# CELL THEORY, PROPERTIES OF CELLS AND THEIR DIVERSITY

**Michelle Gehringer**
*Department of Biochemistry and Microbiology, University of Port Elizabeth, South Africa*

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## Summary

The cell is the basic unit of life on Earth. All cells probably arose from a single common ancestor cell which evolved about three billion years ago. This cell is thought to have arisen from the enclosure of self-replicating RNA molecules inside a lipid membrane. The earliest cells were prehistoric prokaryotes which evolved to survive the harsh

conditions on Earth. Eukaryotes are proposed to have arisen from the incorporation of smaller bacteria by a larger bacterium. A symbiotic relationship developed between hunter and prey, yielding the chloroplast and mitochondria of modern day eukaryotes. Individual eukaryotic cells associate to form tissues which perform specific functions. These tissues again combine to form the complex organs of present day animals. Despite containing similar basic biochemical pathways, eukaryotes demonstrate a great diversity in cellular organization in multicellular organisms. Plants have the three basic tissues types: dermal, vascular and ground tissue. The major differences between plant and animal cells are that plant cells contain large vacuoles and have a rigid cell wall on their outer surface. Animal tissues comprise several essential tissue types: epithelial, muscle, connective and nervous tissues as well as blood, sensory and germ cells. Tissues need to be maintained and replaced within the organism. Stem cells play an important role in this process.

## 1. The Composition of Life

The cell is the basic unit of life on our planet. It is a small, fragile unit of chemicals functioning in the aqueous environment of the cytoplasm, enclosed in a fatty membrane. How did the complex pathways found in life today originally come into being?

Most living organisms on the planet are made out of mostly four essential elements: hydrogen, nitrogen, oxygen and carbon. They make up 99% of all plants and animals, the remainding 1% consisting of essential elements such as magnesium, iron, sulfur and phosphorous, to name a few. Molecules containing carbon are referred to as organic compounds and it is their origin that determined the arrival of life on the planet.

### 1.1. Origin of organic molecules

The first organic molecules probably formed spontaneously in the warm primordial soup of the Earth's oceans. Initial conditions on the planet during those first billion years are known to have been anaerobic and probably extremely violent. The atmosphere was thin, allowing radiation to penetrate and generate numerous reactive molecules. Ammonia, lightning and torrential downpours formed part of the daily climate on pre-biotic earth.

Scientists have conducted various experiments in an attempt to mimic conditions on pre-biotic Earth. Experiments were done whereby water is heated in a closed system and the water vapor mixes with methane, ammonia and hydrogen. An electric discharge is released into the gaseous mixture and the compounds that are formed, are studied. Most of the major classes of organic molecules have been generated this way, including purines and pyrimidines, the major components of nucleic acids, amino acids and sugars. There is some conjecture as to the exact composition of the prebiotic earth atmosphere, but experiments such as the one described previously illustrate how easily organic compounds could have formed, given the correct conditions. It is suggested that polynuclotides could have spontaneously associated in dry shallow pools. Wet conditions would have favored the degradative conditions of hydrolysis. A current theory supposes that inorganic molecules could have assisted in catalyzing the polymerization of early nucleotides. Once formed, it is essential that a molecule be able to generate the machinery necessary to produce more molecules of itself in order to fulfill the property of life.

Catalysts are able to further reactions and, once developed, would have diverted raw materials from the environment to their specific pathways. An autocatalyst would ensure its own regeneration by catalyzing its own production. Systems could have arisen whereby groups of organic molecules worked together to replicate themselves, at the expense of other systems competing for the same raw materials. Such a system would be teetering on being alive.

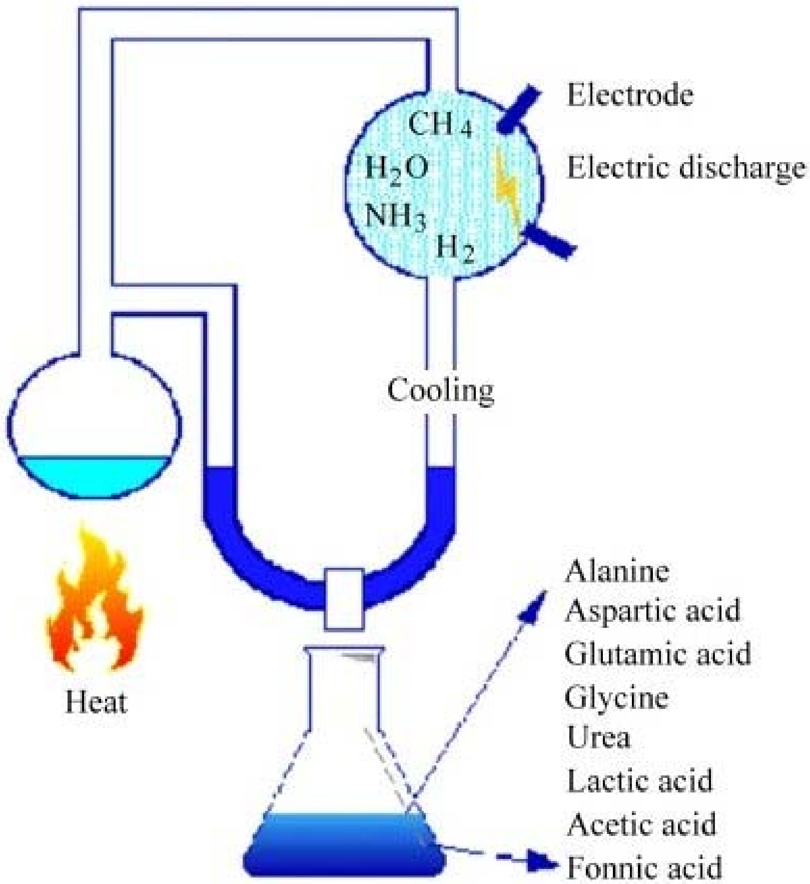



Figure 1. Scheme of a typical experiment to demonstrate the origin of organic molecules

## 1.2. RNA and the origin of life

The basic necessity for life to evolve on earth was that the original chemical polymers could replicate themselves. RNA is synthesized by complementary base pairing from a DNA template, during transcription, in the nucleus of present day cells. Complementary base pairing of RNA bases to RNA templates, is observed in RNA viruses. They replicate themselves by forming an RNA template from which more of the original RNA strand can be synthesized. In order to accurately copy strands of polynucleotides, catalysts are essential to promote correct binding of complementary bases, as well as extension of growing chains. RNA itself, is able to function as a catalyst as shown by ribozymes. They are RNA molecules which have folded into a certain conformation and are capable of catalyzing specific cleavage reactions. These enzymes are limited in the reactions they are capable of catalyzing as they comprise only four different RNA bases.

How then, did DNA arise? The first cells on our planet were presumably simple complexes of lipid bilayers encircling basic biochemical processes and some self replicating molecules and essential raw materials. Evidence exists to indicate that RNA predated DNA in the evolutionary origins of the cell. RNA nucleotides form with relative ease from formaldehyde, which is readily formed *in vitro* in experiments mimicking conditions in prebiotic earth.

DNA, or deoxyribonucleic acid, is a derivative of RNA which has lost its 2' hydroxyl group. A double stranded DNA molecule is thought to have provided a more stable repository of genetic information than the workhorse RNA molecule in the cell. The structural differences between RNA and DNA, namely the incorporation of thymine instead of uracil, as well as the double helical structure, provide an easy template to repair and replicate.

To summarize, RNA appears to carry the information needed for self replication. It is also capable of catalyzing certain biochemical reactions. The development of DNA allowed cells to become more complex, as they were able to store far more genetic information in a reliable format. Few ribozymes exist in cells today and RNA appears to have taken on the role of messenger between the more stable DNA information center and the protein synthesis machinery.

## 2. Cell as the unit of life

### 2.1. Cell theory

The development of the microscope was a precondition for the discovery of cells. This instrument magnifies objects too small to be seen by the naked eye. The first rudimentary microscope was developed by the Englishman, Robert Hooke in 1665. He used this to study a thin section of cork oak bark and observed lots of tiny boxes which he named *cellulae*. A few years later, in 1673, the Dutch botanist, Anton van Leeuwenhoek, made a more advanced microscope and reported seeing a myriad of microscopic "animalcules" in water. He also made further studies of red blood cells and sperm cells. Most studies that followed were done on the easily studied plant tissues. Plant cells, rigidly encased in their cell walls, were ideal to study *in situ*. It took another 150 years before techniques were developed to study other, less rigid, living animal cells. The study of cells is called cytology and is based on the cell theory, which proposes that nucleated cells are the basic structure of plants and animals. This concept was observed and published separately, first by the botanist, Matthias Schleiden, in 1838, and then by the zoologist, Theodor Schwann, in 1839. Their work demonstrated that cells form the basic unit of life of plants and animals. An Austrian pathologist by the name of Rudolf Virchow concluded that all living organisms are the sum of single cellular units and that cells multiply. His arguments led to the basic postulates of the modern cell theory:

1. All living substance is localized in cells.
2. The cell is the basic unit of structure and function.

3. Cells replicate to make more cells.
4. A unicellular organism can exist as a single cell.
5. A multicellular organism is an aggregate of individual cells at similar levels of organization.

The sum concept of this theory is that the cell is an independent, fully functional unit which is independent of other cells in structure and function. An organism which behaves in a manner representative of the cell theory is a slime mold, which lives as an independent unit for most of its life, only aggregating at the reproductive stage to form a sporulating organism. However, studies of a complete multicellular organism clearly demonstrate that the individual cells cannot survive without the services of other specialized cells. A liver cell, for example, could not live without the nutrients obtained from the gastrointestinal tract or gaseous exchange from red blood cells.

A further problem in the cell theory is revealed when studying the carbohydrate storage tissues of plants. Their nutritional tissues start off as multinucleated cytoplasm before being organized into cells and tissues. Plants also frequently have incomplete division between dividing cells, so there is continuous cytoplasmic connections with between cells. This connection of plant cells generates a symplast. Mammalian cells do not have direct cytoplasmic connections with each other, but are able to interact by intercellular signaling on their cell surfaces.

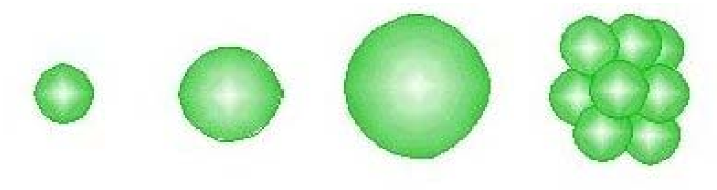
### 2.2. The theory of organisms

The theory of organisms holds that the organism or system is the functional unit of life. This theory promulgates the idea that the organism is a large cell, compartmentalized into functional units. These units comprise various tissues and organs providing function essential for survival of the entire organism. The arrival of large, multicellular organisms had to be preceded by the ability of eukaryotic cells to regulate differential gene expression. They had to evolve mechanisms of expressing their genome in various ways, in different cells, and, yet, function as a single, co-operative unit.

### 2.3. Cell size

Why do organisms consist of many cells in an ordered group, as opposed to a single large cell performing the same functions?

The surface of the cell serves to modulate its interactions with the environment. It is the site of respiration and nutrient uptake as well as release of waste products from within the cell. The cell surface can therefore only serve a certain volume of cytoplasm or a certain number of biochemical processes occurring in its domain. As a cell becomes larger, its surface area decreases in proportion to its interior mass. A molecule has to travel a longer distance from the surface to the center of a large cell, than if it were to travel to the center of a small cell in a large conglomerate. This is referred to as the "surface to volume ratio", which must have a lower limit to prevent the cell from being too big for its volume. By keeping its cells small, the organism is able to maintain an ideal surface to volume ratio of 0.24. A further determining factor in keeping cell size small is the rate of protein synthesis coupled to the transport of molecules within the cell.



| | | | | |
|---|---|---|---|---|
| Radius (um) | 10 | 20 | 40 | 10 |
| Surface area | 1257 | 5029 | 20114 | 1257 |
| Volume | 4190 | 33523 | 268190 | 4190 |
| Area/volume | 0.3 | 0.15 | 0.075 | 0.3 |

Figure 2. The size limitation of cells.

## 3. The diversity of life

Until the 1970s, scientists divided life forms into two kingdoms: Animalia and Plantae. All the unicellular organisms, whether prokaryotic or eukaryotic, were thought to be plants. The modern day classification system of five major kingdoms was proposed by Robert Whittaker in 1969. The five kingdoms of life he proposed were:

1. **Monera or Prokaryotae:** this includes the two groups of Eubacteria and Archaeobacteria. These organisms are prokaryotic and unicellular. They obtain nutrition either by absorption or photosynthesis and may or may not be motile. They have cell walls of which the major component is peptidoglycan. They mainly reproduce asexually, with only rare exceptions having a sexual reproduction cycle.

2. **Protista:** the unicellular eukaryotes. These cells obtain their nutrition by adsorption, photosynthesis or, in some cases, by ingestion. Some species, such as the algae, may have cell walls. They reproduce either sexually or asexually. They include algae, protozoa and simple fungi.

3. **Fungi:** usually multicellular eukaryotes, with specialized cells for feeding and reproduction. Their reproduction can be either sexual or asexual and they obtain nutrition by absorption. Their cell walls consist mainly of chitin.

4. **Plantae:** Plants are multicellular eukaryotes that are non-motile and produce energy by photosynthesis. The cell walls consist mainly of cellulose, and they can reproduce either by sexual or asexual reproduction.

5. **Animalia:** Multicellular eukaryotes which ingest food and are comprised of organisms as diverse as the invertebrate insects, to the vertebrate, mammalian whale. Their reproduction is varied, depending on the species.

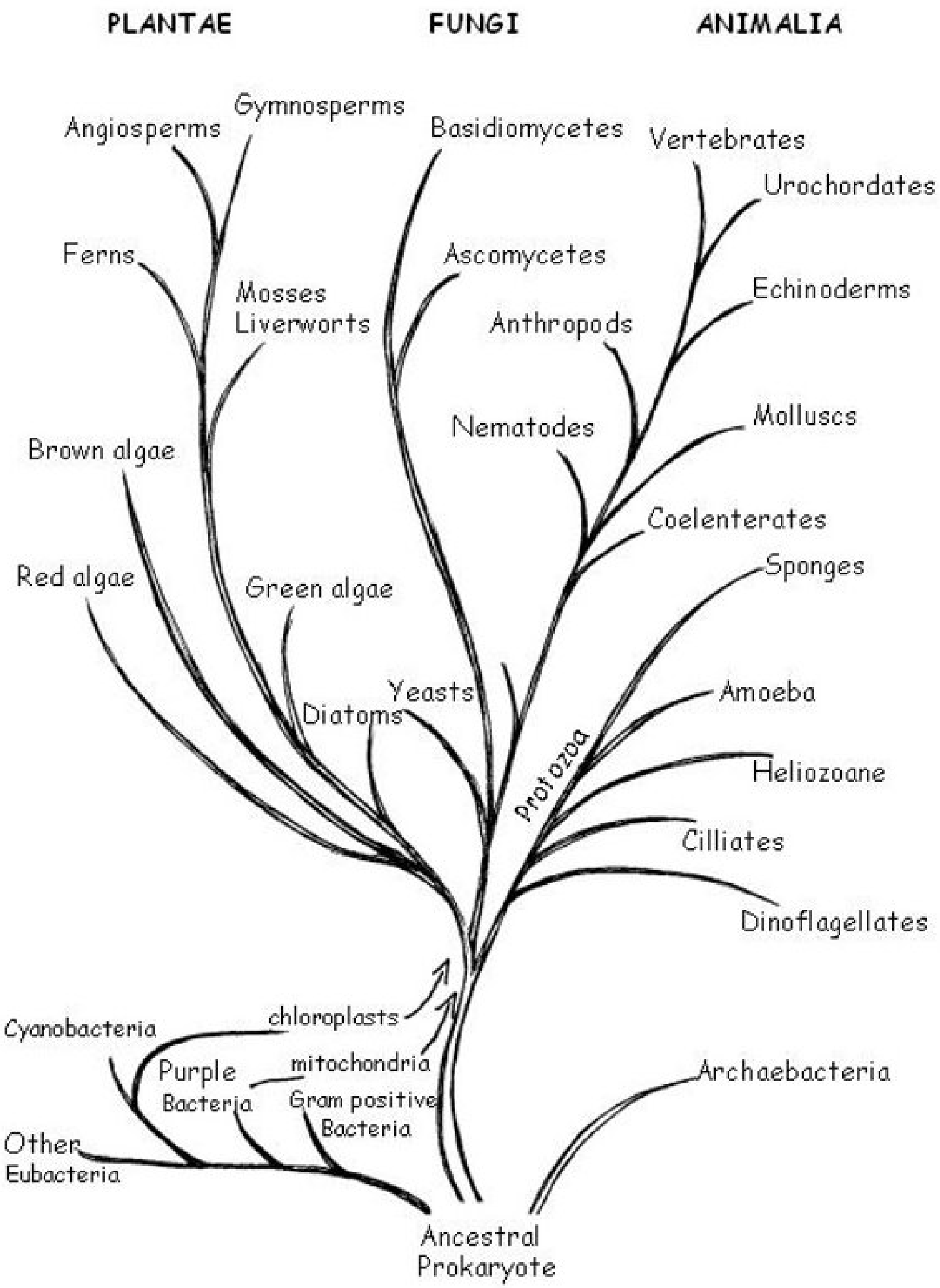



Figure 3. The evolutionary tree of life.

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## Bibliography

### Books

Alberts B., Bray D., Johnson A., Lewis J., Raff. M., Roberts K. and Walter P. (1998). Essential Cell Biology. Garland Publishing, NY, USA. [This is an excellent introductory text on the structure of eukaryotic cells and their functions.]

Audesirk T and Audesrik G. (1996). Biology: Life on Earth, Fourth edition. Prentice Hall, New Jersey, USA. [This is a good introductoy text for biology.]

Cooper G. M. (1997). The cell: a molecular approach. ASM press, Washington D.C., USA.

Lewin B. (2000) Genes VII. Oxford University Press, New York, USA. [This text offers the reader an excellent detailed summary of the complex processes of the molecular structure, organization and regulation of cells.]

Mathews C. K., van Holde K. E. and Ahern, K. G. (2000). Biochemistry, third edition. Addison Wesley Longman, San Francisco, USA. [This book is a comprehensive text on the biochemistry of the cell.]

### Reviews

Ferris J. P. (1999). Prebiotic synthesis on mineral: bridging the prebiotic and RNA worlds. *Biol. Bull*. **196**: 311-314. [This entire edition of the Biological Bulletin is dedicated to papers presented at a workshop titled: Evolution: A molecular point of view.]

Lopez-Garcia P. & Moreira D. (1999). Metabolic synbiosis and the origin of eukaryotes. *TIBS* **24**:88-93.

Woese C. (1998). The universal ancestor. *Proc. Natl. Acad. Sci. USA* **95**:6854-6859.

## Biographical Sketch

**Michelle Gehringer** is a visiting scientist at the School of Biotechnology and Biomolecular Sciences of the University of New South Wales in Sydney, Australia. She is continuing her work on the toxic effects of the cyanobacterial toxins, microcystin and cylindrospermopsin, on humans and animals that accidently ingest them from contaminated drinking water sources. This research has provided insight into the way the body deals with the toxin as well as potential means of offering dietary protection to potential victims.

Dr Gehringer has several years of lecturing experience form the University of Port Elizabeth, South Africa, where she was actively involved in introducing the topics of Biochemistry and Microbiology to the general public and school goers. Her MSc was obtained at the University of Cape Town, South Africa where she worked on means to control Cucumber Mosaic Virus infections of crop plants.