CHAPTER I. FUNCTIONAL COMPARTMENTATION OF THE CELL

I. History of the cellular concept

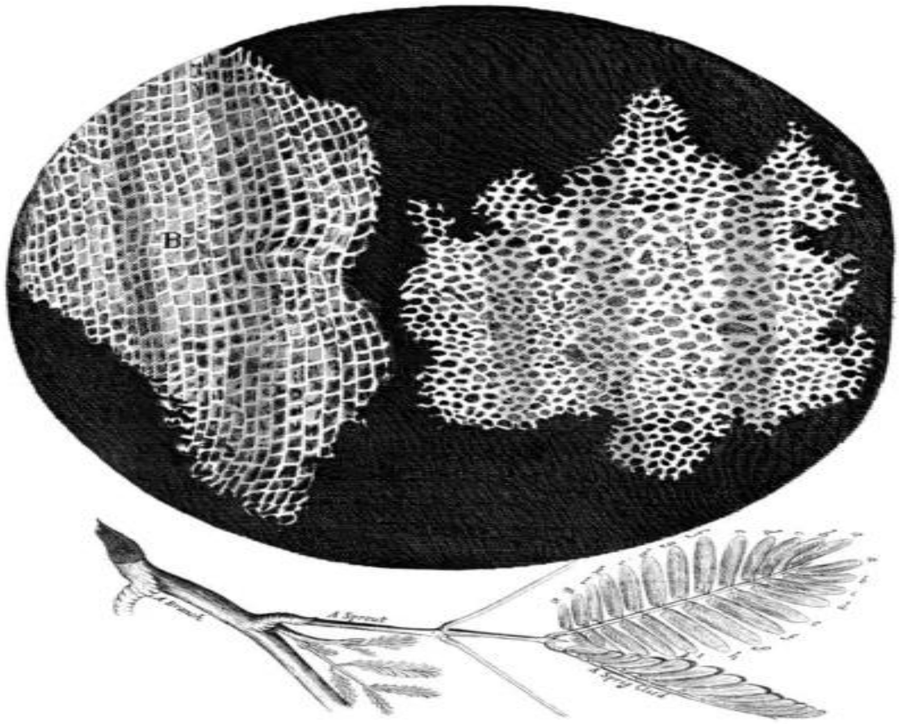

Figure1: Drawing of the structure of cork: Robert Hooke's drawings of the cellular structure of cork and a sprig of sensitive plant from Micrographia (1665) **[1].**

- Cell discovery began in the 1600s when a Dutch shopkeeper, Antony van Leeuwenhoek, discovered simple lenses and used them to visualize single-celled organisms, which he collectively termed 'animalcules.'
- The discovery of a compound optical microscope by Hans and Zacharias Janssen in 1590 made it even easier to observe and study cells.
- In 1665, an English scientist, Robert Hooke, published his work "Micrographia", which contained a number of microscopic observations, and in which he coined the term cell, so called because his observations of plant cells reminded him of the small rooms that monks inhabited, which were called "cellula." Hooke is often credited with the discovery of the cell.
- The first man to witness a live cell under a microscope was Antonie van Leeuwenhoek, who in 1674 described the algae Spirogyra and named the moving organisms animalcules, meaning "little animals."
- In the early 19th century, Matthias Schleiden, a German botanist, studied plant tissues and proposed that all plants are composed of cells. He postulated that cells were the fundamental

building blocks of plants, responsible for their growth and development. Schleiden's work laid the foundation for the idea that cells play a vital role in the structure and function of living organisms.

- Around the same time, Theodor Schwann, a German physiologist, conducted extensive studies on animal tissues. He observed that animal tissues were also composed of cells, similar to what Schleiden had discovered in plants. Schwann concluded that all living organisms, plants, and animals, were made up of cells. This realization was a crucial step toward the formulation of the cell theory.
- In the 1850s, Rudolph Carl Virchow promoted the cell theory and had the credo "all cells arise from cell". Virchow's contribution in 1858 that all cells come from pre-existing cells completed the third component of classical cell theory. Thus, Virchow often is credited with cell theory along with Schleiden and Schwann.
- The image below shows a detailed timeline that led to the discovery of cell and the cell theory:

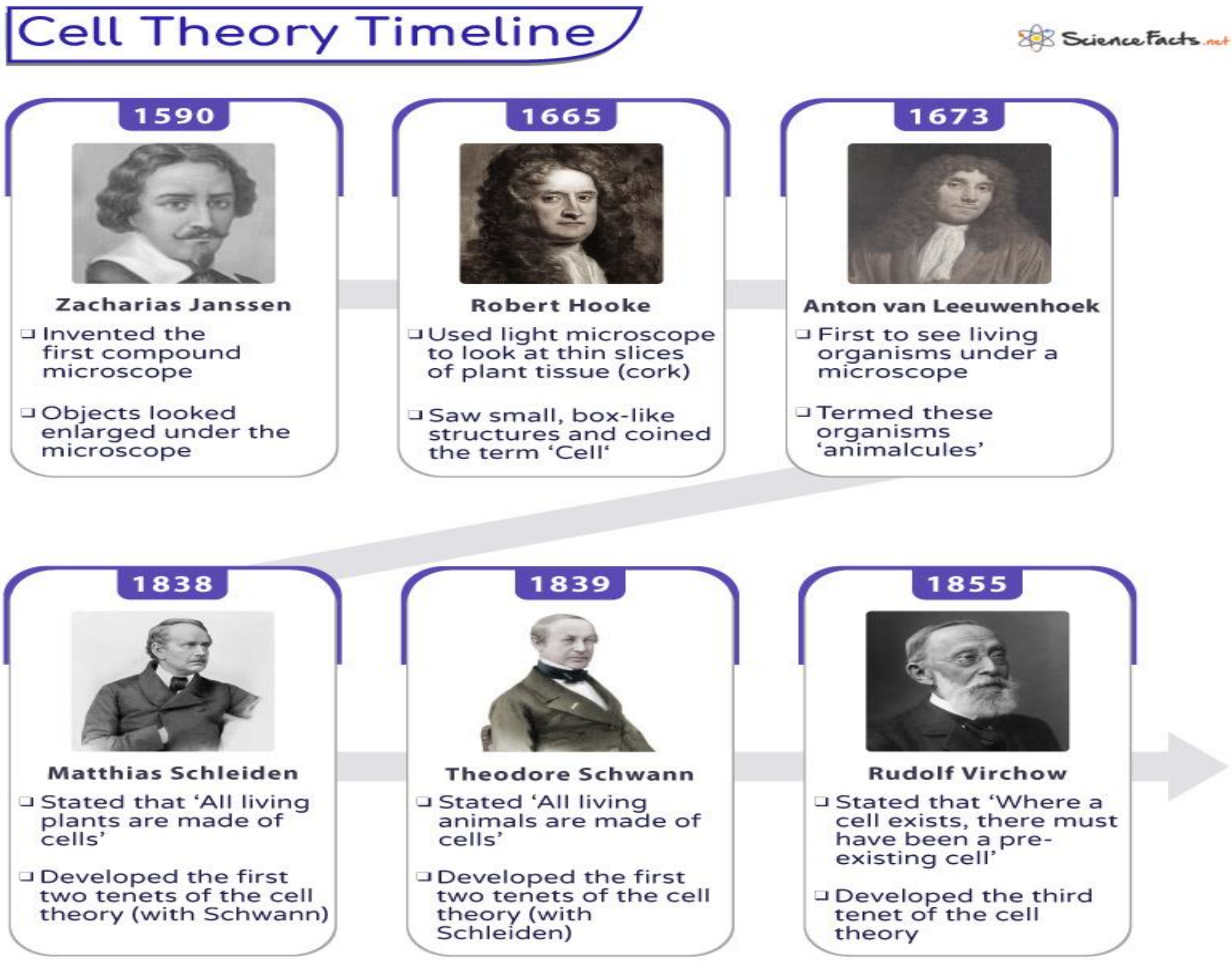

Figure 2: Cell theory timeline **[2].**

II. The Cell Theory

The traditional cell theory has three tenets. It states that:

1. All living organisms are made up of one or more cells.
2. The cell is the basic structural and functional unit of life.
3. All cells arise from pre-existing cells through cell division.

Since the formation of classical cell theory, further studies on cells with the advancement of microscope have led to the formation of the modern cell theory:

1. The cell is the fundamental unit of structure and function in living things.
2. All cells come from pre-existing cells by division.
3. Energy flow (metabolism and biochemistry) occurs within cells.
4. Cells contain hereditary information (DNA) which is passed from cell to cell during cell division.
5. All cells are basically the same in chemical composition.
6. All known living things are made up of cells.
7. Some organisms are unicellular, made up of only one cell. Other organisms are multicellular, composed of countless number of cells.
8. The activity of an organism depends on the total activity of independent cells.

The Cell – Definition

A cell is the smallest structural and functional unit of an organism. It is the building block that makes up all living organisms, whether unicellular (consisting of a single cell, such as bacteria and yeast) or multicellular (consisting of many specialized cells, such as plants, animals, and humans). Cells carry out essential functions such as energy conversion, reproduction, and communication.

III. Endosymbiotic Theory and Eukaryotes

The endosymbiotic theory, proposed by Lynn Margulis in the 1960s, suggests that eukaryotic cells arose when larger prokaryotic cells engulfed smaller ones. The engulfed cells became organelles such as mitochondria and chloroplasts, forming a mutually beneficial relationship.

Research findings that seem to back up this theory implicate that the mitochondria arose from proteobacteria (aerobic bacteria) whereas the chloroplasts arose from cyanobacteria.

Evidence for Endosymbiosis includes

1. Both mitochondria and plastids are capable of reproducing their own through a process akin to prokaryotic binary fission.
2. Both mitochondria and plastids have single circular DNA similar to that of bacteria in terms of size and structure but different from that of the nucleus of the cell.
3. These organelles divide independently, similar to bacteria.
4. Their membranes and ribosomes resemble those of prokaryotes.
5. Porins in the outer membranes of mitochondria and chloroplasts are similar to those in the bacterial cell membrane. *Cardiolipin*, a membrane lipid, is found only in the bacterial cell membrane and inner mitochondrial membrane.

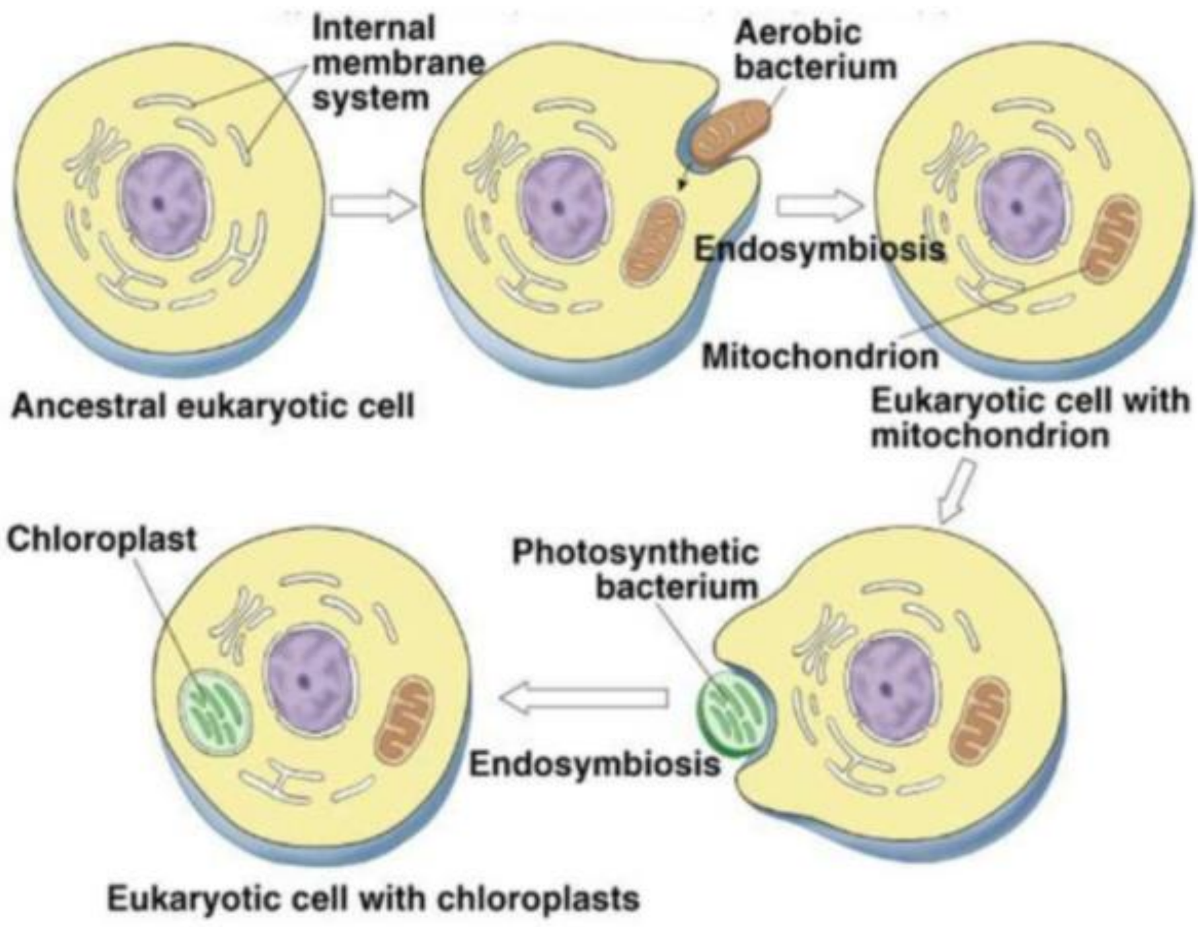

Figure I. 5. The endosymbiotic theory of the origin of eukaryotic cells **[5]**.

IV. Types of cells

Cells can be subdivided into two basic categories: prokaryotes and eukaryotes.

VI.1. Prokaryotic Cells

The term “prokaryote” is derived from the Greek word “pro”, (meaning: before) and “karyon” (meaning: kernel). It translates to “before nuclei”.

These are simpler, smaller cells found in organisms like bacteria and archaea. Prokaryotic cells lack a nucleus and other membrane-bound organelles. Their genetic material is found in a single circular strand of DNA that floats freely in the cytoplasm. Despite their simplicity, prokaryotes are incredibly diverse and can survive in a wide range of environments, from the deepest ocean trenches to the hottest volcanic vents.

VI.2. Eukaryotic Cells

The term “Eukaryotes” is derived from the Greek word “eu”, (meaning: good) and “karyon” (meaning: kernel), therefore, translating to “good or true nuclei”.

These are more complex cells found in plants, animals, fungi, and protists. Eukaryotic cells have a well-defined nucleus that contains the cell’s DNA, as well as other membrane-bound organelles, such as the mitochondria, endoplasmic reticulum, and Golgi apparatus. Eukaryotic cells are typically larger and more specialized than prokaryotic cells, with different organelles performing specific functions to keep the cell alive and functioning.

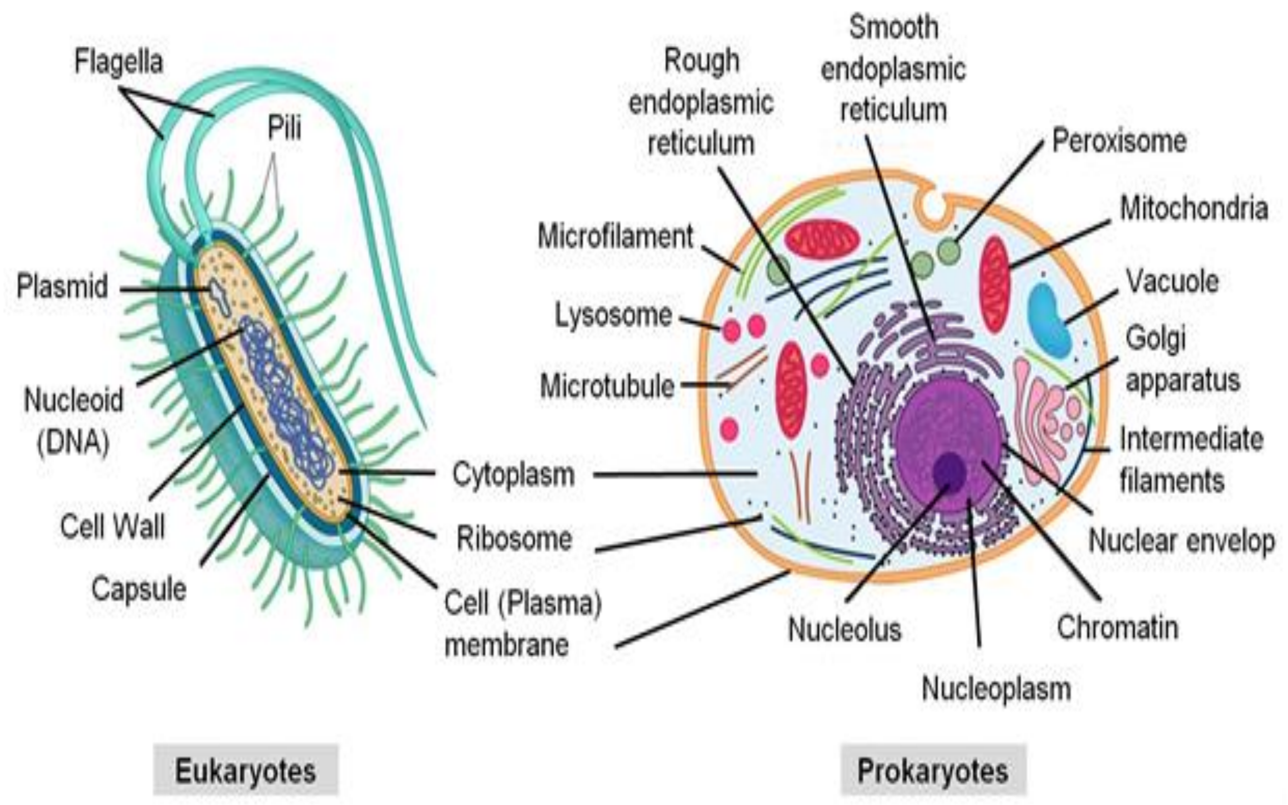

Figure 3. Comparison of the general structure of prokaryotic and eukaryotic cells **[3].**

Prokaryotic and eukaryotic cells are the basic units of life on Earth. The basic distinction between prokaryotes and eukaryotes is that prokaryotes lack a membrane-bound nucleus and organelles. Instead, genetic material and processes occur within prokaryotic cytoplasm. Both prokaryotic and eukaryotic cells contain cytoplasm that is enclosed by a cell membrane. Both perform protein synthesis using ribosomes. The differences between prokaryotic and eukaryotic cells is summarized as follows:

Table 1: Comparison between Eukaryotic and Prokaryotic Cell **[4].**

	Prokaryotes	**Eukaryotes**
Examples	bacteria, archaea	protists, fungi, plants, animals (humans)
Nucleus	nucleoid region (no true nucleus)	nucleus with double membrane
Size	~ 1–5 µm	~ 10–100 µm
DNA	usually circular	linear chromosomes with histone proteins

RNA/protein synthesis	coupled in the cytoplasm	RNA synthesis in nucleus protein synthesis in cytoplasm
Ribosomes	50S and 30S	60S and 40S
Chromosomes	single chromosome	more than one chromosome
Cell division	binary fission	mitosis (budding or fission) meiosis
Membranes	cell membrane only	cell membrane and membrane-bound organelles
Organization	usually single cells	single cells, colonies, multicellular organisms
Movement	flagella (with flagellin)	flagella (with microtubules), cilia, lamellipodia, filopodia
Mitochondria	none	one to thousands
Chloroplasts	none	mainly in plants and algae

V. Cellular compartmentalization

V.1. Definition

Cellular compartmentalization is a kind of cellular organization that divides the internal volume of the cell into discrete (but often interconnected) compartments. These compartments each have distinct properties and functions.

Cellular compartmentalization refers to the organization of different biochemical processes within distinct regions of the cell, primarily facilitated by the cell membrane. This selective barrier, with unique chemical properties, separates organelles and the cytoplasm, ensuring efficient functioning and regulation of cellular activities.

V.2. Importance of Cellular Compartmentalization

1. **Efficiency**: By confining specific reactions to distinct areas, cells can increase the efficiency of metabolic processes.

2. **Regulation**: Compartmentalization allows for the regulation of different cellular processes. Enzymes and substrates can be localized to specific compartments, ensuring proper control.
3. **Protection**: Harmful substances or reactions can be isolated from the rest of the cell. For example, lysosomes contain digestive enzymes that break down macromolecules.

V.3. Benefits of Compartmentalization

1. **Specialization**: Different cellular processes can occur simultaneously without interference.
2. **Optimal Conditions**: Each compartment can maintain an environment suitable for its specific functions (pH, ion concentration…).
3. **Increased Surface Area**: Organelles like the ER and mitochondria have extensive internal membranes, providing a large surface area for biochemical reactions.

VI. Major cellular compartments

Cellular compartments, or organelles, play vital roles in maintaining the structure and functionality of eukaryotic cells. Each compartment has specialized structures and functions that allow cells to efficiently carry out essential processes.

Plasma Membrane

The plasma membrane is also termed as a cell membrane or cytoplasmic membrane. It is a selectively permeable membrane of the cells, which is composed of a lipid bilayer and proteins. The plasma membrane is present both in plant and animal cells. It functions as the selectively permeable membrane, by permitting the entry of selective materials in and out of the cell according to the requirement.

Cytosol

The cytosol is the fluid portion of the cytoplasm that surrounds organelles and other compartments. It is the site of many metabolic processes, such as glycolysis, and acts as a medium for molecular transport within the cell. Although not membrane-bound, the cytosol plays a vital role in maintaining the overall homeostasis of the cell by allowing free movement of ions, proteins, and other molecules.

Nucleus

The nucleus is encased in a double membrane known as the nuclear envelope, which contains numerous nuclear pores that regulate the passage of molecules in and out of the nucleus. It serves as the storage site for genetic material, specifically deoxyribonucleic acid (DNA). The nucleus is also the site where transcription occurs, converting DNA into messenger RNA (mRNA).

Ribosomes

Ribosomes are found in the form of tiny particles in a large number of cells and are mainly composed of 2/3rd of RNA and 1/3rd of protein. Ribosomes are either encompassed within the endoplasmic reticulum or are freely traced in the cell's cytoplasm. Ribosomal RNA and Ribosomal proteins are the two components that together constitute ribosomes. The primary function of the ribosomes includes protein synthesis in all living cells that ensure the survival of the cell.

Endoplasmic Reticulum (ER)

- **Rough ER**: Characterized by membranes studded with ribosomes, giving it a rough appearance. It is primarily involved in synthesizing proteins that are either secreted from the cell or integrated into cellular membranes.
- **Smooth ER**: Lacks ribosomes and has a more tubular appearance. This compartment is responsible for lipid synthesis, detoxification of harmful substances, and the storage of calcium ions, which are crucial for various cellular processes.

Golgi Apparatus

Comprised of stacked, flattened membranous sacs known as cisternae. The Golgi apparatus modifies, sorts, and packages proteins and lipids synthesized in the ER for secretion or delivery to other organelles. This processing is essential for the proper functioning of proteins and lipids within the cell.

Lysosomes

Membrane-bound vesicles containing hydrolytic enzymes capable of breaking down various biomolecules. Lysosomes are crucial for the degradation of macromolecules, recycling of old organelles, and the digestion of foreign substances, thus maintaining cellular health and homeostasis.

Cytoskeleton

It is a continuous network of filamentous proteinaceous structures that run throughout the cytoplasm, from the nucleus to the plasma membrane. It is found in all living cells, notably in the eukaryotes. The cytoskeleton matrix is composed of different types of proteins that can divide rapidly or disassemble depending on the requirement of the cells. The primary functions include providing the shape and mechanical resistance to the cell against deformation, the contractile nature of the filaments helps in motility during cytokinesis.

Mitochondria

These organelles feature a double membrane, with the inner membrane folded into structures called cristae. Mitochondria are known as the powerhouse of the cell, as they are the primary site for aerobic respiration and adenosine triphosphate (ATP) production, which provides energy for cellular activities.

Chloroplasts (specific to plant cells)

Comprised of a double membrane surrounding internal thylakoid membranes arranged in stacks called granum. Chloroplasts are responsible for photosynthesis, converting light energy into chemical energy stored in glucose.

Peroxisomes

Small, membrane-bound organelles scattered throughout the cytoplasm. They play a critical role in the breakdown of fatty acids and detoxification of hydrogen peroxide, a harmful by-product of metabolic processes.

Vacuoles

Membrane-bound sacs that vary in size, typically larger in plant cells. Vacuoles are primarily involved in the storage of nutrients, waste products, and maintaining turgor pressure, which is essential for plant cell rigidity and overall health.

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