, saliva and milk.



**Figure 2.8:** Ciliated Epithelial Tissue.

*Source:* Taylor, Green and Stout (1997).

**(iii) Muscular Tissue**

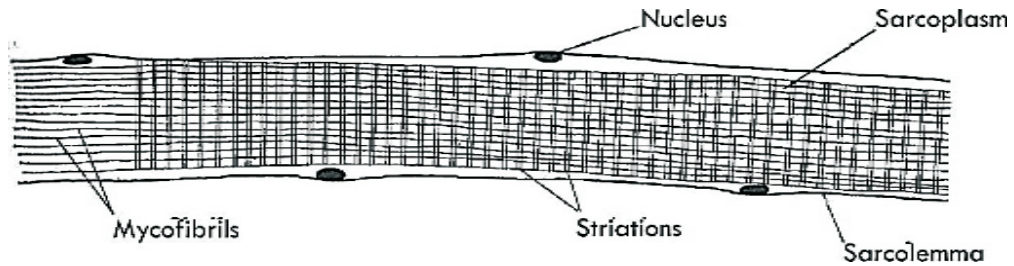
**Muscular tissues** are made up of elongated cylindrical cells consisting of contractile fibres called myofibril. The fibres are of two types of protein namely: **myosin** and **actin**. In mammalian body there are three types of **muscular tissues**.

- The skeletal muscle tissue
- The cardiac muscle tissue
- The smooth muscle tissue

The **skeletal muscle** also called **voluntary muscle** forms the mass of muscles of the body attached to the bones by tendons and their contraction provides force, motion and other voluntary body movements. Owing to the stripe-like appearance as observed under the microscope, hence these muscles are known as striated or **visceral muscles** and are composed of fibrils which exhibit cross patterns. Each fibre is a cell with many nuclei located at the **periphery** of the cell (see Figure 2.9).

Cardiac muscles tissues are found in the walls of the heart of mammals. These muscles are involuntary and possess one nucleus centrally located per cell, they cause the mechanical motion of pumping blood throughout the rest of the body.

Smooth muscle tissues are found in the walls of the digestive, urinary and genital tracts as well as the walls of the arteries and veins. The cells have pointed ends and centrally located nuclei. They are involved in the involuntary movements of internal organs including movement of the stomach and intestine and also in contraction of the walls of blood vessels.



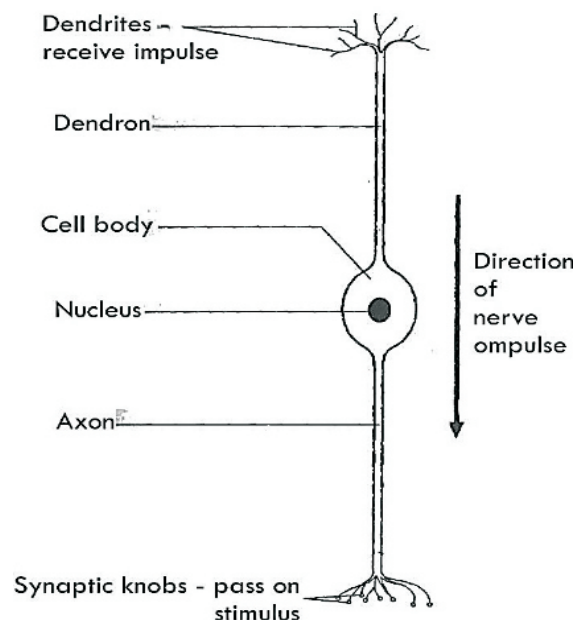
**Figure 2.9:** Longitudinal section of Muscle Fibre.

**Source:** Taylor, Green and Stout (1997).

**(iv) Nervous Tissues**

*Nervous tissues* are special tissues possessing highly specialized cells known as neuron or motor nerve cells. This cell specializes in the reception of stimuli and the transmission of impulse. Neurons possess large cell body containing nucleus and two processes namely;

*Axon* which transmits impulse away from the cell body and dendrites which transmit impulse to the cell body. The axon of one neuron and the dendrite of another meet at a point. The small gap between the two at the point is called synapse. Impulse gets across the synapse with the help of secreted chemical substance called *acetylcholine*. The *synapse* serves as a valve that prevents back flow of the chemical impulse. Cell bodies of neurons which occur in groups are found in the spinal cord and over the surface of the back of the brain(see Figure 2.10).



**Figure 2.10:** Diagram showing interneuron cell in mammals.

**Source:** Taylor, Green and Stout (1997).

(v) **Blood and lymph**

The blood is composed of a liquid part called plasma and several suspended substances such as red blood cells (Erythrocytes), white blood cells (Leucocytes) and **platelets (Thrombocytes)**. The amount of blood in an adult human body ranges from 5-6 liters. Blood is classified as connective tissue because blood cells and connective tissue cells originate from similar cells but differ because they have no fibres (see Figure 2.11).

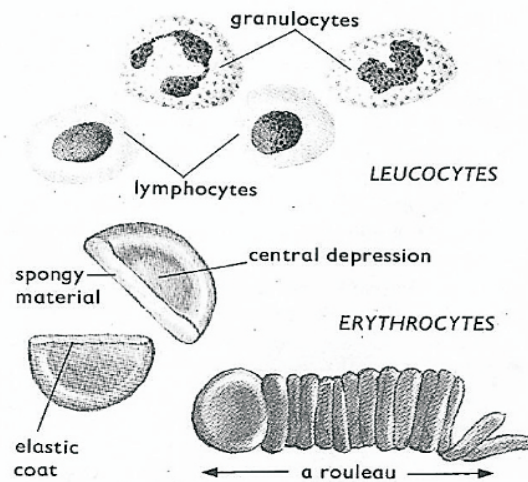


Figure 2.11: Showing different blood tissues.

Source: Ramalingam (2005).

- Red Blood cells (Erythrocytes)**  
Mammalian red blood cells (RBCs) are flattened bi-concave disc lacking nucleus while those of other vertebrates are oval in shape and have nucleus. The absence of the nucleus in mammalian RBC ensures that it contains more haemoglobin. Each human **erythrocyte** contains approximately  $2.80 \times 10^8$  molecules of **haemoglobin** and each of the molecules is a combination of globin protein and four haem groups (an iron containing organic structure). The life span of red blood cells (RBC) in human body is 120 days. The iron is capable of combining loosely with oxygen to form oxyhaemoglobin and aids in the transport and distribution of oxygen throughout the mammalian body.
- White Blood cell (Leucocytes)**  
These are longer in shape than erythrocytes and have large, often irregular shaped nuclei. At least, five types of leucocytes can be distinguished on the basis of the shape of the nuclei and the density of granules in the cytoplasm. These include the **granular cells** (Lymphocytes and monocytes) and the a granular types (neutrophile, eosinophile and basophile). The life span of white blood cell (WBC) in human body is 10 – 15 days. The granular types are formed in the red bone marrow while the agranular types are formed in the **lymph** nodes, spleen and tonsils. Leucocytes lack haemoglobin and play active role in body defense against infections and diseases.
- The Plasma**  
This is a fluid matrix that functions in transport of dissolved gases, soluble and suspended materials in the blood. The basic solvency in **plasma** is water which constitutes about 90% of the blood **plasma**. Apart from blood cells, other materials transported are inorganic cations, organic anions, plasma proteins such as fibrinogen, albumin and globulin, organic nutrients, nitrogenous waste, antibodies and **hormones**.

- **Platelets (Thrombocytes)**

These are small colourless non-nucleated bodies that originate from giant cells in the bone marrow called megakaryocytes. The life span of platelets in human body is 5-9 days. *Thrombocytes* produce thromboplastin, a substance released by disintegrating *platelets* that initiates blood clotting.

- **Lymph**

The *lymph* is a clear, colourless fluid which is like the *plasma* but devoids of red cells and *plasma* proteins with molecules too large to diffuse through the *lymphatic system* capillary walls. These are of course found, in the presence of white blood cells. The *lymph* functions in the transportation of food and oxygen to the body tissue.

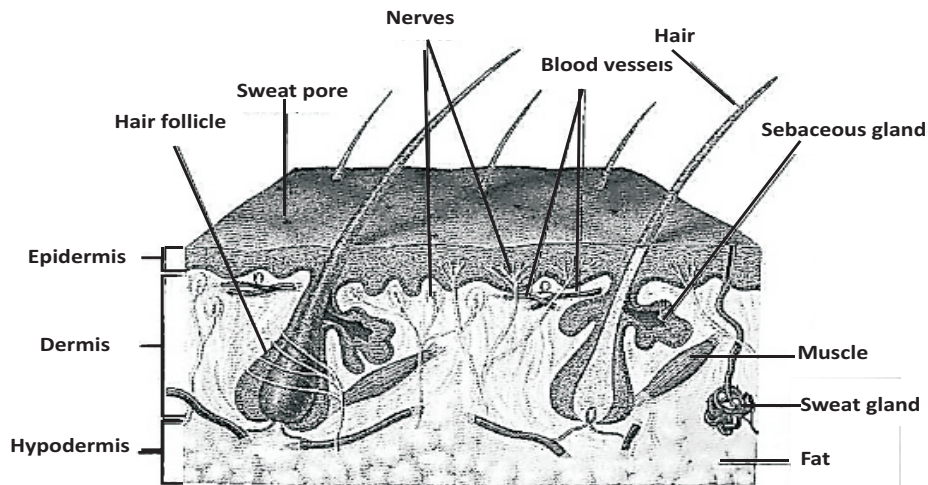
## 2.10 ORGANS AND ORGAN-SYSTEMS

Numerous tasks within the body that exist are too complicated to be undertaken by just one type of tissue. As a result of this, many groups of tissues work together as an organ, thus, an organ can be defined as a collection of tissues joined in a structural unit to serve a common function. The kidney for instance contains blood, and several types of epithelial tissues. These different tissues work together to perform the complex task of excretion. The heart, eye, ear, and tongue are examples of body organs in mammals. **Organs** in plant include Leaf, Stem, Root and Flower. The leaf as plant organ is responsible for photosynthesis. In **organ-system**, a plant or animal internal structures contain many interactions between various organs and tissues which perform specific functions. These tissues and **organs-systems** when working together are known as a system which maintains a constant flow of fluids, nutrients, hormones, etc., throughout the organism.

As cells do not exist in isolation but associate as tissues and tissues for **organs**, so also organs inter-relate to form **organ-system** or simply systems. Organ-systems are composed of several inter-connected **organs**. For instance, the digestive system consists of the intestines and **organs** such as the Pancreas, Liver etc. Some organs may however belong to more than one system, so the pancreas belongs to both the digestive system and the endocrine system. Several other systems exist in the bodies of complex organisms, each consisting of peculiar organs. Examples are reproductive, excretory, respiratory, nervous systems etc. When systems associate together they form an organism. Thus, organizational arrangement starts from cell and ends in system.

### 2.10.1 The Human Skin as an Organ-System

The Human skin can be divided into two parts namely: epidermis and dermis. The epidermis is the outer layer of the skin and is made up of many cells, most especially dead cells. They protect the body against invasion by micro-organism. The dermis is made up of many cells that are protected by the epidermis. The malpighian layer of cells marks the beginning of the dermis. The dermis also houses many specialized cells and tissues e.g. sweat gland, sweat duct, erector muscle, etc. The skin as an organ is responsible for temperature regulation in man as illustrated in Figure.2.12.



**Figure 2.12:**The Mammalian Skin.  
**Source:** Miller and Levine (2006).

*Note:*The skin has an outer layer called the epidermis and an inner layer called to the dermis

### 2.10.2 Two Major Plant Organ Systems:

- (i) The root system: consists of all the roots that lie below the surface of the ground and is responsible for taking in surface water from the ground and mineral from the soil thereby transporting these substances to the system.
- (ii) The shoot system: consists of the remainders of the plant above the ground and is responsible for supporting the plant and performing photosynthesis and transportation of water minerals and sugar.

- **The Root of Plant as a System**

The root systems of most plants usually serve to anchor the plant, absorb water and dissolved mineral salts from the soil. However, many plants may have their roots modified to perform other functions such as storing photosynthetic products. Root system is made up of set of connected organs and tissues which are formed from thousands of cells.

In a young root of a dicotyledonous plant, it is bounded on the outside by a protective layer called pilliferous layer or epidermis. The *pilliferous layer* bears the root hairs to the outside. The root hairs are important in the absorption of water and mineral salt from the soil. The Epidermis is followed by the cortex which has many *parenchymatous cells*. Food and water are stored in the cortex. The innermost layer of the cortex is a single layer endodermis. After the endodermis is the pericycle. The center of the dicot root is occupied by vascular or conducting tissues: xylem and phloem. The xylem tissue is responsible for conducting water and mineral salts within the plants whereas the phloem conducts food substances around the plant.

Xylems are star- shaped i.e. it has radiating arms called *protoxylem* (i.e. young xylem vessels) while the center is occupied by metaxylem (older xylem vessels). The xylem could be diarch, tetrarch or polyarch depending on whether there are two, four or many xylem arms. The phloem alternates with the *protoxylem* by arrangement.

Between the xylem of a dicot root is the *vascular cambium*. However in a young monocotyledonous root, vascular cambium is absent which is the major difference between a dicot root and a monocot root.

## 2.11 IMPORTANCE OF COMPLEX AND SIMPLE ORGANISATION

### (a) Complexity in Cellular Organization

- (i) There is a considerable division of labour with many cells sharing the functions usually carried out by a single cell in unicellular organization.
- (ii) The specialization of cells into certain functions leads to greater efficiency;
- (iii) Complex multicellular organization gives greater insurance against death by accidents. The organism can for instance, survive the death of some of their cells unlike the single cells which are completely destroyed by injury of some of the parts say the cell membrane;
- (iv) The division of labour and subsequent enhanced efficiency can enable complex organisms exploit wider range of habitats;
- (v) Multicellular organisms have potentials for indefinite growth since they increase and multiply by cell division.

### (b) Simple Cellular Organization

- (i) Simple or unicellular organisms possess large surface area needed for efficient uptake of water and gases. So the transport of materials is quite easy;
- (ii) Lesser amount of food and energy are required to maintain simple organisms than complex ones;
- (iii) Independence is usually encouraged in simple organism. Individual cells and tissues of complex organism have more or less lost their independence since they depend on one another's activities.

## 2.12 CHAPTER SUMMARY

- Organization is one of the defining features of living things, and the discovery of the cell as the fundamental unit of life was a milestone in scientific discovery.
- The works of Hooke and Leeuwenhoek, in association with the Royal Society of London, laid the foundation for the development of the concept of the cell.
- The basis for this understanding is that a cell is the basic unit of structure of all organisms, and all organisms consist of one or more cells, which were provided by the work of Robert Brown, Mathias Schleiden, and Theodore Schwann.
- Cytology is the study of individual cells in the body of living organisms, as opposed to histology, which is the study of whole human tissues.
- Viruses are non-cellular and are considered inert.
- Individual cells can be organized into groups of specialized cells to perform a particular function as tissues, organs, and systems.
- In man, the skin is a typical organ in the body that is responsible for temperature regulation, while in plants, an example of an organ is the plant root, which primarily serves as an anchorage for water and mineral absorption from the soil through the tissues of xylem and phloem, respectively.
- Tissues found in multicellular include: connective tissues, epithelial tissues, muscular tissues, nervous tissues and blood tissues.
- Major groups of tissues and systems show the different levels of organization in plants and animals, and the interrelationship between them.

## 2.13 STUDENTS' PRACTICAL ACTIVITIES

### ACTIVITY 1: Observation of Plant Cells

**AIM:** To Observe Plant Cells

#### PROCEDURE

- (i) Carefully peel off thin piece of skin from the inside of an onion scale leaf.
- (ii) Then, place it in a watch-glass and add a drop of methylene blue to stain the skin.
- (iii) Lift the skin and spread it on a clean glass slide. Add a drop of water to it, place a cover slip over it, and examine under the low power of the microscope.
- (iv) Make a sketch of your specimen and label the parts that you can identify.

#### OBSERVATION 1: Under low power objectives of the microscope

- (i) What can you see? (Long rows of rectangular cells in the unstained onion peel)
- (ii) Which structures of the cell can you see? Do you see the cell wall, the nucleus and a large vacuole contained in the cytoplasm?

#### OBSERVATION 2: After staining the onion peel

- (i) Do you see large number of cells in the peel or only one? what is the general shape of these cells (rectangular, circular, triangular, polygonal etc.)?
- (ii) What is the darkly stained body in each cell?
- (iii) Can you see any vacuole in the cell cytoplasm?
- (iv) Does the nucleus become more conspicuous after staining?
- (v) What is the position of the cytoplasm in the cell? (Central or peripheral)?
- (vi) What is the shape of the nucleus? (Spherical, oval, irregular etc.)?
- (vii) Sketch the onion peel cell as seen under the microscope. Label the parts such as the cell wall, cytoplasm, vacuole and the nucleus.
- (viii) Record all the observations in your record book.

### ACTIVITY 2: Observation of Animal Cells

**AIM:** To Observe Animal Cells

#### PROCEDURE

- (i) Using the blunt end of a toothpick, scrape the cheek lining in your mouth.
- (ii) Transfer the scraping to a slide and add drop of methylene blue to it.
- (iii) Place a cover slip over the specimen, and observe it under the low power of the microscope.
- (iv) Do these cells look like the onion skin cells?
- (v) Make a sketch of the cell from the cheek lining, and compare them with the onion skin cells.

Give the magnification of your microscope using:

Total magnification = Magnification of ocular x Magnification of objective lens.

*Note: label only observed features.*

**OBSERVATION: Cheek cell under microscope**

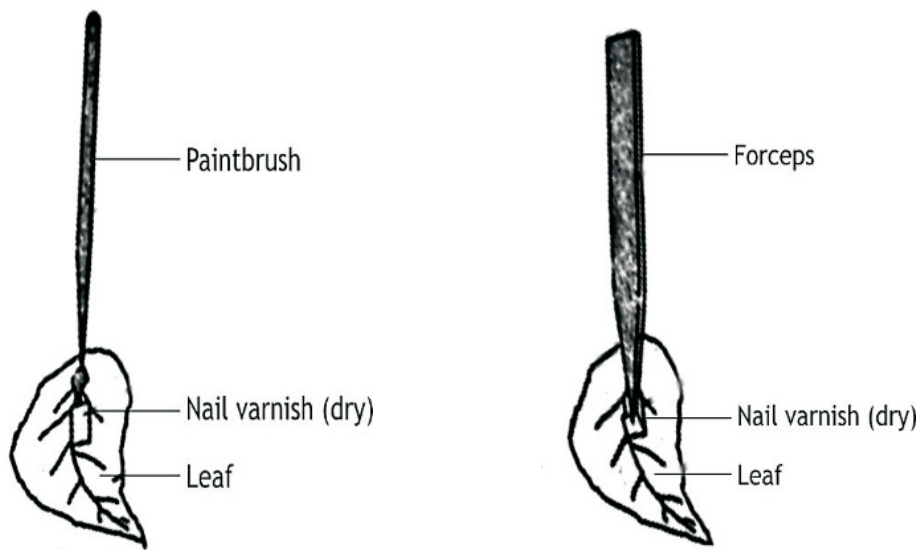
- (i) Draw a few cells in your record book as you see them.
- (ii) What is the shape of cheek cells?
- (iii) What is the location of nucleus in a cheek cell?
- (iv) List the differences between the cells you see in this exercise (cheek cells) and the cells you saw in onion peel with respect to the following:
  - (a) Presence or absence of cell wall.
  - (b) Presence or absence of large vacuole.
  - (c) Difference in shape.
- (v) Is there any cell wall in the cheek cells?
- (vi) Cheek cells are epithelial cells. What is the name of this type of epithelium?

**ACTIVITY 3: Observing the stomata in leaves**

**AIM:** To Observe the Stomata in Leaves (Figure2.13).

**MATERIALS**

- (i) Microscope
- (ii) A pair of forceps
- (iii) Freshly cut leaf of a plant or leafy shoot in water
- (iv) Nail varnish



**Figure 2.13:** Observing the stomata in leaves:(a) & (b).

**Source:** [Adapted from SRC Biology: (2006) Philip Harris/itec].

**PROCEDURE**

- (i) Cut a green leaf off a plant.
- (ii) With a paintbrush apply a thin layer of clear nail varnish to a small area on the lower surface of the leaf. (see Figure 3.13)
- (iii) When the nail varnish is dry, peel it off with a pair of forceps. The nail varnish will have made an exact replica of the leaf surface.
- (iv) Put the nail varnish in a drop of water on a slide, and cover it with a coverslip.
- (v) Examine it under the low power of the microscope.
- (vi) Can you see the stomata?
- (vii) Approximately how many stomata are visible in the field of view?
- (viii) Now look at a single stoma under the high power.
- (ix) Can you see the guard cells?
- (x) Repeat the activity with the upper surface of the leaf.

**DISCUSSION**

- (a) How many stomata are visible in the field of view this time?
- (b) Which side of the leaf has the greater number of stomata, the upper side or the lower side?
- (c) Why do you think the two sides of the leaf differ in this respect?

**2.14 TUTOR MARKED ASSESSMENT QUESTIONS**

HAVING READ THROUGH **CHAPTER TWO**, ANSWER THE FOLLOWING QUESTIONS IN THE SPACES PROVIDED.

1.(a) Define the Term Cytology?  
.....  
.....  
.....  
.....

**2 × ½ = 1 Marks**

(b) Write Down any **Four** Statements that Represents the Modern Cell Theory.  
.....  
.....  
.....  
.....  
.....  
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**4 × ½ = 2 Marks**

- (c) (i) What is a Cell? and (ii) List **Four** Colonial Cells that associate to form a Colony.  
(ii) Meaning of a Cell.

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**$2 \times \frac{1}{2} = 1$  Marks**

- (ii) State **Four** Colonial Cells that associate to Form a Colony.

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**$4 \times \frac{1}{2} = 2$  Marks**

- (d) State **Three** Characteristic Features Common to all Cells.

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**$3 \times \frac{1}{2} = 1\frac{1}{2}$  Marks**

- 2(a) Write Down the **Four** levels of Organization in Multicellular Organisms

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**$4 \times \frac{1}{2} = 2$  Marks**

(b) Multicellular Plant Tissues can be divided into **Two** groups:

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$2 \times \frac{1}{2} = 1 \text{ Marks}$

(c) State **Four** characteristic of Meristematic Tissues.

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$4 \times \frac{1}{2} = 2 \text{ Marks}$

(d) Give the meaning of Meristematic Tissue in Plants

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$2 \times \frac{1}{2} = 1 \text{ Marks}$

3. (a) State **Four** functions of Connective Tissues in Animals.

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$4 \times \frac{1}{2} = 2 \text{ Marks}$

(b) Epithelial Tissues are grouped into **Three**, list them.

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$4 \times \frac{1}{2} = 2$  Marks

(b) Epithelial Tissues are grouped into **Three**, list them.

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$3 \times \frac{1}{2} = 1\frac{1}{2}$  Marks

(c) State **Four** Cartilages found in Man.

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$4 \times \frac{1}{2} = 2$  Marks

(d) Write **Four** main types of Connective Tissues in Animal.

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$4 \times \frac{1}{2} = 2$  Marks

4. (a) Define the term Bone?

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$2 \times \frac{1}{2} = 1$  Marks

(b) List **Three** types of Muscular Tissues in Mammals.

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$3 \times \frac{1}{2} = 1\frac{1}{2}$  Marks

(c) Distinguish between Cardiac Muscle Tissues and Smooth Muscle Tissues.

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$4 \times \frac{1}{2} = 2$  Marks

(d) List **Four** components of the Blood.

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$4 \times \frac{1}{2} = 2$  Marks

5. (a) List **Eight** parts of the Mamalian Skin.

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$8 \times \frac{1}{2} = 4$  marks

(b) Distinguish between Dermis and Epidermis of the Mammalian Skin.

(i) Dermis

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**$2 \times \frac{1}{2} = 1$  Marks**

(ii) Epidermis

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**$2 \times \frac{1}{2} = 1$  Marks**

(c) State the functions of Sebaceous Gland of the Mammalian Skin.

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**$2 \times \frac{1}{2} = 1$  Marks**

(d) What are the **Two** Major Organ Systems in Plants?

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**$2 \times \frac{1}{2} = 1$  Marks**

# Chapter Three

## PROKARYOTIC AND EUKARYOTIC CELLS

Dr. Samuel E. Osim & Inah Onete Inah [Msc]

### 3.1 INTRODUCTION

**B**odies of all living organisms (bacteria, blue green algae, plants, and animals) except viruses have *cellular organization* and may contain one or many cells. Organisms with only one cell in their bodies are called unicellular organisms (e.g. bacteria, blue green algae, and protozoa). Organisms that have many cells in their bodies are called multicellular organisms (e.g., most plants and animals). Microorganisms and all other living organisms are classified as *prokaryotes* or *eukaryotes*. *Prokaryotes* and *eukaryotes* are distinguished on the basis of their cellular characteristics. Prokaryotic and eukaryotic cells are similar in several ways. Both types of cells are enclosed by cell membranes and both use DNA for their genetic information. The terms prokaryotic and eukaryotic were suggested by Hans R is in the 1960's. *Prokaryotes* are organisms made up of cells that lack a definite cell nucleus or any membrane-encased organelles, while *eukaryotes* are organisms made up of cells that possess membrane-bound organelles.

### 3.2 LEARNING OBJECTIVES

After reading this chapter, you should be able to:

- (i) Explain the term prokaryotes.
- (ii) Compare the structure, size and morphology of bacteria.
- (iii) Explain nutrition and respiration of bacteria.
- (iv) Examine the reproduction in bacteria and population growth.
- (v) Highlight the factors affecting the growth of bacteria.
- (vi) State the types of bacteria.
- (vii) Explain the diseases caused by bacteria as well as its benefits.
- (viii) Highlight examples of prokaryotes.
- (ix) Discuss the differences between bacteria and cyanobacteria as well as uses of bacteria.
- (x) Explain the term eukaryotes.
- (xi) Show the differences between prokaryotic and eukaryotic cells.

### 3.3 GENERAL DESCRIPTION OF PROKARYOTES

*Prokaryotes* are small, simple and most primitive single-celled organisms. They are probably the first to come into existence perhaps 3.5 billion years ago. For example, the *stromatolites* (i.e, giant colonies of extinct cyanobacteria or blue green algae) of Western Australia are known to be at least 3.5 billion years old. The eukaryotes have evolved from the prokaryotic cells and the first eukaryotic (nucleated) cells may have arisen 1.4 billion years ago. *Prokaryotes* are unicellular organisms made up of cells that lack a definite cell nucleus or any membrane-encased organelles. This means the *genetic material* (DNA) in *prokaryotes* is not bound within a nucleus, but bundles together in a region called the *nucleoid*. In addition, the DNA is less structured in *prokaryotes* than in eukaryotes: in *prokaryotes*, DNA is a single loop. Most *prokaryotes* are made up of just a single cell (unicellular) but there are a few that are made of collections of cells (multicellular). Scientists have divided the *prokaryotes* into two groups: Bacteria, and *Archaea*. Some bacteria, including *Escherichia coli*, *Salmonella*, and *Listeria*, are found in foods and can cause diseases. Others are helpful to human digestion and other functions.

*Archaea* were discovered to be a unique life form which is capable of living indefinitely in extreme environments such as *hydrothermal vents* or arctic ice.

Organisms that have prokaryotic cells are unicellular. They are called “prokaryotes”. The prokaryotic cell has several elements that allow it to function as a living organism. First, prokaryotes are covered in a cell membrane. This membrane allows them to create a specific environment within the cytosol that allows biochemical reactions to take place. Secondly, these cells house both loose DNA and *ribosomes*. Though *ribosomes* are organelles, they are not bounded by a plasma membrane. Together, the DNA and *ribosomes* work to produce the proteins that the cells need to gather nutrients, reproduce, and even defend themselves in the face of predators or environmental changes. In a nutshell, the prokaryotic cells are distinguished from the eukaryotic cells primarily on the basis of what they lack, i.e., prokaryotes lack the nuclear envelope, and any other cytoplasmic membrane. They also do not contain nucleoli, *cytoskeleton* (microfilaments and microtubules), *centrioles* and basal bodies.

#### Bacteria as example of Prokaryotes

Bacterial cells do not have well-organized nucleus. The *genetic material* is a single molecule of DNA lying in the cytoplasm. Not only is the nuclear membrane absent, cell organelles like *mitochondria*, *lysosomes*, *endoplasmic reticulum*, *chloroplast* and *nucleolus*, are also not present in prokaryotic cells. Like the Bacteria and blue-green algae or cyanobacteria. Each cell has one long DNA molecule called plasmid, which replicate independently of the large DNA molecule or *chromosome*. Bacteria are mostly less than 2 or 3 micrometers in diameter. They occur as spheres (cocci), rods (bacilli), and spirals (spirilli). They are also classified by their biochemistry and as gram-positive or gram-negative.

### 3.4 STRUCTURE OF BACTERIA

A single-celled *bacterium* has a cell wall made of the compound peptidoglycan that covers the cell membrane. The cell has *ribosomes* but no membrane bound organelles. Note the following parts of a *bacterium* in (Figure 3.1). Outer most covering is the cell wall.

**Cell Wall:** All prokaryotes have a rigid cell wall, which protect and give shape to the cell. It is made up of a chemical, *peptidoglycan*, which is unique to bacteria.

**Pili:** Pili are short and thin thread-like structures projecting from the cell wall in some bacteria. Some are involved in mechanism of transfer of DNA, while some initiate gliding and twitching motions and attachments.

**Flagella:** Some bacteria move with the help of one or two *flagella*. *Flagella* are longer and thicker than pili. Their structure is different from *flagella* of eukaryotes.

**Plasma Membrane:** Plasma membrane occurs below the cell wall and encloses the cytoplasm and other cell contents. It is made up of lipids and protein, as in eukaryotes.

**Nucleoid:** A central region of the cell that contains its DNA.

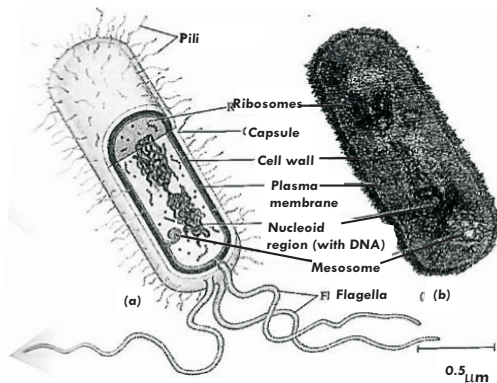
**Ribosome:** They are responsible for protein synthesis.

**Capsule:** Some bacteria have a layer of carbohydrates that surrounds the cell wall called the capsule. The capsule helps the bacterium to attach to surfaces and prevent desiccation and injury.

**Fimbriae:** They are thin, hair-like structures that help with cellular attachment.

**Genetic Material:** A circular *chromosome* made of a double **helical molecule** of DNA is located in a region of the cytoplasm called *nucleoid*. Since the *chromosome* is not lodged within a true nucleus, bacteria are termed prokaryotes. Apart from the *chromosome* many species of bacteria possess rings of DNA called plasmids, which replicate along with bacterial *chromosome* and bear genes for *antibiotic* resistance and sex factor.

*Note:* The prokaryotic cell. Prokaryotes include the bacteria and the cyanobacteria. (a) The diagram in Figure 3.1 depicts a typical rod-shaped bacterium. Lacking the membrane-enclosed organelles of a eukaryote, the prokaryote is much simpler in structure. The DNA is in the **nucleoid**, and no membrane separates the DNA from the rest of the cell. A prokaryote has a large number of ribosomes, where proteins are synthesized. The border of the cell is the plasma membrane, which in some prokaryotes folds in to form structures called mesosomes. Outside the plasma membrane are a fairly rigid cell wall and often an outer capsule, usually jellylike. Some bacteria have *flagella* (locomotion organelles), *pili* (attachment structures), or both projecting from their surface. (b) The electron micrograph shows a thin section through the bacterium *Bacillus coagulans* (TEM).



**Figure 3.1:** Prokaryotic cell (bacterium).

**Source:** Campbell (1993).

### 3.4.1 Morphology and Size of Bacteria

Typically, bacteria diameter or length is between 1 μm (one micrometer) and 3 μm, therefore, they are barely visible under the light microscope. The smallest bacteria are *Dialister pneumosintes* (0.15 to 0.3 μm in length). The largest **bacterium** is *Spirillum volutans* (13 to 15 μm in length).

As shown in Figure 3.2, bacteria vary in their shapes and are classified into the following groups:

- (i) **Cocci** (Singular Coccus): These bacteria are spherical or round in shape. These

### 3.4.2 Morphology and Size of Bacteria

Typically, bacteria diameter or length is between 1  $\mu$ m (one micrometer) and 3  $\mu$ m, therefore, they are barely visible under the light microscope. The smallest bacteria are *Dialister pneumosintes* (0.15 to 0.3  $\mu$ m in length). The largest **bacterium** is *Spirillum volutans* (13 to 15  $\mu$ m in length).

As shown in Figure 3.2, bacteria vary in their shapes and are classified into the following groups:

- (i) **Cocci** (Singular Coccus): These bacteria are spherical or round in shape. These cells may occur singly (micrococcus); in pairs (diplococci e.g., *Pneumonia* causing **bacterium**, *Diplococcus pneumoniae*); in groups of four (**tetrads**); in a cubical arrangement of eight or more (sarcinae); in irregular clumps resembling bunches of grapes (staphylococcus, e.g. boil causing bacterium, *Staphylococcus aureus* or in a bead-like chain *Streptococcus pyogenes*).
- (ii) **Bacilli** (singular, bacillus): These are rod-like bacteria. They generally occur singly, but may occasionally be found in pairs (diplobacilli) or chains (streptobacilli). Bacilli cause tuberculosis (*Mycobacterium*), tetanus (*Clostridium tetani*) typhoid (*Salmonella* or *Bacillus*), diphtheria (*Corynebacterium diphtheriae*), leprosy (*Mycobacterium leprae*), dysentery and food poisoning (*Clostridium botulinum*). Certain well known diseases of animals are also caused by bacilli e.g. Anthrax (*Bacillus anthracis*) and black leg (*Clostridium chauveii*).
- (iii) **Spirilla** (singular, spirillum): These are also called spirochetes. These are spiral-shaped and motile Bacteria. **Spirilla** cause human disease such as syphilis (*Treponema pallidum*).
- (iv) **Vibrios** (singular, vibrio): These are comma-shaped or bent-rod bacteria. Vibrios cause human disease such as cholera (*Vibrio cholerae*).
- (v) **Actinomycetes** are branching filamentous bacteria, so called because of a fancied resemblance to the radiating rays of the sun when seen in tissue lesions.
- (vi) **Mycoplasmas or Amorphous Bacteria**: these are bacteria that are cell wall deficient and hence do not possess a stable morphology. They occur as round or oval bodies and as interlacing filaments. These bacteria are the smallest known organisms.

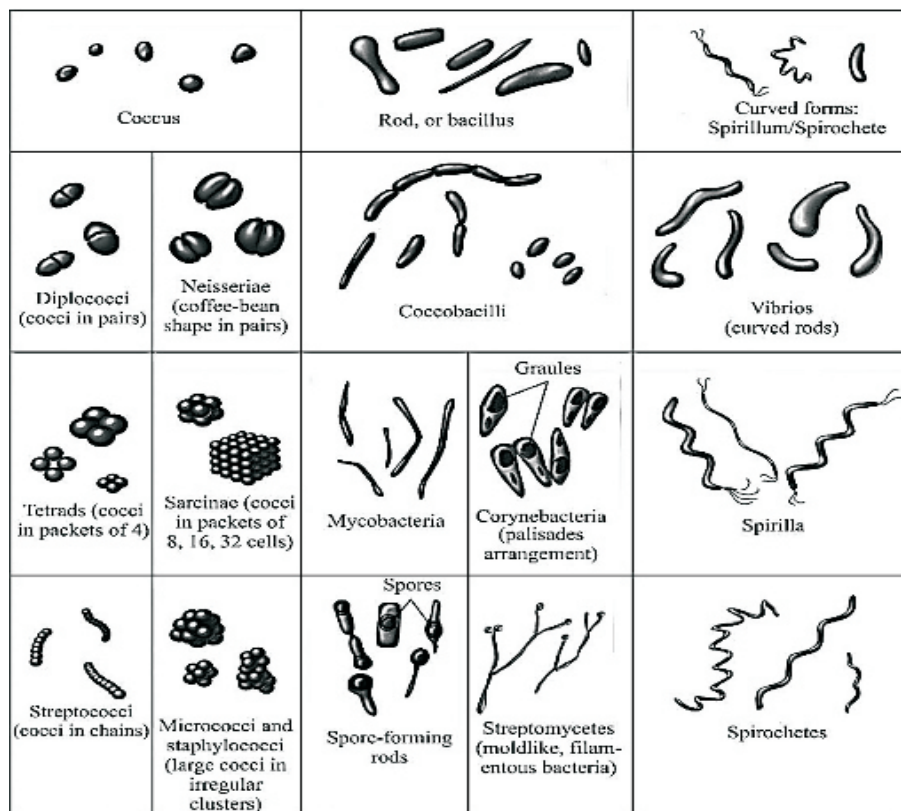


Figure 3.2: Types of Bacteria.  
Source: NIOS (2017).

### 3.4.3 DESCRIPTION OF ARCHAEA

*Archaea* are prokaryotes, which implies that their cells lack a definite nucleus and other membrane-bound organelles. Cells, like bacteria, have a coiled ring of DNA, and the cytoplasm contains ribosomes, which are responsible for the manufacture of cell proteins and other chemicals required by the cell. The cell wall and membrane, unlike bacteria, can be rigid and give the cell a particular form, such as flat, rod-shaped, or cubic. *Archaea* species have similar form and metabolism to bacteria, and they can reproduce by binary fission like bacteria. Horizontal gene transfer is a very common occurrence. *Archaea* cells, on the other hand, may take up DNA-containing plasmids from their environment or exchange DNA with other cells. As a result, archaeal organisms have the ability to adapt and change rapidly. This group of organisms thrives in extreme environments.

### 3.5 NUTRITION IN BACTERIA

Bacteria, like other living things have certain nutritional requirements. Although water is not regarded as a nutrient, it is fundamental requirement of all micro-organisms. A carbon-source and a nitrogen-source provide the bulk of the nutritional requirements of bacteria.

Some bacteria can utilize the carbon from carbon dioxide i.e. they can make use of an inorganic carbon source. These bacteria are able to synthesize their carbohydrates from carbon dioxide and water by the process of photosynthesis. They are known as the Autotrophs or **Autotrophic Bacteria**.

Other bacteria are unable to manufacture their own carbohydrates and require complex organic matters, such as glucose, as their carbon source. These are known as the Heterotrophs or Heterotrophic Bacteria.

The autotrophs utilize inorganic nitrogen source, such as ammonia and nitrites or even nitrogen gas. The heterotrophs, however, need complex nitrogen – containing organic compound such as **asparagine**.

Carbon and nitrogen, because they are required in large quantities, are referred to as **macronutrients** or major mineral elements. Other **macronutrients** which may be required by bacteria are sulphur, phosphorus and potassium. Simple inorganic salts can be utilized by all bacteria.

In addition to the **macronutrients**, smaller quantities of other mineral elements may be required by bacteria. These are referred to as the **micronutrients** or minor mineral elements. These include copper, molybdenum, zinc, manganese and various vitamins. Examples of the vitamins that may be required are riboflavin (vit. B<sub>2</sub>), thiamine (vit. B<sub>1</sub>) and pyridoxine (vit. B<sub>6</sub>).

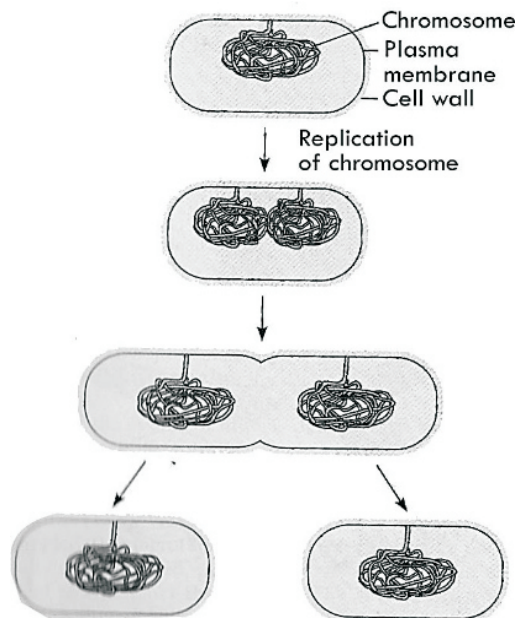
### 3.6 RESPIRATION IN BACTERIA

**Respiration in Bacteria** may be either

- (i) Aerobic i.e. using oxygen for respiration or
- (ii) Anaerobic i.e. respiration in the absence of oxygen. Some of the end products of bacterial anaerobic respiration are useful to man, so they are used in the production of various foods such as butters, cheese and vinegar. *Pseudomonas* is a gram negative heterotrophic aerobic form which can decompose a wide variety of organic compound such as **hydrocarbons**. So it is used in remediating water pollution due to petroleum spillage.

### 3.7 REPRODUCTION IN BACTERIA

When environmental conditions are favourable, bacteria can reproduce rapidly, forming a large group, or colony. Sometimes colonies contain millions of cells and can be seen easily without magnification. Some bacteria populations can double in number every 20 minutes and the population often occurs in nature (see Figure 3.3). Sometimes an entire pond or lake can be overrun by a cyanobacteria bloom. Colonies of cyanobacteria often form slime on rocks, in ponds or at the edges of swamps.



**Figure 3.3:** Cell Division in Prokaryotic Bacteria.

**Source:** Campbell (1993).

*Note:* In prokaryotic cell division, called binary fission, a membrane attachment mechanism is used to allocate chromosome copies to the two daughter cells. When the bacterial chromosome replicates, it is attached to the plasma membrane; after replication, the duplicate chromosomes attach to the membrane at separate points. Continued growth of the cell gradually separates the chromosomes. Eventually, the plasma membrane pinches inward to divide the cell in two, as new cell wall material is deposited between the daughter cells.

### 3.7.1 Asexual Reproduction in Bacteria

Bacteria reproduce asexually by a very simple kind of cell division called fission. Unlike the mitotic division found in eukaryotic cells, fission requires no special structures such as spindles. The hereditary information for bacteria cells is coded into a single closed circle of DNA that can be over 500 times longer than the cell itself. In fission, the single molecule of DNA doubles. Then the cell divides into half, taking identical **genetic material** to each new cell. Notice the bacterium dividing in the second photograph to the left. The two offsprings are identical to the parent (See Figure 3.3).

### 3.7.2 Sexual Reproduction in Bacteria

Sexual reproduction involves the transfer of **genetic materials**. It is known to occur infrequently in a few bacteria species. One method of bacteria sexual reproduction involves the formation of a bridge between two cells. One cell acts as a donor and one as a recipient, as DNA passes through the bridge. After some **genetic material** is transferred, the two bacteria separate. This method of reproduction is called **conjugation**.

A second method of sexual reproduction called **transformation** and occurs when a living bacteria absorbs DNA fragments from dead cells. A third method called **transduction** involves the carrying of bacterial DNA fragments from one bacteria cell to another by viruses.

### 3.7.3 Factors affecting Growth of Bacteria

Many factors affect the generation time of the organisms; examples are **nutrition**, temperature, oxygen, carbon dioxide, light, pH, moisture and drying and osmotic effect.

- (i). **Nutrients:** The principal constituents of the cells are water, proteins, polysaccharides, lipids, nucleic acid and mucopeptides. For growth and multiplication of bacteria, the minimum **nutrition** requirement is water, a source of carbon, nitrogen and some inorganic salts. Bacteria can be classified nutritionally, based on their energy requirement and on their ability to synthesize essential **metabolites**. Bacteria which derive their energy from sunlight are called phototrophs; those who obtain energy from chemical reactions are called chemotrophs. Bacteria which can synthesize all their organic compounds are called autotrophs and those that are unable to synthesize their own **metabolites** are heterotrophs. Nutrients required include carbon source, nitrogen source, sources of sulphur, potassium etc.
- (ii). **Temperature:** Bacteria vary in their requirement of temperature for growth. The temperature at which growth occurs best is known as the optimum temperature. Bacteria which grow best at temperatures of 25-40°C are called **mesophilic**. **Psychrophilic bacteria** are those that grow best at temperatures below 20°C. Another group of bacteria, **thermophiles** grow best at high temperatures (55-80°C). The lowest temperature that kills a bacterium under standard condition in a given time is known as thermal death point.
- (iii). **Oxygen:** Depending on the influence of oxygen on growth and **viability**, bacteria are divided into aerobes and anaerobes. Aerobic bacteria require oxygen for growth. They may be obligate aerobes like *Vibrio cholera*, which will grow only in the presence of oxygen or **facultative anaerobes** which are ordinarily aerobic but can grow in the absence of oxygen. Most bacteria of medical importance are **facultative anaerobes**. Anaerobic bacteria, such as *Clostridia*, grow in the absence of oxygen and the obligate anaerobes may even die on exposure to oxygen. **Microaerophilic** bacteria are those that grow best in the presence of low oxygen tension.
- (iv). **Carbon dioxide:** All bacteria require small amounts of carbon dioxide for growth. This requirement is usually met by the carbon dioxide present in the atmosphere. Some bacteria like *Brucella abortus* require much higher levels of carbon dioxide.
- (v). **Light:** Bacteria except phototrophic species grow well in the dark. They are sensitive to ultraviolet light and other radiations. Cultures die if exposed to light.
- (vi). **Hydrogen ion concentration:** Bacteria are sensitive to variations in pH. Each species has a pH range, above or below which it cannot survive and an optimum pH at which it grows best. Majority of **pathogenic bacteria** grow best at neutral or slightly alkaline pH.
- (vii). **Moisture and Drying:** Water is an essential ingredient of bacterial protoplasm and hence drying is lethal to cells. The effect of drying varies in different species.

(viii). **Osmotic Effect:** Bacteria are more tolerant to osmotic variation than other cells due to the mechanical strength of their cell wall. Sudden exposure to hypertonic solutions may cause osmotic withdrawal of water and shrinkage of the protoplasm called plasmolysis.

### 3.8 TYPES OF BACTERIA

On the basis of structure of cell wall and its reaction to Gram stain, bacteria can be categorized into two:

(i) Gram positive bacteria

(ii) Gram negative bacteria

The Gram staining method is named after Christian Gram who developed it in Denmark in 1884. In this technique, when heat-fixed bacteria are stained with the basic dye, crystal violet, they become blue or purple. Such blue stained cells are treated with a mordant (i.e. agent that fixes stains to tissues) such as iodine (i.e. potassium iodide KI solution) and ultimately washed with some organic solvent such as alcohol. Some bacteria retain the blue colour, while others lose it and pick up the counter stain safranin to appear pink. The former are Gram positive bacteria (e.g. *Bacillus subtilis*, *Staphylococcus*) and the latter are Gram negative bacteria (e.g. *Escherichia coli*, *Klebsiella*, *Cyanobacteria* etc). The long search for the chemical basis of this differentiating staining reaction ended in 1950's when it was detected that cell wall of Gram negative bacteria has high lipid content which tends to be dissolved away by alcohol. The alcohol then can enter the cell and leach out the stain. Whereas the cell walls of Gram positive bacteria has a barrier (i.e. thick peptidoglycan layers) that prevents the penetration of the solvent inside the cell.

### 3.9 DISEASES AND BENEFITS OF BACTERIA

Bacteria can harm us by causing many diseases as shown in Table 3.1. On the other hand some bacteria are very beneficial to man.

**Table 3.1:** Some diseases caused by Bacteria

Name of Bacteria	Diseases Caused
i. <i>Vibrio Cholerae</i>	Cholera
ii. <i>Salmonella typhi</i>	Typhoid
iii. <i>Clostridium tetani</i>	Tetanus
iv. <i>Corynebacterium diphtheriae</i>	Diphtheria
v. <i>Mycobacterium tuberculosis</i>	Tuberculosis
vi. <i>Escherichia coli</i>	Food poisoning
vii. <i>Staphylococcus aureus</i>	Pneumonia, food poisoning
viii. <i>Neisseria gonorrhoeae</i>	Gonorrhoea

Source: (Bruce *et al*, 2002).

The vast majority of bacteria are beneficial to the society as shown in Table 3.2.

**Table 3.2: Benefits of Bacteria**

Bacteria	Benefits
i. <i>Rhizobium</i>	Found in roots of legums, (Peas, grams, Pulses etc.) fixes atmospheric nitrogen as ammonia, which is then converted into useful amino acid.
ii. <i>Azotobacter</i>	Makes the soil fertile. It fixes atmospheric nitrogen in the soil.
iii. <i>Streptomyces</i>	Produces streptomycin antibiotic.
iv. <i>Lactobacillus</i>	Ferments lactose (milk sugar) to lactic acid. This helps in setting of milk into curd.
v. <i>Methanomonas</i>	Sewage treatment

Source: Deborah (2001)

### 3.10 USES OF BACTERIA

- (i) **Food Processing:** Sour dough bread is made to rise by fermentation with a leaven that consists of yeast. The milk-souring bacteria of the genus *Lactobacillus* is used to make yoghurt and cheese. Bacteria are also used to form organic acid in pickles and vinegar.
- (ii) **Biotechnology:** This involves the use of microorganisms including bacteria and fungi in the manufacturing and servicing industries. These include chemicals manufacturing such as ethanol, acetone, organic acid, enzymes and perfumes. Bacteria are important in the production of many dietary supplements and pharmaceuticals. For examples, *Escherichia coli* is used for commercial preparation of riboflavin and vitamin K., *Escherichia coli* is also used to produce D-amino acid such as D-p-hydroxyphenylglycine, an important intermediate for synthesis of the **antibiotic** amoxicillin.
- (iii) **Genetic Engineering:** This involves the manipulation of genes. It is also called recombinant DNA technology. In **genetic engineering**, pieces of DNA (genes) are introduced into a host by a variety of techniques, one of the earliest being the use of a virus vector. The foreign DNA becomes a permanent feature of the host, and is replicated and passed on to daughter cells along with the rest of its DNA. Bacterial cells are transformed and used in production of commercially important products. Examples include production of human insulin (used to treat diabetes) and human growth hormone (somatotropin used to treat pituitary dwarfism).
- (iv) **Fibre retting:** Bacteria such as *Clostridium butyricum* are used to separate fibres of jute, hemp and flax in the process of retting. The plants are immersed in the water and when they swell, inoculated with bacteria which hydrolyze pectic substance of the cell walls and separate the fibres. These separated fibres are used to make ropes, sacks etc.
- (v) **Pest Control:** Bacteria can also be used in the place of pesticides in biological pest control. This commonly uses *Bacillus thuringiensis* (BT), a Gram-positive, soil-dwelling bacterium. This bacterium is used as a Lepidopteran-specific insecticide under trade names such as Dipel and Thuricide. Due to their specificity, these pesticides are regarded as environmentally friendly, with little effect on humans, wildlife, pollinators or other beneficial insects.
- (vi) **Bioremediation:** Bacteria can be used to remove pollutants from contaminated sediment, water, soil and subsurface material, during the mega boring oil spill, for example, bacteria can be sprayed over an acre of oil slick to break down the **hydrocarbons** present into more benign by-products.

- (vii) **Digestion:** Bacteria living in the gut of cattle, horse and other herbivores, for example, *Ruminococcus species*, help to digest cellulose by secreting the enzyme cellulase. This is how herbivores are able to get the energy they need from grass and other plants. Also, *Escherichia coli*, as part of intestinal microbiota of humans and other herbivorous animals converts consumed food into vitamin K<sub>2</sub>, this is absorbed in the colon and, in animal models, is sufficient to meet their daily requirement of the vitamin.
- (viii) **Tanning of Leather:** Bacteria helps purify animal hides to make them easy, clean and fit for use.
- (ix) **Medicine:** Bacteria are used to create multiple **antibiotics** such as streptomycin from the bacteria *Streptococcus*. Bacteria can also be used to manufacture vaccines to prevent several diseases.

### 3.11 OTHER EXAMPLES OF PROKARYOTES

The three types of prokaryotes that are well studied are:

- (i) **Mycoplasma (PPLO)** (pleuropneumonia-like organisms): Among living organisms that have the smallest mass, are small bacteria called **mycoplasma** which produce infectious diseases in animals including humans. **Mycoplasma** are unicellular, prokaryotic, containing a plasma membrane, DNA, RNA and a metabolic machinery to grow and multiply in the absence of other cells (i.e., they are capable of autonomous growth). They can be cultured *in vitro* like other bacteria, forming pleomorphic colonies depending on the type of culture medium. **Mycoplasma** tends to form different shaped colonies such as spheroid, thin, branching filaments, stellate, asteroid or irregular. They differ from the bacteria in the following way:
  - (a) **Mycoplasmas** are filterable through the bacterial filters.
  - (b) They do not contain cell wall and **Mesosome**.
  - (c) Like the viruses and animal cells, they are resistant to **antibiotics** such as penicillin which kills bacteria by interfering with cell wall synthesis.
  - (d) Their growth is inhibited by tetracyclines and similar **antibiotics** that act on metabolic pathways.
- (ii) **Escherichia coli** is a Gram negative, **monotrichous**, symbiotic bacillus of colon of human beings and other vertebrates. It is heterotrophic bacteria producing some vitamins (e.g. vitamin K) for human use. Some strains are known to recognize and bind specifically to sugar containing target cells on the surface of gut lining of mammals. *Escherichia coli* is one of the best studied bacteria. It has served well in the field of molecular biology, since this bacterium is particularly easy to grow in an artificial medium where it divides every 20 minutes at 37°C under optimal conditions.
- (iii) **Cyanobacteria (Blue-green Algae):** The Gram-negative cyanobacteria or oxyphoto bacteria (i.e. oxygen yielding photosynthetic blue-green algae) are one of the most successful and primitive (3.5 billion years old) groups of organism on earth. They even inhabit the steaming hot springs and the undersides of icebergs. Cyanobacteria occur as individual cells, as small clusters or colonies of cells, or as long, filamentous chains. They lack **flagella** but are able to perform movement by rotator motive or gliding over a gelatinous layer secreted through the cell surface. A typical cell of blue green algae is composed of outer cellular covering and cytoplasm. The outer cellular coverings include an outermost gelatinous or slimy layer, the capsule, a middle cell wall of blue green algae resemble the cell wall of bacteria and contains an outer bimolecular membrane of phospholipids, lipoproteins and lipo polysaccharides and a grid of peptidoglycans (muramic acid) in the periplasmatic space existing in between cell wall and plasma membrane.

The cytoplasm of cyanobacteria appears more organised than that of other bacteria. The matrix extends throughout the cell. The cytoplasm (protoplast) is differentiated into two regions; (a) outer or peripheral pigmented region, the chromoplasma having photosynthetic lamellae or thylakoids (b) inner or central colourless region called centroplast or DNA plasm having DNA and crystalline granules.

Because the metabolism of the blue-green algae is based on photosynthesis, therefore, the cells contain the photosynthetic pigment, viz; the chlorophyll and carotenoid. In addition to these pigments, these algae contain certain unique pigment collectively called phycobilin. Being earliest oxygenic photosynthesizers on earth, they made early earth's atmosphere aerobic providing the condition favourable for the evolution of aerobic bacteria and eukaryotes. The two subunits of 70s ribosomes of cyanobacteria are freely distributed in the cytoplasm and form *polyribosomes* during protein synthesis. As in all prokaryotes, the DNA molecule of blue-green algae is circular, double-stranded helix and occurs in the centroplast. This area (*nucleoid*) is not bound by the nuclear membrane and it does not contain a nucleolus.

### 3.12 DIFFERENCES BETWEEN BACTERIA AND CYANOBACTERIA

Outstanding differences between bacteria and cyanobacteria are shown in Table 3.3.

**Table 3.3:** Differences between Bacteria and Cyanobacteria

Bacteria	Cyanobacteria
(i). Smaller cells	Comparatively larger cells
(ii). May have flagella	Do not have flagella
(iii). Some bacteria (green) carry out photosynthesis in a different way and do not release oxygen	They all carry out photosynthesis in the usual manner as in green plants and release oxygen
(iv). Sexual reproduction by conjugation	Asexual reproduction by binary or multiple fission (Conjugation has not been observed). Sexual reproduction is completely absent.

**Source:** NIOS (2017)

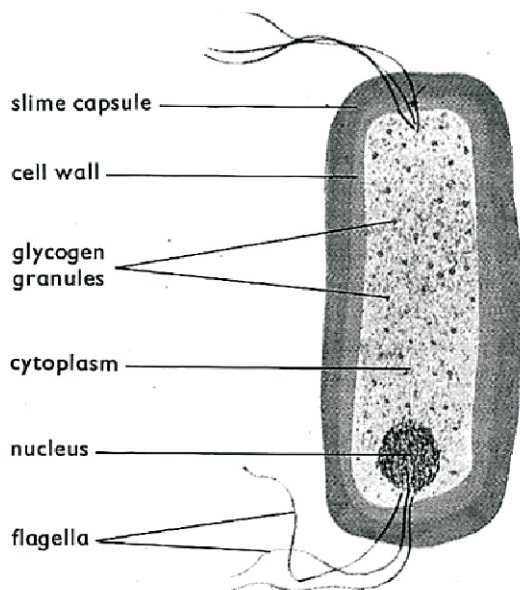
### 3.13 EUKARYOTIC CELLS

The eukaryotic cells are essentially two envelope systems and are very much larger than prokaryotic cells. Secondary membranes envelope the nucleus and other internal organelles and to a great extent the eukaryotes are true cells which occur in the plants (from algae to angiosperms) and the animals (from protozoa to mammals), though the eukaryotes have different shape, size and physiology; all of the cells are typically composed of plasma membrane, cytoplasm and its organelles, viz. *mitochondria*, endoplasmic reticulum, golgi apparatus, ribosomes and a true nucleus. The nuclear contents such as DNA, RNA, nucleoproteins and nucleolus remain separated from the cytoplasm by the thin, perforated nuclear membranes. Examples of eukaryotic cells are shown in figure. 3.4b.

#### How Prokaryotic Cells Differ in their Structure from Eukaryotic Cells

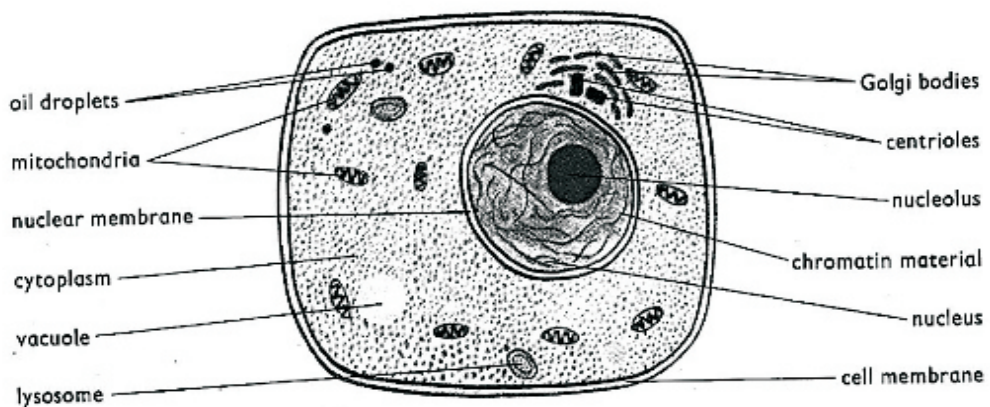
Nearly all higher plant and animal cells share most of the various features that are found in eukaryotic cells. Organisms whose cells normally contain a nucleus are called Eukaryotes; those (generally smaller) organisms whose cells lack a nucleus and have no membrane-bound organelles are known as Prokaryotes. The cells of some very primitive organisms such as bacteria do not have a number of these features (e.g.

nuclei and plastids). Such cells are called prokaryotic to distinguish them from the typical eukaryotic cells (see Figure 3.4a and 3.4b). Like prokaryotic cell, a eukaryotic cell has a plasma membrane, cytoplasm, and ribosomes, while a eukaryotic cell is typically larger than a prokaryotic cell with true nucleus having DNA surrounded by a membrane, and has other membrane bound organelles that allow for compartmentalization of function. Prokaryotic cells do not have membrane bound organelles and have their DNA in the cytoplasm. Unlike Archae and eukaryotes, bacteria have a cell wall made up of peptidoglycan, comprise of sugar and amino acids, and many have a polysaccharide capsule.



*Note: A bacterium such as E.coli has the basic structure typical of most prokaryotes: cell wall, cell membrane, and cytoplasm. Some prokaryotes have flagella that they use for movement. The pili are involved in cell -to-cell contact. The cell walls of eubacteria contain peptidoglycan.*

**Figure 3.4: (a) Structure of a Bacterium: a Prokaryotic Cell.**  
 Source: Ramalingam (2005).



**Figure 3.4: (b) Structure of Animal cell: a Eukaryotic Cell.**  
 Source: Ramalingam (2005).

**Note:** A Eukaryotic cell is a cell that has a membrane-bound nucleus and other membrane bound compartments or sacs called organelles, which have specialized functions. Difference in cellular structure of prokaryotes and eukaryotes include the presence of **mitochondria** and chloroplasts, the cell wall, and the structure of chromosomal DNA.

The basic differences between prokaryotic and eukaryotic cells are shown in Table 3.4

**Table 3.4:** Differences between Prokaryotic and Eukaryotic Cell

Prokaryotic Cell	Eukaryotic Cell
1 Usually simple, primitive and unicellular	Complex, advanced and may be unicellular or multicellular
2 Very minute ranging from 1-10µm in size	Large ranging from 10-100µm in size
3 Poorly developed nucleus (known as nucleoid) without nuclear membrane, nucleoplasm, nucleolus and chromosomes	Well-developed, true nucleus with the entire nuclear characteristic.
4 <b>Genetic material</b> only a simple, naked DNA (usually circular)	Genetic material consists of DNA housed in chromosomes. DNA usually helical.
5 Proteins and RNA synthesis occur within the same compartment (i.e. cytoplasm)	Protein synthesis occurs in cytoplasm while RNA synthesis occurs in the nucleus.
6 Cell wall when present consists of protein-polysaccharides.	Cell wall present only in plant cells and usually consist of cellulose or chitin.
7 Lack organelles such as mitochondria, Endoplasmic reticulum, plastids, lysosomes, centromeres, Golgi bodies and Vacuoles.	Contains numerous and elaborate organelles including mitochondria, Endoplasmic reticulum and plastids etc.
8 Lack cytoskeleton and cytoplasmic streaming	Cytoskeleton and cytoplasmic streaming are present
9 Cell multiplication is usually by fission, sexuality is unknown	Cell multiplication involves mitosis and meiosis, sexuality is present.

Source: NIOS 2017

### 3.14 CHAPTER SUMMARY

- All life on Earth consists of either eukaryotic cells or prokaryotic cells.
- Prokaryotes were the first forms of life. Scientists believe that eukaryotes evolved from prokaryotes around 2.7 billion years ago.
- The primary distinction between these two types of organisms is that eukaryotic cells have a membrane-bound nucleus and prokaryotic cells do not.
- The nucleus is where eukaryotes store their genetic information.

- In prokaryotes, DNA is bundled together in the nucleoid region, but it is not stored within a membrane-bound nucleus.
- In eukaryotes, the nucleus is just one of many membrane-bound organelles.
- Prokaryotes, on the other hand, have no membrane-bound organelles.
- Another important difference is the DNA structure.
- Eukaryotic DNA consists of multiple molecules of double-stranded linear DNA, while that of prokaryotes is double-stranded and circular.
- In prokaryotic cells, transcription and translation begin during mRNA (messenger ribonucleic acid) synthesis.
- In eukaryotic cells, transcription and translation are not coupled.
- Transcription occurs in the nucleus, producing mRNA.
- The mRNA then exits the nucleus, and translation occurs in the cell's cytoplasm.
- All cells, whether prokaryotic or eukaryotic, share these four features: (i) DNA; (ii) plasma membrane; (iii) cytoplasm; and (iv) ribosomes. Bacteria, which are examples of prokaryotes, have been used extensively in the following areas: Food processing, biotechnology, genetic engineering, fiber retting, pest control, bioremediation, digestion, leather tanning, and medicine.

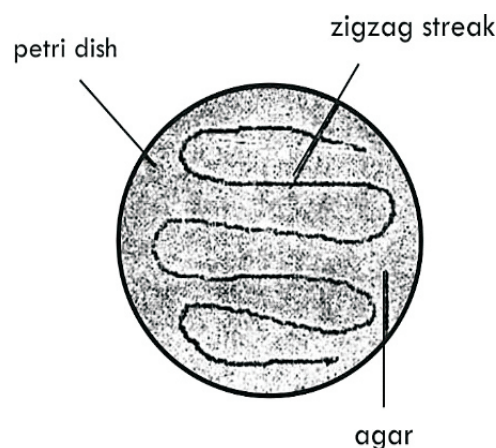
### 3.15 STUDENTS' PRACTICAL ACTIVITIES

#### ACTIVITY 1: Culturing Bacteria

**AIM:** To culture Bacteria in the Laboratory (Figure 3.5).

#### MATERIALS

- Agar
- Bunsen burner
- Sterile cotton swab x5
- Incubator
- Petri dish and cover
- Source of bacteria



**Figure 3.5:** Culturing Bacteria.

**Source:** [Adapted from SRC Biology (2006): Philip Harris/itec].

### **PROCEDURE**

1. Obtain a Petri dish containing sterile nutrient agar. Keep the lid on whenever possible.
2. Use a sterile cotton swab to obtain bacteria by rubbing it against:
  - i) forehead
  - ii) palm
  - iii) door knob
  - iv) in your finger nails
  - v) your lip
3. With the contaminated cotton swab make a zigzag streak on the surface of the agar in the new Petri dish. Do not break the surface of the agar. (see Figure 5.4).
4. Replace the cover on the Petri dish and fix it firmly with sellotape.
5. Place the Petri dish upside down in an incubator set at 37°C after a day or two examine the dish

### **ACTIVITY 2: Isolation of Bacteria**

**AIM:** To observe bacteria in colony forms

### **MATERIALS**

- (i) Soil sample,
- (ii) Sterile petri dishes,
- (iii) Sterile molten nutrient agar,
- (iv) Incubator,
- (v) Bunsen burner,
- (vi) Pipette.

### **PROCEDURE**

- (i) Prepare a soil suspension (soil in water)
- (ii) Shake the soil suspension rigorously and place 1 ml in each of the petri dishes or petri plates
- (iii) Add about 15ml of molten nutrient agar at 45°C to each petri plate and mix
- (iv) Allow the agar to set and incubate inverted at room temperature for 18 to 24 hours
- (v) Examine and record your observation.

### **EXERCISE**

- (i) How many colonies do you have in each?

### **ACTIVITY 3: Staining Bacteria to reveal Cell Shape**

**AIM:** To investigate the staining of bacteria in order to observe the cell morphology (shape)

### **MATERIALS**

- (i) Wire loop,
- (ii) Clean glass slide,
- (iii) Bunsen burner,
- (iv) Basic strain,