Chapter I : Introduction to cytology

Objectifs: The Cell Biology course aims to achieve the following objectives:

1- Acquire theoretical and practical knowledge in Cell Biology.

2- Understand the structure and functions of the cell.

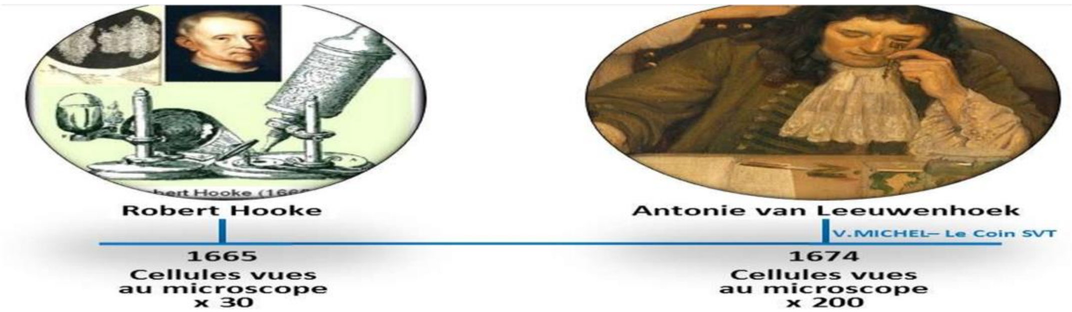
I. Cell Biology / Cytology

Cell Biology (formerly called Cytology): A branch of biology that studies cells from a structural and functional perspective, such as: Reproduction, Metabolism, Homeostasis, Communication, etc. Cell death, which can be genetically programmed (apoptosis) or be the result of injury (necrosis).

The initial objective of cytology and cell biology is to describe, with maximum precision, all the characteristic structures of animal, plant, or unicellular cells, their modifications during the life of the cells, and their diversity within organisms or during embryonic development….:

II. Brief history

The first microscopic observations:



(**1635-1703**) Robert Hooke first observed the cells on a cork sample..

(**1632 – 1723**) Antonie van **Leeuwenhoek** describes the existence of microorganisms.

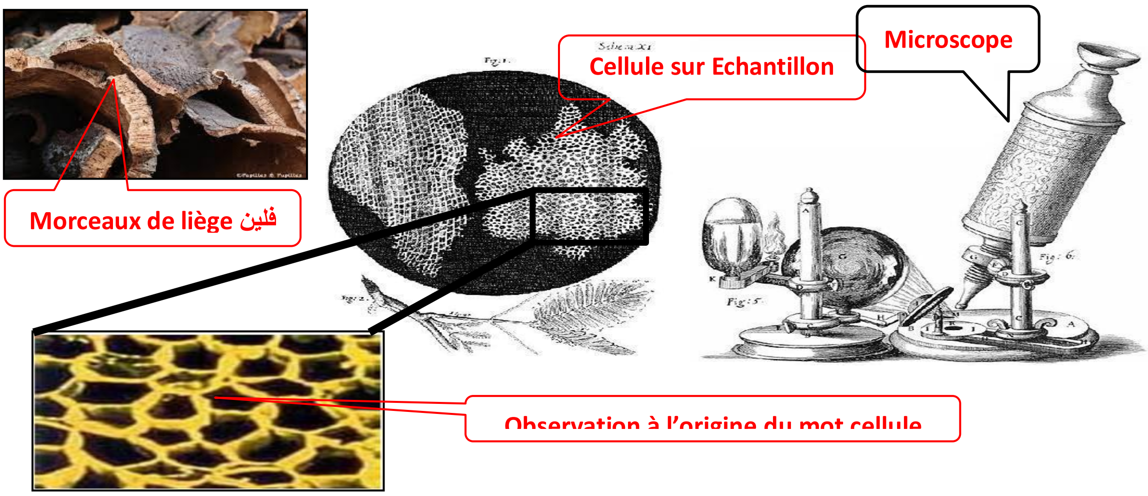


Fig1 : Observation of the cell for the first time 1665-1674 (Hooke et Leeuwoek)

Microscopy, which originated with the work of Hooke and Van Leeuwenhoek, gradually established itself as one of the main techniques for studying living matter. Three centuries later, cytology emerged. Around 1825: The study of microorganisms (bacteria) became truly accessible with the development of the optical microscope, thus giving rise to cytology.

III. The major stages of cytology

1- Discovery of the cell

1665-1820: Development of light microscopy = Description of cellular structures. 1824-1839: Formulation of cell theory (Schleiden and Schwann).

1855: Formulation of the theory of cell continuity (Virchow). Cells always originate from other pre-existing cells. (*omnis cellula e cellula*).

1830-1900: Description of the main cellular structures and organelles; development of cytological and histological techniques. Cell biology is established as a discipline.

In summary: The gradual emergence of the concept of the cell and cytology

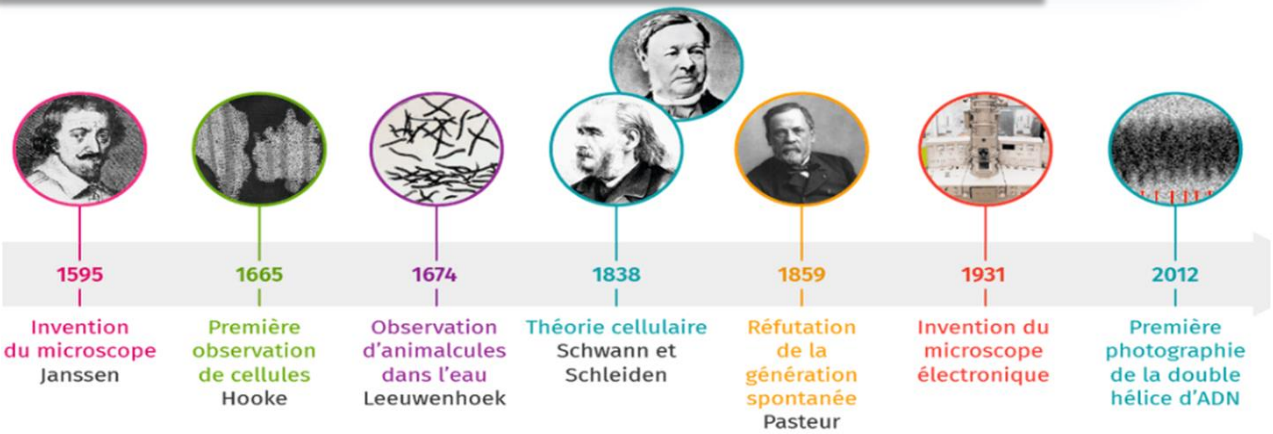


Fig. 2 : The gradual emergence of the concept of the cell and cytology

Cytology has evolved over time to become an essential discipline of biology, contributing significantly to our understanding of cells, their structure, function, and role in the biology of living organisms.

IV. The axioms of cell theory

First axiom: In 1838, Schleiden and Schwann formulated the first axiom of cell theory: "All organisms (bacteria, plants, and animals) are made of small units: cells."

Second axiom: In 1855, Virchow (a German physician) suggested that every cell originates from another cell (the principle of cell division).

Third axiom: A cell is an autonomous entity capable of performing a number of functions necessary and sufficient for its survival.

❑ Summary of the axioms of cell theory

a) Unit of composition: All organisms are made up of one or more cells.

b) Functional unit: The cell is the basic unit of structure and function in living things.

d) Unit of reproduction: Every cell originates from a pre-existing cell.

These three principles are the foundations of modern cell biology and have revolutionized our understanding of life at the microscopic level.

❑ Complementing classical theory with current cellular data XX^{e}–XXI^{e} Century

Domaine	Classical cell theory (XIXth Century)	Modern cell theory (XXth–XXIth Century)
1. Fundamental structure of living beings	All living things are made up of one or more cells.	All living things, regardless of their diversity, are composed of cells that are similar in their basic chemical composition (water, proteins, nucleic acids, lipids).
2. Functional unit of life	The cell is the fundamental functional unit; all vital activities take place within it.	The activity of the organism results from the set of coordinated and integrated activities of its cells, through molecular signals.
3. Origin of cells	Every cell originates from a pre-existing cell through cell division.	All cells derive from a common primitive cell called LUCA (Last Universal Common Ancestor), which proves the unity and evolution of life over time.
4. Genetic material	Not precisely known in classical theory.	Each cell contains DNA which carries the genetic information transmitted during division and controls protein synthesis and cellular functions.
5. Internal organization of the cell	The cell is considered a simple unit composed of cytoplasm, a membrane, and a nucleus.	The cell contains specialized organelles (mitochondria, Golgi apparatus, etc.) that perform different functions in an organized and precise manner.
6. Energy and metabolism	Not mentioned in the original version of the theory .	The cell is an open system that captures and transforms energy through metabolic processes (respiration, photosynthesis, degradation).
7. Evolutionary vision	Absent from ancient cellular thought.	All cells share a common evolutionary origin, and their molecular changes form the basis of organismal evolution.

The **<u>L</u>ast <u>U</u>niversal <u>C</u>ommon <u>A</u>ncestor** (**LUCA**) is a single-celled ancestral organism that lived approximately 3.5 to 4 billion years ago. It is considered the starting point of cell evolution, giving rise to the three domains of life**: Bacteria**, **Archaea**, and **Eukaryotes**. It serves as a model for understanding how life evolved on Earth.

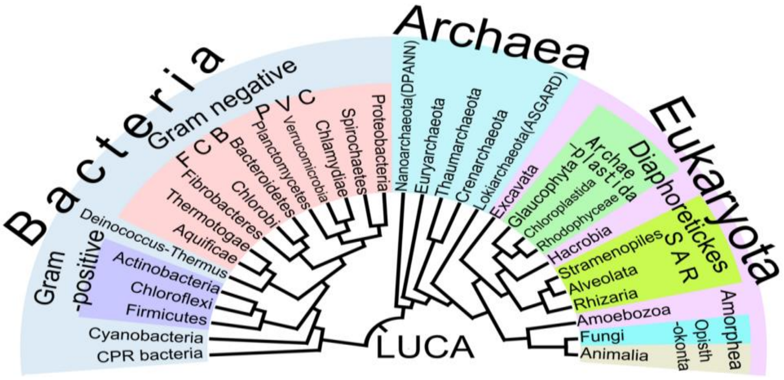


Fig 3 : Family tree and common root

- **Evidence of the existence of a common ancestor**
- **The universal genetic code:** all living beings use the same basic elements (A, T, G, C).
- The mechanisms of replication, transcription, and translation are similar in all organisms.
- Fundamental proteins and enzymes have a great similarity in their structure and function.
- The **significant genetic similarity** between microorganisms and complex organisms confirms this common relationship..

V. Prokaryotic to eukaryotic evolution

The endosymbiotic theory, **or endosymbiosis theory**: explains the origin of eukaryotic cells from prokaryotic cells through a process of symbiosis. This theory was proposed in the 1960s by biologist Lynn Margulis. According to this theory, certain organelles of eukaryotic cells, such as mitochondria and chloroplasts, originated from ancient prokaryotic organisms that were incorporated into host cells via endocytosis.

Points clés de la théorie :

- ✓ **Origin of mitochondria:** They are thought to have originated from an aerobic bacterium (probably a proteobacterium) that was integrated into a primitive ancestral cell. This gave the host cell the ability to respire oxygen, a significant evolutionary advantage.
- ✓ **Origin of chloroplasts:** Chloroplasts, on the other hand, are thought to have derived from a photosynthetic cyanobacterium that was phagocytosed by a primitive cell, thus giving it the ability to perform photosynthesis.

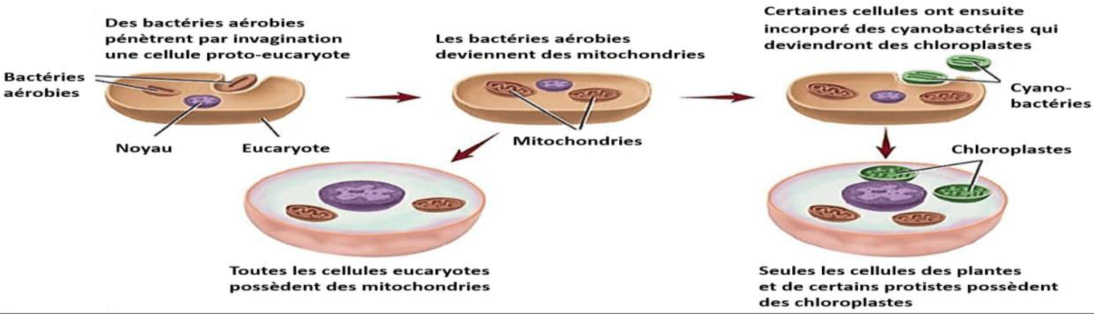


Fig 4 : Endosymbiotic theory

Evidence for the theory:

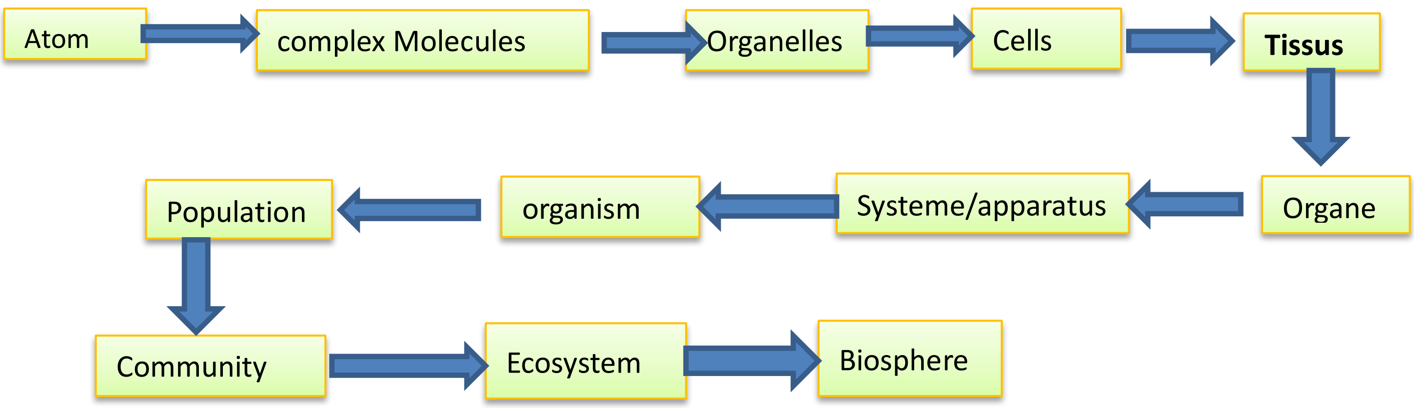
- ✓ **DNA**: Mitochondria and chloroplasts possess their own DNA, which is circular like that of bacteria, suggesting an independent origin.
- ✓ **Double membrane**: These organelles are surrounded by two membranes, one from the symbiotic organism and the other from the host cell, which could be explained by their integration via endocytosis.
- ✓ **Ribosomes:** The ribosomes present in mitochondria and chloroplasts resemble those of bacteria.
- ✓ **Independent replicability**: These organelles divide by binary fission, a mode of reproduction typical of bacteria

Importance of the endosymbiotic theory:

The endosymbiotic theory has had a major impact on our understanding of cell evolution. It explains how complex cells (eukaryotes) evolved from simple organisms (prokaryotes) and is widely accepted in the field of biology. It also helps us understand symbiotic relationships in nature and shows how cooperation between organisms can lead to major evolutionary innovations.

VI. La notion du vivant et Organisation des êtres vivants aux différentes échelles

The living world today is the result of evolutionary processes that began billions of years ago with the formation of organic molecules from a few atoms of carbon, hydrogen, and oxygen. Life depends on the integrity of these structural levels.



VII. Classification of the living world

Living things are divided into different groups. Based on their anatomy (animals that have the same shape are classified in the same group), the classification can be based on lifestyle (autotrophic or heterotrophic, symbiotic, parasitic, saprophytic…), on the other hand: the closer the species are in terms of evolution, the closer they should be in the classification. **Whittaker** (1969) proposes a division of the living world into 5 kingdoms:

1. Monera: Prokaryotic organisms (bacteria), consisting of a single cell without a nucleus. They were the first living beings. They have evolved very little over the last several billion years.

2. Protists: Eukaryotic organisms, mostly unicellular. Their cells have a nucleus. This kingdom is divided into three main groups.

- ***Protozoa:*** *closely related to animals;*
- ***Single-celled algae:*** *closely related to plants* ;
- ***Fungiform protists:*** related to mycetes (fungi)

3. **Fungi** (Fam.): Multicellular, heterotrophic eukaryotic organisms. They absorb their nutrients and possess a cell wall.

4. **Plants**: Multicellular, autotrophic (photosynthetic) eukaryotic organisms. They possess a cell wall made of cellulose.

5. **Animals**: Multicellular, heterotrophic eukaryotic organisms. They ingest their nutrients and do not possess a cell wall made of cellulose.

Since 1970, a distinction has been made between classic bacteria (eubacteria), such as cyanobacteria (photosynthetic blue-green algae), and Archaea, which have a very particular lifestyle (extreme living conditions) and are divided into 3 groups, namely:

- Methanogens (methane is the product of their metabolism);
- Halophiles (saline environments);
- Thermophiles (hot environments).

- <u>Hierarchical order of classification of living things: Kingdom, Phylum, Class, Order, Family, Genus and Species</u>
- Currently, the living world is divided into 3 domains based on cytological characteristics:

1- Eubacteria :

- These are prokaryotic organisms (they lack a nucleus enclosed by a membrane). Their DNA is free within the cell, often in the form of a circular chromosome.
- **Bacteria** represent a large group of unicellular organisms, with cell walls that generally contain peptidoglycan.

2- Archaea :

- Like bacteria, archaea are prokaryotes, but they differ from bacteria in specific genetic and biochemical characteristics.
- They possess cell membranes composed of unique lipids, and their metabolic processes and DNA share similarities with eukaryotes.
- They are often found in extreme environments (high temperature, salinity, acidity, etc.), but they are also present in more ordinary habitats..

3- Eukarya :

- These are organisms whose cells possess a nucleus delimited by a membrane and organelles (such as mitochondria, the endoplasmic reticulum, etc.).
- Eukaryotes include animals, plants, fungi, and protists. They can be unicellular (like some algae or protozoa) or multicellular (like animals and plants).

1- Concept of species and binomial nomenclature

A species is the fundamental unit of classification, grouping together living organisms that share a common set of morphological, anatomical, physiological, biochemical, and genetic characteristics. It is a population whose individuals can potentially reproduce with each other and produce viable and fertile offspring. Each species is designated by two names: the first for the genus and the second for the species. This scientific nomenclature is universal; for example:

Streptococcus pneumoniae: for Pneumococcus

Staphylococcus aureus: for Staphylococcus

Equus caballus: for the horse

VIII. The importance of cytology

1- **Medical Diagnosis**: Cytology is widely used in medicine to diagnose conditions and diseases based on the observation of cells. **Example**: Cytological examination of cells taken from a tumor can help determine whether it is malignant or benign.

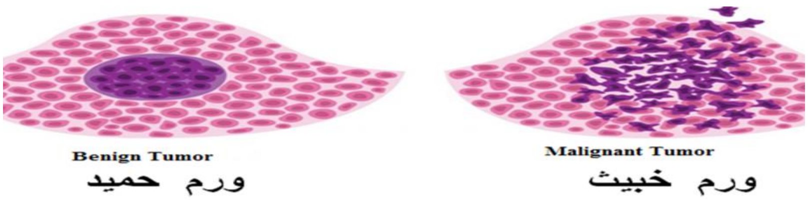


Fig 5 : Cell Culture

2- Research: Cytology is an essential tool in Biomedical and Biotechnology research such as cell culture, drug production, stem cell research and gene therapy.

For your information, cell culture is a technique that allows researchers to reproduce and study cellular processes in vitro. It is of great importance in basic research, medicine, toxicology, and drug development. It is an essential tool for better understanding cell biology, diseases, and potential treatments.

3- In Virology: Cell cultures are used to study viruses, including research on vaccines, antivirals, and understanding the mechanisms of viral infection.

4- Toxicity Testing: Cell cultures are used in toxicity testing to evaluate the potential harmful effects of chemicals, drugs, cosmetics, etc.

To learn more:

1. **Archibald, J. M. (2023).** Endosymbiosis and Eukaryotic Cell Evolution: From Mitochondria to Plastids. Academic Press. This work explores the evolutionary role of endosymbiosis in the formation of eukaryotic cells.
2. **Doolittle, W. F. (2022).** A Century of the Origin of Eukaryotes: The Role of Symbiosis in Cellular Evolution. Oxford University Press, 500 pages. This text examines the history of research into eukaryotic origins and symbiotic theories.
3. **Harris, H.** (2002). The Birth of the Cell. Yale University Press.
4. **Hazen, R. M.** (2023). The Story of Life: How Living Things Evolved and Continue to Evolve. University of Chicago Press. This publication offers a contemporary look at the concept of life and the processes that have driven its evolution.
5. **Luisi, P. L.** (2016). The Emergence of Life: From Chemical Origins to Synthetic Biology. 2nd Edition. Cambridge University Press.
6. **Magner, L. N.** (2002). A History of the Life Sciences. 3rd Edition. CRC Press.
7. **Margulis, L.** (1993). *Symbiosis in Cell Evolution: Microbial Communities in the Archean and Proterozoic Eons*. 2nd Edition. W. H. Freeman and Company.
8. **Margulis, L.** (2022). Symbiosis in Cell Evolution. Freeman & Co., 452 pages. This foundational text continues to be updated and discussed in recent studies about the evolutionary relationship between prokaryotes and eukaryotes.
9. **Mayr, E.** (2023). The Growth of Biological Thought: Diversity, Evolution, and Inheritance. Harvard University Press, 850 pages. This book offers a deep dive into the historical development of evolutionary biology, including cellular evolution.

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