Lecture 7&8: Cell Structure and Function

Much of the diversity of forms and functions in living organisms results from small atoms being combined in different ways to form a number of molecules and molecules form macromolecules. Eventually, these macromolecules build cells, tissues, organs and finally, an entire organism.

Cells

A cell is the smallest unit of life that can survive and reproduce on its own, given information in DNA, energy, and raw materials. Some cells live and reproduce independently. Others do so as part of a multicelled organism.

Discovery of cells

In the middle of the 17th century, one of the pioneers of microscopy, Robert Hooke (1635–1703), decided to examine a piece of cork tissue with his home-built microscope. He saw numerous box shaped structures that he thought resembled row of empty boxes or rooms, so he called them 'cells'.

Cell theory

Matthias Schleiden and Theodor Schwann, hypothesized that a plant cell is an independent living unit even when it is part of a plant and both concluded that the tissues of animals as well as plants are composed of cells and their products. Together, the two scientists recognized that cells have a life of their own even when they are part of a multicelled body.
Later, physiologist Rudolf Virchow realized that all cells he studied descended from another living cell. These and many other observations yielded three generalizations that today constitute the cell theory:

1) Every organism is composed of one or more cells
2) Cell is smallest unit having properties of life
3) Continuity of life arises from growth and division of single cells

Thus, **Cell theory** is that all organisms consist of one or more cells, which are the basic unit of life.

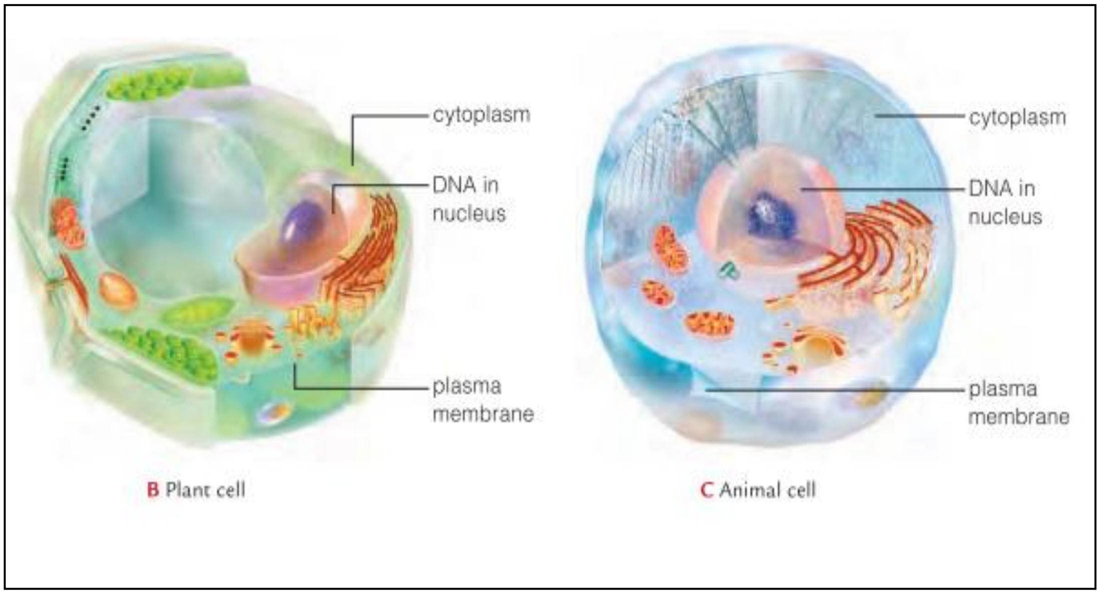
Cell Properties

A cell is the smallest unit that shows the properties of life.
These properties include -

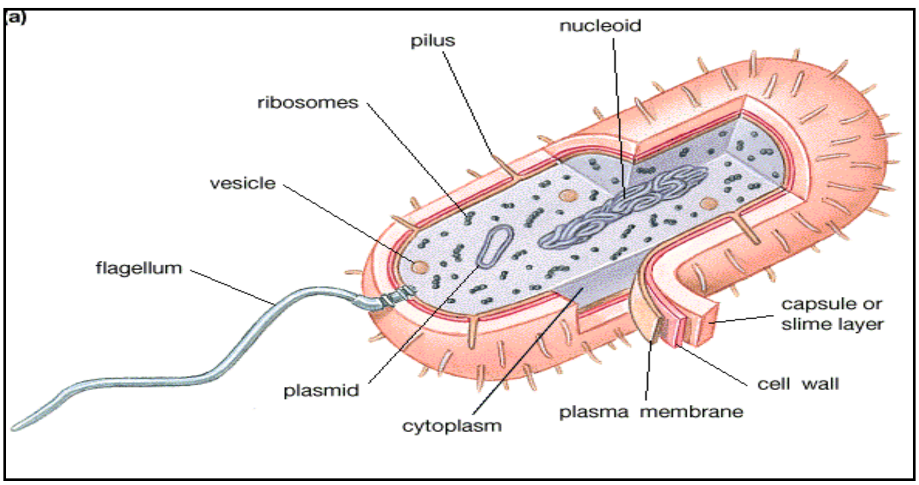
- Can survive on its own or has potential to do so
- Is highly organized for metabolism
- Senses and responds to environment
- Has potential to reproduce

Cell types

Biologists have categorized cells into two general types: **eukaryotic and prokaryotic cells.**
The cells of plants, animals, fungi, protozoa, and algae are eukaryotic, and are placed in a category called Eucarya . All eukaryotic cells have their genetic material surrounded by a nuclear membrane forming the cellular nucleus. They also have a large number and variety of complex organelles, each specialized in the metabolic function it performs. In general, they are large in comparison to Prokaryotic cells. These cell types do not have a nuclear membrane; therefore they lack a cellular nucleus. In addition, they display unique chemical and metabolic characteristics but do not have the variety and number of organelles seen in eukaryotes.



Eukaryotic Cells

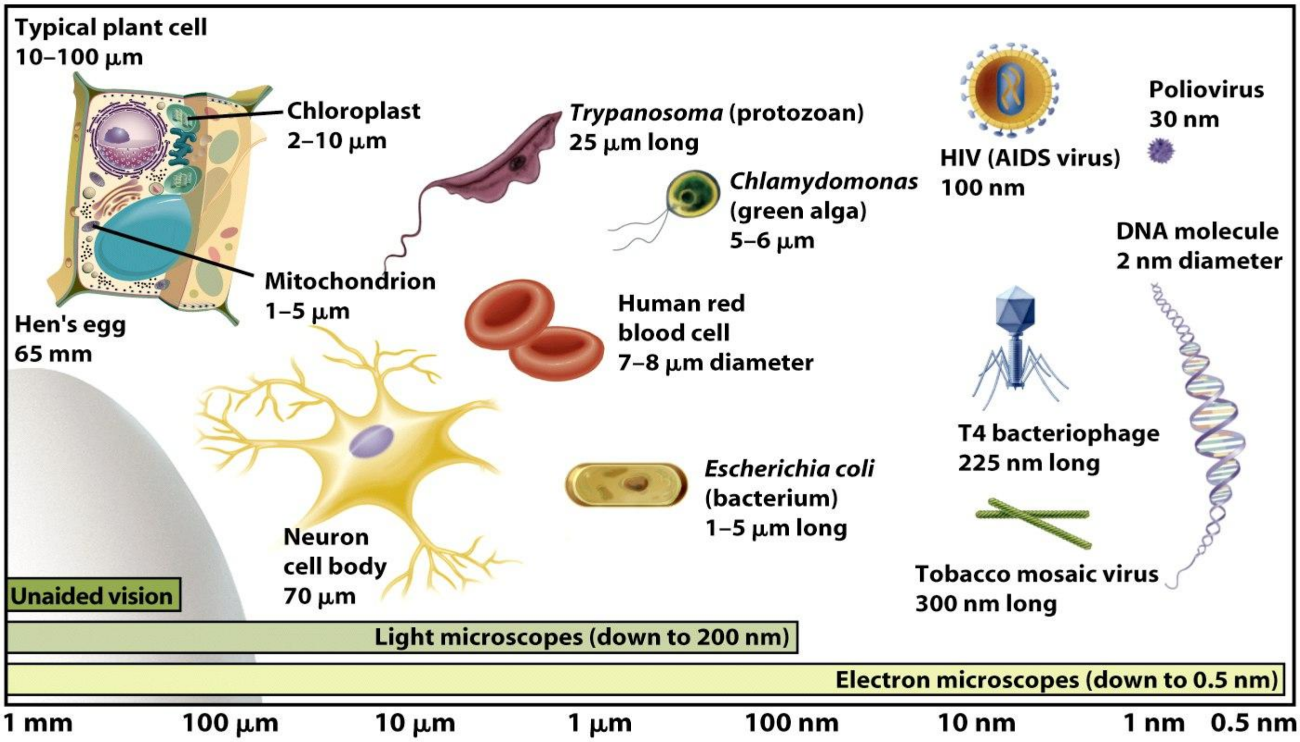


Prokaryotic Cell

Prokaryotic Cell	Eukaryotic Cell
1. Generally small (1-10 μm) in size and volume	**1.** Generally large (5-100 μm). Eukaryotic cells are about 15 times the size of a typical prokaryote and can be as much as 1000 times greater in volume.
2. Cell wall is present	**2.** Cell walls may or may not be present.
3. Nucleus is absent	**3.** Nucleus is present
4. Prokaryotic cell division occurs through fission or budding, no mitosis occurs.	**4.** Mitosis, including mitotic spindle, centrioles in many species.
5. Prokaryotes generally lack membrane-bound cell compartments: such as mitochondria and chloroplasts.	**5.** Mitochondria and chloroplasts are present in Eukaryotes.
6. Single circular chromosome	**6.** Multiple linear chromosomes
7. Chromosome found in a cytoplasmic region called the nucleoid.	**7.** Chromosomes found in a membrane-bound nucleus.
8. No internal membranes Some infolded plasma membrane, No Cytoskeleton	**8.** Extensive network of internal membranes, Complex, with microtubules, intermediate filaments and actin filaments
9. Intracellular movement is absent	**9.** Cytoplasmic streaming, endocytosis, phagocytosis, mitosis, vesicle transport.

Cell size

Almost all cells are too small to see with the naked eye. Why? The answer begins with the processes that keep a cell alive. A living cell must exchange substances with its environment at a rate that keeps pace with its metabolism. These exchanges occur across the plasma membrane, which can handle only so many exchanges at a time. Thus, cell size is limited by a physical relationship called the surface-to-volume ratio. By this ratio, an object's volume increases with the cube of its diameter, but its surface area increases only with the square. If the cell gets too big, the inward flow of nutrients and the outward flow of wastes across that membrane will not be fast enough to keep the cell alive.



Observation of Cells: Microscopes

Microscopes allow us to study cells in detail. The ones that use visible light to illuminate objects are called light microscopes. There are two types: Simple and Compound. A more powerful microscope is the Electron microscopes use electrons instead of visible light to illuminate samples. Because electrons travel in wavelengths that are much shorter than those of visible light, electron microscopes can resolve details that are much smaller than you can see with light microscopes. Electron microscopes use magnetic fields to focus beams of electrons onto a sample.

Limitations of Light Microscopy

- Wavelengths of light are 400-750 nm
- If a structure is less than one-half of a wavelength long, it will not be visible
- Light microscopes can resolve objects down to about 200 nm in size

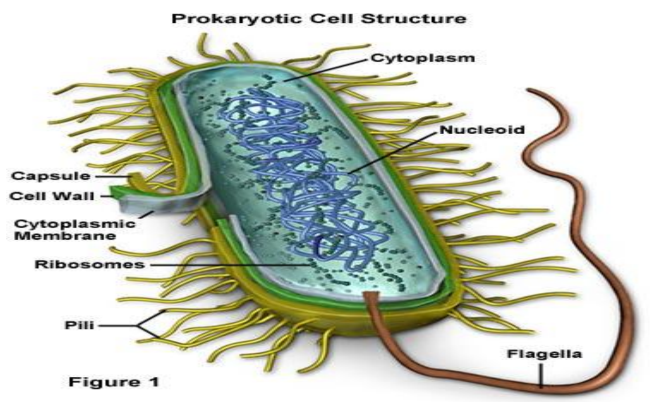
Electron Microscopy

- Uses streams of accelerated electrons rather than light
- Electrons are focused by magnets rather than glass lenses
- Can resolve structures down to 0.5 nm

Cell Structure:

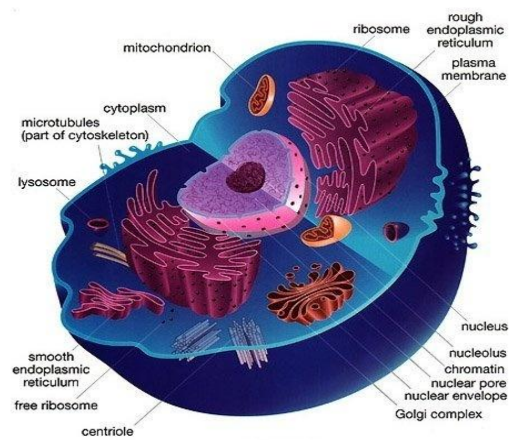
Bacterial cells (Prokaryote)

- Cell Wall
- Cell/Plasma membrane
- Cytoplasm
- Genetic Material(Nucleoid)
- Ribosomes
- Capsules
- Flagella
- Pili



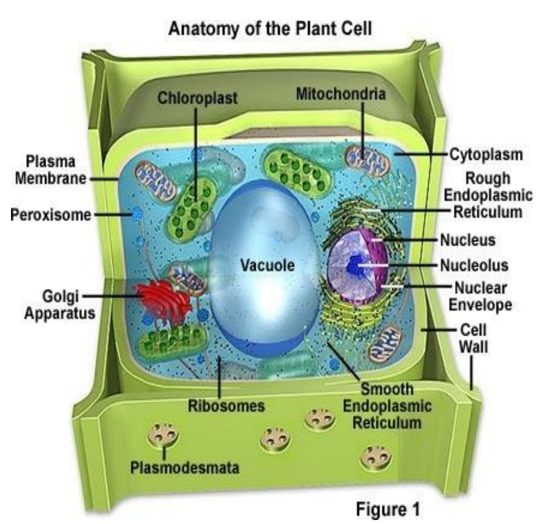
Animal cells (Eukaryotes)

- Plasma membrane
- Nucleus
- Ribosomes
- Endoplasmic reticulum
- Golgi body
- Vesicles
- Mitochondria
- Cytoskeleton



Plant cells (Eukaryotes)

- Plasma membrane
- Nucleus
- Ribosomes
- Endoplasmic reticulum
- Golgi body
- Vesicles
- Mitochondria
- Cytoskeleton
- Cell wall
- Central vacuole
- Chloroplast



Some of the organelles are common to all cells. These are;

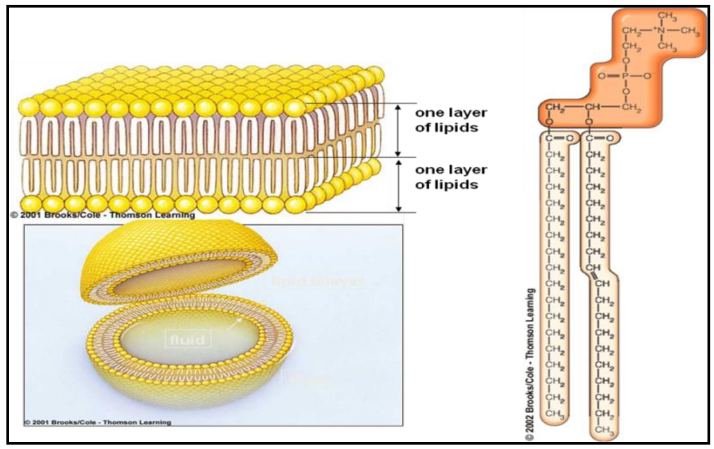
- Cell/Plasma Membrane
- Genetic Material
- Cytosol/Cytoplasm
- Ribosomes

Structure common to all cells: Plasma Membrane

The plasma membrane is the boundary between the cell and its environment. It isolates the cell, regulates what enters and leaves the cell. It allows interaction with other cells. It comprises of **lipids and proteins**.

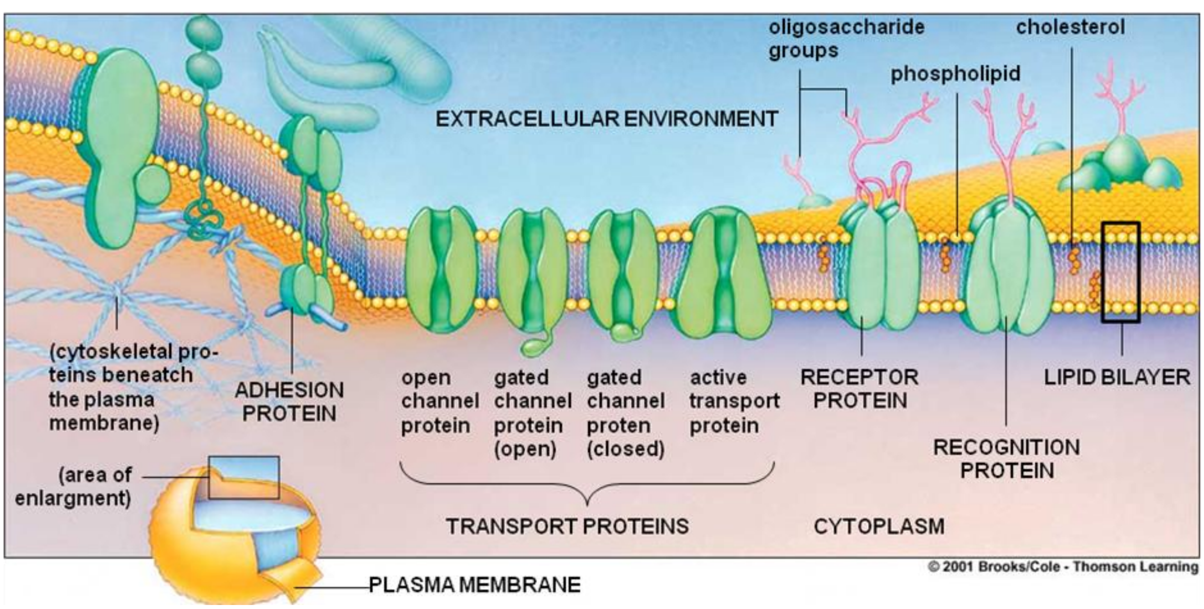
Lipid Bilayer

Lipids—mainly phospholipids—make up the bulk of a cell membrane. A phospholipid consists of a phosphate containing head and two fatty acid tails. The polar head is hydrophilic, which means that it interacts with water molecules. The nonpolar tails are hydrophobic, so they do not interact with water molecules, but they do interact with the tails of other phospholipids. Lipid bilayers are the basic structural and functional framework of all cell membranes, gives membrane it's fluidity.



Fluid mosaic

Other molecules, including steroids and proteins, are embedded in or associated with the lipid bilayer of every cell membrane. Most of these molecules move around the membrane more or less freely. A cell membrane behaves like a two-dimensional liquid of mixed composition, so we describe it as a fluid mosaic. The "mosaic" part of the name comes from a cell membrane's mixed composition of lipids and proteins. The fluidity occurs because the phospholipids in a cell membrane are not bonded to one another. They stay organized as a bilayer as a result of collective hydrophobic and hydrophilic attractions.

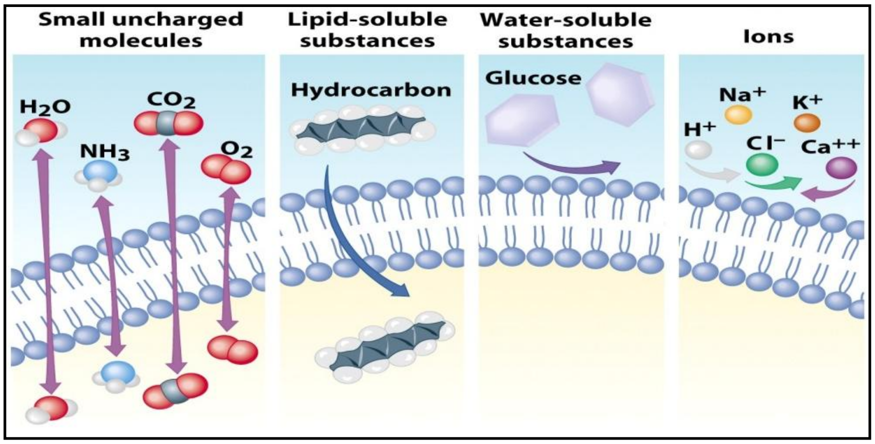


Functions of different Membrane proteins:
Many types of proteins are associated with a cell membrane, and each type adds a specific function to it, different cell membranes can have different characteristics depending on which proteins are associated with them. For example, a plasma membrane has certain proteins that no internal cell membrane has. Many plasma membrane proteins are enzymes. Others are adhesion proteins, which fasten cells together in animal tissues. Recognition proteins function as identity tags for a cell type, individual, or species. Being able to recognize "self" means that foreign cells (harmful ones, in particular) can also be recognized. Receptor proteins bind to a particular substance outside of the cell, such as a hormone or toxin (Figure 4.8C). Binding triggers a change in the cell's activities that may involve metabolism, movement, division, or even cell death. Receptors for different types of substances occur on different cells, but all are critical for homeostasis. Additional proteins occur on all cell membranes. Transport proteins move specific substances across a membrane, typically by forming a channel through it. These proteins are important because lipid bilayers are impermeable to most substances, including ions and polar molecules. Some transport proteins are open channels through which a substance moves on its own across a membrane.

<u>Functions of Cell membrane</u>:

<u>Membrane structure results in selective permeability</u>

- A cell must exchange materials with its surroundings, a process controlled by the plasma membrane
- Plasma membranes are selectively permeable, regulating the cell's molecular traffic
- Hydrophobic (nonpolar) molecules, such as hydrocarbons, can dissolve in the lipid bilayer and pass through the membrane rapidly



Polar molecules, such as sugars, do not cross the membrane easily. Cells must continuously receive nutrients and rid themselves of waste products—one of the characteristics of life. Many of the proteins that are associated with the plasma membrane are involved in moving molecules across the membrane. Some proteins are capable of moving from one side of the plasma membrane to the other and shuttle certain molecules across the membrane. Others extend from one side of the membrane to the other and form channels through which substances can travel. Some of these channels operate like border checkpoints, which open and close when circumstances dictate. Some molecules pass through the membrane passively, whereas others are assisted by metabolic activities within the membrane.

<u>Transport proteins</u>
Transport proteins allow passage of hydrophilic substances across the membrane Some transport proteins, called channel proteins, have a hydrophilic channel that certain molecules or ions can use as a tunnel. Channel proteins called **aquaporins** facilitate the passage of water. Other transport proteins, called carrier proteins, bind to molecules and change shape to shuttle them across the membrane. A transport protein is specific for the substance it moves

<u>Passive transport is diffusion of a substance across a membrane</u>

- **Diffusion** is the tendency for molecules to spread out evenly into the available space
- Although each molecule moves randomly, diffusion of a population of molecules may be directional
- At dynamic equilibrium, as many molecules cross the membrane in one direction as in the other

Substances diffuse down their **concentration gradient**, the region along which the density of a chemical substance increases or decreases. No work must be done to move substances down the concentration gradient.The diffusion of a substance across a biological membrane is **passive transport** because no energy is expended by the cell to make it happen.

Structure common to all cells: Genetic Material

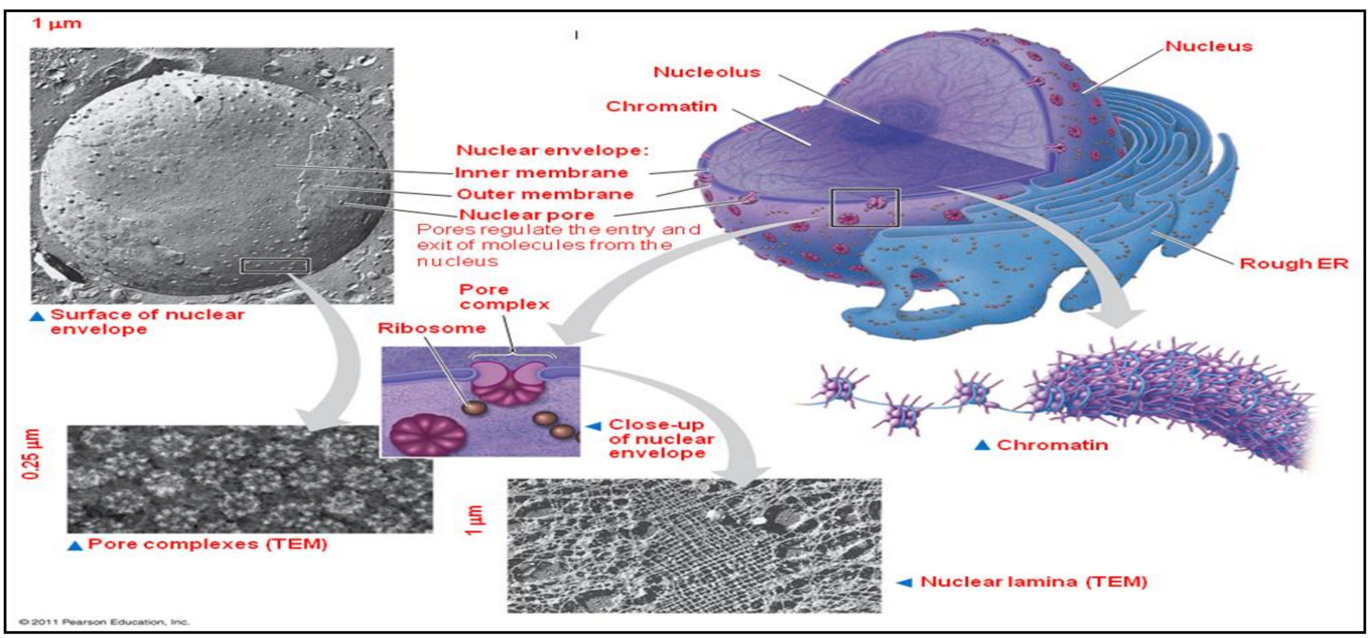
Eukaryotic Cell: Nucleus

The nucleus is the defining organelle of eukaryotic cells. The nucleus is separated from the cytoplasm by a double membrane (two phospholipid bilayers); known as the nuclear envelope. The nuclear envelope controls the passage of molecules between the nucleus and cytoplasm. The nucleus contains the DNA, the stored genetic instructions of each cell. In addition, important reactions for interpreting the genetic instructions occur in the nucleus.

- ❑ In the nucleus, DNA is organized into discrete units called **chromosomes**
- ❑ Each chromosome is composed of a single DNA molecule associated with proteins
- ❑ The **nucleolus** is located within the nucleus and is the site of ribosomal RNA (rRNA) synthesis.

Components of Nucleus

- Nuclear envelope
- Nucleoplasm
- Nucleolus
- Chromosome
- Chromatin



Functions of Nucleus

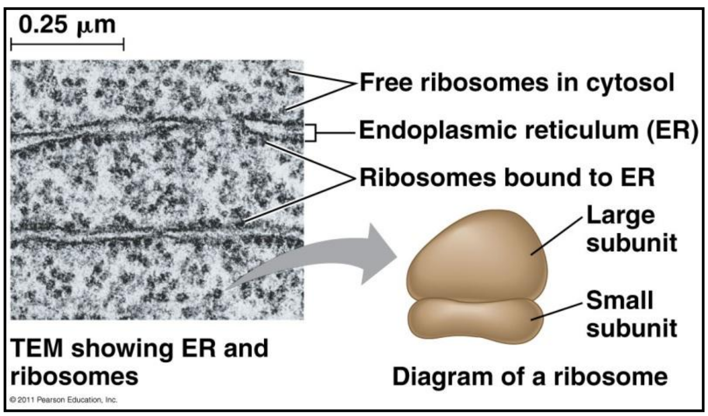
- Keeps the DNA molecules of eukaryotic cells separated from metabolic machinery of cytoplasm
- Makes it easier to organize DNA and to copy it before parent cells divide into daughter cells

Prokaryotic Cell: Nucleoid
The genetic material (DNA) in bacteria is packaged into a region of the cell called the **nucleoid.** The DNA is not contained in a nuclear envelope and also it is 'naked' – that is, not associated with any proteins. Bacteria also contain additional small circles of DNA called plasmids. Plasmids replicate independently and may be passed from one cell to another.

Structure common to all cells: Ribosomes

Ribosomes are found in all prokaryotic and eukaryotic cells, where they synthesize proteins. Ribosomes are non-membranous organelles responsible for the synthesis of proteins from amino acids. They are composed of RNA and protein. Each ribosome is composed of two subunits—a large one and a small one. As mentioned before, they are constructed in the Nucleolus. In eukaryotes, ribosomes carry out protein synthesis in two locations

- bound ribosomes: Many ribosomes are attached to the endoplasmic reticulum. Because ER that has attached ribosomes appears rough when viewed through an electron microscope it is called rough ER. Areas of rough ER are active sites of protein production.
- free ribosomes: Many ribosomes are also found floating freely in the cytoplasm wherever proteins are being assembled. Cells that are actively producing protein (e.g., liver cells) have great numbers of free and attached ribosomes.



Structure common to all cells: Cytoplasm

In prokaryotes, cytoplasm inside the membrane is a jelly-like substance comprises of water, enzymes and some proteins. It also contains the genetic material.In eukaryotes, the cytoplasm is a network of fibers that organizes structures and activities in the cell and known as cytoskeleton

- Between the nucleus and plasma membrane of all eukaryotic cells is a system of interconnected protein filaments collectively called the cytoskeleton. The **cytoskeleton** is a network of fibers extending throughout the cytoplasm. Elements of the cytoskeleton reinforce, organize, and move cell structures, anchoring many organelles.

Cytomembrane System

The cytomembrane system is a series of interacting organelles between the nucleus and the plasma membrane of eukaryotic cells. Its main function is to make lipids, enzymes, and proteins for secretion, or for insertion into cell membranes. It also destroys toxins, recycles wastes, and has other specialized functions. The system's components vary among different types of cells, but here we present the most common ones:

Components of Cytomembrane System

- Endoplasmic reticulum
- Golgi bodies
- Vesicles

Endoplasmic Reticulum

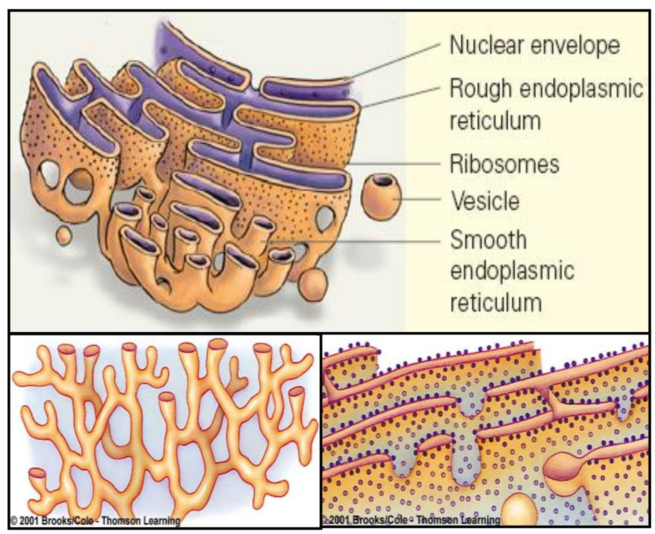
Part of the cytomembrane system is an extension of the nuclear envelope called endoplasmic reticulum, or ER. ER forms a continuous compartment that folds into flattened sacs and tubes. The space inside the compartment is the site where many new polypeptide chains are modified. Two kinds of ER, rough and smooth, are named for their appearance in electron micrographs. Thousands of ribosomes are attached to the outer surface of rough ER.

Rough ER

- Arranged into flattened sacs
- Ribosomes on surface give it a rough appearance
- Some polypeptide chains enter rough ER and are modified
- Cells that specialize in secreting proteins have lots of rough ER

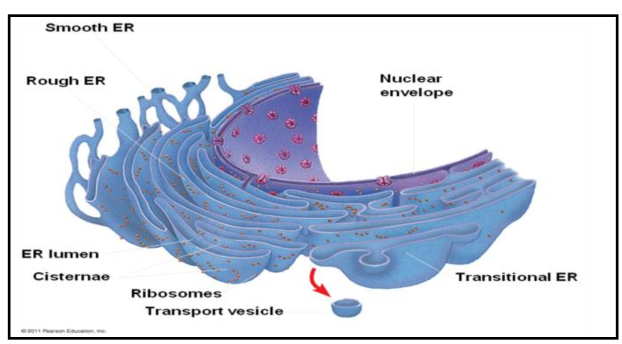
Smooth ER

- A series of interconnected tubules
- No ribosomes on surface
- Lipids assembled inside tubules
- Smooth ER of liver inactivates wastes, drugs
- Sarcoplasmic reticulum of muscle is a specialized form that stores calcium



Functions of Smooth & Rough ER

- **The smooth ER**
  1. Synthesizes lipids
  2. Metabolizes carbohydrates
  3. Detoxifies drugs and poisons
  4. Stores calcium ions



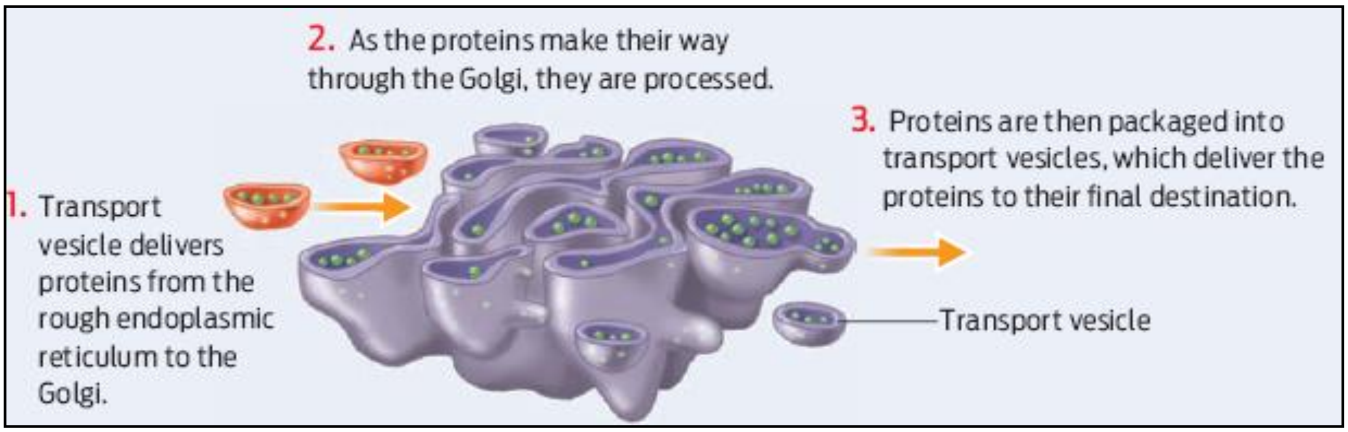
- **The rough ER**
  1. Has bound ribosomes
  2. Distributes **transport vesicles,** proteins surrounded by membranes
  3. Is a membrane factory for the cell

<u>Golgi Bodies</u>

Golgi : The Golgi is a series of flattened membrane compartments, whose purpose is to process and package proteins produced in-the rough endoplasmic reticulum. The processed molecules are packaged into membrane vesicles, then targeted and transported to-their final destinations.

Functions of the Golgi apparatus

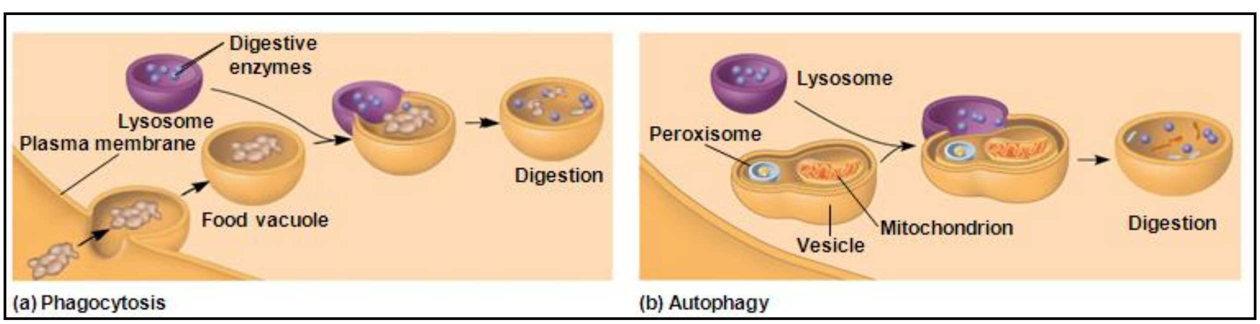
- Modifies products of the ER
- Manufactures certain macromolecules
- Sorts and packages materials into transport vesicles



<u>Vesicles</u>

Small, membrane-enclosed, saclike vesicles form in great numbers, in a variety of types, either on their own or by budding. There are many types but two main are:

<u>i)</u> Lysosomes: Digestion & recycling centers



i) Lysosomes that bud from Golgi bodies take part in intracellular digestion. They contain powerful enzymes that can break down carbohydrates, proteins, nucleic acids, and lipids. Vesicles inside white blood cells or amoebas deliver ingested bacteria, cell parts, and other debris to lysosomes for destruction. The enzymes work best in the acidic environment inside the lysosome. Lysosomes break down worn out cell parts or molecules so they can be used to build new cellular structures. Some types of cell can engulf another cell by **phagocytosis**; this forms a food vacuole. A lysosome fuses with the food vacuole and digests the molecules Lysosomes also use enzymes to recycle the cell's own organelles and macromolecules, a process called autophagy

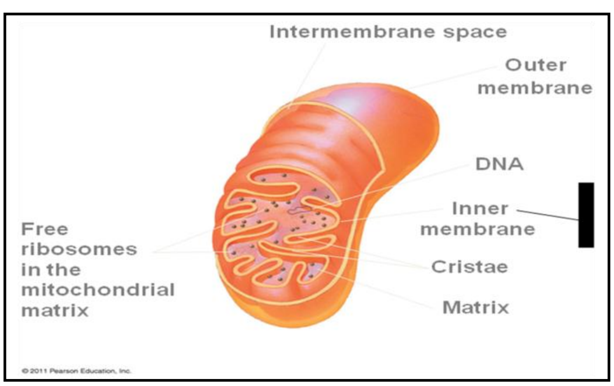
ii) Peroxisomes: In plants and animals, vesicles called peroxisomes
form and divide on their own, so they are not part of the endomembrane system. Peroxisomes contain enzymes that digest fatty acids and amino acids. They also break down hydrogen peroxide, a toxic by-product of fatty acid metabolism. Peroxisome enzymes convert hydrogen peroxide to water and oxygen, or use it in reactions that break down alcohol and other toxins.

Energy Related Organelles: Mitochondria & Chloroplast

Mitochondria:
The mitochondrion (plural, mitochondria) is a type of organelle that specializes in making ATP (molecule used by cells as main energy source). They have various enzymes to catalyze cellular respiration. Bacteria have no mitochondria; they make ATP in their cell walls and cytoplasm. Cells that have a very high demand for energy tend to have many mitochondria *e.g.* liver needs more because needs more energy. Mitochondria, like most organelles, can move within the cell and they grow and divide independently. Each has two membranes, one highly folded inside the other. Double-membrane system: **Smooth outer membrane** (lipid bilayer) faces cytoplasm and permeable to small solutes; blocks macromolecules wheras **Inner Membrane (cristae)** folds back on itself to enlarge surface area for chemical reactions to take place. Membranes form two distinct compartments. ATP-making machinery is embedded in the inner mitochondrial membrane.

- Mitochondria and chloroplasts have similarities with bacteria,
- Enveloped by a double membrane
- Contain free ribosomes and circular DNA molecules
- Grow and reproduce somewhat independently in cells

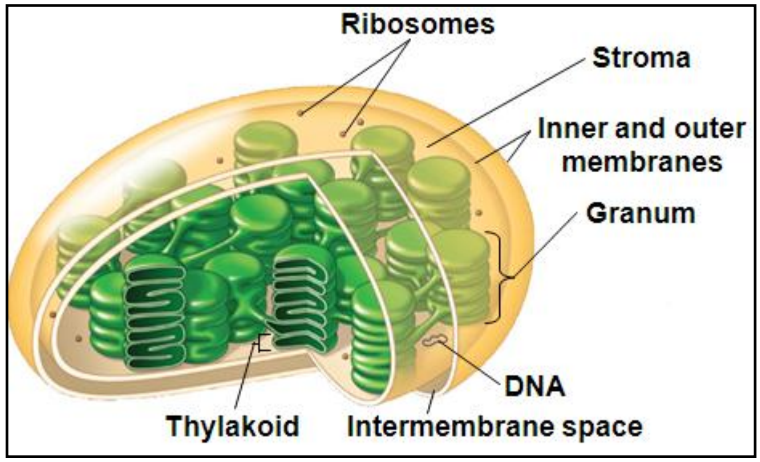
They may have evolved from ancient bacteria that were engulfed but not digested. Mitochondria and chloroplasts developed because as a prokaryote it gained protection by living inside the eukaryote and in turn produced energy for the eukaryote (symbiotic relationship).



Chloroplasts: Capture of Light Energy

Plastids are a category of membrane-enclosed organelles that function in photosynthesis or storage in plant and algal cells. Plastids called chloroplasts are organelles specialized for photosynthesis. Chloroplasts contain the green pigment chlorophyll, as well as enzymes and other molecules that function in photosynthesis. Chloroplasts are found in leaves and other green organs of plants and in algae.

- Chloroplast structure includes
  - ✓ **Stroma**: Each has two outer membranes enclosing a semifluid interior, the stroma, that contains enzymes and the chloroplast's own DNA.
  - ✓ **Thylakoids**: Inside the stroma, a third, highly folded membrane forms a single, continuous compartment. The folded membrane resembles stacks of flattened disks. The stacks are called grana (singular, granum). Photosynthesis takes place at this membrane, which is called the thylakoid membrane. The abundance of chlorophylls in thylakoids is the reason most plants are green. By the process of photosynthesis, chlorophylls and other molecules in the thylakoid membrane harness the energy in sunlight to drive the synthesis of ATP. The ATP is then used inside the stroma to build carbohydrates from carbon dioxide and water.



Locomotor appendages: Cilia & Flagella

Cilia – Cilia (singular, cilium) are short, hairlike structures that project from the surface of some cells.Mainly found in eukaryotic cells. Cilia are usually more profuse than flagella. The coordinated waving of many cilia propels cells through fluid, and stirs fluid around stationary cells.

Flagella –Flagella are long hair-like structure and present in both prokaryotic and eukaryotic cells.In prokaryotes flagellum projects from the cell wall and enables a cell to move. In eukaryotes, flagellum structure is different from the prokaryotic cells and whip back and forth to propel cells such as sperm through fluid. They have a different internal structure and type of motion than flagella of bacteria.