# NATIONAL OPEN UNIVERSITY OF NIGERIA

## SCHOOL OF SCIENCE AND TECHNOLOGY

**COURSE CODE: BIO 205**

**COURSE TITLE: Introductory Developmental Cell Biology**

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| Course Code | BIO 205 |
| Course Title | Introductory Developmental Cell Biology |
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**PAGE**

Introductory Developmental Cell Biology is a 3 units course, available to students offering biology related courses.

The idea about cell structure expatiates that the membranes are fluid, with components that move, change, and perform vital physiological roles as they allow cells to communicate with each other and their environment.

The course introduces you to the cell as the fundamental unit of life. The Cell Cycle and Mitosis increase your understanding of the various events that occur in the cell cycle and the process of mitosis that divides the duplicated genetic material, creating two identical daughter cells. The meiosis session makes you to understand the events that occur in the process of meiosis that takes place to produce gametes during sexual reproduction. You will get to know more on prokaryotic and eukaryotic cells that make up all living systems, as well as their organelles, and the differences between living cells.

## What you will learn in this Course

This course guide tells you briefly what the course is about, what course materials you will be using and how you can work with these materials. In addition, it advocates some general guidelines for the amount of time you are likely to spend on each unit of the course in order to complete it successfully. It gives you guidance in respect of your Tutor-Marked Assignments which will be made available in the assignment file. There will be regular tutorial classes that are related to the course. It is advisable for you to attend these tutorial sessions. The course will prepare you for the challenges you will meet in the field of developmental cell biology.

## Course Aims

The course aims to provide you with an understanding of Cell Biology in the areas of cell division, cell differentiation, cell growth, cell structure, cell development, and functions.

## Course Objectives

For the above aims to be achieved the course has a set of objectives. Each unit has specific objectives which are included at the beginning of the unit. You should read these objectives before you study the unit. You may wish to refer to them during your study to check on your progress. You should always look at the unit objectives after completion of each unit. By doing so, you would have followed the instructions in the unit.

The listed items are the comprehensive objectives of the course as a whole. By meeting these objectives, you should have achieved the aims of the course as a whole. In addition to the aims above, this course sets to achieve some objectives. Thus, after going through the course, you should be able to:

- Discuss key events in scientific history and itemize cell biology historical timeline.
- Write on the historical development of Science and explore profiles of influential scientists and philosophers.
- Analyze the modern cell theory and evaluate evidence to support cell theory.
- Outline the basic knowledge on cell division and observe the characteristics that distinguish each of the phases in Cell Cycle.
- Discuss and diagrammatically illustrate Mitosis.
- Identify each phase of the cell cycle.
- Diagrammatically outline, label and illustrate most of the structures disclosed in plant cell structure.
- Write on the current understanding of prokaryotic cell structure and clearly outline and label bacterial cell structure.
- Able to identify plant and animal cells from printed copies of the cell photograph page.
- Able to explain why you have identified each cell as either a "plant" or an "animal".
- Observe the characteristics that distinguish plant and animal cells.
- Define proteins and list the 20 amino acids found in proteins
- Show diagrammatically amino acid structure and the peptide bond
- State the types and functions of proteins
- Describe transcription and translation
- Define nucleic acid, list and describe the two types of nucleic acids
- Show diagrammatically nucleic acid structure and state the functions of nucleic acids.

## Working through this Course

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

Each unit contains self-assessment exercises and at certain points in the curse you would be required to submit assignments for assessment purposes. At the end of the course there is a final examination. The course should take you about 17 weeks to complete. Below you will find listed all the components of the course, what you have to do and how you should allocate your time to each unit in order to complete the course on time and successfully.

of time to read. I would advise that you avail yourself the ssions where you have the opportunity of comparing your knowledge with that of other people.

## The Course Materials

The main components of the course are:

1. The Course Guide
2. Study Units
3. References/Further Readings
4. Assignments
5. Presentation Schedule

## Study Units

The study units in this course are as follows:

Module 1 History and Present Trends in Cell Biology

Unit 1 History of Cell Biology

Unit 2 Historical Viewpoint

Unit 3 The Cell Theory

Module 2 Reproductive Cell Division, Differentiation and Growth of Cells

Unit 1 Cell Division Processes in Prokaryotic and Eukaryotic Cells

Unit 2 The Cell Cycle

Unit 3 Phases of Cell Cycle (Mitosis)

Unit 4 Cell Growth

Unit 5 The Cell Cycle and Mitosis

Module 3 Molecular Basis of Cell Structure and Development

Unit 2 Plant Cell Structure

Unit 3 Eukaryotic Cell Structure

Unit 4 The Animal Cell

Unit 5 Review of Cell Structures of Prokaryotes and Eukaryotes

Module 4 Proteins and Nucleic Acids

Unit 1 Proteins and Their Structures

Unit 2 Types and Functions of Proteins

Unit 3 Protein Synthesis

Unit 4 Introduction to Nucleic Acids

Unit 5 Nucleic Acid Components and Functions

Unit 6 Review of Proteins and Nucleic Acid

Although the units of these modules can be read independently of one another, they are arranged in a logical sequence of four modules. The units of the first module cover history and present trends in cell biology. They can serve either as an introduction for those who have not studied cell biology or as a refresher course for those who have.

Module 2 represents the central core of cell biology and is concerned with prokaryotic and eukaryotic cell division, cell growth, cell size, cell population and the stages in mitosis.

Module 3 deals with the molecular basis of cell structure and development. A reader will find it simple and detailed enough to appreciate cell structure.

Module 4 discusses a simplified introduction to proteins, It lists the functions of proteins, and protein synthesis; and two units are dedicated to nucleic acids.

Each unit consist of one or two weeks' work and includes an introduction, objectives, reading materials, exercises, conclusion, summary, Tutor Marked Assignments (TMAs), references and other resources. The unit directs you to work on exercises related to the required reading. In general, these exercises test you on the materials you have just covered or required you to apply it in some way and thereby assist you to evaluate your progress and to reinforce your comprehension of the material. Together with TMAs, these exercises will help you in achieving the stated learning objectives of the individual units and the entire course, Bio 205.

## Presentation Schedule

Your course materials have important dates for the early and timely completion and submission of your TMAs and the attendance of the tutorials. You should remember that you are required to submit all your assignments by the stipulated time and date. You should guard against falling behind in your work

## Assessment

There are three aspects to the assessment of the course. First is made up of self assessment exercises, second consists of the tutor-marked assignments and third is the written examination/end of course examination.

You are advised to do the exercises. In tackling the assignments, you are expected to apply information, knowledge and techniques that you might have gathered during the course. The Tutor Marked Assignments (TMAs) must be submitted as directed for formal assessment in accordance with the deadlines stated in the presentation schedule and the assignment file. The TMAs you submit for assessment will count for 30% of your total course work. At the end of the course you will need to sit for a final or end of course examination. This examination will count for 70% of your total course mark.

## Tutor-Marked Assignments

The TMA is a continuous assessment component of your course. It accounts for 30% of the total score. You will be given four (4) TMAs to answer. Three of these must be answered before you are allowed to sit for the end of course examination. The TMAs would be given to you as when due and returned after you have done the assignment. Assignment questions for the units in this course are contained in the assignment file. You will be able to complete your assignment from the information and material contained in your reading, references and study units. However, it is desirable in all degree level of

ead and researched more into your references, which will give
ou with a deeper understanding of the subject.

Please make sure that each assignment is submitted on or before the deadline given in the presentation schedule and assignment file. If for any reason you can not complete your work on time, make the necessary contact before the assignment is due to discuss the possibility of an extension. Extension will not be granted after the due date unless in exceptional circumstances.

## Final Examination and Grading

The end of course examination for Introductory Developmental Cell Biology will be for about 3 hours and it has a value of 70% of the total course work. The examination will consist of questions, which will reflect the type of self-testing, practice exercise and tutor-marked assignment problems you have previously encountered. All areas of the course will be assessed.

Revise the whole course before the examination time. You might find it useful to review your self-tests, TMAs and comments on them before the examination. The end of course examination covers information from all parts of the course.

## Course Marking Scheme

| **Assignment** | **Marks** |
|---|---|
| Assignments 1-4 | Four assignments, best three scores out of the four. Each TMA is 10% – 30% of course marks. |
| End of course examination | 70% of overall course marks. |
| Total | 100% |

## ıtorials

There are 12 hours of tutorials provided in support of this course. You will be notified of the dates, times and location of these tutorials as well as the name and phone number of your facilitator, as soon as you are allocated a tutorial group. However, you need to read ahead before any tutorial class.

Your facilitator will grade and comment on your assignments, keep a close watch on your progress and any difficulties you might face and provide assistance to you during the course. You are expected to submit your Tutor Marked Assignments as when due to the appropriate office before the schedule date. These assignments are to be marked by your facilitator and returned to you as soon as possible.

Do not delay to contact your facilitator by telephone or email if you need assistance.

The following might be circumstances in which you would find assistance necessary, hence you would have to contact your facilitator if:

- You do not understand any part of the study or the assigned readings
- You have difficulty with the self-tests
- You have a question or problem with an assignment or with the grading of an assignment.

You should endeavor to attend the tutorials. This is the only chance to have face to face contact with your course facilitator and to ask questions which are answered instantly. You can raise any problem encountered in the course of your study.

To gain much benefit from course tutorials prepare a question list before attending them. You will learn a lot from participating actively in discussions.

## Summary

Introductory Developmental Cell Biology is a course that intends to provide concept of cell division, cell differentiation, cell growth, cell structure, cell development, and cell functions. Upon completion of this course, you will be equipped with the basic knowledge of history and present trends in cell biology,

and growth of cells, molecular basis of cell structure and In addition, you will be able to answer questions in the following areas:

- The history of cell biology.
- The Cell Biology timeline.
- The contributions of any five ancient scientists to Cell Biology.
- A timeline showing the chronological order of these scientists and their contributions.
- Prokaryotic and eukaryotic cell divisions
- The five distinct phases of the cell cycle.
- Mitotic cell division
- Important differences between plant and animal cells.
- Features of plant and animal cells
- Prokaryotic cell as observed in bacteria
- The structures and functions of endoplasmic reticulum, Golgi complex and cytosol in eukaryotic cells
- Differences between smooth endoplasmic reticulum and rough endoplasmic reticulum
- Proteins and the 20 amino acids found in proteins.
- The primary, secondary, tertiary, and quaternary structures of a protein.
- Structural proteins lock and key hypothesis
- Importance of enzymes in cellular activities
- Striking characteristics of enzymes
- The process of protein synthesis on a ribosome and the different kinds of RNA that participate in protein synthesis
- Types of nucleic acids
- The three parts of a nucleotide
- Distinguishing features of a nucleoside and nucleotide
- The functions of nucleic acids
- One amino acid
- The rules and nature of protein structure

Of course, the list of questions that you can answer is not limited to the above list. To gain the most from this course you should endeavor to apply the principles you have learnt to your understanding of developmental cell biology.

I wish you success in the course and I hope you will find it both interesting and useful.

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# Unit1: History of Cell Biology

## Contents

cuss the cell theory. The cell theory or cell doctrine states that all living organisms are composed of similar units of organization, called cells. A cell is the basic unit of a living organism. The concept of cell theory was formally articulated in 1839 by Schleiden and Schwann and has remained as the foundation of modern biology. This unit buttresses the fact that the idea of cell theory predates other great paradigms (examples) of biology including Darwin's theory of evolution (1859), Mendel's laws of inheritance (1865), and the establishment of comparative biochemistry (1940).

# 2.0 Objectives

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

- Discuss the history of cell biology.
- Itemize cell biology historical timeline.
- Discuss key events in scientific history.

# 3.0 Main Contents

## 3.1 First Cells Seen in Cork

While the invention of the telescope made the Cosmos accessible to human observation, the microscope revealed the identities of microbes and shows what living forms were composed of. The cell was first discovered and named by Robert Hooke in 1665. He remarked that it looked strangely similar to cellular or small rooms which monks inhabited, thus depriving the name. However, what Hooke actually saw was the dead cell walls of plant cells called the cork as it appeared under the microscope. Hooke's description of these walls was published in Micrographia. The cell walls observed by Hooke gave no identification of the nucleus and other organelles found in most living cells. The first man to witness a live cell under a microscope was Anton van Leeuwenhoek, who in 1674 described the alga spirogyra.

*Fig. 1 Electron Microscope of Cell*

*(source: Dennis Kunkel Microscopy, 2009)*

## 3.2 Formulation of the Cell Theory

In 1838, Theodor Schwann and Matthias Schleiden were enjoying after-dinner coffee and talking about their studies on cells. It has been suggested that when Schwann heard Schleiden describe plant cells with nuclei, he was struck by similarity of these plant cells to cells he had observed in animal tissues. The two scientists went immediately to Schwann's lab to look at his slides. Schwann published his book on animal and plant cells Schwann (1839) the next year, an account (a treatise) devoid of acknowledgements of anyone else's contributions, including that of Schleiden (1838). He summarized his observations into three conclusions about cells:

- The cell is the unit of structure, physiology, and organization in living things.
- The cell retains a dual existence as a distinct entity and a building block in the construction of organisms.
- Cells form by free-cell formation, similar to the formation of crystals (spontaneous generation).

We know today that the first two principles (tenets) are correct, but the third is clearly wrong. The correct interpretation of cell formation by division was finally promoted by others and formally enunciated in Rudolph Virchow's powerful dictum, Omnis cellula e cellula…….. "All cells arise from pre-existing cells".

hat represent the modern cell theory:

All known living things are made up of cells;

The cell is the structural functional unit of all living things;

All cells arise from pre-existing cells by division. (Spontaneous Generation does not occur);

Cells contain hereditary information which is passed from cell to cell during cell division;

All cells are basically the same in chemical composition;

All energy flow (metabolism and biochemistry) of life occurs within cells.

As with the rapid growth of molecular biology in the mid-20$^{th}$ century, cell biology research exploded in the 1950's. it became possible to maintain, grow and manipulate cells outside of living organisms. The first continuous definition to be so cultured was in 1951 by George Otto Gey and coworkers, derived from cervical cancer cells taken from Henrietta Lacks, who died from the cancer in 1951. The cell line, which was eventually referred to as HeLa cells, have been the watershed in studying cell biology just as the structure of DNA was significant breakthrough of molecular biology.

In an avalanche of progress in the study of cells, the coming decade included the characterization of the minimal media requirements for cells and development of sterile cell culture techniques. You should also know that the study of cells was also aided by the prior advances in electron microscopy, and later advances such as development of transfection methods, discovery of small interfering RNA (siRNA), among others.

## 3.4 A Timeline

The following historical events are important in discussing cells and cell theory.

1595- Jansen credited with 1$^{st}$ compound microscope

1655- Hooke described 'cells' in cork

1674- Leeuwenhoek discovered protozoa. He observed bacteria some nine years later

1833- Brown described the cell nucleus in cells of the orchid

1838- Schleiden and Schwann proposed cell theory

1840- Albrecht von Roelliker realized that sperm cells and egg cells are also cell

1856- N. Pringsheim observed how a sperm cell penetrate an egg cell

1858- Rudolf Virchow (physician, pathologist and anthropologist) expounds his famous conclusion: omnis cellulae cellula, that is cells develop only from pre-existing cells (cells come from pre-existing cells)

havior during mitosis

1883- Germ cells are haploid, chromosome theory of heredity

1898- Golgi described the Golgi apparatus

1938- Behrens used differential centrifugation to separate nuclei from cytoplasm

1939- Siemens produced the first commercial transmission electron microscope

1952- Gey and coworkers established a continuous human cell line

1955- Eagle systematically defined the nutritional needs of animal cells in culture

1957- Meselson, Stahl and Vinograd developed density gradient centrifugation in cesium chloride solutions for separating nucleic acids

1965- Ham introduced a defined serum-free medium. Cambridge Instruments produced the first commercial scanning electron microscope.

1976- Sato And colleagues published different cell line that required different mixtures of hormones and growth factors in serum-free media.

1981- Transgenic mice and fruit flies were produced. Mouse embryonic stem cell line was established.

1995- Tsien identified mutant GFP with enhanced spectral properties

1998- Mice were cloned from somatic cells

1999- Hamilton and Baulcombe discovered siRNA as part of post-transcriptional gene silencing (PTGS) in plants

## 4.0 Conclusion

The cell is the basic unit of all living organisms and all cells are derived from pre-existing cells by cell division.

## 5.0 Summary

In this unit we have learnt that:

- The cell was first discovered and named by Robert Hooke in 1665.
- The cell is the structure, physiology, and organization in living things.

a distinct entity and a building block in the construction of

## 6.0 Tutor Marked Assignment

1. What is the important information that shapes the modern cell theory?

2. Write short notes on any five scientists on cell theory.

## 7.0 Further Reading and Other Resources

Landmark Papers in Cell Biology: Selected Research Articles Celebrating Forty Years of the American Society for Cell Biology.2000. Cold Spring Harbor Laboratory Press.

Mazzarello P. A. 1999. Unifying concept: the history of cell theory. Nat Cell Biology. 1(1):E13-5

# Unit 2: Historical Viewpoint

# 1.0 Introduction

In the previous unit you should recollect that microscope was mentioned. With the invention of the microscope at the beginning of the seventeenth century, it became possible to take a first glimpse at the previously invisible world of microscopic life. A bewildering array of new structures appeared before the astonished eyes of the first microscopists. You will come across the contributions of the microscope in revealing cellular structures and microbes.

# 2.0 Objectives

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

- Write on the historical development of Science.
- Explore profiles of influential scientists and philosophers.

# 3.0 Main contents

## 3.1 Histories of cell discoveries

After the first observations of life under the microscope, it took two centuries of research before the 'cell theory'; the idea that all living things are composed of cells or their products were formulated. It proved even harder to accept that individual cells also make up nervous tissue.

The Jesuit priest Athanasius Kircher (1601−1680) showed, in 1658, that maggots and other living creatures developed in decaying tissues. In the same period, oval red-blood corpuscles were described by the Dutch naturalist Jan Swammerdam (1637−1680), who also discovered that a frog embryo consists of globular particles.

Another new world of extraordinary variety, that of microorganisms, was revealed by the exciting investigations of another Dutchman, Antoni van Leeuwenhoek (1632−1723). The particles that he saw under his microscope were motile and, assuming that motility equates to life, he went on to conclude, in a letter of 9 October 1676 to the Royal Society, that these particles were indeed living organisms. In a long series of papers van Leeuwenhoek then described many specific forms of these microorganisms (which he called "animalcules"), including protozoa and other unicellular organisms.

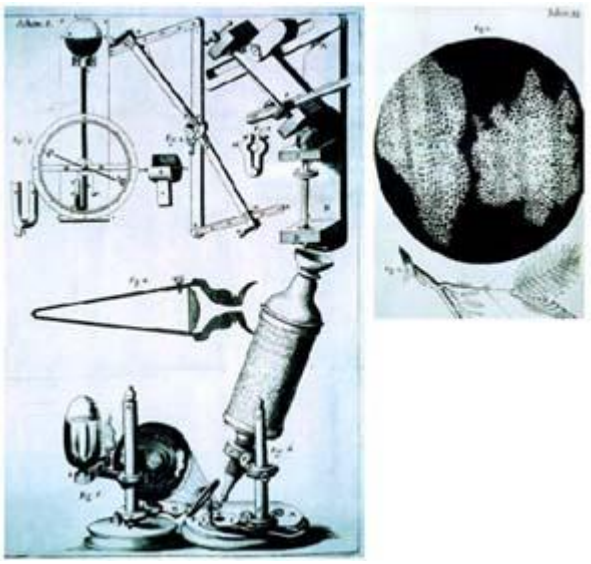


*Fig. 2* **Leeuwenhoek Microscope**

*Source: Pelczar M.J. et al.,1986. Microbiology McGraw-Hill International Editions*

Under the microscope: drawings of the instruments used by Robert Hooke (left) and the cellular structure of cork according to Hooke (right) (reproduced from Micrographia, 1665).

nerally attributed to Robert Hooke (1635–1702), an English icroscopist. In 1665 Hooke published Micrographia, the first important work devoted to microscopical observation, and showed what the microscope could mean for naturalists. He described the microscopic units that made up the structure of a slice of cork and coined the term "cells" or "pores" to refer to these units. Cella is a Latin word meaning 'a small room' and Latin-speaking people applied the word Cellulae to the six-sided cells of the honeycomb. By analogy, Hooke applied the term "cells" to the thickened walls of the dead cells of the cork. Although Hooke used the word differently to later cytologists (he thought of the cork cells as passages for fluids involved in plant growth), the modern term 'cell' comes directly from his book

Please note that the following scientists have contributed to the knowledge of the discoveries of cells. They are

Hans and Zacharias Janssen (1595)

- Dutch lens grinders, father and son
- produced first compound microscope of two lenses

Robert Hooke (1665)

- English scientist
- looked at a thin slice of cork (oak cork) through a compound microscope
- observed tiny, hollow, roomlike structures
- called these structures 'cells' because they reminded him of the rooms that monks lived in
- only saw the outer walls (cell walls) because cork cells are not living

Anton van Leeuwenhoek (1674)

- Dutch fabric merchant and amateur scientist
- looked at blood, rainwater, scrapings from teeth through a simple microscope of one lens
- observed living cells; called some 'animalcules'
- some of the small 'animalcules' are now called bacteria

Matthias Schleiden (1838)

- German botanist
- viewed plant parts under a microscope
- discovered that plant parts are made of cells

- German zoologist
- viewed animal parts under a microscope
- discovered that animal parts are made of cells

Rudolph Virchow (1855)

- German physician
- stated that all living cells come only from other living cells

## 3.2 Bridge between life and 'non-life'?

The existence of an entire world of microscopic living things (microbes) was seen as a bridge between inanimate matter and living organisms that are visible to the naked eye. This seemed to support the old aristotelian doctrine of 'spontaneous generation', according to which water or land bears the potential to generate, 'spontaneously', different kinds of organism. This theory, which implied continuity between living and non-living matter, natura non facit saltus, was disproved by the masterful experiments of the Italian naturalist Lazzaro Spallanzani (1729–1799). He and other researchers showed that an organism derives from another organism(s) and that a gap exists between inanimate matter and life. (But it was a century later before the idea of spontaneous generation was definitively refuted, by Louis Pasteur, 1822–1895) As a consequence, the search for the first elementary steps in the scala naturae was a motif in early-nineteenth-century biological thought: what could be the minimal unit carrying the potential for life?

## 3.3 Protoplasmic constituents

After Schleiden and Swann's formulation of cell theory, the basic constituents of the cell were considered to be a wall or a simple membrane and the nucleus. This simple membrane called “protoplasm” is a viscous substance. It soon became evident that the protoplasm was not a homogeneous fluid. Some biologists regarded its fine structure as fibrillary, whereas others described it as a reticular, alveolar or granular protoplasmic architecture. This discrepancy resulted partly from artefactual and illusory images due to fixation and staining procedures that caused a non-homogeneous precipitation of colloidal complexes.

Later, some staining of real cellular components led to the description of differentiated cellular elements, which were subsequently identified. The introduction of the oil-immersion lens in 1870, the development of the microtome technique and the use of new fixing methods and dyes greatly improved the identities of cellular components. Towards the end of the nineteenth century, the principal

e parts of the cell were identified. The term "ergastoplasm" n 1897; mitochondria were observed by several authors and named by Carl Benda (1857–1933) in 1898. Camillo Golgi (1843–1926) discovered the intracellular apparatus, the golgi bodies in 1898.

The protoplasm was not the only structure to have a heterogeneous appearance. Within the nucleus, the nucleolus and a stainable substance could be seen. Moreover, a number of structures (ribbons, bands and threads) appeared during cell division. As these structures could be heavily stained, they were called "chromatin" by Walther Flemming (1843–1905), who also introduced the term "mitosis" in 1882 and gave a superb description of its various processes. Flemming observed the longitudinal splitting of salamander chromosomes during metaphase and established that each half-chromosome moves to the opposite pole of the mitotic nucleus. This process was also observed in plants, providing further evidence of the deep unity of the living world.

## 3.4 The neuron theory

There was, however, a tissue that seemed to belie the cell theory, the nervous tissue. Because of its softness and fragility, it was difficult to handle and susceptible to deterioration. But it was its structural complexity that prevented a simple reduction to models derived from the cell theory. Nerve-cell bodies, nervous prolongations and nervous fibres were observed in the first half of the nineteenth century. However, attempts at reconstructing a three-dimensional structure of the nervous system were frustrated by the impossibility of determining the exact relationships between cell bodies (somas), neuronal protoplasmic processes (dendrites) and nervous fibres.

In 1865, Karl Deiters posthumously published work contains beautiful descriptions and drawings of nerve cells studied by using histological methods and microdissections made with thin needles under the microscope. These nerve cells were characterized by a soma, dendrites and a nerve prolongation (axon) which showed no branching. Kölliker, in the fifth edition of his important book on histology, published in 1867, proposed that sensory and motor cells of the right and left halves of the spinal cord were linked "by anastomoses" (direct fusion)

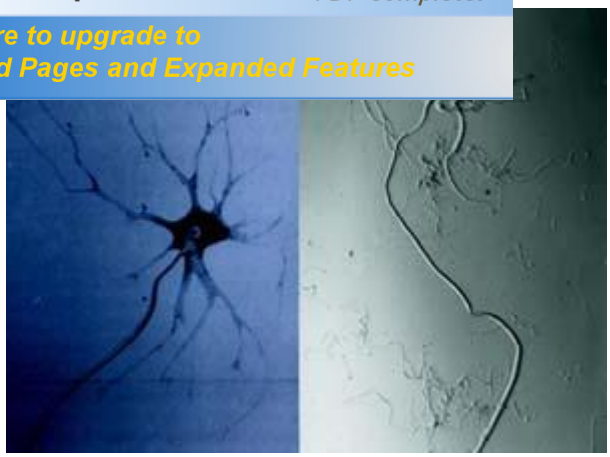


*Fig. 3:* ***The Neuron***

*Source: Karl Deiters (reproduced from Deiters, O. F. K. (Braunschweig, Vieweg, 1865).). The long axon in both cases does not appear ramified because branchings were disrupted during the procedure.*

In 1872, the German histologist, Joseph Gerlach (1820–1896) expanded Kölliker's view and proposed that, in all of the central nervous system, nerve cells established anastomoses with each other through a network formed by the minute branching of their dendrites. According to this concept, the network or reticulum was an essential element of grey matter that provided a system for anatomical and functional communications, a protoplasmic continuum from which nerve fibres originated

The most important breakthrough in neurocytology and neuroanatomy came in 1873 when Golgi developed the 'black reaction', which he announced to a friend with these few words, "I am delighted that I have found a new reaction to demonstrate, even to the blind, the structure of the interstitial stroma of the cerebral cortex. I let the silver nitrate react with pieces of brain hardened in potassium dichromate. I have obtained magnificent results and hope to do even better in the future." This reaction provided, for the first time, a full view of a single nerve cell and its processes, which could be followed and analysed even when they were at a great distance from the cell body. The great advantage of this technique is that, for reasons that are still unknown, a precipitate of silver chromate randomly stains black only a few cells (usually from 1 to 5%), and completely spares the others, allowing individual elements to emerge from the nervous puzzle.

Aided by the black reaction, Golgi discovered the branching of the axon and found that, contrary to Gerlach's theory, dendrites are not fused in a network. Golgi, however, failed to go beyond the

the branched axons stained by his black reaction formed a the nervous impulse propagated. In fact, he was misled by an illusory network created by the superimposition and the interlocking of axons of separate cells. Golgi's network theory was, however, a substantial step forward because it emphasized, for the first time, the function of branched axons in connecting nerve cells.

According to Gerlach and Golgi, the nervous system represented an exception to cell theory, being formed not by independent cells but rather by a gigantic syncytium. The unique structure and functions of the nerve cell could well justify an infringement of the general rule.

Matters changed quickly in the second half of the 1880s. In October 1886, the Swiss embryologist Wilhelm His (1831−1904) put forward the idea that the nerve-cell body and its prolongations form an independent unit. In discussing how the axons terminate at the motor plate and how sensory fibres originate at peripheral receptors such as the Pacinian corpuscles, he suggested that a separation of cell units might be true of the central nervous system. The nervous tissue began to be considered, like any other tissue, as a sum of anatomically and functionally independent cells, which interact by contiguity rather than by continuity.

Similar conclusions were reached, at the beginning of 1887, by another Swiss scientist, the psychiatrist August Forel (1848−1931), and, in 1891, Waldeyer introduced the term "neurons" to indicate independent nerve cells. Thereafter, cell theory as applied to the nervous system became known as the 'neuron theory'.

Ironically, it was by using Golgi's black reaction that the Spanish neuroanatomist Santiago Ramón y Cajal (1852−1934) became the main supporter and of the neuron theory. His neuroanatomical investigations contributed to the foundations of the basic concepts of modern neuroscience. However, definitive proof of the neuron theory was obtained only after the introduction of the electron microscope, which allowed identification of synapses between neurons.

## 4.0 Conclusion

Cell theory obtained its final triumph when the nervous system was also found to be made up of independent units.

In this unit we have learnt that:

- The microscope means much to the naturalists.
- The idea of spontaneous generation was refuted by Louis Pasteur.

## 6.0 Tutor Marked Assignment

Name and state the contributions of any five ancient scientists of Cell Biology.

## 7.0 Further Reading and Other Resources

Dutta AC (1963) Botany for degree students 5th edition. Oxford University Press, Delhi.

Paolo Mazzarello(1999) A unifying concept: the history of cell theory Nature Cell Biology 1, E13 - E15.

# Unit 3: The Cell Theory

# 1.0 Introduction

This unit will review the history of the development of the cell theory on the previous units. Throughout time, thoughts and ideas of life have been formed, stretching from abiogenesis and spontaneous generation to the modern cell theory. Here is an overview of the progression of thought that has contributed to today's cell theory.

# 2.0 Objectives

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

- Analyze the modern cell theory;
- Evaluate evidence to support cell theory;
- Have knowledge of basic historical science facts.

# 3.0 Main contents

## 3.1 People and things that have made history

Anaximander

A member of the Greeks in the sixth century B.C. who resided on the Ionian Islands. He is credited with coming up with the primary thoughts of evolution. His perspective was that creatures from the sea were forced to come ashore, thereby evolving into land creatures.

Plato

Plato did not directly aid in the progress of biological thinking. His view was not experimental, but more philosophical. Many of his students went on to influence the progression of biological studies in the field of classification.

The Atomists

The most noted of this group of Greek philosophers was Democritus (460 - 370 B.C.). He followed Anaximander's view of evolution. Democritus is credited as being the father of atomic theory which

nt theory of his was simply that if you have nothing, nothing

Aristotle

Aristotle (384 - 322 B.C.) was known for his experimental approach and numerous dissections. He was drawn to animal classification in order to discover aspects of connection between the soul and the human body. Some of his animal classifications still stand today. One of his famous thoughts is a foreshadowing of Mendelian genetic concepts:

"It is evident that there must be something or other really existing, corresponding to what we call by the name of Nature. For a given germ does not give rise to any random living being, nor spring from any chance one, but each germ springs from a definite parent and gives rise to a predictable progeny. And thus it is the germ that is the ruling influence and fabricator of the offspring."

The Microscope

This instrument opened up new doors in the field of biology, by allowing scientists to gaze into a new world: the cellular world. Galileo is credited with the invention of the microscope. Two of the main pioneers in microscope usage were Athanasius Kircher and Antonie von Leeuwenhoek.

Robert Hooke

This English naturalist (1635 - 1703) coined the term "cell" after viewing slices of cork through a microscope. The term came from the Latin word cella which means "storeroom" or "small container". He documented his work in the Micrographia, written in 1665.

Jean-Baptiste De Lamarck

The majority of this Frenchman's work (1744 - 1829) dealt with animal classification and evolution. He is credited with taking steps towards the creation of the cell theory with this saying:

"Every step which Nature takes when making her direct creations consists in organizing into cellular tissue the minute masses of viscous or mucous substances that she finds at her disposal under favorable circumstances."

In 1824, Rene Dutrochet discovered that 'the cell is the fundamental element in the structure of living bodies, forming both animals and plants through juxtaposition." In Berlin, Johannes Muller created connections between biology and medicine, prompting the connective thinking of his students, such as those of Theodore Schwann. Schwann created the term "cell theory" and declared that plants consisted of cells. This declaration was made after that of Matthias Schlieden's (1804 - 1881) that animals are composed of cells.

Biogenesis

German pathologist Rudolf Virchow (1821 - 1902) altered the thought of cellular biology with his statement that "every cell comes from a cell". Not even twenty years after this statement, processes of cell reproduction were being described--Virchow had completed the thought behind the basic cell theory.

## 3.1 The cell theory

Hints at the idea that the cell is the basic component of living organisms emerged well before 1838–39, which was when the cell theory was officially formulated. Cells were not seen as undifferentiated structures. Some cellular components, such as the nucleus, had been visualized, and the occurrence of these structures in cells of different tissues and organisms hinted at the possibility that cells of similar organization might underlie all living matter.

The abbot Felice Fontana (1730–1805) glimpsed the nucleus in epithelial cells in 1781, but this structure had probably been observed in animal and plant cells in the first decades of the eighteenth century. The Scottish botanist Robert Brown (1773–1858) was the first to recognize the nucleus (a term that he introduced) as an essential constituent of living cells (1831). In the leaves of orchids Brown observed "a single circular areola, generally somewhat more opaque than the membrane of the cell... This areola, or nucleus of the cell as perhaps it might be termed, is not confined to the epidermis, being also found not only in the pubescence of the surface... but in many cases in the parenchyma or internal cells of the tissue". Brown recognized the general occurrence of the nucleus in these cells and apparently thought of the organization of the plant in terms of cellular constituents.

Meanwhile, technical improvements in microscopy were being made. The principal drawback of microscopes since van Leeuwenhoek's time was what we now call 'chromatic aberration', which

instrument at high magnifications. Only in the 1830s were wing more precise histological observations. Improvements were also made in tissue-preservation and -treating techniques.

In 1838, the botanist Matthias Jakob Schleiden (1804–1881) suggested that every structural element of plants is composed of cells or their products. The following year, a similar conclusion was elaborated for animals by the zoologist Theodor Schwann (1810–1882). He stated that "the elementary parts of all tissues are formed of cells" and that "there is one universal principle of development for the elementary parts of organisms and this principle is in the formation of cells". The conclusions of Schleiden and Schwann are considered to represent the official formulation of 'cell theory' and their names are almost as closely linked to cell theory as are those of Watson and Crick with the structure of DNA

According to Schleiden, however, the first phase of the generation of cells was the formation of a nucleus of "crystallization" within the intracellular substance (which he called the "cytoblast"), with subsequent progressive enlargement of such condensed material to become a new cell. This theory of 'free cell formation' was reminiscent of the old 'spontaneous generation' doctrine (although as an intracellular variant), but was refuted in the 1850s by Robert Remak (1815–1865), Rudolf Virchow (1821–1902) and Albert Kölliker (1817–1905) who showed that cells are formed through scission of pre-existing cells. Virchow's aphorism omnis cellula e cellula (every cell from a pre-existing cell) thus became the basis of the theory of tissue formation, even if the mechanisms of nuclear division were not understood at the time.

Cell theory stimulated a reductionist approach to biological problems and became the most general structural paradigm in biology. It emphasized the concept of the unity of life and brought about the concept of organisms as "republics of living elementary units"

As well as being the fundamental unit of life, the cell was also seen as the basic element of pathological processes. Diseases came to be considered (irrespective of the causative agent) as an alteration of cells in the organism. Virchow's Cellularpathologie was the most important pathogenic concept until, in this century, the theory of molecular pathology was developed.

**Activity**

1. What theory did these scientists provide evidence for?

the cell theory could be developed?

ed evidence for the cell theory?

4. How did the earlier scientists and their contributions directly affect the discoveries of later scientists (see #2)? For example, what had to come first?

5. List the three parts of the cell theory.

## 4.0 Conclusion

Cell is the structural unit of life

## 5.0 Summary

In this unit we have learnt that:

- Chromatic aberration is a principal drawback of microscopes since van Leeuwenhoek's time.
- Cells are formed through scission of pre-existing cells.
- Mitosis observed in plants, provides further evidence of the deep unity of the living world.
- Historical events leading to the development of the cell theory.
- Contributions made by the following people/scientists -Robert Hooke, Hans and Zacharias Janssen, Anton van Leeuwenhoek, Matthias Schleiden, Theodor Schwann, Rudolph Virchow, etc. and dates of their contributions.
- Constructing a timeline showing the chronology of the historical events leading to the development of the cell theory.

## 6.0 Tutor Marked Assignment

Research the following people: List some of their contributions to science and dates of these contributions.-

Robert Hooke-

Hans and Zacharias Janssen-

Anton van Leeuwenhoek-

Matthias Schleiden-

Theodor Schwann-

Rudolph Virchow.

Draw a timeline showing the chronological order of these scientists and their contributions.

Label the timeline with dates of the above scientists' discoveries.

The earliest date should be on the left of the timeline and the most recent date on the right.

Label each date with the corresponding scientist's name and contribution(s) in an organized and legible manner.

Be sure your spacing shows a reasonable approximation of the amount of time elapsed between dates.

## 7.0 Further Reading and Other Resources

Bruce Alberts, Alexander Johnson, Julian Lewis, Martin Raff, Keith Roberts, and Peter Walter(2002) Molecular Biology of the Cell 4th edition. Garland Science, Taylor & Francis Group, New York. ISBN 0-8153-3218-1 (hardbound) -- ISBN 0-8153-4072-9 (pbk.)

Deborah Sweet (2001) Trends in Cell Biology, A trend worth following, Volume 11, Issue 12, 1 December, Page 536.

Wagner M. 2009 Single-Cell Ecophysiology of Microbes as Revealed by Raman Microspectroscopy or Secondary Ion Mass Spectrometry Imaging. Annu Rev Microbiol. Vol 63

# Module 2: Reproductive Cell Division, Differentiation and Growth of Cells

## Unit 1: Cell Division Processes in Prokaryotic and Eukaryotic Cells

# 1.0 Introduction

In the next few units we shall examine cell reproduction and the way in which they are differentiated according to the main functions which the cells perform in the body. This unit examines, in simple terms, what may be learnt of cell division and cell cycle.

# 2.0 Objectives

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

- Outline the basic knowledge on cell division.

# 3.0 Main contents

## 3.1 The Cell

Cell is the smallest unit of an organism that is able to function independently, the basic unit of living matter in all organisms, consisting of protoplasm enclosed within a cell membrane. All cells except bacterial cells have a distinct nucleus that contains the cell's DNA as well as other structures (called organelles) that include mitochondria (Fig. 4), the endoplasmic reticulum, and vacuoles. The main source of energy for all of a cell's biological processes is ATP.

The elaboration of plant form and function depends on the ability of a plant cell to divide and differentiate. The decisions of individual cells to enter the cell cycle, maintain proliferation competence, become quiescent, expand, differentiate, or die depend on cell-to-cell communication and on the perception of various signals. These signals can include hormones, nutrients, light, temperature, and internal positional and developmental cues. In recent years, progress has been made in understanding the molecular control of plant pattern formation, especially in the model plant, *Arabidopsis thaliana*. Furthermore, specific genes have been found that are necessary for normal pattern formation and the control of the rates of cell division and differentiation. Cloning of these genes is revealing the molecular basis of plant pattern formation and the key players on plant signal transduction systems.

Table 1: Organelles and components of cells

| Organelle | Location | Description | Functions |
|---|---|---|---|
| cell wall | in plants, absent in animal | *outer layer<br>*rigid, strong, stiff<br>*made of cellulose | *support (growth)<br>*protection<br>*allows water, oxygen, carbon-dioxide to pass into and out of cell |
| cell membrane | in both plant/animal | *plant - inside cell wall<br>*animal - outer layer; cholesterol<br>*selectively permeable | *support<br>*protection<br>*controls movement of materials in/out of cell<br>*barrier between cell and its environment<br>*maintains homeostasis |
| nucleus | in both plant/animal | *large, oval | *controls cell activities |
| nuclear membrane | in both plant/animal | *surrounds nucleus<br>*selectively permeable | *Controls movement of materials in/out of nucleus |
| cytoplasm | in both plant/animal | *clear, thick, jellylike material and organelles found inside cell membrane | *supports /protects cell organelles |
| Endoplasmic reticulum (E.R.) | in both plant/animal | *network of tubes or membranes | *carries materials through cell |
| ribosome | in both plant/animal | *small bodies free or attached to E.R. | *produces proteins |

| | | | |
|---|---|---|---|
| | | an-shaped with inner nbranes | *breaks down sugar molecules into energy |
| vacuole | in plant - in few/large<br><br>animals – (small) | *fluid-filled sacs | *store food, water, waste (plants need to store large amounts of food) |
| lysosome | plant – (uncommon)<br><br>animal – (common) | *small, round, with a membrane | *breaks down larger food molecules into smaller molecules<br><br>*digests old cell parts |

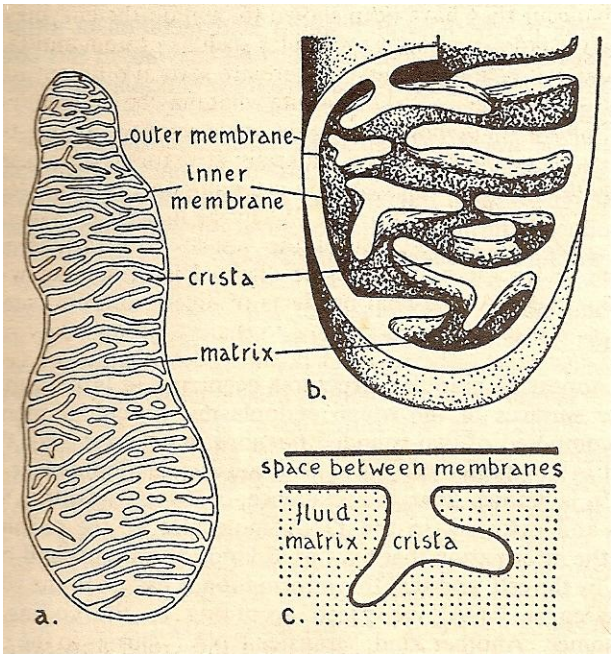


*Fig. 4 Mitochondrion*

*(a) Natural appearance as seen with the electron microscope. (b) and (c) Diagrams to show the arrangement of membranes, cristae and matrix.*

*Source: Plant and Animal Biology, Vol. 2, Vines and Rees*

## 3.2 The Cell Cycle

Eukaryotic cells have a membrane-enclosed nucleus. Prokaryotic cells lack a true, membrane – delimited nucleus. Examples of prokaryotes are bacteria while other organisms – algae, fungi, protozoa, higher plants and animal are eukaryotes.

Despite the differences between prokaryotes and eukaryotes, there are several common features in their cell division processes. Replication of the DNA must occur. Segregation of the "original" and its "replica" follow. Whether the cell is eukaryotic or prokaryotic, these basic events must occur. Cytokinesis is the process where one cell splits off from its sister cell and ends the cell division process. It usually occurs after cell division.

The Cell Cycle is the sequence of growth, DNA replication, growth and cell division that all cells go through. Beginning after cytokinesis, the daughter cells are quite small and low on ATP. They acquire ATP and increase in size during the G1 phase of Interphase. Most cells are observed in Interphase, the longest part of the cell cycle.

After acquiring sufficient size and ATP, the cells then undergo DNA synthesis (replication of the original DNA molecules, making identical copies, one "new molecule" eventually destined for each new cell) which occurs during the S phase. Since the formation of new DNA is an energy draining process, the cell undergoes a second growth and energy acquisition stage, the G2 phase, a gap between DNA synthesis and mitotic cell division. The energy acquired during G2 is used in cell division (in this case mitosis). Regulation of the cell cycle is accomplished in several ways. Some cells divide rapidly (beans, for example take 19 hours for the complete cycle; red blood cells must divide at a rate of 2.5 million per second). Others, such as nerve cells, lose their capability to divide once they reach maturity. Some cells, such as liver cells, retain but do not normally utilize their capacity for division. Liver cells will divide if part of the liver is removed. The division continues until the liver reaches its former size.

Cancer cells are those which undergo a series of rapid divisions such that the daughter cells divide before they have reached "functional maturity". Environmental factors such as changes in temperature and pH, and declining nutrient levels lead to declining cell division rates. When cells stop dividing, they stop usually at a point late in the G1 phase, the R point (for restriction).

## 3.3 Cell division

Cell division is the process by which a cell divides to form two or more new cells. Upon completion of the process, each daughter cell contains the same genetic material as the original cell and roughly half of its cytoplasm. Among prokaryotes, cell division occurs by simple fission. Among eukaryotes, the cell nucleus divides first, and then a new cell membrane is formed between the nuclei to form the new cell. Cell division is used as a means of reproduction in organisms that reproduce asexually, as by fission or spore formation, and sexually reproducing organisms form gametes. Cell division is also the source of tissue growth and repair in multicellular organisms. The two types of cell division in eukaryotic organisms are mitosis and meiosis.

### 3.3.1 Prokaryotic Cell Division

Prokaryotes are much simpler in their organization than are eukaryotes. There are a great many more organelles in eukaryotes and also more chromosomes. The usual method of prokaryote cell division is termed binary fission, an example of asexual reproduction. The prokaryotic chromosome is a single, simple DNA molecule that first replicates, then attaches each copy to a different part of the cell membrane. When the cell begins to pull apart, the replicate and original chromosomes are separated. Following cell splitting (cytokinesis), there are then two cells of identical genetic composition (except for the rare chance of a spontaneous mutation).

The prokaryote chromosome is much easier to manipulate than the eukaryotic one. We thus know much more about the location of genes and their control in prokaryotes. One consequence of this asexual method of reproduction is that all organisms in a colony are genetic equals. When treating a bacterial disease, a drug that kills one bacterium (of a specific type) will also kill all other members of that clone (colony) it comes in contact with. For example, *Escherichia coli*, a bacterium divides by binary division.

### 3.3.2 Eukaryotic Cell Division

Due to their increased numbers of chromosomes, organelles and complexity, eukaryote cell division in eukaryotes is more complicated, although the same processes of replication, segregation, and cytokinesis still occur.

**Table 2 Phases of cell cycle**

| | |
|---|---|
| Interphase | G1 phase - S phase - G2 phase |
| M phase | Mitosis (Preprophase, Prophase, Prometaphase, Metaphase, Anaphase, Telophase) - Cytokinesis |
| Cell cycle checkpoints | Restriction point - Spindle checkpoint - Postreplication checkpoint |
| Other cellular phases | G0 phase - Apoptosis |

These phase (Table 2) will be discussed in details under module 2 unit 2 that follows this unit.

## 4.0 Conclusion

The ATP is the source of energy for a cell while the sequence of growth, DNA replication and cell divisions are the major processes in cell cycle

## 5.0 Summary

In this unit we have learnt that:

- Cell division is the method by which a single cell divides to create two cells.
- There are two main types of cell division, mitosis and meiosis, in eukaryotes

## 6.0 Tutor Marked Assignment

Itemize the events involved in the cell cycle of a cell.

## 7.0 Further Reading and Other Resources

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K., and Walter, P. (2002). "Mitosis". Molecular Biology of the Cell. Garland Science.

De Souza, C.P. and Osmani, S.A. (2007). "Mitosis, not just open or closed". Eukaryotic Cell 6 (9): 1521–7.

Gubb, D. (1998) Cellular polarity, mitotic synchrony and axes of symmetry during growth. Where does the information come from? Int. J. Dev. Biol. 42:369-377.

vided: the common basis of plant and animal cell division". logy 7 (2): 147–52.

# Module 2: Reproductive Cell Division, Differentiation and Growth Of Cells

## Unit 2: The Cell Cycle

# 1.0 Introduction

The unit examines a form of nuclear division in the eukaryotic cells because they are characterized by complex chromosome movement and exact chromosome duplication. This type of cell division is called mitosis.

# 2.0 Objectives

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

- Observe the characteristics that distinguish each of the phases in the Cell Cycle.
- Diagrammatically illustrate Mitosis

# 3.0 Main contents

## 3.1 Sequence of Events in Cell cycle

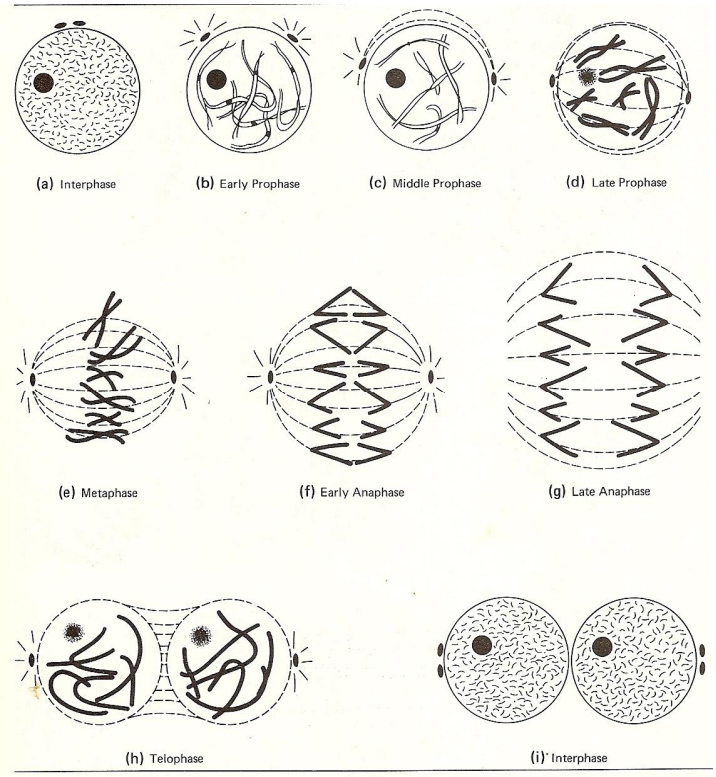


**Fig. 5: Mitosis in An Animal Cell**

*(Source: Genetics, Ursula Goodenough, 1978, 2nd edition)*

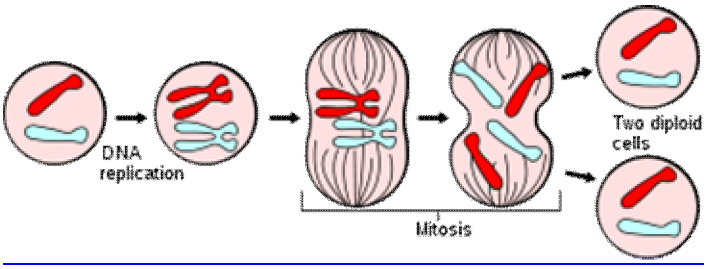



*Fig. 6: Division of a parent cell into two daughter cells*

*(Source: Harl et al., 2002 Essential genetics)*

Each turn of the cell cycle divides the chromosomes in a cell nucleus.

The cell cycle, or cell-division cycle, is the series of events that take place in a cell leading to its division and duplication (replication). In cells without a nuclear membrane (prokaryotes), the cell cycle occurs via a process termed binary fission. In cells with a nucleus (eukaryotes), the cell cycle can be divided in two brief periods: interphase—during which the cell grows, accumulating nutrients needed for mitosis and duplicating its DNA—and the mitosis (M) phase, during which the cell splits itself into two distinct cells, often called "daughter cells". The cell cycle is a vital process for both reproductive and vegetative cells development. A single-celled fertilized cell (egg) develops into a mature organism while hair, skin, and blood cells are renewed as vegetative cells.

## 3.2 The Phases

The cell cycle consists of five distinct phases: G0, G1 phase, S phase (synthesis), G2 phase (collectively known as interphase) and M phase (mitosis). M phase is itself composed of two tightly coupled processes: karyokinesis, in which the cell's chromosomes are divided between the two daughter cells, and cytokinesis, in which the cell's cytoplasm divides forming distinct cells. Activation of each phase is dependent on the proper progression and completion of the previous one. Cells that have temporarily or reversibly stopped dividing are said to have entered a state of quiescence called G0 phase (Table 3).

| State | Phase | Abbreviation | Description |
|---|---|---|---|
| quiescent/ senescent | Gap 0 | G0 | A resting phase where the cell has left the cycle and has stopped dividing. |
| Interphase | Gap 1 | G1 | Cells increase in size in Gap 1. The G1 checkpoint control mechanism ensures that everything is ready for DNA synthesis. |
| | Synthesis | S | DNA replication occurs during this phase. |
| | Gap 2 | G2 | During the gap between DNA synthesis and mitosis, the cell will continue to grow. The G2 checkpoint control mechanism ensures that everything is ready to enter the M (mitosis) phase and divide. |
| Cell division | Mitosis | M | Cell growth stops at this stage and cellular energy is focused on the orderly division into two daughter cells. A checkpoint in the middle of mitosis (Metaphase Checkpoint) ensures that the cell is ready to complete cell division. |

*(Source: Vines and Rees, Plant and Animal Biology, Vol. 2).*

After cell division, each of the daughter cells begins the interphase of a new cycle. Although the various stages of interphase are not usually morphologically distinguishable, each phase of the cell cycle has a distinct set of specialized biochemical processes that prepare the cell for initiation of cell division.

### 3.2.1 Resting (G0 phase)

The following are the summary of events in mitotic cell division (Fig. 5 to 6 and Table 2)The term "post-mitotic" is sometimes used to refer to both quiescent and senescent cells. Non proliferative cells in multicellular eukaryotes generally enter the quiescent G0 state from G1 and may remain quiescent for long periods of time, possibly indefinitely (as is often the case for neurons). This is very common for cells that are fully differentiated. Cellular senescence is a state that occurs in response to DNA damage or degradation that would make a cell's progeny (offspring) nonviable. It is often a biochemical alternative to the self-destruction of such a damaged cell by apoptosis (programmed cell death).

### 3.2.2 Interphase

The interphase can be divided into three phases – G1, S and G2

#### G1 phase

This is the first phase within interphase, from the end of the previous M phase until the beginning of DNA synthesis which is termed the G1 (G indicating gap). During this phase, the biosynthetic activities of the cell, which had been considerably slowed down during M phase, resume at a high rate. This phase is marked by synthesis of various enzymes that are required in S phase, mainly those needed for DNA replication. Duration of G1 is highly variable, even among different cells of the same species.

#### S phase

The ensuing S phase starts when DNA synthesis commences; when the synthesis is complete, all of the chromosomes have been replicated, i.e., each chromosome has two (sister) chromatids. Thus, during this phase, the amount of DNA in the cell has effectively doubled, though the ploidy, basic number of chromosomes of the cell remains the same. Rates of RNA transcription and protein synthesis are very low during this phase. An exception to this is histone production, most of which occurs during the S phase.

#### G2 phase

The cell then enters the G2 phase, which lasts until the cell enters mitosis. Again, significant protein synthesis occurs during this phase, mainly involving the production of microtubules, which are required during the process of mitosis. Inhibition of protein synthesis during G2 phase prevents the cell from undergoing mitosis.

### 3.2.3 M Phase

This phase involves the mitotic cell division. The relatively brief M phase consists of nuclear division (karyokinesis) and cytoplasmic division (cytokinesis). In plants and algae, cytokinesis is accompanied by the formation of a new cell wall. The M phase has been broken down into several distinct phases, sequentially known as prophase, prometaphase, metaphase, anaphase and telophase leading to cytokinesis (Fig. 5b-h).

Mitosis is the process in which a eukaryotic cell separates the chromosomes in its cell nucleus into two identical sets in two daughter nuclei. It is generally followed immediately by cytokinesis, which divides the nuclei, cytoplasm, organelles and cell membrane into two daughter cells containing roughly equal

yokinesis and cytokinesis together define the M phase of the nto two daughter cells, genetically identical to each other and to their parent cell.

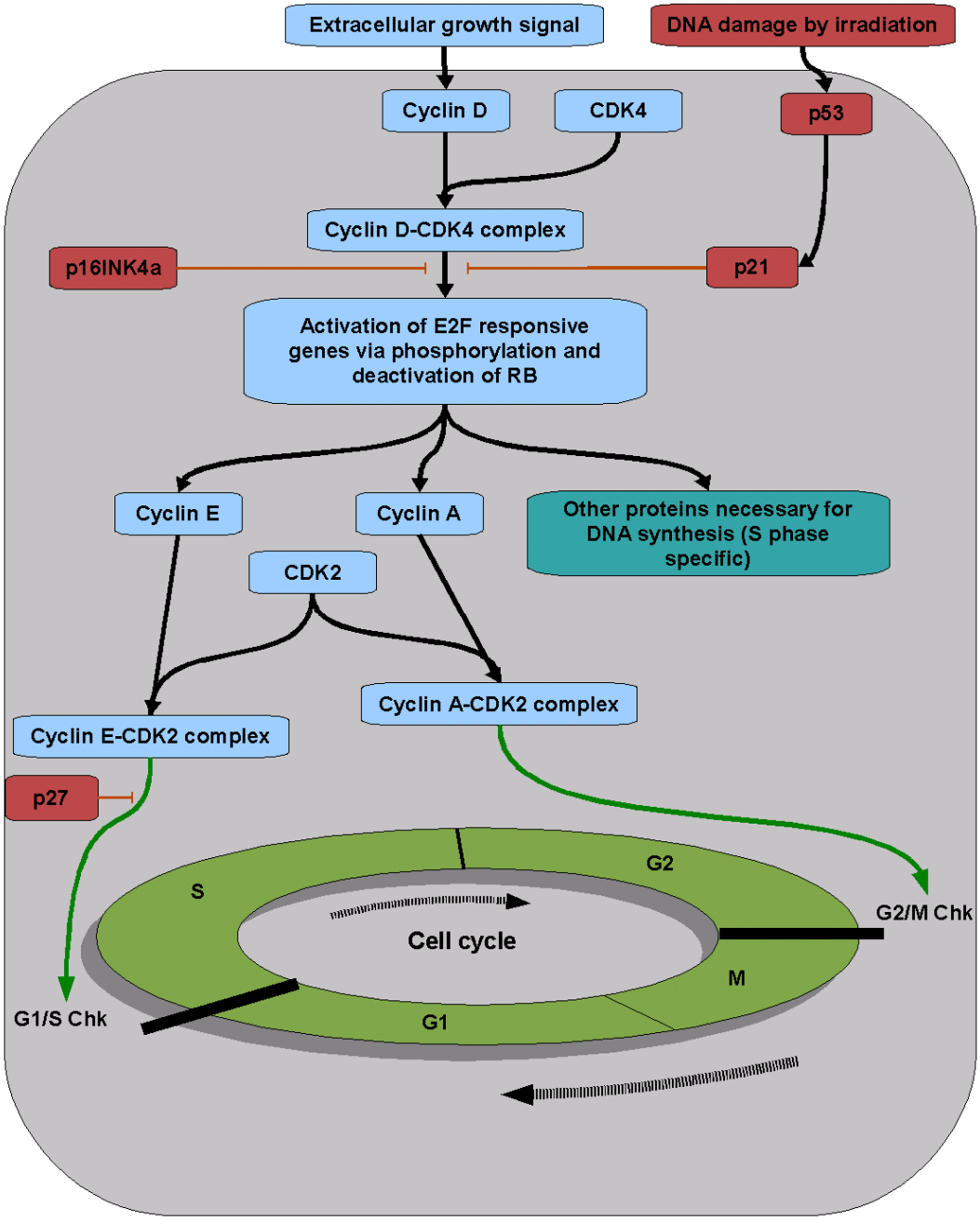
Mitosis occurs exclusively in eukaryotic cells, but occurs in different ways in different species. For example, animals undergo an "open" mitosis, where the nuclear envelope breaks down before the chromosomes separate, while fungi such as *Aspergillus nidulans* and *Saccharomyces cerevisiae* (yeast) undergo a "closed" mitosis, where chromosomes divide within an intact nuclear membrane. Prokaryotic cells, which lack a nuclear membrane, divide by a process called binary fission.

The process of mitosis is complex and highly regulated. During the process of mitosis the pairs of chromosomes condense and attach to fibers that pull the sister chromatids to opposite sides of the cell. The cell then divides during cytokinesis, to produce two identical daughter cells.

Because cytokinesis usually occurs in conjunction with mitosis, "mitosis" is often used interchangeably with "mitotic phase". However, there are many cells where karyokinesis and cytokinesis occur separately, forming single cells with multiple nuclei. This occurs most notably among the fungi and slime moulds, but is found in various different groups. Even in animals, cytokinesis and karyokinesis may occur independently, for instance during certain stages of fruit fly embryonic development. Errors in mitosis can either kill a cell through apoptosis or cause mutations that may lead to cancer.

## 3.3 Regulation of eukaryotic cell cycle

# l cycle - Schematic




CDK – Cyclin Dependent Kinase
G1/S Chk – G1/S checkpoint
G2/M Chk – G2/M checkpoint

of cell cycle

*(Source: McGowan 2005, Progress in cell cycle, vol. 5)*

Regulation of the cell cycle involves processes crucial to the survival of a cell, including the detection and repair of genetic damage as well as the prevention of uncontrolled cell division. The molecular events that control the cell cycle are ordered and directional; that is, each process occurs in a sequential fashion and it is impossible to "reverse" the cycle.

Cyclin is any of several related proteins whose concentrations rise and fall during the course of the eukaryotic cell cycle. Cyclins form complexes with cyclin-dependent kinases, thereby activating and determining the substrate specificity of these enzymes

**NOTE**: We shall not dwell much on the regulation of cell cycle as it is beyond the scope of this introductory course.

## 4.0 Conclusion

Karyokinesis and cytokinesis are cellular processes interwoven and are highly regulated within the cells.

## 5.0 Summary

In this unit we have learnt that:

- The cell cycle consists of five distinct phases:
- Mitosis occurs exclusively in eukaryotic cells, but occurs in different ways in different species.
- The stages of mitosis proper are prophase, prometaphase, metaphase, anaphase and telophase.

## 6.0 Tutor Marked Assignment

The cell cycle consists of five distinct phases, expatiate.

# Other Resources

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K. and Walter, P. (2002). "Chapter 17". Molecular Biology of the Cell (4th ed.). New York: Garland Science. ISBN 0-8153-3218-1.

Krieger, M., Scott, M.P.; Matsudaira, P.T., Lodish, H.F., Darnell, J.E., Zipursky, L., Kaiser, C.; Berk, A. (2004). Molecular Cell Biology. New York: W.H. Freeman and CO. ISBN 0-7167-4366-3.

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# Module 2: Reproductive Cell Division, Differentiation and Growth of Cells

## Unit 3: Phases Of Cell Cycle (Mitosis)

# 1.0 Introduction

In the last unit, we discussed mainly the phases associated with karyokinesis and cytokinesis in mitosis. In this unit, we shall look at mitosis in details, the processes following DNA replication in a eukaryotic cell, and its importance for the maintenance of the chromosomal set. Do you now remember that mitosis consists of two sets of processes – karyokinesis and cytokinesis?

# 2.0 Objectives

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

- Identify each phase of the cell cycle, leading to mitotic cell division.

# 3.0 Main contents

## 3.1 A Review of Mitosis

Mitosis is the process of forming identical daughter cells by replicating and dividing the original chromosomes, in effect making a cellular duplicate. Mitosis deals with the segregation of the chromosomes and organelles into daughter cells. Eukaryotic chromosomes occur in the cell in greater numbers than prokaryotic chromosomes. The condensed replicated chromosomes have several points of interest. Replicated chromosomes consist of two molecules of DNA (along with their associated histone proteins) known as chromatids. The area where both chromatids are in contact with each other is known as the centromeres. The kinetochores (where microtubules of the spindle apparatus attach) are on the outer sides of the centromere. Remember that chromosomes are condensed chromatin (DNA plus histone proteins).

You should also not forget that during mitosis replicated chromosomes are positioned near the middle of the cytoplasm and then segregated so that each daughter cell receives a copy of the original DNA (if you start with 46 in the parent cell, you should end up with 46 chromosomes in each daughter cell). To do this, cells utilize microtubules (referred to as the spindle apparatus) to "pull" chromosomes into each "cell". Animal cells (except for a group of worms known as nematodes) have a centriole. Plants and most other eukaryotic organisms lack centrioles. Prokaryotes, of course, lack spindles and centrioles; the cell membrane assumes this function when it pulls the by-then replicated chromosomes apart during binary fission. Cells that contain centrioles also have a series of smaller microtubules, the aster, that extend from the centrioles to the cell membrane. The aster is thought to serve as a brace for the functioning of the spindle fibers. The phases of mitosis are sometimes difficult to separate. Remember that the process is a dynamic one, not the static process displayed of necessity in a textbook.

# s in cells After Mitosis

up of two different processes – karyokinesis and cytokinesis. The following events describe karyokinesis. The primary result of mitosis is the division of the parent cell's genome (full set of gene) into two daughter cells. The genome is composed of a number of chromosomes - complexes of tightly-coiled DNA that contain genetic information vital for proper cell function. Because each resultant daughter cell should be genetically identical to the parent cell, the parent cell must make a copy of each chromosome before mitosis. This occurs during S phase, in interphase, the period that precedes the mitotic phase in the cell cycle where preparation for mitosis occurs.

Each new chromosome now contains two identical copies of itself, called sister chromatids, attached together in a specialized region of the chromosome known as the centromere. Each sister chromatid is not considered a chromosome in itself, and a chromosome does not always contain two sister chromatids. This is because in most eukaryotes, the nuclear envelope that separates the DNA from the cytoplasm disassembles. The chromosomes align themselves in a line spanning the cell. Microtubules, essentially miniature strings, splay (spread) out from opposite ends of the cell and shorten, pulling apart the sister chromatids of each chromosome. As a matter of convention, each sister chromatid is now considered a chromosome, so they are renamed to sister chromosomes. As the cell elongates, corresponding sister chromosomes are pulled toward opposite ends. A new nuclear envelope forms around the separated sister chromosomes.

After karyokinesis cytokinesis is well underway. In animal cells, the cell pinches inward where the imaginary line used to be (the pinching of the cell membrane to form the two daughter cells is called cleavage furrow), separating the two developing nuclei. In plant cells, the daughter cells will construct a new dividing cell wall (called cell plate) between each other. Eventually, the mother cell will be split in half, giving rise to two daughter cells, each with an equivalent and complete copy of the original genome.

Prokaryotic cells undergo a process similar to mitosis called binary fission. However, prokaryotes cannot be properly said to undergo mitosis because they lack a nucleus and only have a single chromosome with no centromere. The next few pages (3.2.1 – 3.2.7) will discuss the proper nucleus events leading to karyokinesis which can be regarded as the major process in mitosis.

## 3.2.1 Interphase

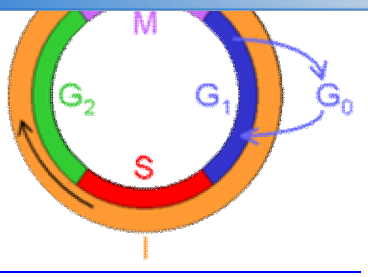


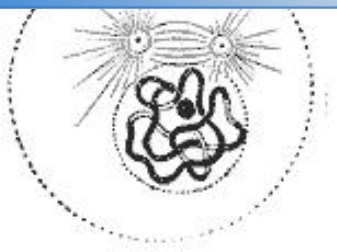

*Fig. 8 The cell cycle*

*(Source: The Biology Project, Univ. of Arizona, 1997).*

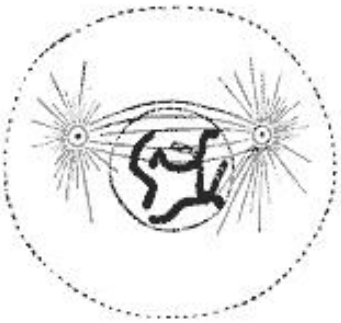
The mitotic phase (mitosis) is a relatively short period of the cell cycle. It alternates with the much longer interphase, where the cell prepares itself for cell division. Interphase is therefore not part of mitosis. Interphase is divided into three phases, G1 (first gap), S (synthesis), and G2 (second gap). During all three phases, the cell grows by producing proteins and cytoplasmic organelles. However, chromosomes are replicated only during the S phase. Thus, a cell grows (G1), continues to grow as it duplicates its chromosomes (S), grows more and prepares for mitosis (G2), and finally divides (M) before restarting the cycle.

### 3.2.2 Preprophase

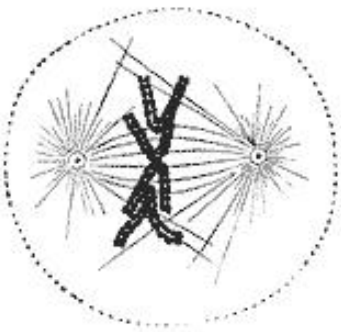
In plant cells only, prophase is preceded by a pre-prophase stage. In highly vacuolated plant cells, the nucleus has to migrate into the center of the cell before mitosis can begin. This is achieved through the formation of a phragmosome, a transverse sheet of cytoplasm that bisects the cell along the future plane of cell division. In addition to phragmosome formation, preprophase is characterized by the formation of a ring of microtubules and actin filaments (called preprophase band) underneath the plasma membrane around the equatorial plane of the future mitotic spindle. This band marks the position where the cell will eventually divide. The cells of higher plants (such as the flowering plants) lack centrioles: with microtubules forming a spindle on the surface of the nucleus and then being organized into a spindle by the chromosomes themselves, after the nuclear membrane breaks down. The preprophase band disappears during nuclear envelope disassembly and spindle formation in prometaphase.



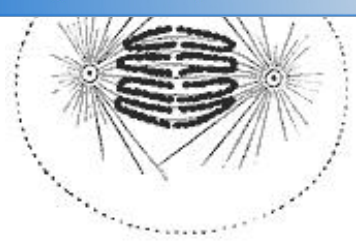
(a) Prophase: The two round objects above the nucleus are the centrosomes. The chromatin has condensed.



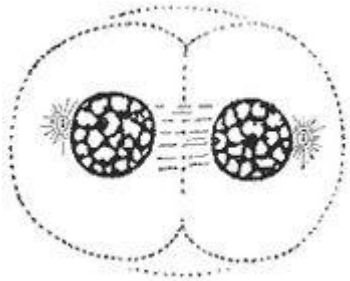
(b) Prometaphase: The nuclear membrane has degraded, and microtubules have invaded the nuclear space. These microtubules can attach to kinetochores or they can interact with opposing microtubules.



(c) Metaphase: The chromosomes have aligned at the metaphase plate.



(d) Early anaphase: Kinetochore microtubules shorten.



(e) Telophase: The decondensing chromosomes are surrounded by nuclear membranes. Note cytokinesis has already begun, the pinching is known as the cleavage furrow.

*Fig. 9 Stages of mitosis (a) Prophase, (b) Prometaphase, (c) Metaphase, (d) Early Anaphase, (e) Telophase.*

*(Source: Ursula Goodenough, 1978, Genetic, 2nd edition)*

### 3.2.3 Prophase

Prophase is the first stage of mitosis proper. Chromatin condenses (remember that the replica chromosomes replicate to chromatins during Interphase), the nuclear envelope dissolves, centrioles (if present) divide and migrate, kinetochores and kinetochore fibers form, and the spindle forms.

Normally, the genetic material in the nucleus is in a loosely bundled coil called chromatin. At the onset of prophase, chromatin condenses together into a highly ordered structure called a chromosome. Since the genetic material has already been duplicated earlier in S phase, each replicated chromosome has two sister chromatids, bound together at the centromere by the cohesion complex. Chromosomes are visible at high magnification through a light microscope.

s called centrosomes, which are made of a pair of centrioles. for the cell's microtubules. A cell inherits a single centrosome at cell division, which replicates before a new mitosis begins, giving a pair of centrosomes. The two centrosomes nucleate microtubules (which may be regarded as cellular ropes or poles) to form the spindle by polymerizing soluble tubulin. Molecular motor proteins then push the centrosomes along these microtubules to opposite side of the cell. Although centrosomes help organize microtubule assembly, they are not essential for the formation of the spindle, since they are absent from plants, and centrosomes are not always used in meiosis, the cell division in reproductive cells.

### 3.2.4 Prometaphase

The nuclear envelope disassembles and microtubules invade the nuclear space. This is called open mitosis, and it occurs in most multicellular organisms. Fungi and some protists, such as algae or trichomonads, undergo a variation called closed mitosis where the spindle forms inside the nucleus or its microtubules are able to penetrate an intact nuclear envelope.

Each chromosome forms two kinetochores at the centromere, one attached at each chromatid. A kinetochore is a complex protein structure that is analogous to a ring for the microtubule hook; it is the point where microtubules attach themselves to the chromosome. Although the kinetochore structure and function are not fully understood, it is known that it contains some form of molecular motor. When a microtubule connects with the kinetochore, the motor activates, using energy from ATP to "crawl" up the tube toward the originating centrosome. This motor activity, coupled with polymerisation and depolymerisation of microtubules, provides the pulling force necessary to later separate the chromosome's two chromatids.

When the spindle grows to sufficient length, kinetochore microtubules begin searching for kinetochores to attach to. A number of nonkinetochore microtubules find and interact with corresponding nonkinetochore microtubules from the opposite centrosome to form the mitotic spindle. Prometaphase is sometimes considered as part of prophase.

### 3.2.5 Metaphase

Metaphase follows Prophase. The chromosomes (which at this point consist of chromatids held together by a centromere) migrate to the equator of the spindle, where the spindles attach to the kinetochore fibers.

As microtubules find and attach to kinetochores in prometaphase, the centromeres of the chromosomes convene along the metaphase plate or equatorial plane, an imaginary line that is equidistant from the two centrosome poles. This even alignment is due to the counterbalance of the pulling powers generated by the opposing kinetochores, analogous to a tug-of-war between people of equal strength.

not line up at the metaphase plate and instead move back and forth roughly lining up along the midline. Metaphase means "after."

Because proper chromosome separation requires that every kinetochore be attached to a bundle of microtubules (spindle fibres), it is thought that unattached kinetochores generate a signal to prevent premature progression to anaphase without all chromosomes being aligned. The signal creates the mitotic spindle checkpoint.

### 3.2.6 Anaphase

Anaphase begins with the separation of the centromeres, and the pulling of chromosomes (we call them chromosomes after the centromeres are separated) to opposite poles of the spindle.

When every kinetochore is attached to a cluster of microtubules and the chromosomes have lined up along the metaphase plate, the cell proceeds to anaphase.

Two events then occur; first, the proteins that bind sister chromatids together are cleaved, allowing them to separate. These sister chromatids, which have now become distinct sister chromosomes, are pulled apart by shortening kinetochore microtubules and move toward the respective centrosomes to which they are attached. Next, the nonkinetochore microtubules elongate, pushing the centrosomes (and the set of chromosomes to which they are attached) apart to opposite ends of the cell. The force that causes the centrosomes to move towards the ends of the cell is still unknown, although there is a theory that suggests that the rapid assembly and breakdown of microtubules may cause this movement.

These two stages are sometimes called early and late anaphase. Early anaphase is usually defined as the separation of the sister chromatids, while late anaphase is the elongation of the microtubules and the microtubules being pulled farther apart. At the end of anaphase, the cell has succeeded in separating identical copies of the genetic material into two distinct populations.

### 3.2.7 Telophase

Telophase (means "end") is a reversal of prophase and prometaphase events. It "cleans up" the after effects of mitosis. At telophase, the nonkinetochore microtubules continue to lengthen, elongating the cell even more. Corresponding sister chromosomes attach at opposite ends of the cell. A new nuclear envelope, using fragments of the parent cell's nuclear membrane, forms around each set of separated sister chromosomes. Both sets of chromosomes, now surrounded by new nuclear envelopes, unfold back into chromatin. Mitosis is complete, but cell division is not yet complete.

Telophase is when the chromosomes reach the poles of their respective spindles, the nuclear envelope reforms, chromosomes uncoil into chromatin form, and the nucleolus (which had disappeared during Prophase) reform. Where there was one cell there are now two smaller cells each with exactly the same

n develop into different mature forms via the processes of

## 3.3. Cytokinesis

Cytokinesis is the second process involved in cell division. It is the process of splitting the daughter cells apart. Whereas mitosis (karyokinesis) is the division of the nucleus, cytokinesis is the splitting of the cytoplasm and allocation of the golgi, plastids and cytoplasm into each new cell.

Cytokinesis is often mistakenly thought to be the final part of telophase; however, cytokinesis is a separate process that begins at the same time as telophase. Cytokinesis is technically not even a phase of mitosis, but rather a separate process, necessary for completing cell division. In animal cells, a cleavage furrow (pinch) containing a contractile ring develops where the metaphase plate used to be, pinching off the separated nuclei. In both animal and plant cells, cell division is also driven by vesicles derived from the Golgi apparatus, which move along microtubules to the middle of the cell. In plants this structure coalesces into a cell plate at the center of the phragmoplast and develops into a cell wall, separating the two nuclei. The phragmoplast (Fig. 10) is a microtubule structure typical for higher plants, whereas some green algae use a phycoplast microtubule array during cytokinesis. Each daughter cell has a complete copy of the genome of its parent cell. The end of cytokinesis marks the end of the M-phase.

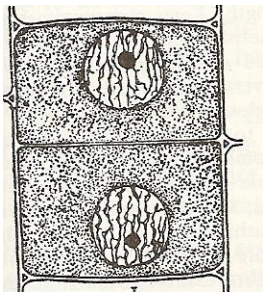


*Fig. 10.* Plant cytokinesis

*(Source: Botany for degree students, Dutta A.C., 5th edition, 1963).*

## 3.4 Significance of Mitosis

Please note that mitosis occurs in reproductive and vegetative cells. Mitosis is important for the maintenance of the chromosomal set; each cell formed receives chromosomes that are alike in composition and equal in number to the chromosomes of the parent cell. Transcription is generally

enetic mechanisms such as bookmarking function during this e "memory" of which genes were active prior to entry into mitosis are transmitted to the daughter cells.

Mitosis occurs immediately after meiosis in reproductive cells. Although errors in mitosis are rare, the process may go wrong, especially during early cellular divisions in the zygote. Mitotic errors can be especially dangerous to the organism because future offspring from this parent cell will carry the same disorder.

In non-disjunction, a chromosome may fail to separate during anaphase. One daughter cell will receive both sister chromosomes and the other will receive none. This results in the former cell having three chromosomes containing the same genes (two sisters and a homologue), a condition known as trisomy, and the latter cell having only one chromosome (the homologous chromosome), a condition known as monosomy. These cells are considered aneuploid, a condition often associated with cancer.

Mitosis is a traumatic process. The cell goes through dramatic changes in ultrastructure, its organelles disintegrate and reform in a matter of hours, and chromosomes are jostled constantly by probing microtubules. Occasionally, chromosomes may become damaged. An arm of the chromosome may be broken and the fragment lost, causing **deletion**. The fragment may incorrectly reattach to another, non-homologous chromosome, causing **translocation**. It may reattach to the original chromosome, but in reverse orientation, causing **inversion**. Or, it may be treated erroneously as a separate chromosome, causing **chromosomal duplication**. The effect of these genetic abnormalities depends on the specific nature of the error. It may range from no noticeable effect to cancer induction or organism death.

# 4.0 Conclusion

It is important to emphasize that mitosis is well defined in eukaryotic cells while prokaryotic cells cannot be said to undergo proper mitosis because they do not have a well defined nucleus.

# 5.0 Summary

In this unit we have learnt that:

- The karyokinesis and cytokinesis are cycle of changes that take place before in a parent cell
- These changes lead to the single parent cell dividing into two daughter cells during mitosis
- Mitosis occurs both in reproductive and vegetative cells
- Mitosis is very important in several aspect of the cell and its constituents

## 6.0 Tutor Marked Assignment

Discuss the five distinct phases of the cell cycle

Distinguish between karyokinesis and cytokinesis. List characteristic features of each phase of the cell cycle.

## 7.0 Further Reading and Other Resources

Lodish, H., Berk, A., Zipursky, L., Matsudaira, P., Baltimore, D. and Darnell, J. (2000). "Overview of the Cell Cycle and Its Control". Molecular Cell Biology. W.H. Freeman.

Morgan, D. L. (2007). The Cell Cycle: Principles of control. London: Published by New Science Press in association with Oxford University Press. ISBN 0-9539181-2-2.

Campbell, N,. and Reece, J. (2001). "The Cell Cycle". Biology (6th ed.). San Francisco: Benjamin Cummings/Addison-Wesley. ISBN 0-8053-6624-5.

# Module 2: Reproductive Cell Division, Differentiation and Growth of Cells

## Unit 3: Phases Of Cell Cycle (Mitosis)

# 1.0 Introduction

In the last unit, we discussed mainly the phases associated with karyokinesis and cytokinesis in mitosis. In this unit, we shall look at mitosis in details, the processes following DNA replication in a eukaryotic cell, and its importance for the maintenance of the chromosomal set. Do you now remember that mitosis consists of two sets of processes – karyokinesis and cytokinesis?

# 2.0 Objectives

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

- Identify each phase of the cell cycle, leading to mitotic cell division.

# 3.0 Main contents

## 3.1 A Review of Mitosis

Mitosis is the process of forming identical daughter cells by replicating and dividing the original chromosomes, in effect making a cellular duplicate. Mitosis deals with the segregation of the chromosomes and organelles into daughter cells. Eukaryotic chromosomes occur in the cell in greater numbers than prokaryotic chromosomes. The condensed replicated chromosomes have several points of interest. Replicated chromosomes consist of two molecules of DNA (along with their associated histone proteins) known as chromatids. The area where both chromatids are in contact with each other is known as the centromeres. The kinetochores (where microtubules of the spindle apparatus attach) are on the outer sides of the centromere. Remember that chromosomes are condensed chromatin (DNA plus histone proteins).

You should also not forget that during mitosis replicated chromosomes are positioned near the middle of the cytoplasm and then segregated so that each daughter cell receives a copy of the original DNA (if you start with 46 in the parent cell, you should end up with 46 chromosomes in each daughter cell). To do this, cells utilize microtubules (referred to as the spindle apparatus) to "pull" chromosomes into each "cell". Animal cells (except for a group of worms known as nematodes) have a centriole. Plants and most other eukaryotic organisms lack centrioles. Prokaryotes, of course, lack spindles and centrioles; the cell membrane assumes this function when it pulls the by-then replicated chromosomes apart during binary fission. Cells that contain centrioles also have a series of smaller microtubules, the aster, that extend from the centrioles to the cell membrane. The aster is thought to serve as a brace for the functioning of the spindle fibers. The phases of mitosis are sometimes difficult to separate. Remember that the process is a dynamic one, not the static process displayed of necessity in a textbook.

# s in cells After Mitosis

up of two different processes – karyokinesis and cytokinesis. The following events describe karyokinesis. The primary result of mitosis is the division of the parent cell's genome (full set of gene) into two daughter cells. The genome is composed of a number of chromosomes - complexes of tightly-coiled DNA that contain genetic information vital for proper cell function. Because each resultant daughter cell should be genetically identical to the parent cell, the parent cell must make a copy of each chromosome before mitosis. This occurs during S phase, in interphase, the period that precedes the mitotic phase in the cell cycle where preparation for mitosis occurs.

Each new chromosome now contains two identical copies of itself, called sister chromatids, attached together in a specialized region of the chromosome known as the centromere. Each sister chromatid is not considered a chromosome in itself, and a chromosome does not always contain two sister chromatids. This is because in most eukaryotes, the nuclear envelope that separates the DNA from the cytoplasm disassembles. The chromosomes align themselves in a line spanning the cell. Microtubules, essentially miniature strings, splay (spread) out from opposite ends of the cell and shorten, pulling apart the sister chromatids of each chromosome. As a matter of convention, each sister chromatid is now considered a chromosome, so they are renamed to sister chromosomes. As the cell elongates, corresponding sister chromosomes are pulled toward opposite ends. A new nuclear envelope forms around the separated sister chromosomes.

After karyokinesis cytokinesis is well underway. In animal cells, the cell pinches inward where the imaginary line used to be (the pinching of the cell membrane to form the two daughter cells is called cleavage furrow), separating the two developing nuclei. In plant cells, the daughter cells will construct a new dividing cell wall (called cell plate) between each other. Eventually, the mother cell will be split in half, giving rise to two daughter cells, each with an equivalent and complete copy of the original genome.

Prokaryotic cells undergo a process similar to mitosis called binary fission. However, prokaryotes cannot be properly said to undergo mitosis because they lack a nucleus and only have a single chromosome with no centromere. The next few pages (3.2.1 – 3.2.7) will discuss the proper nucleus events leading to karyokinesis which can be regarded as the major process in mitosis.

## 3.2.1 Interphase

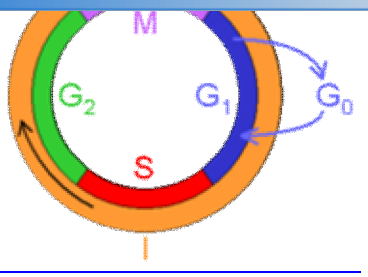


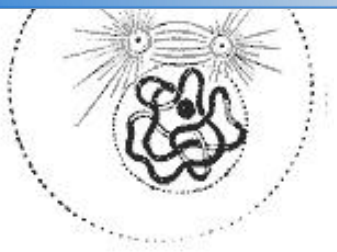

*Fig. 8 The cell cycle*

*(Source: The Biology Project, Univ. of Arizona, 1997).*

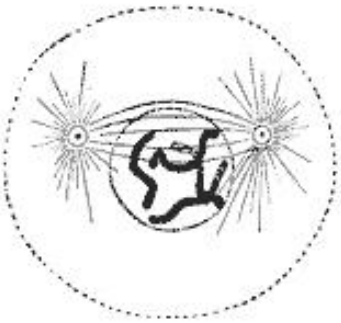
The mitotic phase (mitosis) is a relatively short period of the cell cycle. It alternates with the much longer interphase, where the cell prepares itself for cell division. Interphase is therefore not part of mitosis. Interphase is divided into three phases, G1 (first gap), S (synthesis), and G2 (second gap). During all three phases, the cell grows by producing proteins and cytoplasmic organelles. However, chromosomes are replicated only during the S phase. Thus, a cell grows (G1), continues to grow as it duplicates its chromosomes (S), grows more and prepares for mitosis (G2), and finally divides (M) before restarting the cycle.

### 3.2.2 Preprophase

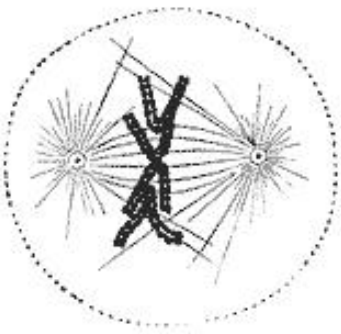
In plant cells only, prophase is preceded by a pre-prophase stage. In highly vacuolated plant cells, the nucleus has to migrate into the center of the cell before mitosis can begin. This is achieved through the formation of a phragmosome, a transverse sheet of cytoplasm that bisects the cell along the future plane of cell division. In addition to phragmosome formation, preprophase is characterized by the formation of a ring of microtubules and actin filaments (called preprophase band) underneath the plasma membrane around the equatorial plane of the future mitotic spindle. This band marks the position where the cell will eventually divide. The cells of higher plants (such as the flowering plants) lack centrioles: with microtubules forming a spindle on the surface of the nucleus and then being organized into a spindle by the chromosomes themselves, after the nuclear membrane breaks down. The preprophase band disappears during nuclear envelope disassembly and spindle formation in prometaphase.



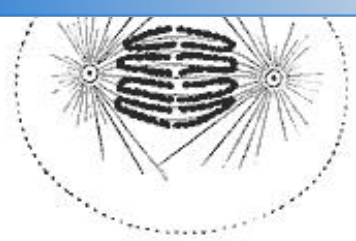
(f) Prophase: The two round objects above the nucleus are the centrosomes. The chromatin has condensed.



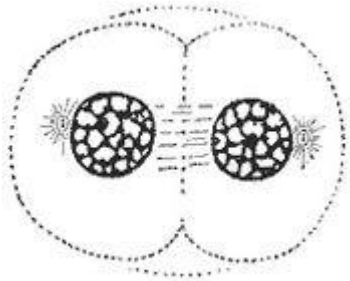
(g) Prometaphase: The nuclear membrane has degraded, and microtubules have invaded the nuclear space. These microtubules can attach to kinetochores or they can interact with opposing microtubules.



(h) Metaphase: The chromosomes have aligned at the metaphase plate.



(i) Early anaphase: Kinetochore microtubules shorten.



(j) Telophase: The decondensing chromosomes are surrounded by nuclear membranes. Note cytokinesis has already begun, the pinching is known as the cleavage furrow.

*Fig. 9 Stages of mitosis (a) Prophase, (b) Prometaphase, (c) Metaphase, (d) Early Anaphase, (e) Telophase.*

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### 3.2.3 Prophase

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Anaphase begins with the separation of the centromeres, and the pulling of chromosomes (we call them chromosomes after the centromeres are separated) to opposite poles of the spindle.

When every kinetochore is attached to a cluster of microtubules and the chromosomes have lined up along the metaphase plate, the cell proceeds to anaphase.

Two events then occur; first, the proteins that bind sister chromatids together are cleaved, allowing them to separate. These sister chromatids, which have now become distinct sister chromosomes, are pulled apart by shortening kinetochore microtubules and move toward the respective centrosomes to which they are attached. Next, the nonkinetochore microtubules elongate, pushing the centrosomes (and the set of chromosomes to which they are attached) apart to opposite ends of the cell. The force that causes the centrosomes to move towards the ends of the cell is still unknown, although there is a theory that suggests that the rapid assembly and breakdown of microtubules may cause this movement.

These two stages are sometimes called early and late anaphase. Early anaphase is usually defined as the separation of the sister chromatids, while late anaphase is the elongation of the microtubules and the microtubules being pulled farther apart. At the end of anaphase, the cell has succeeded in separating identical copies of the genetic material into two distinct populations.

### 3.2.7 Telophase

Telophase (means "end") is a reversal of prophase and prometaphase events. It "cleans up" the after effects of mitosis. At telophase, the nonkinetochore microtubules continue to lengthen, elongating the cell even more. Corresponding sister chromosomes attach at opposite ends of the cell. A new nuclear envelope, using fragments of the parent cell's nuclear membrane, forms around each set of separated sister chromosomes. Both sets of chromosomes, now surrounded by new nuclear envelopes, unfold back into chromatin. Mitosis is complete, but cell division is not yet complete.

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## 3.3. Cytokinesis

Cytokinesis is the second process involved in cell division. It is the process of splitting the daughter cells apart. Whereas mitosis (karyokinesis) is the division of the nucleus, cytokinesis is the splitting of the cytoplasm and allocation of the golgi, plastids and cytoplasm into each new cell.

Cytokinesis is often mistakenly thought to be the final part of telophase; however, cytokinesis is a separate process that begins at the same time as telophase. Cytokinesis is technically not even a phase of mitosis, but rather a separate process, necessary for completing cell division. In animal cells, a cleavage furrow (pinch) containing a contractile ring develops where the metaphase plate used to be, pinching off the separated nuclei. In both animal and plant cells, cell division is also driven by vesicles derived from the Golgi apparatus, which move along microtubules to the middle of the cell. In plants this structure coalesces into a cell plate at the center of the phragmoplast and develops into a cell wall, separating the two nuclei. The phragmoplast (Fig. 10) is a microtubule structure typical for higher plants, whereas some green algae use a phycoplast microtubule array during cytokinesis. Each daughter cell has a complete copy of the genome of its parent cell. The end of cytokinesis marks the end of the M-phase.

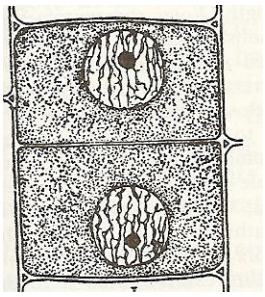

*Fig. 10.* Plant cytokinesis

*(Source: Botany for degree students, Dutta A.C., 5th edition, 1963).*

## 3.4 Significance of Mitosis

Please note that mitosis occurs in reproductive and vegetative cells. Mitosis is important for the maintenance of the chromosomal set; each cell formed receives chromosomes that are alike in composition and equal in number to the chromosomes of the parent cell. Transcription is generally

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In non-disjunction, a chromosome may fail to separate during anaphase. One daughter cell will receive both sister chromosomes and the other will receive none. This results in the former cell having three chromosomes containing the same genes (two sisters and a homologue), a condition known as trisomy, and the latter cell having only one chromosome (the homologous chromosome), a condition known as monosomy. These cells are considered aneuploid, a condition often associated with cancer.

Mitosis is a traumatic process. The cell goes through dramatic changes in ultrastructure, its organelles disintegrate and reform in a matter of hours, and chromosomes are jostled constantly by probing microtubules. Occasionally, chromosomes may become damaged. An arm of the chromosome may be broken and the fragment lost, causing **deletion**. The fragment may incorrectly reattach to another, non-homologous chromosome, causing **translocation**. It may reattach to the original chromosome, but in reverse orientation, causing **inversion**. Or, it may be treated erroneously as a separate chromosome, causing **chromosomal duplication**. The effect of these genetic abnormalities depends on the specific nature of the error. It may range from no noticeable effect to cancer induction or organism death.

## 4.0 Conclusion

It is important to emphasize that mitosis is well defined in eukaryotic cells while prokaryotic cells cannot be said to undergo proper mitosis because they do not have a well defined nucleus.

## 5.0 Summary

In this unit we have learnt that:

- The karyokinesis and cytokinesis are cycle of changes that take place before in a parent cell
- These changes lead to the single parent cell dividing into two daughter cells during mitosis
- Mitosis occurs both in reproductive and vegetative cells
- Mitosis is very important in several aspect of the cell and its constituents

## 6.0 Tutor Marked Assignment

Discuss the five distinct phases of the cell cycle

Distinguish between karyokinesis and cytokinesis. List characteristic features of each phase of the cell cycle.

## 7.0 Further Reading and Other Resources

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# Module 2: Reproductive Cell Division, Differentiation and Growth of Cells

## Unit 3: Phases Of Cell Cycle (Mitosis)

# 1.0 Introduction

In the last unit, we discussed mainly the phases associated with karyokinesis and cytokinesis in mitosis. In this unit, we shall look at mitosis in details, the processes following DNA replication in a eukaryotic cell, and its importance for the maintenance of the chromosomal set. Do you now remember that mitosis consists of two sets of processes – karyokinesis and cytokinesis?

# 2.0 Objectives

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

- Identify each phase of the cell cycle, leading to mitotic cell division.

# 3.0 Main contents

## 3.1 A Review of Mitosis

Mitosis is the process of forming identical daughter cells by replicating and dividing the original chromosomes, in effect making a cellular duplicate. Mitosis deals with the segregation of the chromosomes and organelles into daughter cells. Eukaryotic chromosomes occur in the cell in greater numbers than prokaryotic chromosomes. The condensed replicated chromosomes have several points of interest. Replicated chromosomes consist of two molecules of DNA (along with their associated histone proteins) known as chromatids. The area where both chromatids are in contact with each other is known as the centromeres. The kinetochores (where microtubules of the spindle apparatus attach) are on the outer sides of the centromere. Remember that chromosomes are condensed chromatin (DNA plus histone proteins).

You should also not forget that during mitosis replicated chromosomes are positioned near the middle of the cytoplasm and then segregated so that each daughter cell receives a copy of the original DNA (if you start with 46 in the parent cell, you should end up with 46 chromosomes in each daughter cell). To do this, cells utilize microtubules (referred to as the spindle apparatus) to "pull" chromosomes into each "cell". Animal cells (except for a group of worms known as nematodes) have a centriole. Plants and most other eukaryotic organisms lack centrioles. Prokaryotes, of course, lack spindles and centrioles; the cell membrane assumes this function when it pulls the by-then replicated chromosomes apart during binary fission. Cells that contain centrioles also have a series of smaller microtubules, the aster, that extend from the centrioles to the cell membrane. The aster is thought to serve as a brace for the functioning of the spindle fibers. The phases of mitosis are sometimes difficult to separate. Remember that the process is a dynamic one, not the static process displayed of necessity in a textbook.

# s in cells After Mitosis

up of two different processes – karyokinesis and cytokinesis. The following events describe karyokinesis. The primary result of mitosis is the division of the parent cell's genome (full set of gene) into two daughter cells. The genome is composed of a number of chromosomes - complexes of tightly-coiled DNA that contain genetic information vital for proper cell function. Because each resultant daughter cell should be genetically identical to the parent cell, the parent cell must make a copy of each chromosome before mitosis. This occurs during S phase, in interphase, the period that precedes the mitotic phase in the cell cycle where preparation for mitosis occurs.

Each new chromosome now contains two identical copies of itself, called sister chromatids, attached together in a specialized region of the chromosome known as the centromere. Each sister chromatid is not considered a chromosome in itself, and a chromosome does not always contain two sister chromatids. This is because in most eukaryotes, the nuclear envelope that separates the DNA from the cytoplasm disassembles. The chromosomes align themselves in a line spanning the cell. Microtubules, essentially miniature strings, splay (spread) out from opposite ends of the cell and shorten, pulling apart the sister chromatids of each chromosome. As a matter of convention, each sister chromatid is now considered a chromosome, so they are renamed to sister chromosomes. As the cell elongates, corresponding sister chromosomes are pulled toward opposite ends. A new nuclear envelope forms around the separated sister chromosomes.

After karyokinesis cytokinesis is well underway. In animal cells, the cell pinches inward where the imaginary line used to be (the pinching of the cell membrane to form the two daughter cells is called cleavage furrow), separating the two developing nuclei. In plant cells, the daughter cells will construct a new dividing cell wall (called cell plate) between each other. Eventually, the mother cell will be split in half, giving rise to two daughter cells, each with an equivalent and complete copy of the original genome.

Prokaryotic cells undergo a process similar to mitosis called binary fission. However, prokaryotes cannot be properly said to undergo mitosis because they lack a nucleus and only have a single chromosome with no centromere. The next few pages (3.2.1 – 3.2.7) will discuss the proper nucleus events leading to karyokinesis which can be regarded as the major process in mitosis.

## 3.2.1 Interphase

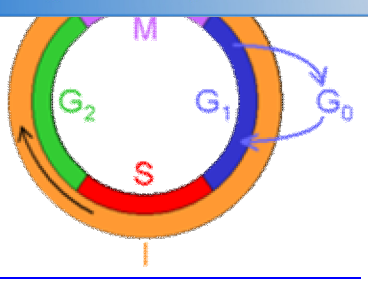


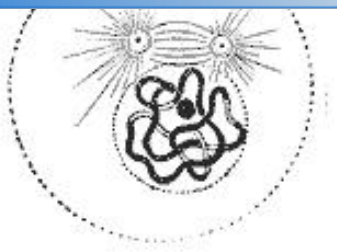

*Fig. 8 The cell cycle*

*(Source: The Biology Project, Univ. of Arizona, 1997).*

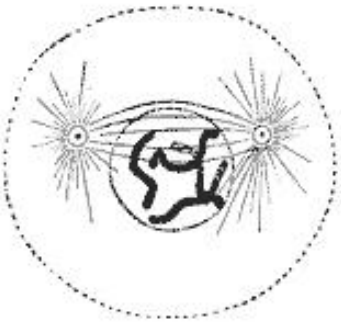
The mitotic phase (mitosis) is a relatively short period of the cell cycle. It alternates with the much longer interphase, where the cell prepares itself for cell division. Interphase is therefore not part of mitosis. Interphase is divided into three phases, G1 (first gap), S (synthesis), and G2 (second gap). During all three phases, the cell grows by producing proteins and cytoplasmic organelles. However, chromosomes are replicated only during the S phase. Thus, a cell grows (G1), continues to grow as it duplicates its chromosomes (S), grows more and prepares for mitosis (G2), and finally divides (M) before restarting the cycle.

### 3.2.2 Preprophase

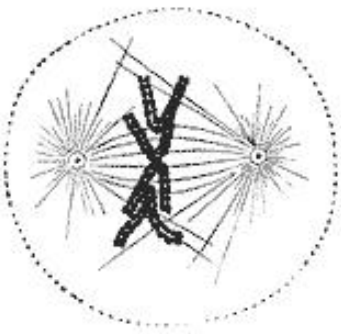
In plant cells only, prophase is preceded by a pre-prophase stage. In highly vacuolated plant cells, the nucleus has to migrate into the center of the cell before mitosis can begin. This is achieved through the formation of a phragmosome, a transverse sheet of cytoplasm that bisects the cell along the future plane of cell division. In addition to phragmosome formation, preprophase is characterized by the formation of a ring of microtubules and actin filaments (called preprophase band) underneath the plasma membrane around the equatorial plane of the future mitotic spindle. This band marks the position where the cell will eventually divide. The cells of higher plants (such as the flowering plants) lack centrioles: with microtubules forming a spindle on the surface of the nucleus and then being organized into a spindle by the chromosomes themselves, after the nuclear membrane breaks down. The preprophase band disappears during nuclear envelope disassembly and spindle formation in prometaphase.



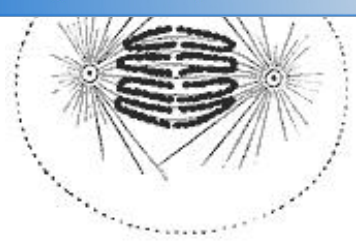
(k) Prophase: The two round objects above the nucleus are the centrosomes. The chromatin has condensed.



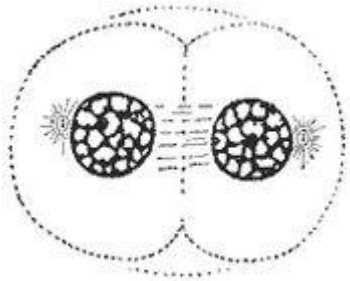
(l) Prometaphase: The nuclear membrane has degraded, and microtubules have invaded the nuclear space. These microtubules can attach to kinetochores or they can interact with opposing microtubules.



(m) Metaphase: The chromosomes have aligned at the metaphase plate.



(n) Early anaphase: Kinetochore microtubules shorten.



(o) Telophase: The decondensing chromosomes are surrounded by nuclear membranes. Note cytokinesis has already begun, the pinching is known as the cleavage furrow.

*Fig. 9 Stages of mitosis (a) Prophase, (b) Prometaphase, (c) Metaphase, (d) Early Anaphase, (e) Telophase.*

*(Source: Ursula Goodenough, 1978, Genetic, 2nd edition)*

### 3.2.3 Prophase

Prophase is the first stage of mitosis proper. Chromatin condenses (remember that the replica chromosomes replicate to chromatins during Interphase), the nuclear envelope dissolves, centrioles (if present) divide and migrate, kinetochores and kinetochore fibers form, and the spindle forms.

Normally, the genetic material in the nucleus is in a loosely bundled coil called chromatin. At the onset of prophase, chromatin condenses together into a highly ordered structure called a chromosome. Since the genetic material has already been duplicated earlier in S phase, each replicated chromosome has two sister chromatids, bound together at the centromere by the cohesion complex. Chromosomes are visible at high magnification through a light microscope.

s called centrosomes, which are made of a pair of centrioles. for the cell's microtubules. A cell inherits a single centrosome at cell division, which replicates before a new mitosis begins, giving a pair of centrosomes. The two centrosomes nucleate microtubules (which may be regarded as cellular ropes or poles) to form the spindle by polymerizing soluble tubulin. Molecular motor proteins then push the centrosomes along these microtubules to opposite side of the cell. Although centrosomes help organize microtubule assembly, they are not essential for the formation of the spindle, since they are absent from plants, and centrosomes are not always used in meiosis, the cell division in reproductive cells.

### 3.2.4 Prometaphase

The nuclear envelope disassembles and microtubules invade the nuclear space. This is called open mitosis, and it occurs in most multicellular organisms. Fungi and some protists, such as algae or trichomonads, undergo a variation called closed mitosis where the spindle forms inside the nucleus or its microtubules are able to penetrate an intact nuclear envelope.

Each chromosome forms two kinetochores at the centromere, one attached at each chromatid. A kinetochore is a complex protein structure that is analogous to a ring for the microtubule hook; it is the point where microtubules attach themselves to the chromosome. Although the kinetochore structure and function are not fully understood, it is known that it contains some form of molecular motor. When a microtubule connects with the kinetochore, the motor activates, using energy from ATP to "crawl" up the tube toward the originating centrosome. This motor activity, coupled with polymerisation and depolymerisation of microtubules, provides the pulling force necessary to later separate the chromosome's two chromatids.

When the spindle grows to sufficient length, kinetochore microtubules begin searching for kinetochores to attach to. A number of nonkinetochore microtubules find and interact with corresponding nonkinetochore microtubules from the opposite centrosome to form the mitotic spindle. Prometaphase is sometimes considered as part of prophase.

### 3.2.5 Metaphase

Metaphase follows Prophase. The chromosomes (which at this point consist of chromatids held together by a centromere) migrate to the equator of the spindle, where the spindles attach to the kinetochore fibers.

As microtubules find and attach to kinetochores in prometaphase, the centromeres of the chromosomes convene along the metaphase plate or equatorial plane, an imaginary line that is equidistant from the two centrosome poles. This even alignment is due to the counterbalance of the pulling powers generated by the opposing kinetochores, analogous to a tug-of-war between people of equal strength.

not line up at the metaphase plate and instead move back and forth roughly lining up along the midline. Metaphase means "after."

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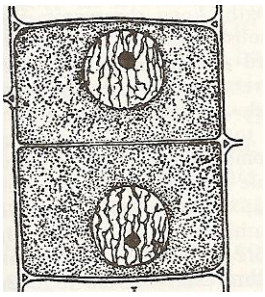

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# Module 3: Molecular Basis of Cell Structure and Development

## Unit 1: Prokaryotic Cell Structure

# 1.0 Introduction

Cells are the fundamental structural and functional units that the plant body and animal body is composed of. In this unit we shall examine the structure of prokaryote cell in some detail and then study other cells in the next few units.

# 2.0 Objectives

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

- Clearly outline and label bacterial cell;
- Write on the current understanding of the prokaryotic cell structure;
- Illustrate some of the structures discloses in the diagrams.

# 3.0 Main Contents

## 3.1 Details of Prokaryotic Cellular Components

An example of prokaryotic organism-*Escherichia coli*. It is a simple single cell, rod-shaped and bacillus

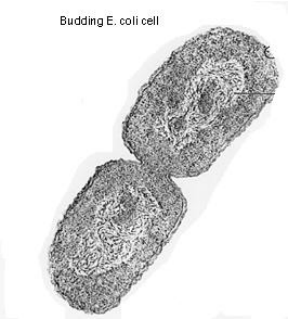



*Fig. 28. Budding Escherichia coli*

*©Wilbur H. Campbell, 1995*

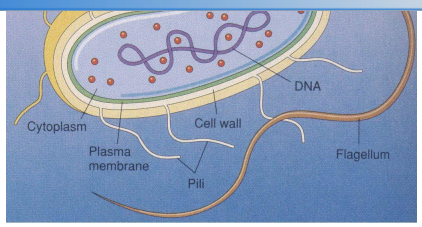



*Fig. 29. A typical bacterial cell*

*Morayeel.louisiana.edu*

*E. coli* grows in human intestine; it has a single, circular chromosome and also contains DNA as plasmids - Plasmids are extra-chromosomal DNA.

## 3.2 Prokaryotic Cell Wall

The cell wall is a very rigid structure (Fig. 29) that gives shape to the cell. Its main function is to prevent the cell from expanding and eventual bursting because of uptake of water, since most bacteria live in hypotonic environments (i.e., environments having a lower osmotic pressure that exists.

Bacterial cell wall is usually essential for bacterial growth and division. Cells whose walls have been completely removed are incapable of normal growth and division. Some bacteria have extra-cellular wall structures such as flagella, pili, slime and others outside the cell wall.

Species of bacteria can be divided into two major groups called Gram-positive and Gram-negative. The distinction between Gram-positive and Gram-negative bacteria is based on their Gram stain reaction. The staining reactions are located in the cell wall region of the bacterium.

However, some bacteria do not have cell walls. Although most prokaryotes cannot survive in nature without their cell walls, some are able to do so. These include the mycoplasmas, a group of pathogenic bacteria that causes a variety of infectious diseases in humans and other animals. The *Thermoplasma* group, species of *Archaea* also naturally lack cell walls. These prokaryotes are essentially free-living protoplasts, and they are able to survive without cell walls either because they have unusually tough cytoplasmic membranes or because they live in osmotically protected habitats such as the animal body.

## mic Membrane

cytoplasmic membrane (Fig. 29). This structure is composed primarily of phospholipids and proteins. The phospholipids form a bilayer in which most of the proteins are tenaciously held (Fig. 30). This membrane is a semi-permeable due to its structure of proteins and phospholipid. It is a selective membrane.

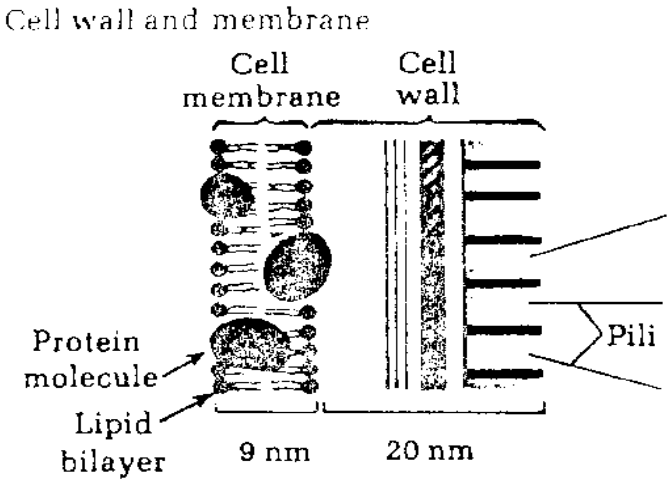



*Fig. 30. Prokaryotic Cell Wall and Membrane.*

*(Modified from Lehninger, Biochemistry, ©Wilbur H. Campbell, 1995)*

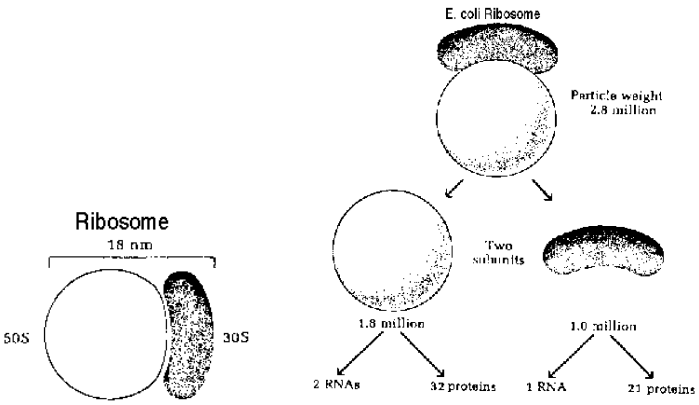
## 3.4 Nuclear Material

In contrast to eukaryotic ells, bacterial cells contain neither a distinct membrane-enclosed nucleus nor a mitotic apparatus. However, they do contain an area near the centre of the cell that is regarded as a nuclear structure, and the DNA of the cell is confined to this area (Fig. 29). Because it is not a discrete nucleus, this indistinct structure has been designated by such terms as the nucleoid; the chromatin body; the nuclear equivalent; and even the bacterial chromosome. It consists of a single, circular DNA molecule in which all the genes are linked.

The cell membrane encloses the cytoplasm called cytosol (Fig. 29). The cytosol bounded by the cytoplasmic membrane may be divided into: (a) cytoplasmic area, granular in appearance and rich in the macromolecular RNA-protein bodies known as ribosomes, on which proteins are synthesized; (b) the chromatinic area, rich in DNA; and (c) the fluid portion with dissolved substances. Unlike animal and plants cells, there is no endoplasmic reticulum to which ribosomes are bound. Some of the ribosomes are free in the cytoplasm, and others, especially those involved in the synthesis of proteins to be transported out of the cell, are associated with the inner surface of the cytoplasmic membrane. Intracellular granules of polyphosphate may be found in certain microorganisms. Such storage granules appear as a deep violet colour when the cells are stained with dilute methylene blue. Mitochondria, which are about the same size as bacterial cells are absent in prokaryotic cells.

## 3.6 Prokaryotic Ribosome

The ribosome - a cytoplasmic structural unit is made up of RNA and protein which is the site of protein synthesis. When the ribosomes of prokaryotes undergo sedimentation in a centrifuge, they have a sedimentation coefficient of 70 Svedberg units (70S) and are composed of two subunits, a 50S and a 30S subunit. This is in contrast to the ribosomes of eukaryotic organisms, which has a sedimentation coefficient of 80S and are composed of a 60S and a 40S subunits. The Svedberg unit is the unit used in expressing the sedimentation coefficient: the greater a particle's Svedberg value, the faster it travels in a centrifuge.

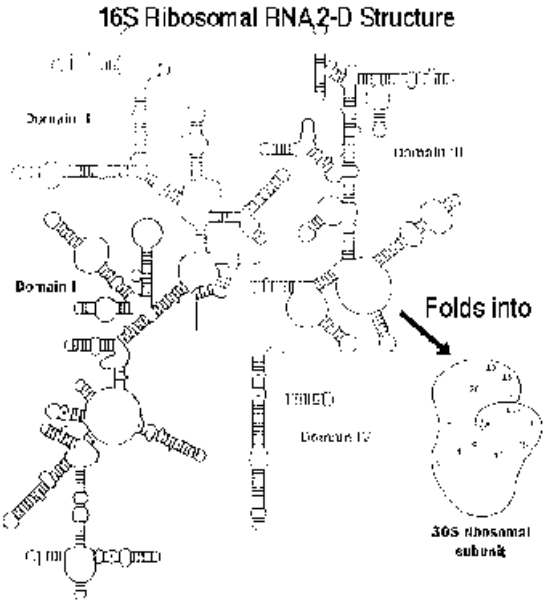



(A) (B)

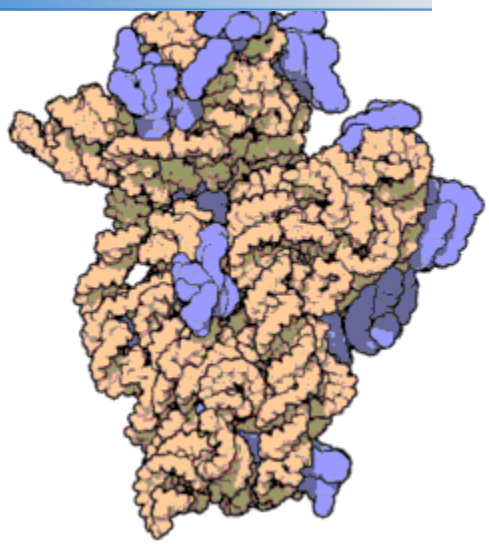
*Fig. 31: (A), Prokaryotic Ribosome; (B) Two Dimensional (2-D) Model of E. coli Ribosomes*

*Modified from Lehninger, Biochemistry, ©Wilbur H. Campbell, 1995*

The structures of each subunit can be further revealed as shown in Fig. 32. The 30S subunit is segmented into different fractions as shown in the Figure.




(a)



(b)

*Fig. 32: Structure of 16S rRNA of 30S Subunit of (a) E. coli Ribosome and (b) Thermus thermophillus*

*(Source: Voet and Voet Biochemistry, ©1990 John Wiley and Sons)*

## 4.0 Conclusion

The cells of prokaryotes are relativelythe various structures coordinate the activities and functions of the cells.

of a bacterial cell differ from one another not only in their physical features but also in their chemical characteristics and in their functions.

## 5.0 Summary

In this unit we have learnt that:

- Cytoplasmic membrane is composed of phospholipids and proteins.
- Bacterial cells contain neither a distinct membrane-enclosed nucleus nor a mitotic
- Bacterial cells have no endoplasmic reticulum to which ribosomes are bound.
- Ribosome is the site of protein synthesis.
- Prokaryotes ribosomes are composed of two subunits, a 50S subunit and a 30S subunit.
- The cell wall is a rigid and protective structure
- Some prokaryotes lack the cell walls in their cells

## ment

- lls? Do all bacteria have cell walls?
- Write a short account of each of the parts of a prokaryotic cell.
- Is it proper to refer to bacterial cells as containing a typical nucleus? Explain.

# 7.0 Further Reading and Other Resources

Madigan, M.T., Martinko, J.M., Dunlap, P.V. and Clark, D.P. (2009). Brock Biology of Microorganisms. 12th edition. Pearson International Edition.

Pelczar, M.J., Chan, E.C.S. and Krieg, N.R. (1986). Microbiology, International edition, McGraw Hill International editions. Pages 73-98. ISBN 0-07-Y66494-3.

Snyder, L. and Champness, W. (2003). Molecular Genetics of Bacteria, Second Edition, Washington, D.C. pages 566.

# Module 3: Molecular Basis of Cell Structure and Development

## Unit 2: Plant Cell Structure

# 1.0 Introduction

As far back as 1665, plant cells were discovered. Since then important concepts on the structures of plant cells have been established. The cell wall being the prominent part of the plant cell was noticed. In this unit we shall discuss the current understanding of the structures that make up plant cell.

# 2.0 Objectives

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

- Diagrammatically outline and label plant cell structure;
- Write on the current understanding of plant cell structure;
- Illustrate some of the structure disclose in the diagrams.

# 3.0 Main Contents

## 3.1 The Nucleic Acids - DNA and RNA

### 3.1.1 DeoxyriboNucleic Acid (DNA)

The DNA is the genetic material of most living systems, including eukaryotes and prokaryotes. Double stranded DNA are found only in natural form. Chromosomes of eukaryotes and prokaryotes are double stranded DNA

### 3.1.2 Ribonucleic Acid (RNA)

RNA is single stranded. It is genetic material in some viruses. The RNA exists in 3 basic forms: tRNA (transfer RNA) = adapter in protein synthesis - matches codon to amino acid; rRNA (ribosomal RNA) = structural RNA in ribosomes and mRNA (messenger RNA) = contains information for protein synthesis

## 3.2 Comparison between Plant and Animal cells.

1. Plant cells have cell wall, but animal cells do not.
2. Plant cells have chloroplasts, but animal cells do not.

ectangular shape because the cell wall is rigid. Animal cells
cause they do not have a cell wall.

4. Plant cells usually have one or more large vacuole(s), while animal cells have smaller vacuoles, if they are present (Fig. 21).

In a typical plant cell, the following structures are usually present: cell wall, cell memberane, endoplasmic reticulum, Golgi apparatus, mitochondria, cytoplasm, vacuoles, nucleolus, nucleus, chloroplast

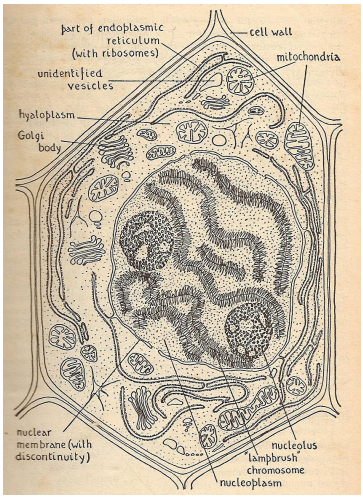



*Fig. 21 Plant cell*

*(Source: Vines and Rees, Plant and Animal Biology, Vol. 2.)*

## 3.3 Plant cell wall

A plant cell as a unit or independent structure is made up of tiny or microscopic mass of protoplasm enclosing in it a denser spherical or oval body, called the nucleus, and bounded by a distinct wall, called cell wall. Cytoplasm and nucleus are living, while the cell wall is non-living, the later having been formed by the protoplasm during cell division, primarily for its own protection. A plant cell thus consists of a protoplast (cytoplasm and nucleus) representing the living parts and a cell wall. The cell wall is a non-living rigid structure that protects the cell.

Plant cells have almost the same components as animal cells, but there are three basic differences between them. One difference is the cell wall. Plant cell walls are reinforced structures containing cellulose and lignin to make them rigid.

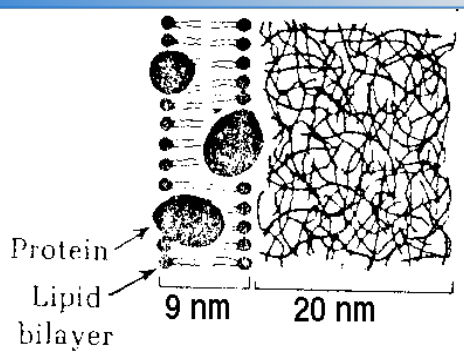



*Fig. 22 Relative Thickness of Plant Cell Membrane and Cell Wall.*

*(©Wilbur H. Campbell, 1995, 1996)*

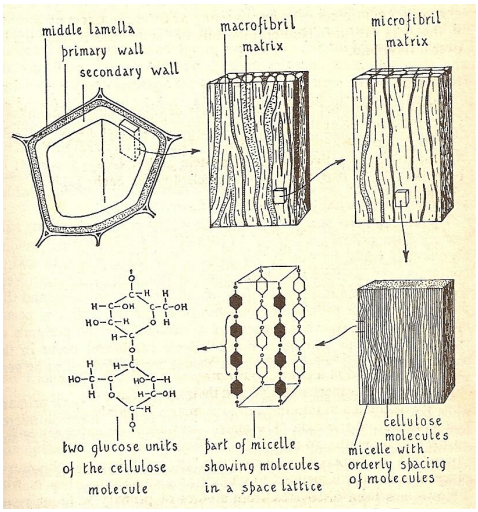



*Fig. 23 Primary and Secondary Plant cell Wall In Increasing Detail*

*(Source: Vines and Rees, Plant and Animal Biology, Vol. 2.)*

### 3.4.1 Chloroplasts

Chloroplasts are examples of plastids (Fig. 24 and 25). They are green. Plants are autotrophic in nature (energetically self supporting) by using the chloroplasts to manufacture food during the process of photosynthesis. This is the second difference between plant and animal cells. Animal cells lack chloroplasts.

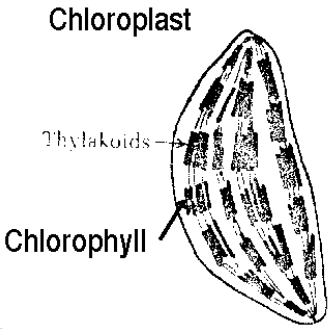



*Fig.25. A detached Chloroplast*

*(Source: Wilbur H. Campbell, 1995, 1996)*

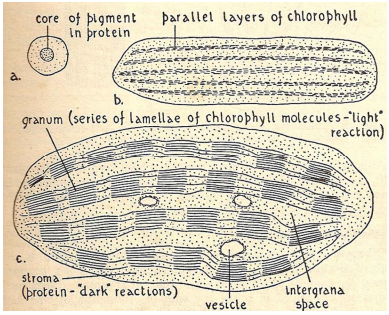



*Fig. 25 Diagrams representing: (a) pigment-carrier of bacteria and blue-green algae, (b) lamellar chloroplast of some green algae, (c) chloroplasts of higher plant.*

*(Source: Vines and Rees, Plant and Animal Biology, Vol. 2.)*

…sts contain the chlorophyll and enzymes for carrying out …asts are green plastids which make plants generally green in colour. They work only in the presence of sunlight and perform some very important functions with the help of their chlorophyll.

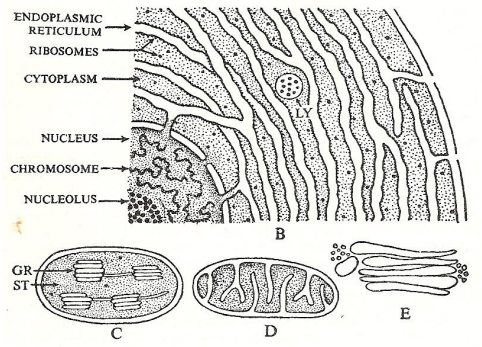



*Fig. 26 Parts of a cell. (A) as seen under a compound microscope; (B-E) as seen under an electron microscope; (B), a portion of the cell (LY, Lysosome); (C), a chloroplast (GR, granum; ST, stroma); (D), mitochondrion; (E), Golgi body.*

*(Source: Dutta, A.C. 1981 Botany 5th edition)*

### 3.4.2 Endoplasmic Reticulum, Mitochondria and Golgi body

Other important plant cell organelles include the endoplasmic reticulum, mitochondrion and Golgi body (Fig. 26). In the next unit, Unit 3, we shall discuss in details on their structures and functions.

## 3.5 Plant Vacuoles

The third difference between plant and animal cells is that, plant cells have a large vacuole. The plant vacuole is a single membrane organelle for storing organic acids, salts, etc. When the cell is very young it remains completely filled with cytoplasm (cell sap), but as the cell grows a large number of small non-protoplasmic but fluid-filled cavities of varying sizes, apparently like little bubbles, called vacuoles appear in the cytoplasm. As the cell enlarges all these small vacuoles begin to fuse together, and finally in the mature cell they form one large central vacuole which occupies the major part of the cell-cavity (Fig. 27).

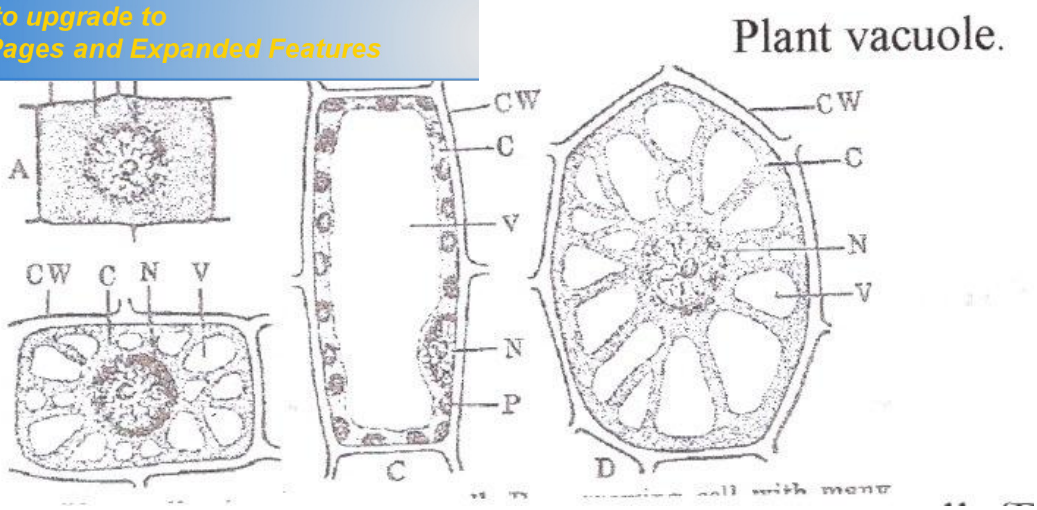



Fig. 27 Plant cells. (A), a very young cell; (B), a growing cell with many small vacuoles; (C) a mature cell with a large vacuole; (D), a mature cell with many vacuoles, CW, cell wall; C, cytoplasm; N, nucleus; V, vacuole; P, plastid (chloroplast)

*(Source: Dutta AC 1981 Botany 5th edition)*

## 4.0 Conclusion

The presence of the cell wall, chloroplast and vacuole in the plant cell distinguish it from the animal cell.

## 5.0 Summary

In this unit we have learnt that:

- Plant cells have a cell wall and usually contain chloroplasts (these are green structures which give plants their green colour). These are absent in animal cells.
- Plant cell walls are reinforced structures containing cellulose and lignin that make them rigid.
- Plants utilize light energy with chloroplasts that contain the chlorophyll and enzymes in carrying out photosynthesis.
- The plant vacuole is a single membrane organelle for storing organic acids, salts, etc.

## 6.0 Tutor Marked Assignment

1. What are the distinguishing features of a plant cell?

## Other Resources

Madigan, M.T., Martinko, J.M., Dunlap, P.V. and Clark, D.P. (2009) Brock Biology of microorganisms. 12th edition. Pearson International edition.

Pelczar, M.J., Chan, E.C.S. and Krieg, N.R. (1986) Microbiology, International edition, McGraw Hill International editions. Pages 73-98. ISBN 0-07-Y66494-3.

Vines, A.E. and Rees, N. (1984). Plant and Animal Biology, Vol. 2, 4th edition. Pitman.

# Module 3: Molecular Basis of Cell Structure and Development

## Unit 3: Eukaryotic Cell Structure

# 1.0 Introduction

In this unit we now discuss the typical eukaryotic cell structures. The eukaryotes include algae, fungi, protozoa, plants and animals. Their cells are more complex than those of the prokaryotes.

# 2.0 Objectives

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

- Diagrammatically outline and label eukaryotic cell structure;
- Write on the current understanding of eukaryotic cell structure
- Understand the functions of the various cell constituents

# 3.0 Main Contents

## 3.1 Eukaryotic Cell Membrane or Plasma Membrane

The typical eukaryotic cell usually has the cell membrane, cytoplasm, endoplasmic reticulum, Golgi body, mitochondria, nucleus, nucleoplasm, nucleolus, lysosomes, peroxisomes. Flagella and cilia may be present especially in the lower eukaryotes. The cell or plasma membrane contains equal amounts of lipids and proteins, which are arranged in a bilayer (Fig. 33). Plasma membrane is semi-permeable and contains transport systems for ions, sugars, and amino acids.

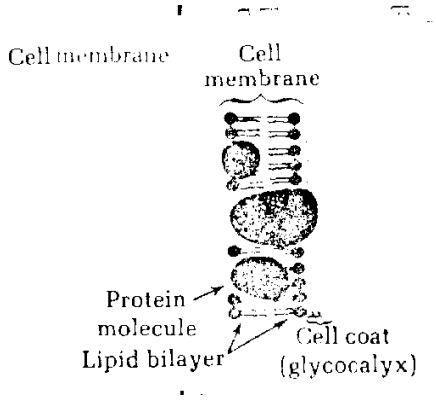



*Fig. 33. Eukaryotic Cell Membrane or Plasma Membrane*

*(Source: Modified from Lehninger, Biochemistry, ©Wilbur H. Campbell, 1995)*

## otic Nucleus

ctron microscope is illustrated below (Fig. 34). This nucleus is not engaging in mitosis and is thus called an interphase nucleus. The chromosomes in an interphase nucleus cannot be distinguished as individual entities but instead appear as an amorphous network; for this reason, interphase chromosomal material is commonly referred to as chromatin. The most prominent landmark of an interphase nucleus is its nucleolus - a large, deeply stained spherical body that contains RNA and protein and represents the site of synthesis and storage of the cell's cytoplasmic ribosomes (Fig. 34). These ribosomes are the structures that are involved in protein synthesis.

The chromatin in an interphase nucleus is surrounded by a membrane that folds back on it to form an envelope. At intervals the envelope is perforated into pores, at other intervals the envelope extends out into the cytoplasm as a network of channels and large cisternae known as the endoplasmic reticulum (Fig. 34). The cell's ribosomes are often bound to the outer surface of the endoplasmic reticulum, forming what is known as "rough" endoplasmic reticulum.

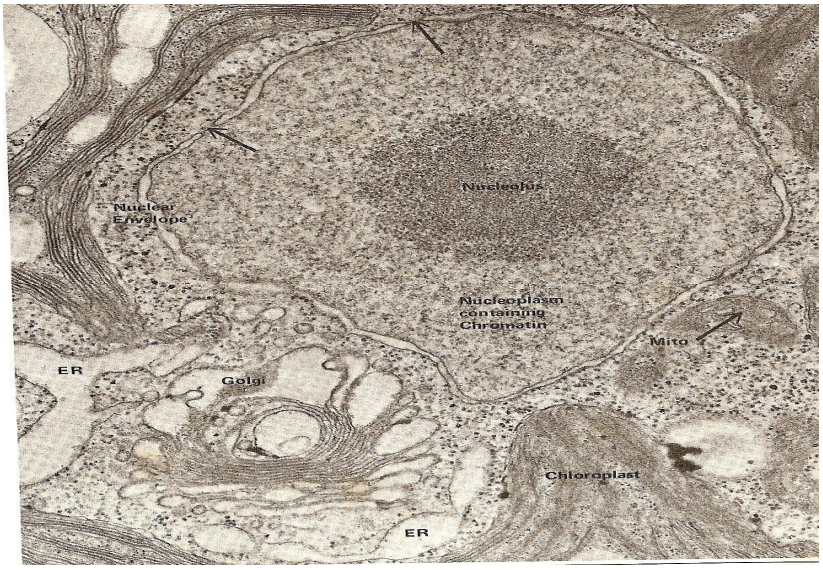



*Fig. 34 Structure of a Eukaryotic cell, Chlamydomonas reinhardi. Arrow point to nuclear pores.*

*(Source: Ursula Goodenough, 1978, Genetic, 2nd edition)*

## nelles

ell organelles. In addition the cytoplasm contains soluble enzymes, free ribosomes, and additional systems of membranes which serve to divide the cell into a number of compartments called organelles. Such organelles include endoplasmic reticulum, mitochondria, and chloroplasts - Chloroplasts are the sites of photosynthetic energy production and $CO_2$ fixation in eukaryotic phototrophs to produce manufactured food.

### 3.3.1 The Endoplasmic Reticulum

The endoplasmic reticulum (E.R.) is a single membrane system with an inner compartment which forms channels throughout the cytoplasm of the cell. The endoplasmic reticulum is a network of tubules and cisternae. The E.R. can be smooth or rough (Fig. 35).

Smooth endoplasmic reticulum (E.R.) provides the cell an organic phase in its membranes and unsaturated fatty acids and cholesterol are synthesized here. Foreign organic compounds are hydroxylated here to make them easier to digest.

Rough endoplasmic reticulum is a single membrane system covered with ribosomes for the synthesis of proteins to be exported from the cell. Eukaryotic ribosomes are very similar to prokaryotic ribosomes.

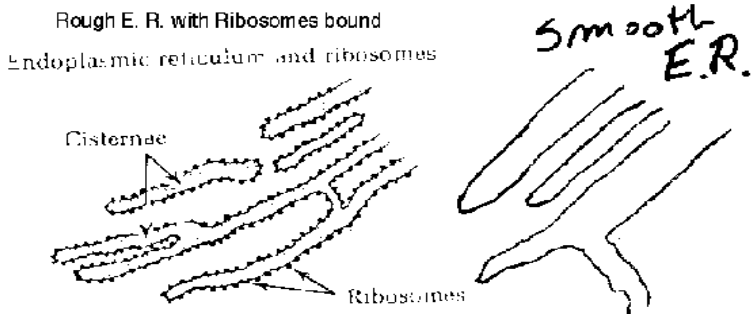



*Fig. 35. Eukaryotic cell Endoplasmic Reticulum*

*Modified from Lehninger, Biochemistry, ©Wilbur H. Campbell, 1995*

### 3.3.2 The Golgi Body

The Golgi body or apparatus is a membraneous organelle composed of flattened, sac-like cisternae stacked on each other (Fig. 36). The Golgi bodies (membranes) like the smooth E.R. lack bound

ed to the Golgi complex which is the system used for exporting membrane.

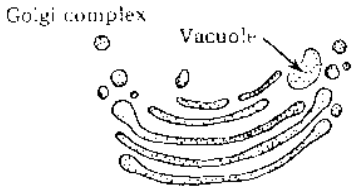



*Fig. 36. Eukaryotic Cell Golgi Complex*

*Source: Modified from Lehninger, Biochemistry, ©Wilbur H. Campbell, 1995*

## 3.4 The Cytoplasm/cytosol

The non-nuclear portion of a eukaryotic cell is called cytoplasm where the various cell organelles are embedded. The cytoplasm contains many enzymes and other compounds of the major aqueous phase of the cell. There are ribosomes floating freely in the cytoplasm which are for synthesizing soluble proteins (Fig. 37). The cytoplasm is dispersed among the organelles and also contains the cytoskeleton which helps the cell keep its shape. The cytoplasm is also called the cytosol.

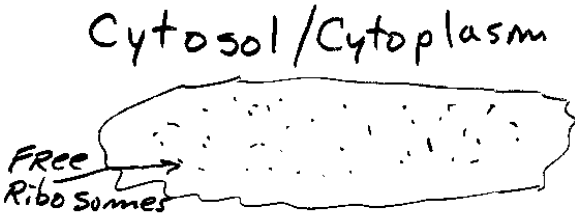



*Fig. 37 Eukaryotic Cell Cytosol*

*Source: Modified from Lehninger, Biochemistry, ©Wilbur H. Campbell, 1995*

### 3.4.1 Eukaryotic Cell Lysosomes

Lysosomes are membrane-enclosed compartments made from proteins and lipids transported from the Golgi complex. Lysosome allows for lytic activities to be partitioned away from the cytoplasm proper. Lysosomes are synthesized by Golgi apparatus and endoplasmic reticulum. They are involved in intracellular digestion and types of macromolecules.

### 3.4.2 Eukaryotic Cell Peroxisomes

The peroxisome is a specialized membrane-enclosed metabolic compartment. Peroxisomes originate in the cell by incorporating proteins and lipids from the cytoplasm, eventually becoming membrane-enclosed entities that can enlarge and divide in synchrony with the cell.

## 3.5 Eukaryotic Cell Flagella and Cilia

Flagella and cilia (Fig 38) are present on many eukaryotic microorganisms. Flagella and cilia are organelles of motility, allowing cells to move by swimming. Cilia are essentially shorter and more numerous than the flagella that beat in synchrony to propel the cell - usually quite rapidly – through the medium. Flagella are long appendages present singly or in groups that propel the cell along- typically more slowly than by cilia –through a whiplike motion. The flagella of eukaryotic cells are structurally quite distinct from the flagella of prokaryotes and do not rotate.

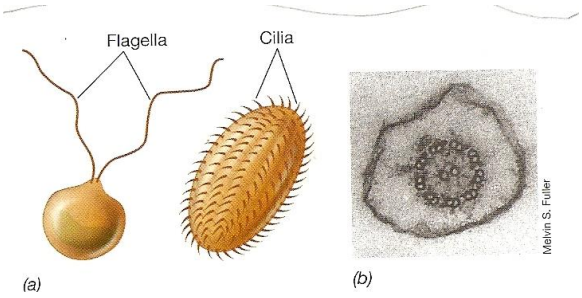



*Fig. 38. Eukaryotic Flagella and Cillia*

*(Source: Madigan MT, et al., 2009 Brock Biology of Microorganisms. 12th edition).*

## 4.0 Conclusion

The eukaryotic cell structure is made up of the cell membrane, nucleus, cytoplasm and a network of organelles while external locomotory appendagesmay be found on the cell membrane or cell wall.

## 5.0 Summary

In this unit we have learnt that:

- Eukaryotic cell contain several different organelles and other important structures in the cytoplasm;

asmic reticulum, the Golgi complex, lysosomes, and the

- Flagella and cilia are organelles of motility.

## 6.0 Tutor Marked Assignment

1. Give an account of the structures and functions of endoplasmic reticulum, Golgi complex and cytosol in eukaryotic cells

2. How does smooth endoplasmic reticulum differ from rough endoplasmic reticulum?

## 7.0 Further Reading and Other Resources

Cavalier-Smith, T (1975). The origin of nuclei and of eukaryotic cells. Nature 256: 463-466.

Vines, A.E. and Rees, N. (1984). Plant and Animal Biology, Vol. 2, 4th edition. Pitman.

# Module 3: Molecular Basis of Cell Structure and Development

## Unit 4: The Animal Cell

# 1.0 Introduction

In this unit, we shall discuss the major components that make up an animal cell. In unit 3, remember that the eukaryotic cell structure was discussed. Cells are a constant feature of all living organisms because cells are basic and functional units of all organisms. We therefore need to understand the structures of the variety of cells.

# 2.0 Objectives

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

- Diagrammatically outline and label animal cell structure as seen from different perspective;
- Write on the current understanding of animal cell structure
- Understand thoroughly the various animal cell components.

# 3.0 Main Contents

## 3.1 Major Structural Constituents of An Animal Cell

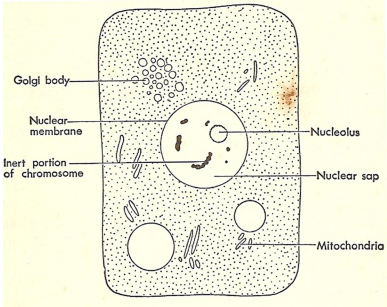



*Fig. 39 Structure of an animal cell as it may be seen in life*

*(Source: Chapman G and Barker W 1968 Zoology Longmans)*

In Fig. 39, the cell membrane, cytoplasm, Golgi body, nucleolus, nucleus, nuclear membrane, mitochondria, nuclear sap (nucleoplasm) may be visible as seen in life situation. However, in the conventional diagram (Fig. 40), the structures labeled may be slightly different from those of Fig. 39. These differences are due to the state and stage of the cells when viewed under the light microscope.

g. 41 and Fig. 42. The major constituents of the animal cell are

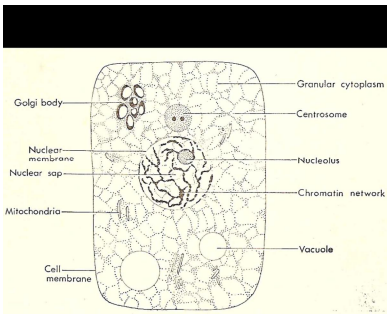



*Fig. 40 A Conventional Diagram of the structure of An Animal Cell*

*(Source: Chapman G and Barker W 1968 Zoology Longmans)*

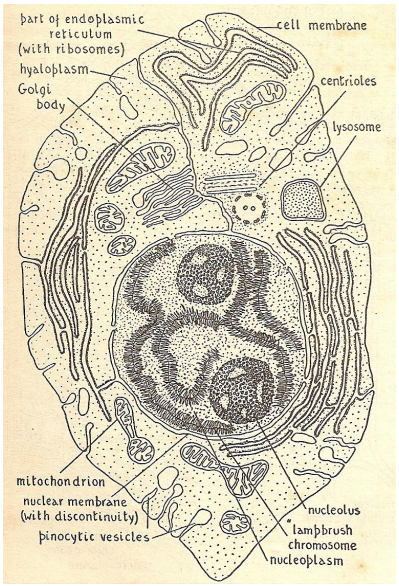



*Fig. 41: Diagrammatic representation of an animal cell as seen with the electron microscope*

*(Source: Vines and Rees, Plant and Animal Biology, Vol. 2)*

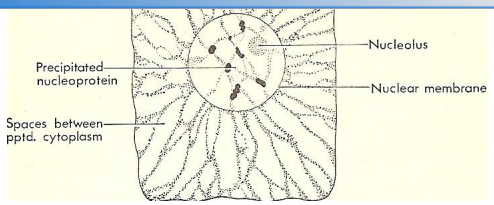



*Fig. 42 Diagram to illustrate the structure of the cell as normally seen in fixed and stained preparations*

*(Source: Chapman G and Barker W 1968 Zoology Longmans)*

### 3.1.1 Endoplasmic Reticulum

The endoplasmic reticulum (ER) is a network of sacs that manufactures, processes, and transports chemical compounds for use inside and outside of the cell. It is connected to the double-layered nuclear envelope, providing a connection between the nucleus and the cytoplasm. ER is a system of membrane-enclosed sacs and tubules in the cell (Remember unit 3, 3.3.1). Their lumens are probably all interconnected, and their membranes are continuous with the outer membrane of the nuclear envelope. All the materials within the system are separated from the cytosol by a membrane.

The endoplasmic reticulum is the site where the cell manufactures the following:

- most of the membranes of the cell (plasma membrane, Golgi apparatus, lysosomes, nuclear envelope);
- lipids (including lipids for membranes, e.g., of the mitochondria, that are not made by the ER);
- transmembrane proteins and secreted proteins

The ER comes in two versions:

- rough endoplasmic reticulum (RER) and
- smooth endoplasmic reticulum (SER).

The Rough Endoplasmic Reticulum (RER)

The RER is typically arranged as interconnecting stacks of disc-like sacs. The cytosolic surface of the RER is studded with ribosomes engaged in protein synthesis. The ribosomes make the RER surface to be rough.

As the messenger RNA is translated by the ribsome, the growing polypeptide chain is inserted into the membrane of the RER. Proteins destined to be secreted by the cell or shipped into the lumen of certain other organelles like the Golgi apparatus and lysosomes pass all the way through into the lumen of the RER. Transmembrane proteins destined for the plasma membrane or the membrane of those organelles are retained within the membrane of the RER.

e cytoplasm of cells specialized for protein synthesis such as g. the pancreas cell); and antibody-secreting plasma cells.

The Smooth Endoplasmic Reticulum (SER)

The smooth endoplasmic reticulum differs from the RER in lacking attached ribosomes and usually being tubular rather than disc-like. A major function of the SER is the synthesis of lipids from which various cell membranes are made or which, like steroids, are secreted from the cell.

The SER represents only a small portion of the ER in most cells, e.g. serving as transport vesicles for the transport of protein to the Golgi apparatus. However, it is a prominent constituent of some cells. Examples:

- the cells of the adrenal cortex (which secrete steroid hormones);
- the cells of the liver (hepatocytes) where it synthesises lipids for secretion of lipoproteins.
- the sarcoplasmic reticulum of muscle cells is SER.

### 3.1.2 Golgi Apparatus

The Golgi apparatus is the distribution and shipping department for the cell's chemical products. It modifies proteins and fats built in the endoplasmic reticulum and prepares them for export to the outside of the cell (Fig. 36, unit 3).

### 3.1.3 Lysosomes

Lysosomes are roughly spherical bodies bounded by a single membrane. They are manufactured by the Golgi apparatus. The main function of these microbodies is digestion. Lysosomes break down cellular waste products and debris from outside the cell into simple compounds, which are transferred to the cytoplasm as new cell-building materials (see unit 3, 3.4.1).

### 3.1.4 Microfilaments

Microfilaments are solid rods made of globular proteins called actin. These filaments are primarily structural in function and are an important component of the cytoskeleton.

### 3.1.5 Microtubules

These straight, hollow cylinders, composed of tubulin protein, are found throughout the cytoplasm of all eukaryotic cells and perform a number of functions.

### 3.1.6 Mitochondria

Mitochondria are oblong shaped organelles that are found in the cytoplasm of every eukaryotic cell. In the animal cell, they are the main power generators, converting oxygen and nutrients into energy. The mitochondrion is made of outer membrane and an inner membrane which contains the electron

...e site of electron transport, oxidative phosphorylation and ...des most of a nonphotosynthetic cell's energy under aerobic conditions.

### 3.1.7 Nucleus

The nucleus is a highly specialized organelle (Fig. 4, module 2, unit 1) that serves as the information and administrative center of the cell. The nucleus is the hallmark of eukaryotic cells; the very term eukaryotic means having a "true nucleus". The nucleus is enveloped by a pair of membranes enclosing a lumen that is continuous with that of the endoplasmic reticulum. The inner membrane is stabilized by a meshwork of intermediate filament proteins called lamins. The nuclear envelope is perforated by thousands of nuclear pore complexes that control the passage of molecules in and out of the nucleus. In module 2, units 2-5 have detailed the functions of the nucleus during the cell division processes.

### 3.1.8 Peroxisomes

These are microbodies of diverse group of organelles that are found in the cytoplasm, roughly spherical and bound by a single membrane. There are several types of microbodies but peroxisomes are the most common (unit 3, 3.4.2).

### 3.1.9 Cell membrane

One universal feature of all animal cells is the presence of an outer limiting membrane called the plasma or cell membrane. In addition, all eukaryotic cells contain elaborate systems of internal membranes which set up various membrane-enclosed compartments within the cell. Cell membranes are built from lipids and proteins. All living cells have a plasma membrane that encloses their contents. In prokaryotes, the membrane is the inner layer of protection surrounded by a rigid cell wall. Eukaryotic animal cells have only the membrane to contain and protect their contents (Fig. 34, unit 3). These membranes also regulate the passage of molecules in and out of the cells. In plant cells, the rigid cell wall protects their cell membrane.

### 3.1.10 Ribosomes

All living cells contain ribosomes These are tiny organelles composed of approximately 60 percent of ribonucleic RNA and 40 percent protein. In eukaryotes, ribosomes are made of four strands of RNA. In prokaryotes, they consist of three strands of (RNA) acid. Please note the following:

- Ribosomes that synthesize proteins for use within the cytosol (e.g., enzymes of glycolysis) are suspended in the cytosol;
- Ribosomes that synthesize proteins destined for:
    - secretion (by exocytosis)
    - the plasma membrane (e.g., cell surface receptors)
    - lysosomes

ngulfed is relatively small. Pinocytosis occurs in almost all cells and it occurs continuously. Pinocytosis is the endocytotic process in which a cell membrane encloses a small amount of the surrounding liquid and its solutes in tiny pinocytotic vesicles (pinosomes).

### 3.1.12 Chromatin

The nucleus contains the chromosomes of the cell. Each chromosome consists of a single molecule of DNA complexed with an equal mass of proteins. Collectively, the DNA of the nucleus with its associated proteins is called chromatin. Most of the protein consists of multiple copies of 5 kinds of histones. These are basic proteins, bristling with positively charged arginine and lysine residues. (Both Arg and Lys have a free amino group on their R group, which attracts protons ($H^+$) giving them a positive charge). Just the choice of amino acids you would make to bind tightly to the negatively-charged phosphate groups of DNA. Chromatin also contains small amounts of a wide variety of nonhistone proteins. Most of these are transcription factors (e.g., the steroid receptors) and their association with the DNA is more transient.

### 3.1.13 Centrioles

Centrioles are self-replicating organelles made up of fine bundles of microtubules and are found only in animal cells. They appear to help in organizing cell division. Do you still rember preprophase stage of mitosis module 2, unit 3, 3.2.2?

### 3.1.14 Centrosome

The centrosome is of the following:

- located in the cytoplasm attached to the outside of the nucleus.
- It is duplicated during S phase of the cell cycle.
- Just before mitosis, the two centrosomes move apart until they are on opposite sides of the nucleus.
- As mitosis proceeds, microtubules grow out from each centrosome with their plus ends growing toward the metaphase plate. These clusters of microtubules are called spindle fibers (Fig. 43).

N.B. You may wish to revise centrosome by reading unit 4 of module 2 (Fig. 12) and Fig. 20, (unit 5 of module 2).

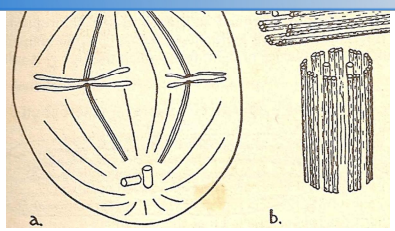



*Fig. 43 Centrosome. (a) Positions of centrioles and spindle during nuclear division. (b) Diagram representing the structure of the centrioles.*

*(Source: Vines and Rees, Plant and Animal Biology, Vol. 2).*

## 4.0 Conclusion

Under different conditions the features of the animal cell structure vary but each cellular component has specific functions in the cell.

## 5.0 Summary

In this unit we have learnt that:

- Lysosomes are manufactured by the Golgi apparatus.
- Mitochondria as the powerhouse are found in the cytoplasm of every eukaryotic cell.
- Cell membranes are built from lipids and proteins.
- All living cells have a plasma membrane that encloses their contents.
- All living cells contain ribosomes.
- Pinocytosis occurs in almost all cells.
- The nucleus contains the chromosomes of the cell.
- Endoplasmic reticulum is rough and smooth

## 6.0 Tutor Marked Assignment

1a. Draw and label an animal cell as seen under the light microscope.

b. List the functions of the Golgi apparatus, endoplasmic reticulum and the mitochondrion.

## 7.0 Further Reading and Other Resources

Vines, A.E. and Rees, N. (1984). Plant and Animal Biology, Vol. 2. Pitman Publishing limited, London.

# Module 3: Molecular Basis of Cell Structure and Development

# Unit 5: Review of Cell Structures of Prokaryotes and Eukaryotes

Module 3: Molecular Basis of Cell Structure and Development

# 1.0 Introduction

In units 1-4, you must have gathered enough knowledge and understanding of cells of prokaryotes, plant and animals. In this unit, as a student you are expected to be familiar with cells of prokaryotes and eukaryotes.

This unit is therefore designed to help you review cell structure. You will find information about the structures of prokaryotic cells and eukaryotic cells, with an emphasis on the endomembrane system more useful. Practicing the diagrams will enrich your review experience. You can test your understanding of what you have learnt by answering questions set in the activity exercise at the end of this unit.

# 2.0 Objectives

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

- Recognize cells as basic units of all living organisms;
- Compare and contrast cells of prokaryotes and eukaryotes
- Understand the structure and function of cells;
- You will understand structure and function of cells and organisms;
- Highlight the functions of cell organelles;
- Explain the importance of the endomembrane system.

# 3.0 Main Contents

## 3.1 Cellular organelles and Their Functions

Organelles are intracellular structures that perform specific functions in cells just the organs in our body. The name organelles (“little organ”) was coined because biologists saw a parallel between the relationship of organelles of a cell and that of organs to the whole body. It is not proper to define organelle as membrane-bound structure because this would exclude ribosomes and bacterial flagella.

The following are the major functions of organelles:

Plasma membrane - selectively permeable, mechanical cell boundary, mediates cell-cell interactions and adhesion to surface, secretion

Microfilaments – cell structure and movements, from the cytoskeleton

Endoplasmic reticulum – transport of materials, proteins and lipid synthesis

Golgi apparatus – packaging and secretion of materials for various purposes, lysosome formation

Ribosomes – protein synthesis

Mitochondrion – energy production through the use of the tricarboxylic acid cycle, electron transport, oxidative phosphorylation, and other pathways.

Chloroplasts – photosynthesis-trapping light energy and formation of carbohydrate from carbondioxide and water

Nucleus – repository for genetic information, control cell for cell

Nucleolus – ribosomal RNA synthesis, ribosome construction

Cell wall and pellicle – strengthen and give shape to the cell

Cilia and flagella – cell movement

Vacuole – temporary storage and transport, digestion (as food vacuoles), water balance (contractile vacuole).

## 3.2 Cells as the Starting Point

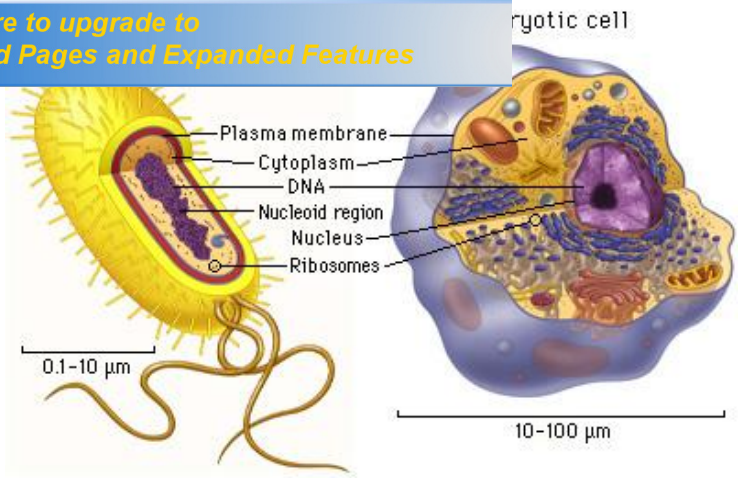
All living organisms are made of individual units that are called cells. Cells make up tissues and tissues make up organs. The cell is well organized and its various structures are so coordinated for the cell to be able to perform different functions. An organism can be a single cell e.g. the bacterium while the human body is made up of trillions of cells.

There are many types of cells. Plant cells are easier to identify because they have a protective structure called a cell wall made of cellulose. Plants have the cell wall; animals do not. Plant cells also have organelles like the chloroplasts (the structures that make them green) or large water-filled vacuoles.

We say that there are many types of cells. Cells are unique to each type of organism. Humans may have several hundred types of cells. Some cells are used to carry oxygen ($O_2$) through the blood (red blood cells) and others might be specific. A cell may have one nucleus (uninucleate) while other cells may have many nuclei (multinucleate). Cells however have many common features whether in prokaryotes or eukaryotes.

## 3.3 Common Features of Cells

All cells, whether they are prokaryotic or eukaryotic, have some common features.




(a) (b)

*Fig. 44: Prokaryotic cell; (b) eukaryotic cell*

*(Source: Pearson Education, Inc. 2009)*

The common features of prokaryotic and eukaryotic cells are:

1. DNA, the genetic material contained in one or more chromosomes and located in a nonmembrane bound nucleoid region in prokaryotes and a membrane-bound nucleus in eukaryotes

2. Plasma membrane, a phospholipid bilayer with proteins that separates the cell from the surrounding environment and functions as a selective barrier for the import and export of materials

3. Cytoplasm, the rest of the material of the cell within the plasma membrane, excluding the nucleoid region or nucleus, that consists of a fluid portion called the cytosol and the organelles and other particulates suspended in it

4. Ribosomes, the organelles on which protein synthesis takes place

## 3.4 Features of Prokaryotic Cells

Prokaryotic cells have the following features:

1. The genetic material (DNA) is localized to a region called the nucleoid which has no surrounding membrane.

2. The cell contains large numbers of ribosomes suspended in the cytoplasm that are used for protein synthesis.

sma membrane. In some prokaryotes the plasma membrane
es, the function of which is not clearly understood.

4. Outside the plasma membrane of most prokaryotes is a fairly rigid wall which gives the organism its shape. The walls of bacteria consist of peptidoglycans. Sometimes there is also an outer capsule. Note that the cell wall of prokaryotes differs chemically from the eukaryotic cell wall of plant cells and of protists.

5. Some bacteria have flagella which are used for locomotion and/or pili, which may be used to pull two cells in close contact, and perhaps to facilitate the transfer of genetic material. Prokaryotes, which include all bacteria and archaea (archaebacteria), are the simplest cellular organisms. Prokaryotic cells are fundamentally different in their internal organization from eukaryotic cells. Notably, prokaryotic cells lack a nucleus and membranous organelles.

## 3.5 Structure and Function in Eukaryotic Cells

In the last unit, unit 4, we have discussed in great details the major structural constituents of animal cell. In unit 2 plant cell was also discussed. Eukaryotic cells contain a membrane-bound nucleus and numerous membrane-enclosed organelles (e.g., mitochondria, lysosomes, Golgi apparatus) which are not found in prokaryotes.

Prokaryotic cells are fundamentally different in their internal organization from eukaryotic cells. Notably, prokaryotic cells lack a nucleus and membranous organelles.

In eukaryotes, the nucleus is bounded by the nuclear envelope, a double membrane with many nuclear pores through which materials enter and leave. Animals, plants, fungi, algae and protists are all eukaryotes. Eukaryotic cells are more complex than prokaryotic cells and are found in a great many different forms.

## 3.6 Sorting of Materials by the Endomembrane System

Certain materials in the cell, including some proteins, are sorted by the functionally interrelated cellular membranes of the endomembrane system. These membranes consist of phospholipid bilayers with organelle-specific proteins embedded in them. This eukaryotic cell system consists of the nuclear envelope; endoplasmic reticulum (ER) and Golgi apparatus; vesicles and other structures derived from them (e.g., lysosomes, peroxisomes); and the plasma membrane (Fig. 45). These various membranes that are involved, though interrelated, differ in structure and function.

The endomembrane system plays a very important role in moving materials around the cell, notably proteins and membranes (the latter is called membrane trafficking). For example, while many proteins

…e cytoplasm and remain in the cytoplasm, other proteins are …endoplasmic reticulum (RER). The latter proteins are inserted into the lumen of the RER, carbohydrates are added to them to produce glycoproteins, and they are then moved to cis face of the Golgi apparatus in transport vesicles that bud from the ER membrane. Within the Golgi, the protein may be modified further and then be dispatched from the trans face in a new transport vesicle. These vesicles move through the cytoplasm to their final destinations using the cytoskeleton. We can think of the system as analogous to a series of switching yards and train tracks, where materials are sorted with respect to their destinations at the switching yards and sent to those destinations along specific tracks in the cytoskeleton.

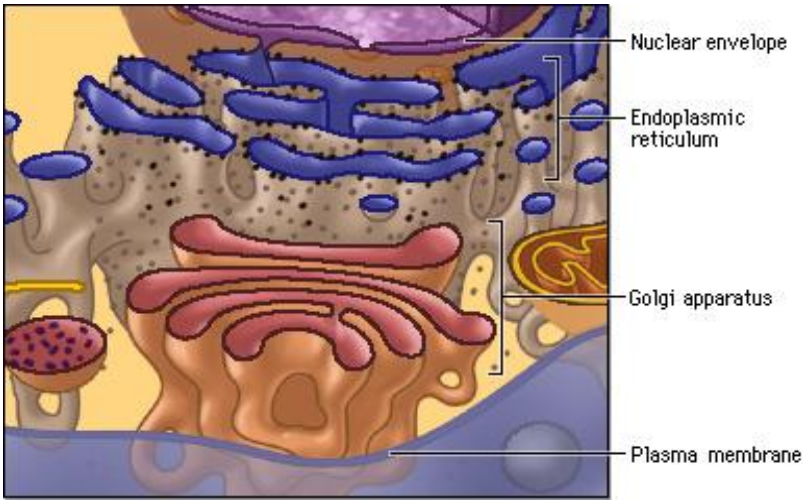



*Fig. 45: Endomembrane system*

*(Source: Pearson Education, Inc. 2009)*

Activity

**1**. Which of the following is not an accurate description of a chromosome?

a. It is a colored body localized in the nucleus.

b. It is a protein and nucleic acid complex.

c. It is the cellular structure that contains the genetic material.

d. In eukaryotes, it is composed of many DNA molecules attached end to end.

**2**. A centriole is an organelle that is:

m

b. composed of microtubules and important for organizing the spindle fibers

c. surrounded by a membrane

d. part of a chromosome

**3**. The rough endoplasmic reticulum is:

a. an intracellular double-membrane system to which ribosomes are attached

b. an intracellular membrane that is studded with microtubular structures

c. a membranous structure found within mitochondria

d. only found in prokaryotic cells

**4**. In the nucleus of eukaryotic cells, the genetic material is complexed with protein and organized into linear structures called:

a. centrioles

b. histones

c. chromosomes

d. plasmids

**5.** Which of the following statements does not apply to the nuclear envelope?

a. It is a double membrane.

b. It has pores through which material enters and leaves.

c. It is continuous with the endoplasmic reticulum.

d. It has infoldings to form cristae.

**6**. Lysosomes are formed by budding from which cellular organelle?

b. Golgi apparatus

c. rough endoplasmic reticulum

d. nucleus

**7**. All peroxisomes carry out this function:

a. break down fats and amino acids into smaller molecules that can be used for energy production by mitochondria

b. digest macromolecules using the hydrolytic enzymes they contain

c. synthesize membrane components such as fatty acids and phospholipids

d. control the flow of ions into and out of the cell

Answers to Module 3 unit 5

1d. The chromosome is not composed of many DNA molecules attached end to end

2b. The centriole is composed of microtubules and is important for organizing the spindle fibers.

3a. The rough endoplasmic reticulum (RER) is an intracellular double-membrane system to which ribosomes are attached.

4c. The genetic material is organized into chromosomes

5d. It is the inner membrane of the mitochondrion that is infolded to form cristae

6b. Lysosomes form by budding from the Golgi apparatus and, during this process, the hydrolytic enzymes made on the rough ER by bound ribosomes are packaged into particles.

7a. All perixisomes break down fats and amino acid into smaller molecules that can be used for energy production by mitochondria.

# 4.0 Conclusion

Eukaryotic cells may be more complex than the prokaryotic cells however there are cellular structures that are common to both groups of cells.

In this unit we have learnt the:

- Cell structures of prokaryotes and eukaryotes.
- Prokaryotes as single cells without nucleus or other organelles
- Eukaryotes as multicellular
- Common features of prokaryotic and eukaryotic cells
- Cells as the basic units of living organisms
- Movement of many materials within the cell by the endomembrane system, including some proteins.
- Functions of cellular organelles

## 6.0 Tutor Marked Assignment

1. Draw and label (i) a prokaryotic cell (ii) a eukaryotic cell

2. List the common features found in prokaryotic and eukaryotic cells

## 7.0 Further Reading and Other Resources

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K. and Walter, P. (2002). Molecular Biology of the Cell. 4th Edition. Garland Science, Taylor & Francis Group, New York. ISBN 0-8153-3218-1 (hardbound) - ISBN 0-8153-4072-9 (pbk.)

# Module 4: Proteins and Nucleic Acids

## Unit 1: Proteins and Their Structures

# 1.0 Introduction

Proteins vary both in structure and function. They are constructed from a set of 20 amino acids and have distinct three-dimensional shapes. The structure of a protein determines its function. For example, collagen has a super-coiled helical shape. It is long, stringy, strong, and resembles a rope. This structure is great for providing support. Hemoglobin on the other hand, is a globular protein that is folded and compact. Its spherical shape is useful for maneuvering through blood vessels. In this unit, we shall discuss the structures of proteins.

# 2.0 Objectives

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

- Define proteins
- List the 20 amino acids found in proteins
- Distinguish the various types of proteins based on their structure

# 3.0 Main Contents

## 3.1 Definition and Diversity of Proteins

When we look at a cell through a microscope or analyze its electrical or biochemical activity, we are, in essence, observing proteins. Proteins constitute most of a cell's dry mass. They are not only the building blocks from which cells are built; they also execute nearly all cell functions. Thus, enzymes provide the intricate molecular surfaces in a cell that promote its many chemical reactions. Proteins embedded in the plasma membrane form channels and pumps that control the passage of small molecules into and out of the cell. Other proteins carry messages from one cell to another, or act as signal integrators that relay sets of signals inward from the plasma membrane to the cell nucleus. Yet others serve as tiny molecular machines with moving parts: kinesin, for example, propels organelles through the cytoplasm; topoisomerase can untangle knotted DNA molecules. Other specialized proteins act as antibodies, toxins, hormones, antifreeze molecules, elastic fibers, ropes, or sources of luminescence. Before we understand how genes work, muscles contract, nerves conduct electricity, how embryos develop, or how our bodies function, we must attain a deep knowledge of proteins.

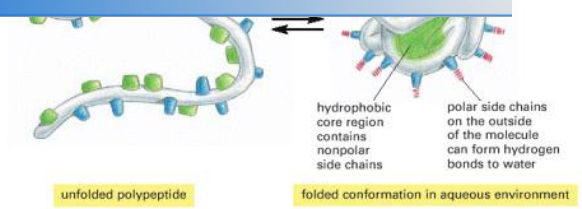



*Fig.46 A peptide bond*

*(Source: Alberts, B., Johnson, A., Lewis, J. Raff, M. Roberts, K. and Walter, P. 2002).*

How does a protein folds into a compact conformation? The polar amino acid side chains tend to gather on the outside of the protein, where they can interact with water; the nonpolar amino acid side chains are buried on the inside to form a tightly packed hydrophobic core of atoms that are hidden from water. The twenty essential amino acids are listed (Fig. 47).

| AMINO ACID | | | SIDE CHAIN |
|---|---|---|---|
| Aspartic acid | Asp | D | negative |
| Glutamic acid | Glu | E | negative |
| Arginine | Arg | R | positive |
| Lysine | Lys | K | positive |
| Histidine | His | H | positive |
| Asparagine | Asn | N | uncharged polar |
| Glutamine | Gln | Q | uncharged polar |
| Serine | Ser | S | uncharged polar |
| Threonine | Thr | T | uncharged polar |
| Tyrosine | Tyr | Y | uncharged polar |

POLAR AMINO ACIDS

| AMINO ACID | | | SIDE CHAIN |
|---|---|---|---|
| Alanine | Ala | A | nonpolar |
| Glycine | Gly | G | nonpolar |
| Valine | Val | V | nonpolar |
| Leucine | Leu | L | nonpolar |
| Isoleucine | Ile | I | nonpolar |
| Proline | Pro | P | nonpolar |
| Phenylalanine | Phe | F | nonpolar |
| Methionine | Met | M | nonpolar |
| Tryptophan | Trp | W | nonpolar |
| Cysteine | Cys | C | nonpolar |

NONPOLAR AMINO ACIDS

*Fig. 47. The 20 amino acids found in proteins. Both three-letter and one-letter abbreviations are listed. As shown, there are equal numbers of polar and nonpolar side chains.*

*(Source: Alberts et al 2002).*

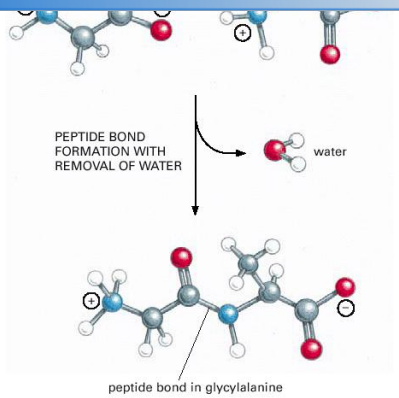



*Fig. 48 A peptide bond. This covalent bond forms when the carbon atom from the carboxyl group of one amino acid shares electrons with the nitrogen atom (blue) from the amino group of a second amino acid. As indicated, a molecule of water is lost in this condensation reaction.*

*(Source: Alberts et al 2002).*

## 3.2 Protein structure

Proteins are an important class of biological macromolecules present in all biological organisms, made up of such elements as carbon, hydrogen, nitrogen and oxygen. Some proteins contain sulphur in addition. All proteins are polymers of amino acids. The polymers, also known as polypeptides, consist of a sequence of 20 different L-α-amino acids, also referred to as residues. For chains under 40 residues the term peptide is frequently used instead of protein. To be able to perform their biological function, proteins fold into one, or more, specific spatial conformations (Fig. 46 and Fig. 48), driven by a number of noncovalent interactions such as hydrogen bonding, ionic interactions, Van Der Waals forces and hydrophobic packing. A number of residues are necessary to perform a particular biochemical function, and around 40-50 residues appear to be the lower limit for a functional domain size. Protein sizes range from this lower limit to several thousand residues in multi-functional or structural proteins. However, the current estimate for the average protein length is around 300 residues. Very large aggregates can be formed from protein subunits, for example many thousand actin molecules assemble into a microfilament. It is often necessary to determine the three dimensional structure of proteins.

### 3.2.1 Primary Structure

Primary structure of a protein refers to the sequence of amino acids in the chain.

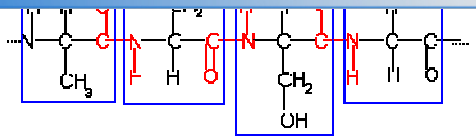


*Fig. 49a: The primary structure of a protein.*

*(Source: Alberts et al 2002).*

The blue boxes surround individual amino acids. The red text shows the position of the peptide bonds (peptide or amide linkages) joining the amino acids together (Fig. 49). Proteins are made up of many amino acids, so a short-hand system has been developed to show the primary structure of proteins.

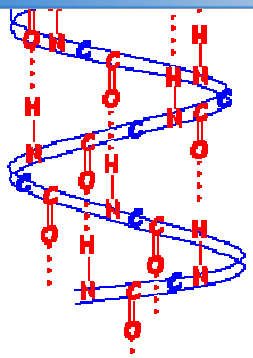

*Fig. 49b*

*Source: Andrew Rader 1997*

As proteins are being built, they begin as a straight chain of amino acids. This chain structure is called the primary structure. Sometimes chains can bond to each other with two sulfur (S) atoms. Those bonds would be called a disulfide bridge.

### 3.2.2 Secondary Structure

Secondary structure of a protein is the shape of the protein molecule caused by hydrogen-bonding between -C=O and -N-H groups within the chain, the two main shapes are α helix and β sheet (Fig. 50 and 51).

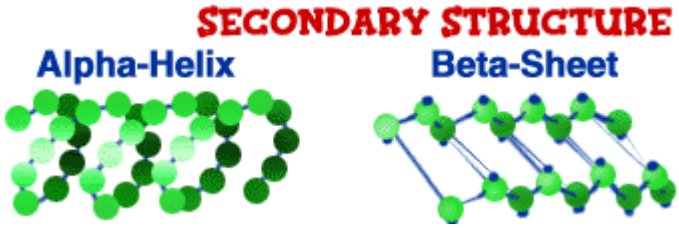


(a)

*Fig. 50: Schematic diagram of an α helix such as is found in wool fibres.*

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

The red dotted lines show the hydrogen bonds between amino acids along the chains maintaining the helical structure.




(b) (c)

*Fig. 50*

*(Source: Andrew Rader 1997)*

After the primary structure comes the secondary structure. The original chain begins to twist. It is as if you take a piece of string and twist one end. It slowly begins to curl up. In the amino acid chain, each of the amino acids interacts with the others and it twists like a corkscrew or a flat folded sheet.

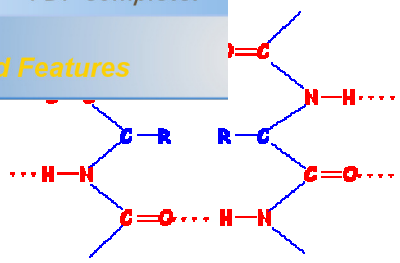


*Fig. 51: Schematic diagram of a β sheet such as is found in silk.*

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

The red dotted lines show the hydrogen bonds between amino acids along the chains maintaining the sheet structure.

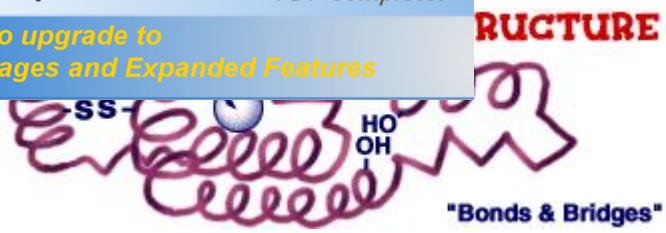
### 3.2.3 Tertiary Structure

Tertiary structure of a protein is the folding and bending of the protein molecule caused by interaction of the R groups. This interaction may be a result of hydrogen bonding, dipole-dipole interactions, covalent bonding or ionic bonding (salt bridges) depending on the polarity of the R groups. The -SH group in cysteine (Cys) can form disulfide links, -C-S-S-C- , between neighbouring groups in the presence of an oxidant (Fig. 52).

(a) (b)

*Fig. 52 Two representations of parts of protein molecules showing disulfide bonds (disulfide links) in blue resulting in the molecule folding and bending.*

*(Source: Alberts et al 2002).*




(c)

*Fig. 52*

*(Source: Andrew Rader 1997)*

Let us move on to the tertiary structure of proteins. By now you are getting the idea that proteins do a lot of folding and twisting. The third step in the creation of a protein is the tertiary structure when the amino acid chains begin to fold even more and bond using more bridges (the disulfide bridges).

### 3.2.4 Quarternary Structure

Quarternary structure of a protein is the interactions between protein subunits that result in the protein being classified as fibrous, globular or conjugated.


*Fig. 53*

*(Source: Andrew Rader 1997)*

We can finally cover the quaternary structure of proteins. Quaternary means four. This is the fourth phase in the creation of a protein. In the quaternary structure, several amino acid chains from the tertiary structure fold together in a blob. They wind in and out of each other. You heard it right. Blob is the scientific term.

## 4.0 Conclusion

As diverse as proteins are, a protein is determined by the sequence of its amino acids, the more complex the structure, the tougher is the protein.

## 5.0 Summary

In this unit we have learnt that:

- Proteins are the building blocks of cells
- A protein is a natural polymer, made up of amino acid monomers joined together by peptide bonds (peptide or amide linkages).
- Proteins are made up of: carbon, hydrogen, oxygen, nitrogen and some proteins contain sulfur.
- A peptide bond (peptide or amide linkage) is a covalent bond formed between the carbon of the carboxyl group of one amino acid and the nitrogen of the amine group of another amino acid.
- There are four types of protein structure:
- Primary structure is the sequence of amino acids in the chain.
- Secondary structure is the shape of the protein molecule caused by hydrogen-bonding between -C=O and -N-H groups within the chain.
- Tertiary structure is the interaction between R-groups that causes folding and bending.
- Quarternary structure: interactions between protein subunits that result in the protein being classified as fibrous, globular or conjugated.

## 6.0 Tutor Marked Assignment

1. Define proteins and list the 20 amino acids found in proteins.

2. What is meant by the primary, secondary, tertiary, and quaternary structures of a protein?

## 7.0 Further Reading and Other Resources

Pelczar, M.J., Chan, E.C.S. and Krieg, N.R. (1986). Microbiology, International Edition, McGraw Hill International editions. ISBN 0-07-Y66494-3.

Snyder, L. and Champness, W. (2003). Molecular Genetics of Bacteria, Second Edition, Washington, D.C. 566 pp.

# Module 4: Proteins and Nucleic Acids

## Unit 2: Types and Functions of Proteins

# 1.0 Introduction

In unit 1, we learnt that proteins constitute most of the cells, therefore proteins are building blocks. Proteins are very important molecules in the cells of our body. They are involved in virtually all cell functions. Each protein within the body has a specific function. Some proteins are involved in structural support; others are involved in bodily movement, or in defense against germs. In this unit, we shall discuss the different proteins and their functions.

# 2.0 Objectives

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

- State the various types of proteins
- Know their functions
- Define enzyme
- Justify protein as enzymes

# 3.0 Main Contents

## 3.1 Protein Composition

As discussed in unit 5, you were told that proteins are organic macromolecules made up of linear chains of amino acids. However, while a protein's basic structure is a linear amino acid chain, the final structure of a protein is not linear. Instead, the protein's amino acid sequence and the physical and chemical properties of the amino acids and of the entire protein molecule influence how it folds into a three dimensional shape. The amino acid sequence of a protein is determined by the base pair sequence in the gene which codes for the protein.

### 3.2.1 Antibodies

Antibodies (also called immunoglobulins) are specialized proteins involved in defending the body from antigens (foreign invaders). One way antibodies destroy antigens is by immobilizing them so that they can be destroyed by white blood cells. Antibodies are present in the blood serum, tissue fluids and mucosal surfaces of vertebrate animal.

### 3.2.2 Contractile Proteins

Contractile proteins are responsible for movement. Examples include actin and myosin. These proteins are involved in muscle contraction and movement.

### 3.2.3 Hormonal Proteins

Hormonal proteins are messenger proteins which help to coordinate certain bodily activities. Examples include insulin, oxytocin, and somatotropin. Insulin regulates glucose metabolism by controlling the blood-sugar concentration. Oxytocin stimulates contractions in women during childbirth. Somatotropin is a growth hormone that stimulates protein production in muscle cells.

### 3.2.4 Structural Proteins

These proteins are less ‘active’ than those involved in catalyzing reactions or those signaling cells, and transporting molecules, but are no less important. They confer strength and rigidity to biological components which would otherwise be unable to support themselves. They tend to have very specific shapes. They are long, thin fibers or other shapes which, when allowed to form polymers, provide strength and support. They are essential components of collagen, cartilage, nails and hair, feathers, hooves, and other such structure.

They are also essential components of muscles, and are necessary to generate the force which allows muscles to contract and move. They are fibrous and stringy and provide support. Examples include keratin, collagen, and elastin. Keratins strengthen protective coverings such as hair, quills, feathers, horns, and beaks. Collagens and elastin provide support for connective tissues such as tendons and ligaments.

bles include ovalbumin and casein. Ovalbumin is found in egg whites and casein is a milk-based protein.

### 3.2.6 Transport Proteins

Proteins are also involved in molecular transport of cells. Transport proteins are carrier proteins which move molecules from one place to another around the body. Examples include haemoglobin and cytochromes. Haemoglobin transports oxygen through the blood. Hemoglobin binds iron molecules and transports them in the blood from the lungs to organs and tissues throughout the body. Cytochromes operate in the electron transport chain as electron carrier proteins.

### 3.2.7 Enzymes

The function of proteins as enzymes is perhaps their best known function. Enzymes are proteins that facilitate biochemical reactions. They are often referred to as organic catalysts because they speed up chemical reactions. Examples include lactase and pepsin. Lactase breaks down the sugar lactose found in milk. Pepsin is a digestive enzyme that works in the stomach to break down proteins in food. The enzyme, however, is itself unchanged at the end of the reaction. Enzymes are responsible for catalyzing reactions in processes such as metabolism, DNA replication, and food digestion. In fact, enzymes are known to be involved in some 4,000 bodily reactions.

Enzymes and their substitutes are similar to locks and keys. When a door is locked can it open itself? No. You need a key that is just the right shape to fit in that lock. Enzymes work in a similar way. Enzymes complete very specific reactions and do nothing else. They are very specific locks and the substrates they work with are the special keys (Fig. 54). In the same way there are door keys, car keys, and bike-lock keys, there are enzymes for neural cells, intestinal cells, and even in our saliva.

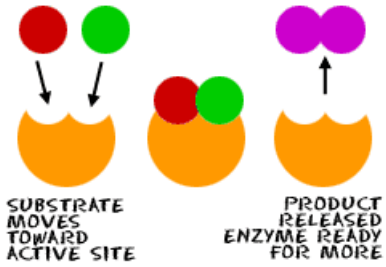


Fig. 54

*(Source: Pelczar M.J. et al., 1986 Microbiology. McGraw-Hill International Editions)*

## 3.3 The Four steps of an Enzyme reaction and Denaturation

1. An enzyme and a substrate are in the same area. The substrate is the biological molecule that the enzyme attacks.

2. The enzyme gets onto the substrate with its own special area called the active site. The active site is a specially shaped area of the enzyme that fits around the substrate. The active site is the keyhole of the lock.

3. A process called catalysis happens. Catalysis is when the substrate is changed. It could be broken down or combined with another molecule to make something new. The substrate is no longer the same. The substrate is now called the product.

4. The enzyme reverts to its former state and it is, ready to carry out another reaction.

Can the catalytic actions of enzymes be stopped?

Good question! We know what you are thinking. What if enzymes just kept going and converting every molecule in the world? They would never stop…. like a monster! There are many factors that can regulate enzyme activity. They include temperature, activators, pH levels, inhibitors, substrate concentration etc.

If the pH, salt concentration, temperature or other aspects of enzyme environment are altered, the protein as enzymes may unravel and lose its native conformation, a changed called denaturation (Fig. 55). The denatured protein becomes biologically inactive if the factor is high temperature (Fig. 55). The heat agitates (affects0 the polypeptide chain enough to overpower the weak interactions that stabilize conformation.

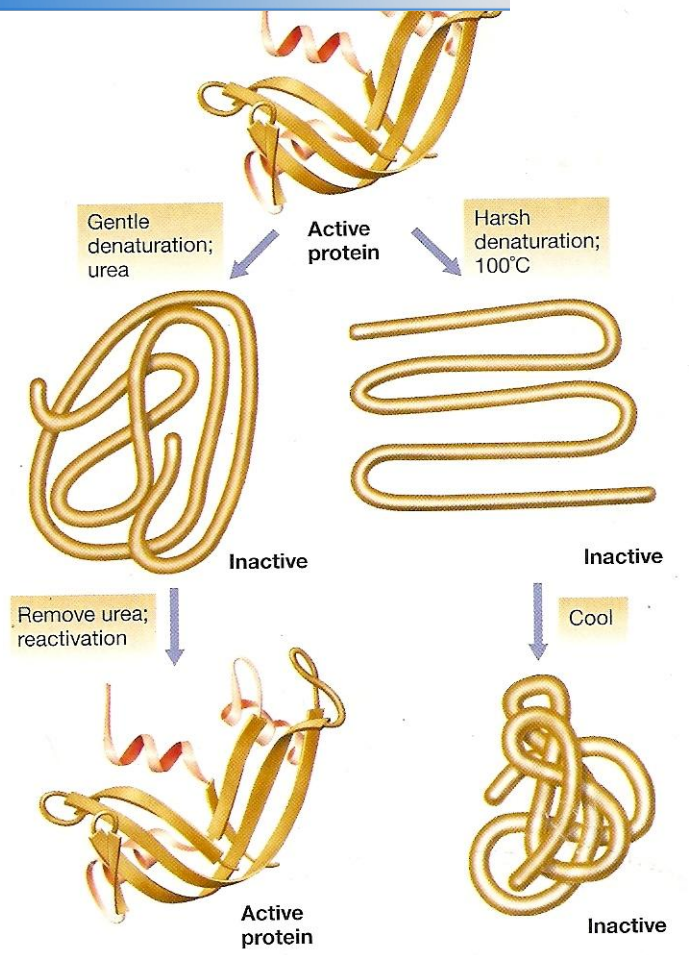



*Fig. 55: Protein Denaturation*

*(Source: Madigan, M.T., et al., 2009 Brock Biology of microorganisms. 12th edition. Pearson International Edition).*

# 4.0 Conclusion

Proteins are diverse in functions and they carry out fundamental and basic cellular actions that affect life.

In this unit we have learnt that:

- Proteins are of different types.
- Proteins serve various functions in the body.
- Enzymes are proteins and are specific in actions.
- Proteins are required for building and repair of body tissues (including muscle)
- Proteins, like most other essential nutrients, absolutely crucial for overall good health.
- Proteins can be denatured

## 6.0 Tutor Marked Assignment

1. With examples and their locations in the human body, list the different proteins that you have studied.

## 7.0 Further Reading and Other Resources

Pelczar, M.J., Chan, E.C.S. and Krieg, N.R. (1986). Microbiology, International edition, McGraw Hill International editions. 918pp. ISBN 0-07-Y66494-3.

Snyder, L. and Champness, W. (2003). Molecular Genetics of Bacteria, Second Edition, Washington, D.C. 566.

Madigan, M.T., Martinko, J.M., Dunlap, P.V., and Clark, D.P. (2009). Brock Biology of Microorganisms. 12th edition. Pearson International Edition.

# Unit 3: Protein Synthesis

## Contents

# 1.0 Introduction

Can you still recollect our earlier discussion on the two nucleic acids, DNA and RNA? In module 3 unit 2, references were made to them. It is also important for you to know that genes are the instructions for making specific proteins. However a gene does not build a protein directly. The bridge between genetic information and protein synthesis is the RNA. Thus RNA, DNA and proteins contain information written in two different chemical languages; transcription and translation. They will form the bases of our discussion.

# 2.0 Objectives

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

- Describe transcription
- Explain translation

# 3.0 Main Contents

## 3.1 The Basis for Protein Synthesis

The genetic information stored in DNA molecules is used as a blueprint for making proteins. Why proteins? Because these macromolecules have diverse primary, secondary and tertiary structures that equip them to carry out the numerous functions necessary to maintain a living organism. As noted in unit 2, these functions include:

- Structural integrity (hair, horn, eye lenses etc.)
- Molecular recognition and signaling (antibodies and hormones)
- Catalyses of reactions (enzymes)
- Molecular transport (hemoglobin transports oxygen)
- Movement (pumps and motors)

The critical importance of proteins in life processes is demonstrated by numerous genetic diseases, in which small modifications in primary structure produce debilitating and often disastrous consequences. Such genetic diseases include Tay-sachs, phenylketonuria (PKU),

Parkinson disease. Transcription and translation are two thesis of proteins.

### 3.1.1 The Central Dogma and Transcription

Francis Crick proposed that information flows from DNA to RNA in a process called transcription, and is then used to synthesize polypeptides by a process called translation. Transcription takes place in a manner similar to DNA replication. Characteristic sequence nucleotides marks the beginning of a gene on the DNA strand, and this region binds to a promoter protein site, and one of the strands serves as a template for RNA formation, as depicted in the following diagram (Fig. 56). The RNA molecule thus formed is single stranded, and serves to carry information from DNA to the protein synthesis machinery called ribosome. These RNA molecules are therefore called messenger ï RNA (mRNA).

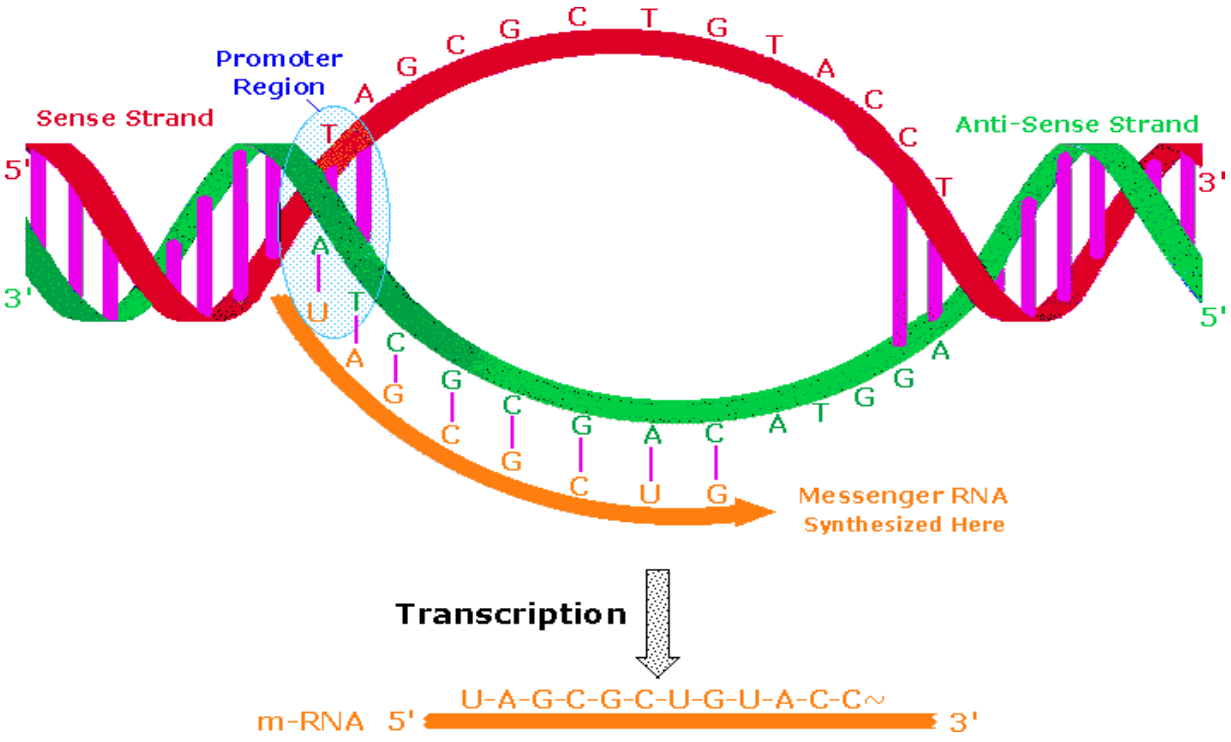



Fig. 56: Transcription

(Source: Ursula Goodenough, 1978, Genetic, 2nd Edition)

An important distinction must be made here. One of the DNA strands in the double helix holds the genetic information used for protein synthesis. This is called the sense strand, or information strand (colored red above). The complementary strand that binds to the sense stand is called the

t serves as a template for generating an mRNA molecule information to a ribosome. The promoter protein binds to a specific nucleotide sequence that identifies the sense strand, relative to the anti-sense strand. RNA synthesis is the initiated in the 3ô direction, as nucleotide triphosphates bind to complementary bases on the template strand, and are joined by phosphate diester linkages. A characteristic ñstop sequenceò of nucleotides terminates the RNA synthesis. The messenger molecule (colored orange, Fig. 56) is released into the cytoplasm to find a ribosome, and the DNA then rewinds to its double helix structure.

The central dogma of molecular biology, which at first was formulated as a simple linear progression of information from DNA to RNA protein, is summarized in the following illustration (Fig. 57). The replication process on the left consists of passing information from a parent DNA molecule to an mRNA molecule. Finally, this information is used by the chemical machinery of the ribosome to make polypeptides.

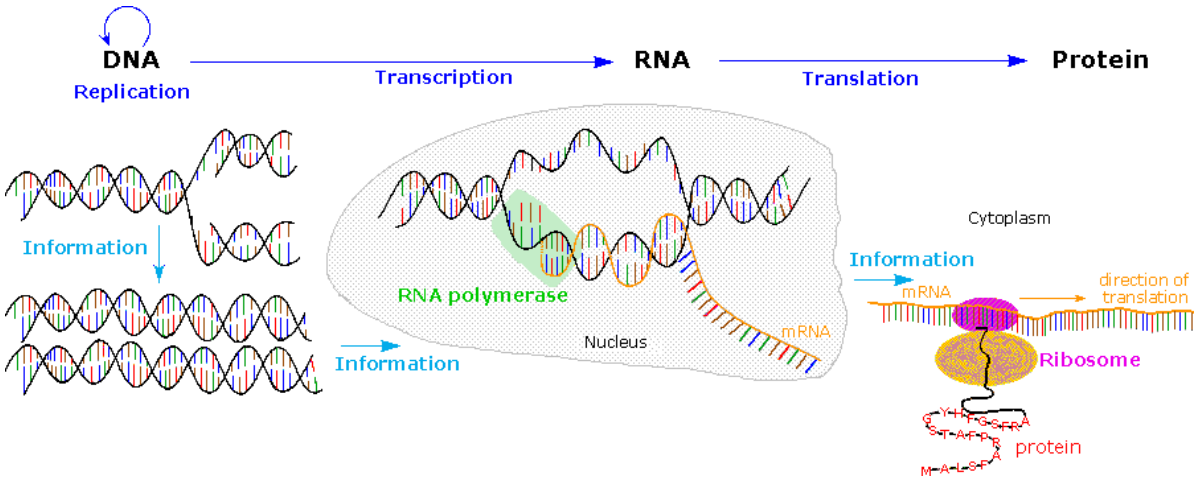
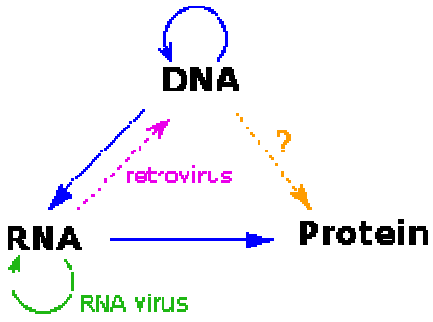



*Fig. 57: Replication, transcription and translation.*

*(Source: William Reusch, 1999)*



(Source: William Reusch, 1999)

As more has been learned about these relationships, the central dogma has been refined to the representation displayed on the right. The dark blue arrows show the general, well demonstrated, information transfers noted above. It is now known that RNA-dependent DNA polymerize enzyme, known as a reverse transcriptase, is able to transcribe a single-stranded RNA sequence into a double-stranded DNA (figure.58) (magenta arrow). Such enzymes are found in all cells and are an essential component of retroviruses (e.g. HIV), which require RNA replication of their genomes (green arrow). Direct translation of DNA information into protein synthesis (orange arrow) has not yet been observed in a living organism. Finally, proteins appear to be an informational dead end, and do not provide a structural blueprint for either RNA or DNA. In the following section the last fundamental relationship, that of structural information, translation from mRNA to protein, will now be described.

### 3.1.2 Translation

This is the actual synthesis of a polypeptide that occurs under the direction of mRNA. Translation is a more complex process than transcription. This would, of course, be expected. DNA replication is simply a complementary base pairing exercise, but the translation of four letter (bases) alphabet code of RNA to the twenty letter (amino acids) alphabet of protein literature is far from trivial. Clearly, there could not be a direct one-to-one correlation of bases to amino acids, so the nucleotide letters must form short words or codons that define specific amino acids.

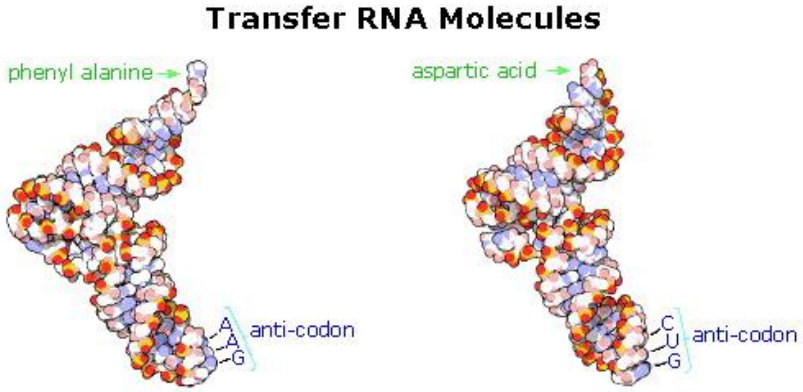



*Fig. 59 transfer RNA molecules*

The translation process is fundamentally straight forward. The mRNA strand bearing the transcribed code for synthesis of a protein interacts with relatively small RNA molecules ( about 70-nucleotides) to which individual amino acids have been attached by an ester bond at the 3ô-end. These transfer RNAôs (tRNA) have distinctive three dimensional structure (Fig. 59) consisting of loops of single-stranded RNA connected by double stranded segments. This cloverleaf secondary structure is further wrapped into an ñL-shapedò assembly, having the amino acids at the end of one arm, and a characteristic anti-codon region at the other end. The anti-codon consists of a nucleotide triplet that is the complement of the amino acids codon(s). Models of two such tRNA molecules are shown to the right. When read from the top to bottom, the anti-codons depicted here should complement a codon in the previous table (Fig 59). A cellôs protein synthesis takes place in the organelle called ribosome. Ribosomes are complex structures made up of two distinct and separable subunits (one about twice the size of the other). Each subunit is composed of one or two RNA molecules (60-70%) associated with 20 to 40 small proteins (30-40%). The ribosome accepts a mRNA molecule, binding initially to a characteristic nucleotide sequence at the 5ô-end. This unique binding assures that polypeptide synthesis starts at the right codon. A tRNA molecule with the appropriate anti-codon then attaches at the starting point and this is followed by a series of adjacent tRNA attachments, peptide bond formation and shifts of the ribosome along the mRNA chain to expose new codons to the ribosomal chemistry. The following diagram is designed as a slide show illustrating these steps (Fig.60). The outcome is synthesis of a polypeptide chain corresponding to the mRNA blueprint. A ñstop codonò at a designated position on the mRNA terminates the synthesis by introduction of a ñRelease Factorò.

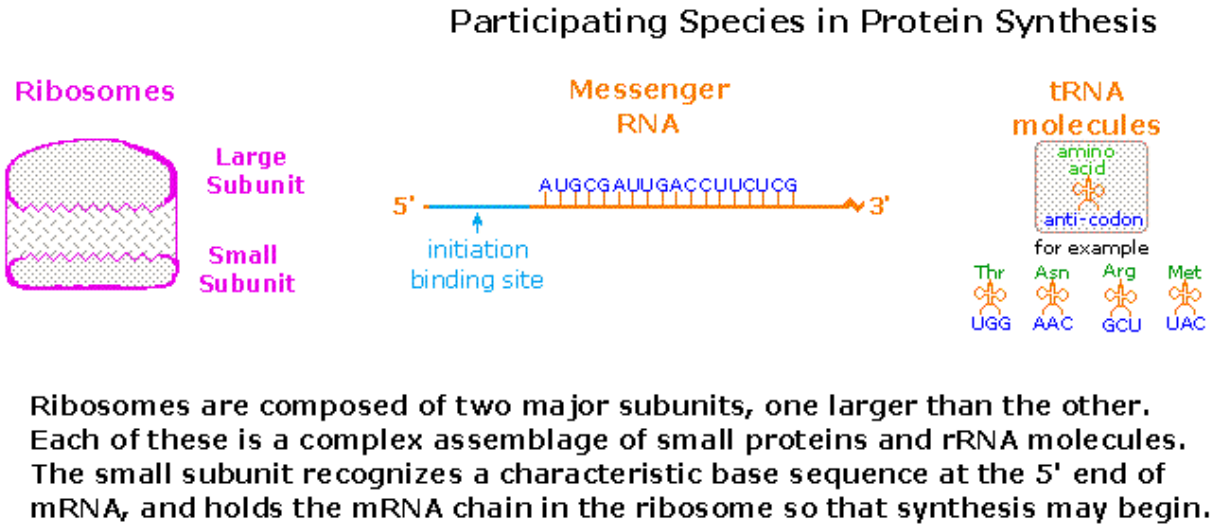



Figure 60: steps involved in the synthesis of a polypeptide chain

(Source: William Reusch, 1999)

## 4.0 Conclusion

Transcription is the synthesis of the RNA by the DNA; while translation is the actual synthesis of a polypeptide under the direction of mRNA during protein synthesis.

## 5.0 Summary

In this unit we have learnt that:

- Transcription is the process by which a DNA sequence is copied to produce complementary strand of RNA.
- Transcription is the transfer of genetic information from DNA into RNA.
- The process of transcription is similar to replication, but in this case, RNA is being built, rather than DNA.
- Transcription is the beginning of the process that ultimately leads to the translation of the genetic code into a peptide or protein.
- Translation is the synthesis of a polypeptide under the direction of mRNA.

## 6.0 Tutor Marked Assignment

1. Outline the process of protein synthesis.

## 7.0 Further Reading and Other Resources

Pelczar, M.J Chan, E.C.S and Krieg N.R. (1986). Microbiology, International Edition McGraw Hill International editions. 918 ISBN 0-07-Y66494-3

Snyder, L. and Champness W. (2003). Molecular Genetics of Bacteria, Second Edition, Anon (1970). Washington D.C 556 pp

Anon (1970). The mechanism of protein synthesis. ñCold Spring Harbor symp. Quant. Biol., Vol. 34. New York: Cold Spring Harbor Laboratory

# Module 4: Proteins and Nucleic Acids

## Unit 4: Introduction to Nucleic Acids

# 1.0 Introduction

Elemental analysis of nucleic acids (RNA and DNA) showed the presence of phosphorus, in addition to the usual carbon, hydrogen, nitrogen and oxygen. Unlike proteins, nucleic acids contained no sulphur.

# 2.0 Objectives

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

- List and describe the two types of nucleic acids
- Differentiate between the two nucleic acids

# 3.0 Main Contents

## 3.1 Types of nucleic acids

### 3.1.1 Ribonucleic acid

Ribonucleic acid, or RNA, is a nucleic acid polymer consisting of nucleotide monomers, which plays several important roles in the processes of transcribing genetic information from deoxyribonucleic acid (DNA) into proteins. RNA acts as a messenger between DNA and the protein synthesis complexes known as ribosomes, forms vital portions of ribosomes, and serves as an essential carrier molecule for amino acids to be used in protein synthesis.

### 3.1.2 Deoxyribonucleic acid

Deoxyribonucleic acid is a nucleic acid that contains the genetic instructions used in the development and functioning of all known living organisms. The main role of DNA molecules is the long-term storage of information and DNA is often compared to a set of blueprints. It contains the instructions needed to construct other components of cells, such as proteins and RNA molecules. The DNA segments that carry this genetic information are called genes, but other DNA sequences have structural purposes, or are involved in regulating the use of this genetic information.

ely cytosine, thymine, guanine and adenine, which are linked attached to each other in this chain by a sugar-phosphate backbone. Two of these chains then coil around each other, forming the DNA double helix.

## 3.2 Nucleic Acid Structure

Nucleotides are the building blocks of these nucleic acids. Each nucleotide is a monomer of nucleic acid and consists of 3 portions:

- a pentose sugar
- one or more phosphate groups
- one of five cyclic nitrogenous bases

### 3.2.1 Phosphate-Sugar Backbone

Nucleotides are linked together by covalent bonds between phosphate of one nucleotide and sugar of next. These linked monomers become the phosphate-sugar backbone of nucleic acids. Nitrogenous bases extend from this phosphate-sugar backbone like teeth of a comb.

### 3.2.2 The Nucleic Acid "Ladder"

Hydrogen bonds form between specific bases of two nucleic acid chains, forming a stable, double-stranded DNA molecule, which looks like a ladder.

Three H bonds form between bases cytosine (C) and guanine (G), which always pair up together between two nucleic acid chains. Two H bonds form between adenine (A) and thymine (T) in DNA or adenine and uracil (U) in RNA molecules.

The structure is analogous to a ladder, with the two deoxyribose-phosphate chains as side rails and the base pairs, linked by hydrogen bonds, forming the rungs

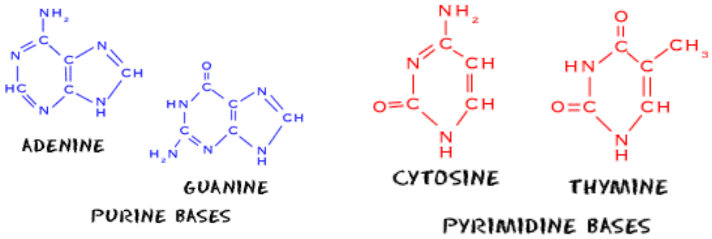



*Fig. 61 Structure of the nitrogen bases (Source: Brock Biology of Microorganism 12th edition Madigan M.T. et al.)*

### es in the Nucleic Acids

abolic polymerization process. Anabolic reactions build bigger molecules. Polymerization is the process of taking nucleotide monomers and putting them together into polymers (large molecules composed of many monomers).

These three-phosphate nucleotide building blocks of DNA bring their own energy for polymerization within their phosphate bonds. When the triphosphate bond of the nucleotide is broken, it contributes the energy required add another nucleotide to the growing nucleic acid.

## 3.3 Chemical structure

The term "nucleic acid" is the generic name for a family of biopolymers, named for their role in the cell nucleus. The monomers from which nucleic acids are constructed are called nucleotides.

Each nucleotide consists of three components: a nitrogenous heterocyclic base, which is either a purine or a pyrimidine (Fig. 61); a pentose sugar; and a phosphate group. Nucleic acid types differ in the structure of the sugar in their nucleotides - DNA contains 2-deoxyribose while RNA contains ribose (where the only difference is the presence of a hydroxyl group). Also, the nitrogenous bases found in the two nucleic acid types are different: adenine, cytosine, and guanine are found in both RNA and DNA, while thymine only occurs in DNA and uracil only occurs in RNA. Other rare nucleic acid bases can occur, for example inosine in strands of mature transfer RNA.

Nucleic acids are usually either single-stranded or double-stranded, though structures with three or more strands can form. A double-stranded nucleic acid consists of two single-stranded nucleic acids held together by hydrogen bonds, such as in the DNA double helix. In contrast, RNA is usually single-stranded, but any given strand may fold back upon itself to form secondary structure as in tRNA and rRNA. Within cells, DNA is usually double-stranded, though some viruses have single-stranded DNA as their genome. Retroviruses have single-stranded RNA as their genome.

The sugars and phosphates in nucleic acids are connected to each other in an alternating chain, linked by shared oxygens, forming a phosphodiester bond. In conventional nomenclature, the carbons to which the phosphate groups attach are the 3' end and the 5' end carbons of the sugar. This gives nucleic acids polarity.

In unit 1, you have already been given some information about amino acids. Proteins are made of amino acids. Even though a protein can be very complex, it is basically a long chain of amino acids, all twisted around like a knot.

Both RNA and DNA are macromolecules and differ in their sugar and nitrogenous bases. RNA can fold into various configurations to obtain secondary structure.

## 5.0 Summary

In this unit we have learnt that:

- RNA is usually single stranded
- DNA is double stranded
- RNA and DNA each consists of a sugar, phosphate, and nitrogenous bases
- RNA has a ribose sugar, phosphate, uracil, adenine, cytosine and guanine
- DNA consists of deoxyribose sugar, phosphate, thymine, adenine, cytosine and guanine.

## 6.0 Tutor Marked Assignment

1. Define the terms primary, secondary, and tertiary with respect to protein structure

2. Write short note on types of nucleic acid

## 7.0 Further Reading and Other Resources

Roberts, K., Raff, M., Alberts, B., Walter, P., Lewis, J. and Johnson, A. (2002). Molecular Biology of the Cell 4th Edition, Routledge, 1616 pages, ISBN 0-8153-3218-1

Pelczar, M.J., Chan, E.C.S. and Krieg, N.R. (1986). Microbiology, International Edition, McGraw Hill International editions. 918pp. ISBN 0-07-Y66494-3.

Snyder, L. and Champness, W. (2003). Molecular Genetics of Bacteria, Second Edition, Washington, D.C. 566pp.

Saenger, W. (1984). Principles of Nucleic Acid Structure. Springer-Verlag New York Inc.

# Module 4: Proteins and Nucleic Acids

## Unit 5: Nucleic Acid Components and Functions

# 1.0 Introduction

The nucleic acids (RNA and DNA) are wonderful discoveries of the modern times. They are universally present in the nucleus and in the cytoplasm of all living cells, and are now definitely known to form the chemical basis of life. This unit examines the complex organic compounds made of phosphate, pentose sugar and nitrogen bases which constitute the components of the two nucleic acids.

# 2.0 Objectives

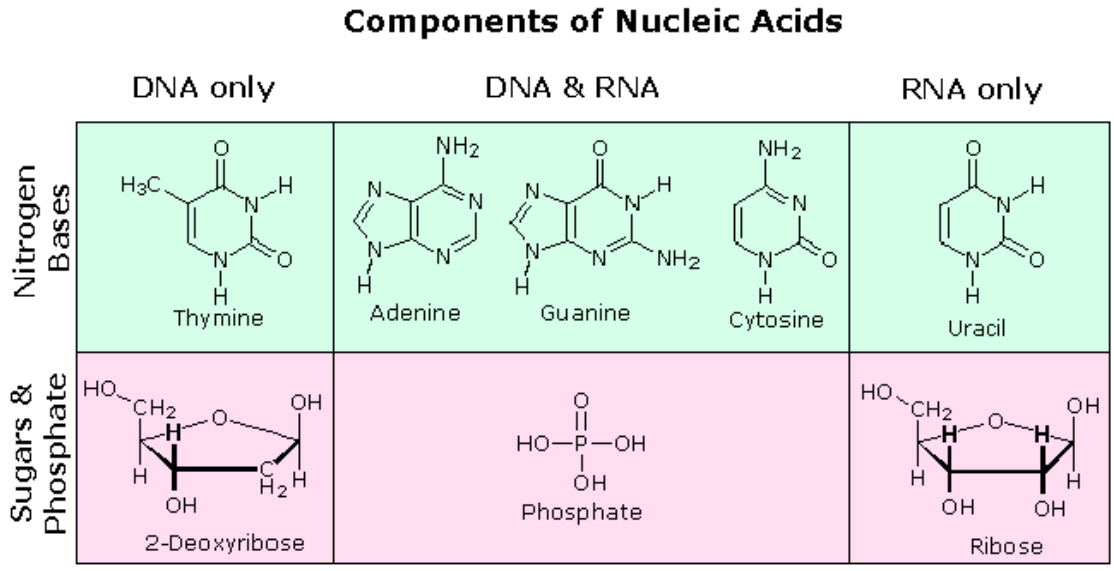
By the end of this unit, you should be able to:

- Recognise nucleic acid components;
- State the functions of nucleic acids.

# 3.0 Main Contents

## 3.1 Nucleic acid components

Adenine, guanine, cytosine and phosphate group are common to both RNA and DNA. Ribose sugar and uracil are found in RNA while thymine and deoxyribose are in the DNA (Fig. 62).



*(Source: Snyder, L. and Champness, W. 2003. Molecular Genetics of Bacteria. 2nd edition. ASM press, Washington, D.C.).*

### 3.1.1 Nucleobases

Nucleobases are heterocyclic aromatic organic compounds containing nitrogen atoms. Nucleobases are parts of RNA and DNA involved in base pairing. Cytosine, guanine, adenine, thymine are found predominantly in DNA, while in RNA uracil replaces thymine. These are abbreviated as C, G, A, T, U, respectively.

Nucleobases are complementary, and when forming base pairs, must always join accordingly: cytosine-guanine, adenine-thymine (adenine-uracil when RNA). The strength of the interaction between cytosine and guanine is stronger than between adenine and thymine because the former pair has three hydrogen bonds joining them while the latter pair has only two. Thus, the higher the GC content of double-stranded DNA, the more stable the molecule and the higher the melting temperature.

Two main nucleobase classes exist, named for the molecule which forms their skeleton. These are the double-ringed purines and single-ringed pyrimidines (Fig. 61 unit 4). Adenine and guanine are purines (abbreviated as R), while cytosine, thymine, and uracil are all pyrimidines (abbreviated as Y).

### 3.1.2 Nucleosides

Nucleosides are glycosylamines made by attaching a nucleobase (often referred to simply as bases) to a ribose or deoxyribose (sugar) ring. In short, a nucleoside is a base linked to sugar. The names derive from the nucleobase names. The nucleosides commonly occurring in DNA and RNA include cytidine, uridine, adenosine, guanosine and thymidine. When a phosphate is added to a nucleoside (by a specific kinase enzyme), a nucleotide is produced.

### 3.1.3 Nucleotides

A nucleotide consists of a nucleoside and one phosphate group. Nucleotides are the monomers of RNA and DNA, as well as forming the structural units of several important cofactors - CoA, flavin adenine dinucleotide, flavin mononucleotide, adenosine triphosphate and nicotinamide adenine dinucleotide phosphate. In the cell nucleotides play important roles in metabolism, and signaling.

Nucleotides are named after the nucleoside on which they are based, in conjunction with the number of phosphates they contain. For example: adenine bonded to ribose forms the nucleoside adenosine. Adenosine bonded to a phosphate forms adenosine monophosphate. As phosphates are added,

riphosphate are formed, in sequence. The ATP, adenosine

## 3.2 Functions of Nucleic Acids

The main function of nucleic acids is to store and transmit genetic information and use that information to direct the synthesis of new protein. The DNA (deoxyribonucleic acid) is the permanent storage place for genetic information in the nucleus of a cell. DNA controls the synthesis of RNA (ribonucleic acid). RNA transmits genetic information from DNA to the protein synthesizers in the cell. RNA is also responsible for directing the production of the new protein by transmitting the genetic information to the protein building structures. The nucleotide, ATP (adenosine triphosphate), which is closely related to DNA and RNA, is the short-term energy storage for all life processes. The function of the sequence of bases (adenine, cytosine, guanine, and thymine) in the backbone of DNA determine what proteins are being synthesized and in what order (note that in RNA, thymine is replaced by uracil). The function of the double helix formation of DNA molecules is to ensure that no disorders occur if genetic information is lost or damaged. Examples of disorders related to damaged or lost genetic information are Down's syndrome and sickle cell anemia.

### 3.2.1 Functions of DNA (deoxyribonucleic acid)

- DNA is a permanent storage place for genetic information.
- DNA controls the synthesis of RNA (ribonucleic acid).
- The sequence of nitrogenous bases in DNA determines the protein development in new cells.
- The function of the double helix formation of DNA is to ensure that no disorders occur. This is because the second identical strand of DNA that runs anti-parallel to the first is a back up in case of lost or destroyed genetic information.

### 3.2.2 Functions of RNA (ribonucleic acid):

- RNA is synthesized by DNA for the transportation of genetic information to the protein building apparatus in the cell.
- RNA also directs the synthesis of new proteins using the genetic information it has transported.
- mRNA (messenger ribonucleic acid) is used to transfer genetic information through plasma membranes

### 3.2.3 Functions of Some Nucleotides

- The nucleotide, ATP (adenosine triphosphate) is the short-term energy storage for all living organisms. Nucleic acids can be used to create energy in the form of ATP. ATP is formed with the nitrogenous bases adenosine and ribose.

with the above nitrogenous bases to form ATP. But how does ovide energy, ATP goes through the process of hydrolysis, producing energy, as well as a phosphate molecule.

- It is important to note that, during cellular respiration, ATP can be accessed either through aerobic (with oxygen) system and anaerobic (without oxygen) system. Aerobic access of ATP energy is much more efficient, creating 36 ATP instead of the 2 with anaerobic.
- cAMP (cyclic adenosine monophosphate) is a messenger in hormone regulation
- Nucleotide derivatives such as NAD + (nictinamide adenine dinucleotide) is used as a coenzyme in photosynthesis.

### 3.2.4 Duplication Abilities of RNA and DNA

Nucleic acids (specifically DNA) carry out a vital role in the human body. In particular, nucleic acids play an essential role in both mitosis and meiosis

In mitosis, the chromosomes (or genetic information) contained inside the nucleus of the parent cell is duplicated. The two resulting daughter cells have identical genetic information to the parent cell. This is possible only through nucleic acid's remarkable ability to create identical copies of itself. It is the only molecule known to have this ability. Mitosis is essential to life because it replaces damaged or dead cells, repairs tissues, and allows the body to grow (in mass and size).

Another use for nucleic acid's duplication ability is meiosis. Meiosis is the process in which sex cells are created. Without nucleic acids, meiosis would be impossible, and therefore there would be no reproductive processes in living organisms.

## 4.0 Conclusion

The nucleic acids, deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) consist of nitrogen bases, sugars and phosphate groups and carry out vital functions in the living cells of organisms

## 5.0 Summary

In this unit we have learnt that:

- DNA and RNA are the genetic materials of cells, their names derived from the type of sugar, contained within the molecules.
- The strength of the interaction between cytosine and guanine is stronger than between adenine and thymine.
- The higher the GC content of double-stranded DNA, the more stable the molecule and the higher the melting temperature.

RNA and DNA

ls is to store and transmit genetic information and use that information to direct the synthesis of new protein.

- DNA or RNA has a sugar, nitrogen base and a phosphate group
- ATP (a nucleotide) is related to RNA and DNA and is the short-term energy storage of the cell.

## 6.0 Tutor Marked Assignment

1. What are the three parts of a nucleotide?

2. How does a nucleoside differ from a nucleotide?

3. State the functions of the DNA and RNA

## 7.0 Further Reading and Other Resources

Pelczar, M.J., Chan, E.C.S. and Krieg, N.R. (1986). Microbiology, International Edition, McGraw Hill International Editions. 918pp. ISBN 0-07-Y66494-3.

Snyder, L. and Champness, W. (2003). Molecular Genetics of Bacteria, Second Edition, Washington, D.C. 566pp.

# Module 4: Proteins and Nucleic Acids

## Unit 6: Review of Proteins and Nucleic Acid

# 1.0 Introduction

We have already considered the functions of proteins (unit 3) while certain features of protein synthesis in unit 3 have been discussed. In the units that follow, we introduce nucleic acid, their components and functions. Some missing linkages may exist. In this unit, a review of proteins and nucleic acid is presented.

# 2.0 Objectives

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

1. Understand the relationship between proteins and DNA;
2. Distinguish between levels of protein structure;
3. Explain amino acids found in proteins (Fig. 64).

# 3.0 Main Contents

## 3.1 Relationship between proteins, RNA and DNA

There is a relationship between proteins, RNA and DNA. Remember that the DNA synthesizes RNA and mRNA is involved in protein synthesis (Fig. 63).

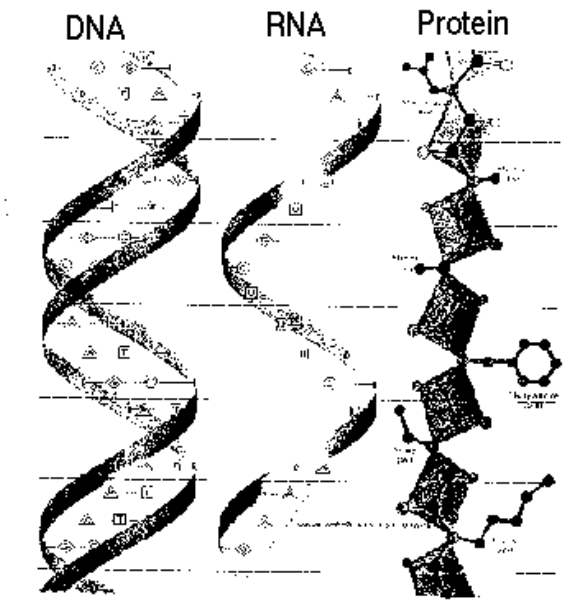



*Figure 4.6.1. Linear relationship between DNA, RNA and Protein Sequence*

*W. 2003. Molecular Genetics of Bacteria. 2nd edition.*

- DNA encodes amino acids of a protein using 3 letter codons.
- DNA is transcribed to make mRNA.
- mRNA is translated by ribosomes to make the protein.

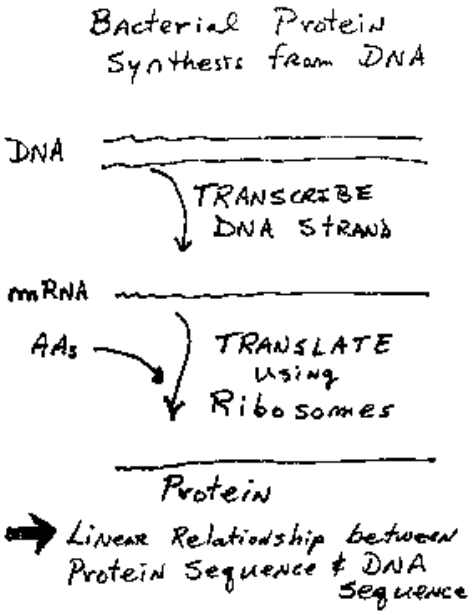
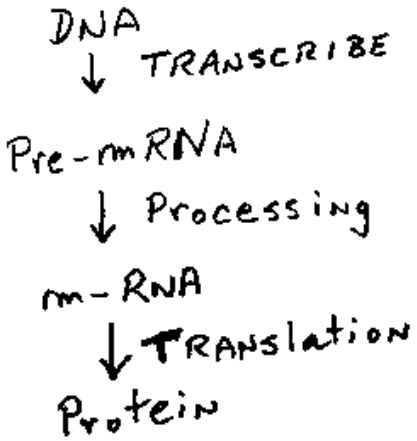



*Fig. 64 Bacterial Protein Synthesis.*



- Eukaryotic DNA is transcribed to make a pre-mRNA, then the pre-mRNA is processed (Fig. 65).
- Processing removes the intervening sequences found in eukaryotic DNA, which are called Introns.
- During processing, the exons containing the coding region for the protein are joined.
- Also some modifications of the ends of the mRNA are made and it goes into the cytosol.
- In the cytosol, ribosomes translate the mRNA to make protein in manner very similar to prokaryotes (Fig. 65).

## 3.2 Amino Acids and Proteins

The first thing you might be asking is, "What is an amino acid?" There are over twenty, and each one of them is different from the other amino acids. Amino acids are used in every cell of your body and are used to build the proteins needed to survive. All organisms need some proteins, whether they are used in muscles or as simple structures in the cell membrane. Even though all organisms have differences, they still have one thing in common, the need for basic chemical building blocks. Amino acids have a two-carbon bond. One of the carbons is part of a group called the carboxyl group. A carboxyl group is made up of one carbon (C), two oxygen atoms (O), and one hydrogen atom (H). The carboxyl group is acidic. The second carbon is a part of the amino group. Amino means there is an $NH_2$ group bonded to the carbon atom.

### 3.2.1 Making Chains

Even though scientists have discovered over 50 amino acids, only 20 are used to make proteins in our body. Of those twenty, eight are defined as essential. The other twelve can be synthesized by an adult body. Thousands of combinations of those twenty are used to make all of the proteins in our body. Amino acids bond together to make long chains and those long chains of amino acids are also called proteins.

### 3.2.2 Side Groups

The side groups are what make each amino acid different from the others. Of the 20 used to make proteins, there are three groups. The three groups are ionic, polar and non-polar. These names refer to the way the side groups (sometimes called "R" groups) interact with the environment. Polar amino acids like to adjust themselves in a certain direction. Non-polar amino acids are different (please refer to unit 1, Fig. 47).

s special because it holds the code for every cell in our body. This means that every cell in your body uses DNA for an instruction manual. In other words DNA is just a long spiral chain of nucleotides. But it's more. So you get all of those nucleotides in two long chains that twist around each other. That twisting shape is called a double-helix. The spiral ladder has the ability to wind and unwind so that the nucleic acid chain can duplicate itself. That duplication process happens every time a cell divides.

When a cell is in its normal state, the DNA is not duplicating and it just looks like a blob of white strands. This nucleic acid chains usually sit around uncoiled and as loose strands called chromatin. When it is time for the cell to reproduce, they condense and wrap up very tightly. The tightly wound DNA is called a chromosome. Chromosomes appear like long, limp hot dogs. They are also found in pairs.

In most organisms, you will find DNA in the nucleus. Chromosomes work with other nucleic acids in the cell to build proteins and help in duplication. You will most likely find mRNA (messenger-ribonucleic acid) in the nucleus with the DNA. The dispersed tRNA (transfer-ribonucleic acid) is found outside of the nucleus, floating in the cell. In a few organisms called prokaryotes, there is no defined nucleus and the DNA is found throughout the cell.

## 3.3 The Rules of Protein Structure

The sequence of amino acids in a protein is determined by the sequence of nucleotides in the gene (DNA) encoding it. The function of a protein (except when it is serving as food) is absolutely dependent on its three-dimensional structure. A number of agents can disrupt this structure thus denaturing the protein.

- changes in pH (alters electrostatic interactions between charged amino acids)
- changes in salt concentration (does the same)
- changes in temperature (higher temperatures reduce the strength of hydrogen
- bonds)
- presence of reducing agents (break S-S bonds between cysteines)

None of these agents breaks peptide bonds, so the primary structure of a protein remains intact when it is denatured. When a protein is denatured, it loses its function.

Examples:

- A denatured enzyme ceases to function.

n bind its antigen.
atured and then is returned to normal physiological conditions of temperature, pH, salt concentration, etc., it spontaneously regains its function (e.g. enzymatic activity or ability to bind its antigen). When denaturation is not gentle like hike high temperature, the protein loses its structure and functions. This tells us that the protein has spontaneously resumed its native three-dimensional shape. Its ability to do so is intrinsic; no outside agent was needed to get it to refold properly.

However, there are:

- enzymes that add sugars to certain amino acids, and these may be essential for proper folding;
- proteins, called molecular chaperones, that may enable a newly-synthesized protein to acquire its final shape faster and more reliably than it otherwise would.

## 3.4 The twenty Amino Acids Found in Proteins

There are twenty amino acids required for human life to exist. Adults have eight essential amino acids that they cannot synthesize. The other twelve can be produced within our bodies. There are some other amino acids found in nature (and some very small amounts in humans). These twenty amino acids are found in proteins (Table 4).

Table 4: List of Twenty Amino Acids

| | |
|---|---|
| Alanine | Leucine |
| Arginine | Lysine |
| Asparagine | Methionine |
| Aspartic Acid | Phenylalanine |
| Cysteine | Proline |
| Glutamic Acid | Serine |
| Glutamine | Threonine |
| Glycine | Tryptophan |
| Histidine | Tyrosine |

## 3.5 Levels of protein structure

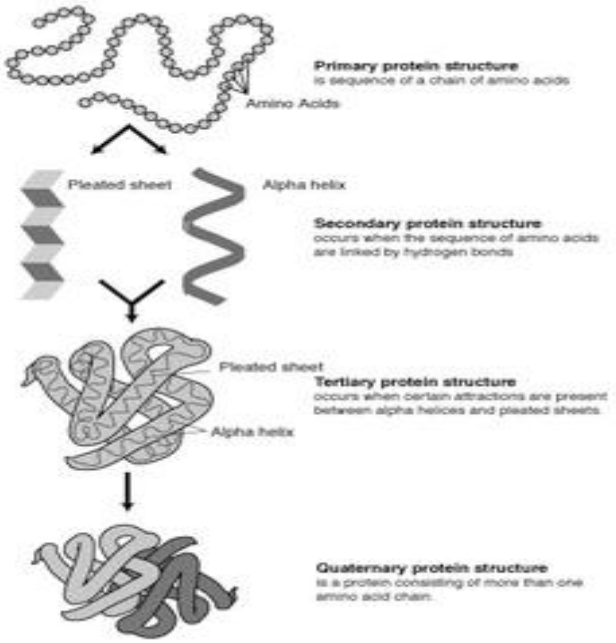



*Fig. 66. Protein structure, from primary to quaternary structure.*

*(Source: Snyder L. and Champness W. 2003. Molecular Genetics of Bacteria. 2nd edition).*

Primary structure - the amino acid sequence of the peptide chains. The primary structure is held together by covalent or peptide bonds, which are made during the process of protein biosynthesis or translation. These peptide bonds provide rigidity to the protein. The two ends of the amino acid chain are referred to as the C-terminal end or carboxyl terminus (C-terminus) and the N-terminal end or amino terminus (N-terminus) based on the nature of the free group on each extremity.

Secondary structure - highly regular sub-structures (alpha helix and strands of beta sheet) which are locally defined, meaning that there can be many different secondary motifs present in one single protein molecule. The various types of secondary structure are defined by their patterns of hydrogen bonds between the main-chain peptide groups. However, these hydrogen bonds are generally not stable by

gen bond is generally more favorable than the amide-amide re is stable only when the local concentration of water is sufficiently low.

Tertiary structure - three-dimensional structure of a single protein molecule; a spatial arrangement of the secondary structures. It also describes the completely folded and compacted polypeptide chain.

Quaternary structure - complex of several protein molecules or polypeptide chains, usually called protein subunits in this context, which function as part of the larger assembly or protein complex.

In addition to these levels of structure, a protein may shift between several similar structures in performing its biological function. This process is also reversible. In the context of these functional rearrangements, these tertiary or quaternary structures are usually referred to as chemical conformation, and transitions between them are called conformational changes.

## 4.0 Conclusion

RNA, DNA and proteins are closely related in terms of structure and synthesis. Amino acids are found in all of them.

## 5.0 Summary

In this unit we have learnt that:

- Eukaryotic protein synthesis is more complex than prokaryotic
- Amino acids are found in proteins
- All organisms have the need for basic chemical building blocks.
- Amino acids bond together to make long chains and those long chains of amino acids are also called proteins.
- DNA holds the code for every cell in human body.
- In prokaryotes, there is no defined nucleus and the DNA is found throughout the cell.
- The primary structure of a protein remains intact when it is denatured
- When a protein is denatured, it loses its function.
- A relationship exists between proteins, RNA and DNA.

## 6.0 Tutor Marked Assignment

1. What is an amino acid?

structures

3. Give a short account of the DNA

## 7.0 Further Reading and Other Resources

Pelczar, M.J., Chan, E.C.S. and Krieg, N.R. (1986). Microbiology, International Edition, McGraw Hill International editions. 918pp. ISBN 0-07-Y66494-3.

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