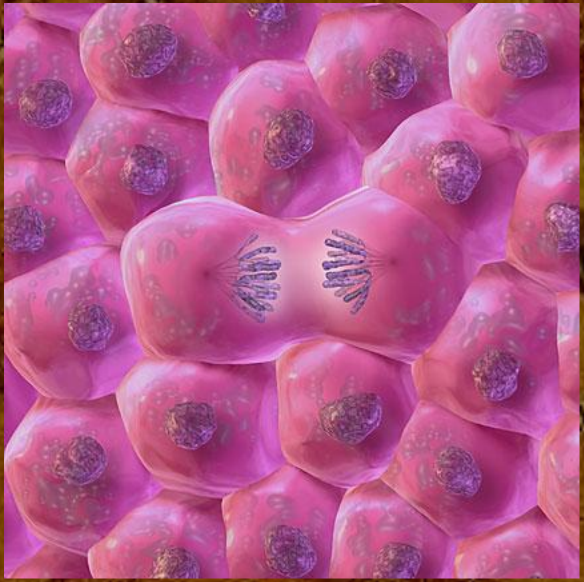
BIOLOGY I

Chapter 6: A Tour of the Cell



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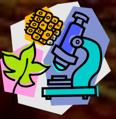
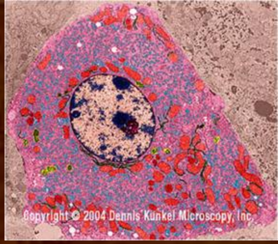
2012

Common Features of All Cells

Cell Theory: All living things are composed of one or more cells, which are the basic **structural and functional units of life**.

Order (organization)	
✓***Molecular components***	✓Proteins (made up of amino acids), lipids, carbohydrates, nucleic acids (DNA and RNA, which are made up of nucleotides).
✓***Structural components***	✓Plasma membrane, cytoplasm, ribosomes, other structures.
Evolution	All cells are related by their descent from earlier cells, however they have been modified in different ways (adaptation).
Metabolism and regulation	All cells obtain energy and nutrients from the environment; using energy and nutrients to build, repair, and replace cellular parts.
Response to environment	Cells interact with their environment; cells sense and respond to environmental fluctuations.
Reproduction and growth	All cells use DNA (deoxiribonucleic acid) as a hereditary blueprint (genetic information), they grow and reproduce.



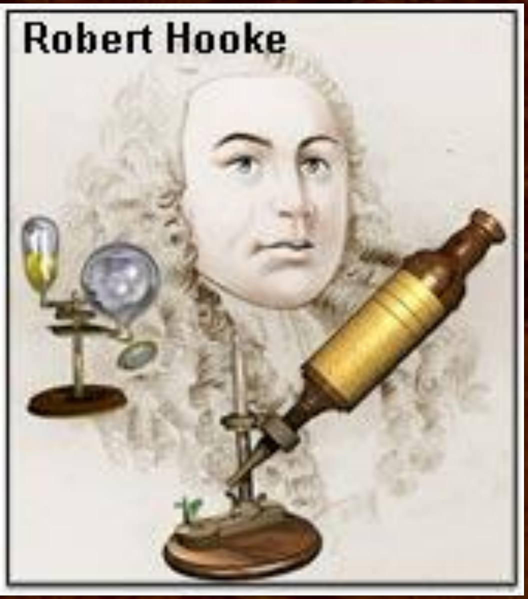


Observing and Studying Cells

- **Microscopy:** The technology of making very small things visible to the human eye.
  - The discovery and early study of cells progressed with the invention of microscopes in 1590 and their refinement during the 1600s.
- **Microscopes** are used to view the cell and its components, microorganisms, and other tiny objects by magnifying their image.
- Examples:
  - ***Light microscopes (LM):*** use visible light rays to focus the specimen or sample.
  - ***Electron microscopes (EM):*** focuses a beam of electrons through the specimen or onto its surface.

Observing and Studying Cells: HISTORICAL MICROSCOPY

- Ancestors of bacteria were the first life on Earth.
- The First Observations
  - **Robert Hooke; 1665:** He used a basic microscope to observe a thin piece of cork (from the dry outer bark of oak). He reported that living things were composed of compartments or **"*little boxes*"** that he called **"cells"** because he thought they resembled the tiny rooms, or cells, occupied by monks. Hooke's discovery marked the beginning of the **cell theory**.
  - **Cell Theory:** All living things are composed of **cells—the basic functional and structural units of life** (formulated by Schleiden and Schwann).



Observing and Studying Cells: *A Brief History of Microscopy*

- **Antonie van Leeuwenhoek (1632-1723)** was probably the first person to see ***individual microorganisms*** using a special magnifying instrument called a **microscope**. He studied several samples (water samples, teeth scrapings, etc.) and described the organisms as very little **"animalcules"**.
- He constructed simple but powerful microscopes, with a glass lens capable of magnifying objects up to 300 times.

Figure 1.2a

van Leeuwenhoek using his microscope

By holding his microscope toward a source of light, van Leeuwenhoek was able to observe living organisms too small to be seen with the unaided eye.

Figure 1.8. An oil painting of Antonie van Leeuwenhoek (1632-1723)

A Brief History of Microbiology: *The First Observations*

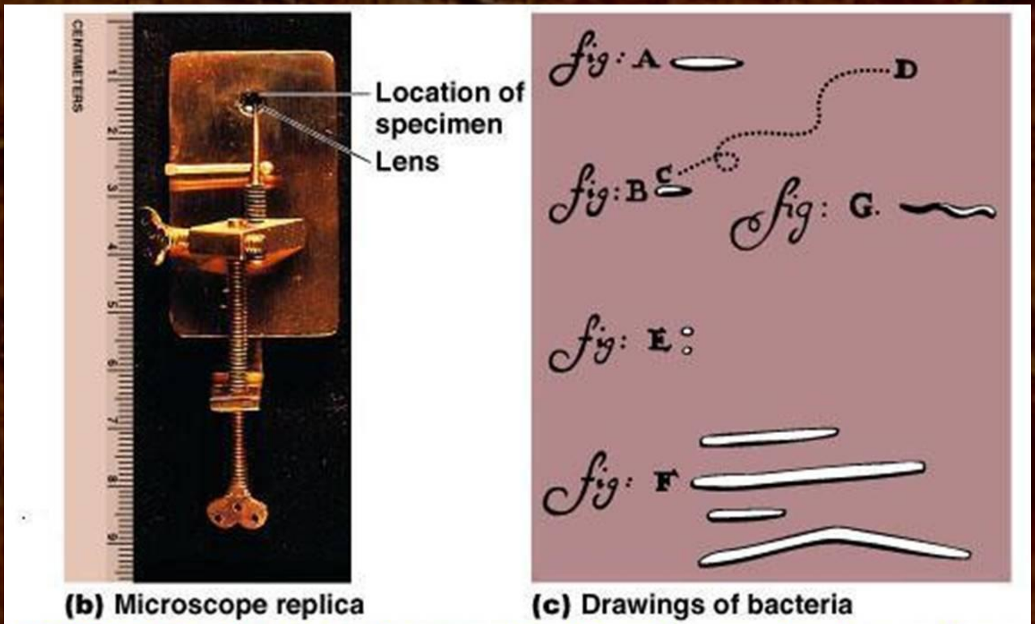


FIGURE 1.2 - Anton van Leeuwenhoek's microscopic observations.

(b) The specimen was placed on the tip of the adjustable point and viewed from the other side through the tiny, nearly spherical lens; the highest magnification possible was about 300X (times). **(c)** The letters represent various shapes of bacteria. C-D represents a path of motion he observed.

FIGURE 3-1b – The proper way of looking through Antonie van Leeuwenhoek's microscope.

FIGURE 3-1c. Vinegar eels (nematodes) that so upset Leeuwenhoek's friends.

MICROSCOPY: **Wavelength**

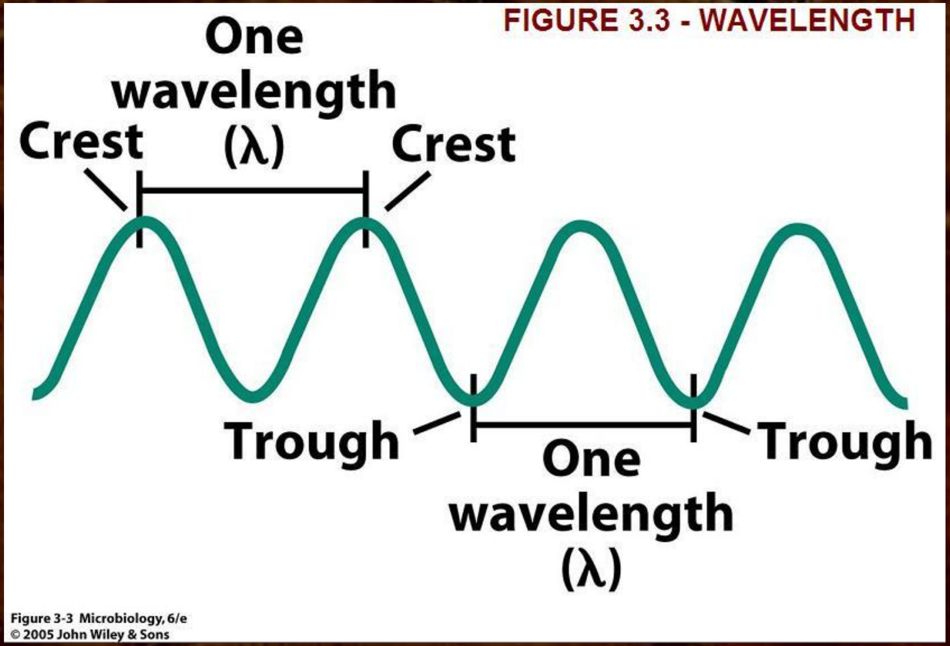


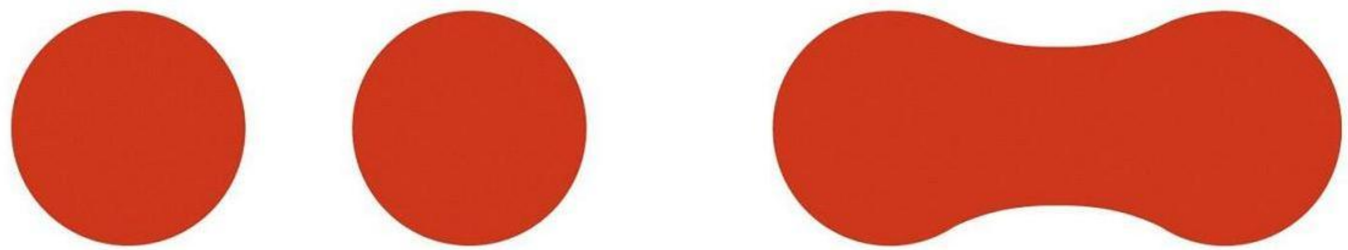
FIGURE 3.3 – Wavelength.

The distance between two adjacent crests or two adjacent troughs is defined as 1 wavelength (1 λ).

- **Wavelength** is the distance between crests of waves (for example, length of a light ray), represented by the letter greek **lambda** (λ).
  - One wavelength is equal to the **distance between two adjacent crests or two adjacent troughs of a wave**.

MICROSCOPY: **Magnification, Resolution, Contrast**

- **Magnification** is the ratio of an object's image size to its real size; magnification simply makes the objects or specimens appear larger.
- **Resolution (resolving power)** is the ability of an optical instrument to ***distinguish between two points*** that are close together, so that they are seen as **separate units**; it is the ability of the lenses to distinguish fine detail and structure (or a measure of the clarity of the image).
  - Example: A microscope with a resolving power of 0.4 nm can distinguish between two points if they are at least 0.4 nm apart.
- **Contrast** is the effect of a striking difference, as in color or tone, of adjacent parts (for example, in a photograph or image). It is based on the differential absorption of light by parts of the specimen. Contrast accentuates differences in parts of the sample and is also an important parameter in microscopy.



(a) The two dots are resolved-- that is, they can clearly be seen as separate structures.

(b) These two dots are not resolved--they appear to be fused.

Figure 3-5 Microbiology, 6/e

FIGURE 3.5 - RESOLUTION

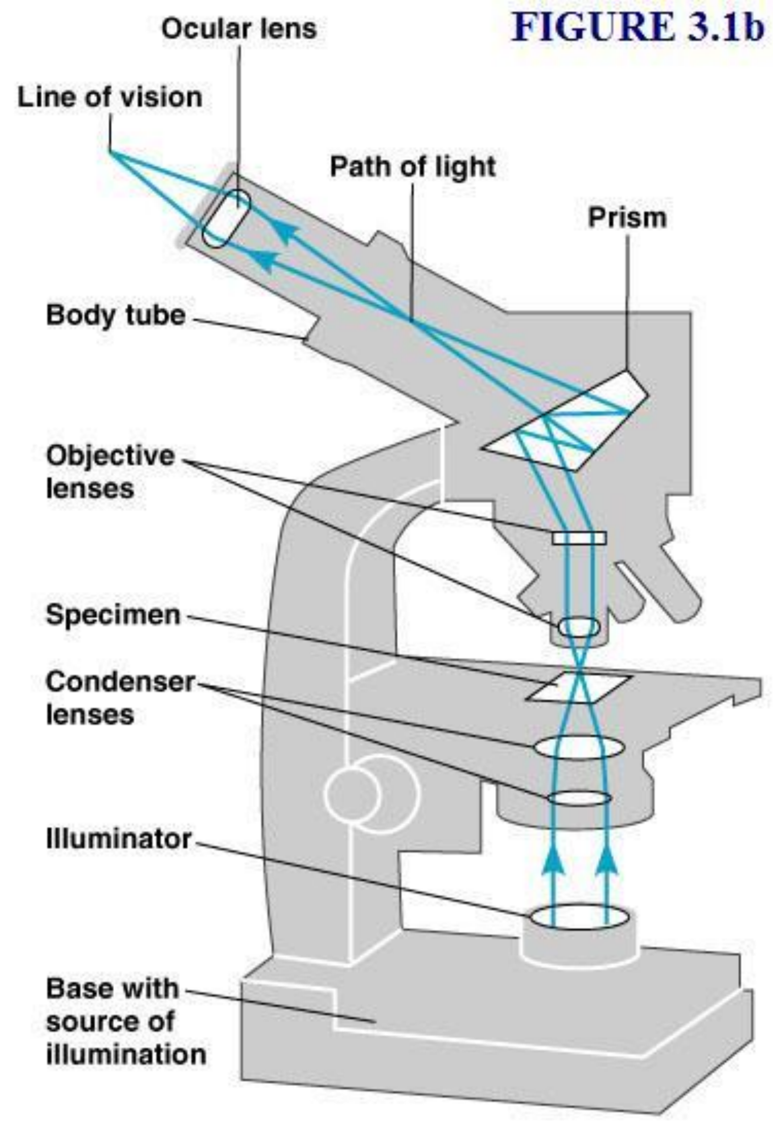
MICROSCOPY AND UNITS OF MEASUREMENT

Table 3.1 Metric Units of Length and U.S. Equivalents

Metric Unit	Meaning of Prefix	Metric Equivalent	U.S. Equivalent
1 kilometer (km)	*kilo* = 1000	1000 m = 10^{3} m	3280.84 ft or 0.62 mi; 1 mi = 1.61 km
1 meter (m)		Standard unit of length	39.37 in or 3.28 ft or 1.09 yd
1 decimeter (dm)	*deci* = 1/10	0.1 m = 10^{-1} m	3.94 in
1 centimeter (cm)	*centi* = 1/100	0.01 m = 10^{-2} m	0.394 in; 1 in = 2.54 cm
1 millimeter (mm)	*milli* = 1/1000	0.001 m = 10^{-3} m	
1 micrometer (µm)	*micro* = 1/1,000,000	0.000001 m = 10^{-6} m	
1 nanometer (nm)	*nano* = 1/1,000,000,000	0.000000001 m = 10^{-9} m	
1 picometer (pm)	*pico* = 1/1,000,000,000,000	0.000000000001 m = 10^{-12} m	

Tortora

- Most cells are between 1 and 100 µm in diameter and are therefore visible only under a microscope.
- Microscopic cellular structures and microorganisms are measured in **micrometers (µm)** and **nanometers (nm)**.
  - 1 µm = 10^{-6} m = 10^{-3} mm
  - 1 nm = 10^{-9} m = 10^{-6} mm
  - 1000 nm = 1 µm
  - 0.001 µm = 1 nm



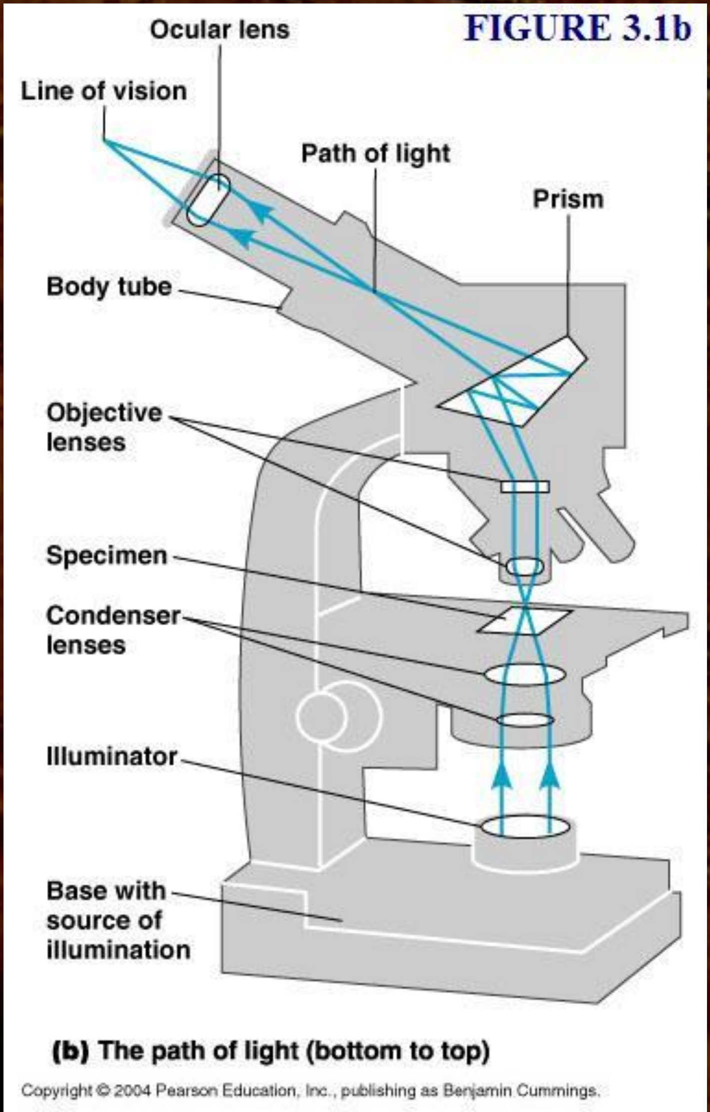
(b) The path of light (bottom to top)

Compound Light Microscope (LM)

- It has ***multiple lenses*** and uses visible light as the source of illumination.
- **Visible light** is passed through a specimen and then through **glass lenses** that **magnify** the image.
- The image from the **objective lens** is remagnified by the **ocular lens**.
- **Total magnification of a specimen** = magnification of objective lens × magnification of ocular lens.
  - **Example:** 10X (objective lens) × 10 X (ocular lens) = 100X (total magnification)
- Maximum resolving power: 0.2 µm.
- Maximum magnification: 1000-2000X.

"X" means "times magnified".

COMPOUND LIGHT MICROSCOPE (LM)



- When focusing a specimen with the microscope, the objective lenses must be used **from the lowest magnification lens to the highest magnification lens**.
- Bring the specimen into sharp **focus** before trying to observe it with the next higher magnification objective lens.
- The *sequential steps* for the correct use of the **objective lenses** are:
  - **4X** → **10X** → **40X** → rotate halfway to the next lens and add one drop of **immersion oil** directly over the area of the microscopic slide to be observed → **100X**. *The **immersion oil** increases the resolution and is used **only with the 100X lens**, or “oil immersion objective”.

COMPOUND LIGHT MICROSCOPE

- **Refractive index** is the relative velocity with which light passes through a substance (the light-bending ability of the medium).
- When two substances have *different indexes of refraction, light will bend* as it passes from one material into the other.
- The light may bend in air so much that it misses the small highest-magnification lens.
- **Immersion oil** is used ONLY with the oil immersion objective lens (**100X**, the highest magnification) to keep light from bending.

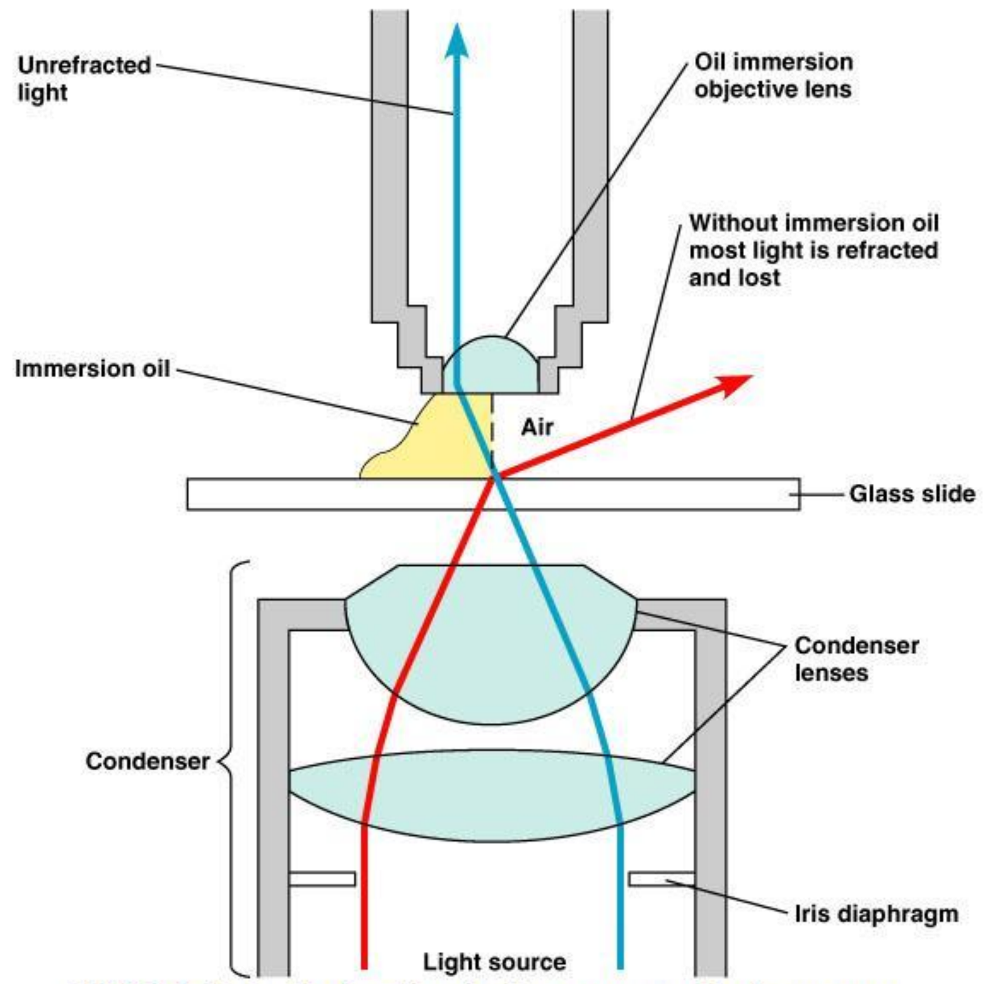
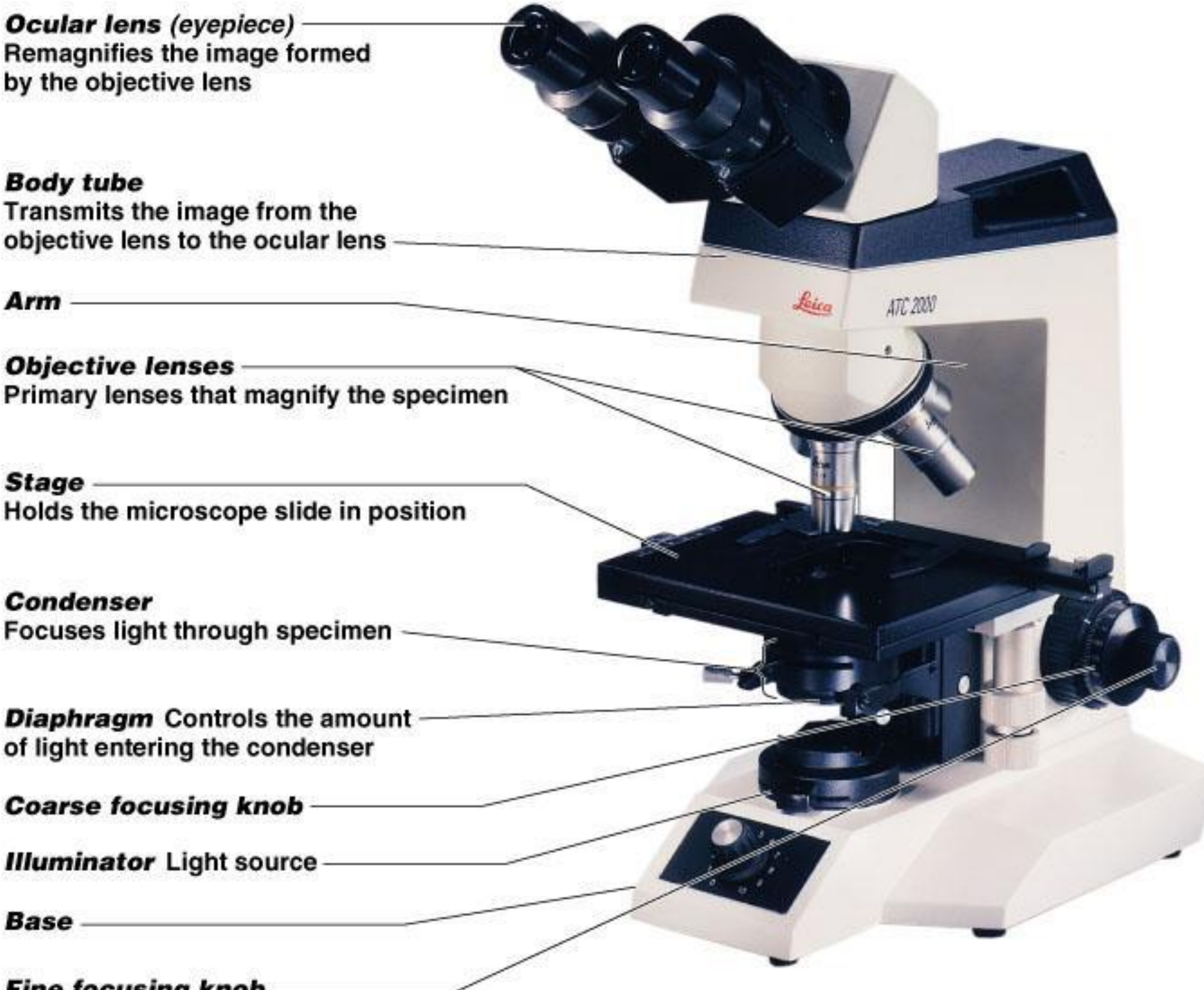


FIGURE 3.3 - Refraction in the compound microscope



(a) Principal parts and functions

FIGURE 3.1- The compound light microscope.

ELECTRON MICROSCOPES

- The **Electron Microscope (EM)** uses a **beam of electrons** instead of a beam of light and **electromagnets** instead of glass lenses for focusing.
- The electrons have much shorter wavelengths than light waves, therefore, the EM allows magnifications of up to **500,000X**, and resolving power of **less than 1 nm** (better than the light microscope).
- It is much more expensive and difficult to use.
- **Viruses** (intracellular parasites) can be seen only by using EMs (not the LM) because they are smaller than bacteria.
- **Scanning tunneling microscope** and **atomic force microscope:** Advanced types of EMs that can visualize actual **molecules** and individual **atoms**.

ELECTRON MICROSCOPES

- Transmission Electron Microscope (TEM)
  - The beam of electrons is passed directly **through a very thin slice (section) of a specimen** placed on a thin wire grid, revealing the **internal structure** of microbial and other cells.
  - Magnification: up to **500,000X**.
  - Resolution: around **1 nm**.
  - The image is projected onto a fluorescent screen or photographic plate, allowing you to get an **electron micrograph**, a permanent record of the specimen observed, which can be enlarged like a photograph.

ELECTRON MICROSCOPES

- Scanning Electron Microscope (SEM)
  - The SEM allows the examination of **external features** of microorganisms by scanning a fine electron beam **over the surface** of specimens rather than projecting electrons through them.
  - The sample does not need to be thinly sliced.
  - SEMs can produce detailed **three-dimensional images** of the surface of objects, whereas a TEM can only produce two-dimensional images.
  - Magnification is up to **200,000X**.
  - Resolution is around **20 nm**.

ELECTRON MICROSCOPE

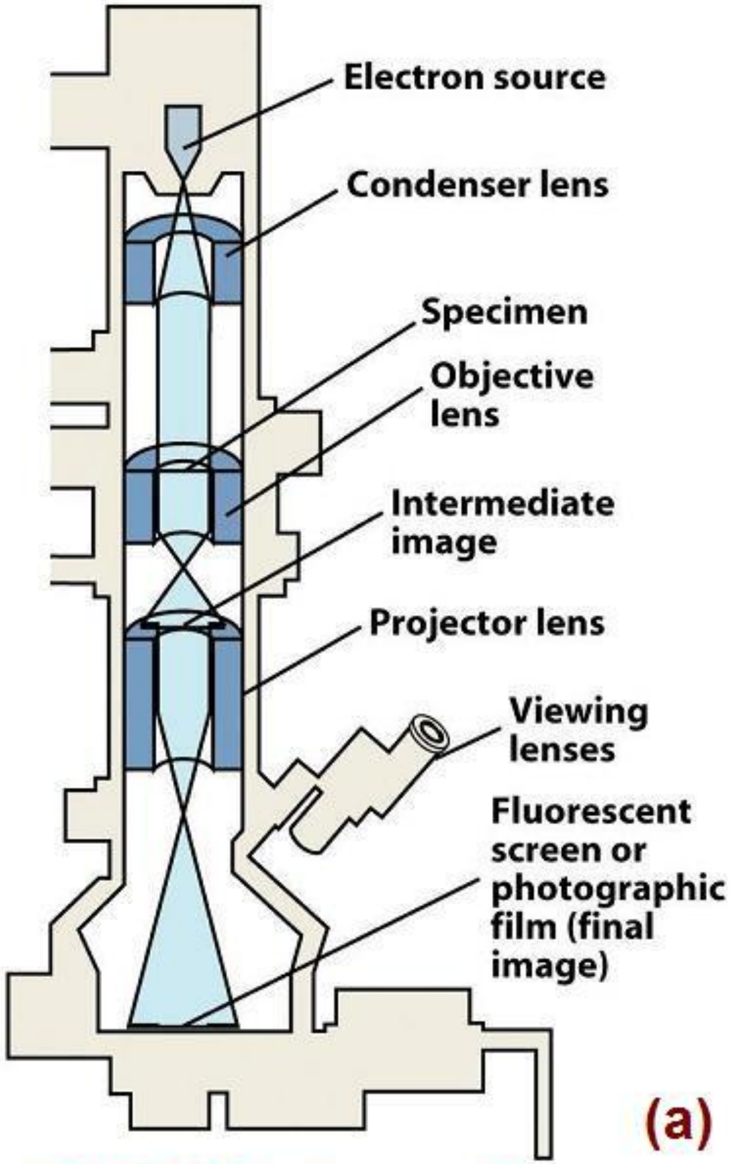


FIGURE 3.21 - Electron Microscopy.

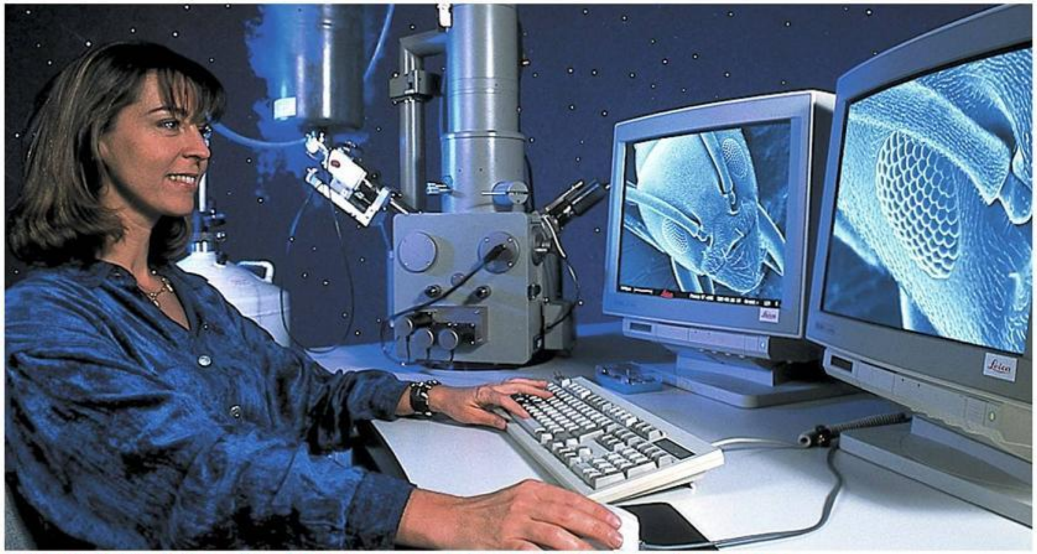


FIGURE 3.21b - A modern scanning electron microscope.

FIGURE 3.21 – Electron Microscopy.

(a) A cross-sectional diagram of an electron microscope, showing the pathways of the electron beam as it is focused by electromagnetic lenses.

(b) A modern scanning electron microscope.

ELECTRON MICROSCOPES: TEM and SEM Compared

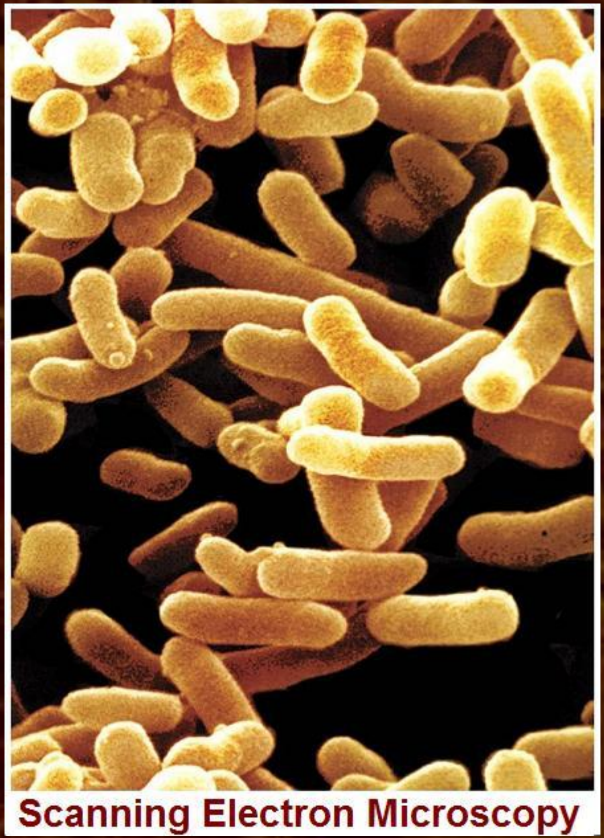


Figure 3.26. Colorized electron micrographs of ***Escherichia coli*** (a species of bacteria) produced by **(a)** transmission electron microscopy (66,952X) and **(b)** scanning electron microscopy (39,487X).

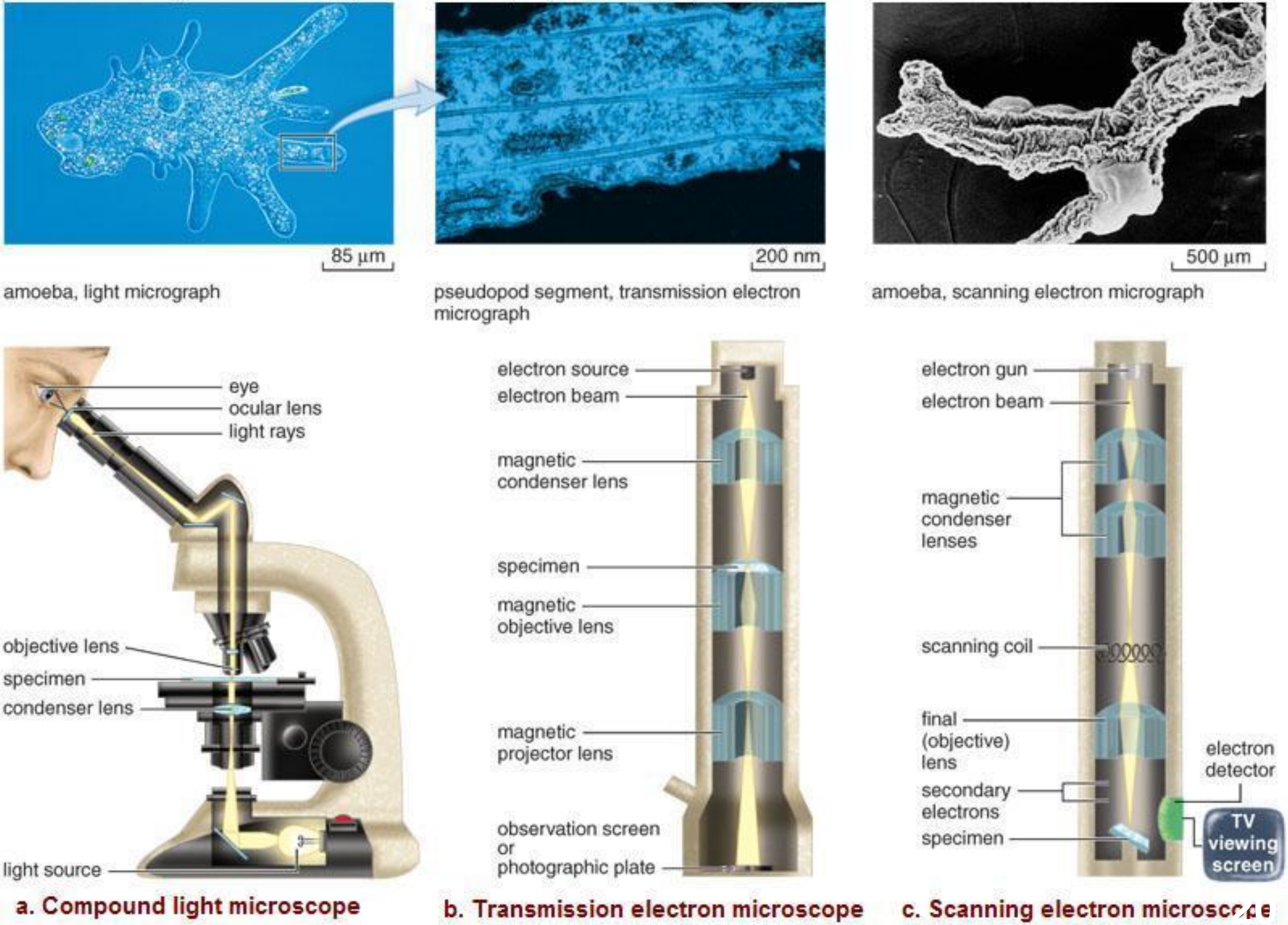
Characteristics of Light and Transmission Electron Microscopes

Feature	Light Microscope	Electron Microscope
Highest practical magnification	About 1,000 – 1,500	Over 100,000
Best resolution[a]	0.2 µm	0.5 nm
Radiation source	Visible light	Electron beam
Medium of travel	Air	High vacuum
Type of lens	Glass	Electromagnet
Source of contrast	Differential light absorption	Scattering of electrons
Focusing mechanism	Adjust lens position mechanically	Adjust current to the magnetic lens
Method of changing magnification	Switch the objective lens or eyepiece	Adjust current to the magnetic lens
Specimen mount	Glass slide	Metal grid (usually copper)

a. The resolution limit of a human eye is about 0.2 mm.

Ref. _Microbiology_. Third Edition. Lansing M. Prescott, John P. Harley & Donald A. Klein. Wm. C. Brown Publishers. USA. © 1996.

FIGURE 4A. Diagram of microscopes with accompanying micrographs of *Amoeba proteus.*



Light and Electron Microscope Images Compared

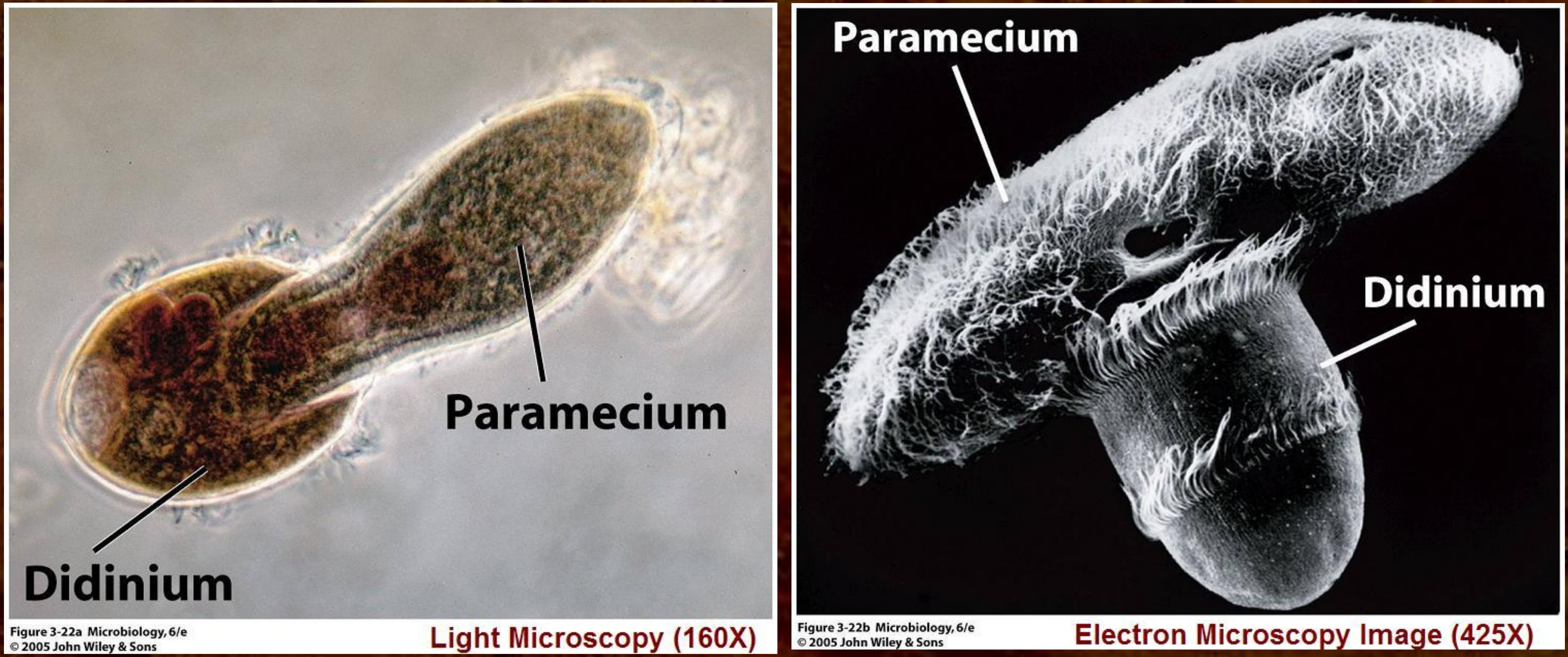


Figure 3.22. (a) Light (160X) and **(b)** electron (425X) microscope images of a *Dididium* eating a *Paramecium* (both protist microorganisms). Notice how much more detail is revealed by the scanning electron micrograph.

TABLE 3.2	A Summary of Various Types of Microscopes - Part 1		
Microscope Type	**Distinguishing Features**	**Typical Image**	**Principal Uses**
Light			
Brightfield	Uses visible light as a source of illumination; cannot resolve structures smaller than about 0.2 μm; specimen appears against a bright background. Inexpensive and easy to use.		To observe various stained specimens and to count microbes; does not resolve very small specimens, such as viruses.
Darkfield	Uses a special condenser with an opaque disc that blocks light from entering the objective lens directly; light reflected by specimen enters the objective lens, and the specimen appears light against a black background.		To examine living microorganisms that are invisible in brightfield microscopy, do not stain easily, or are distorted by staining; frequently used to detect *Treponema pallidum* in the diagnosis of syphilis.

TABLE 3.2 A Summary of Various Types of Microscopes (continued)

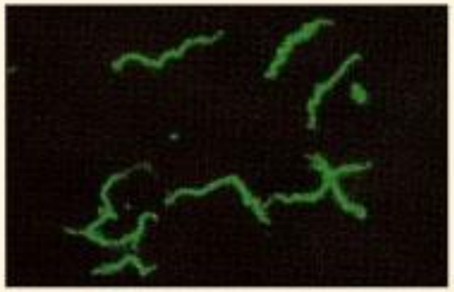
Microscope Type	Distinguishing Features	Typical Image	Principal Uses
Light			
Phase-contrast	Uses a special condenser containing an annular (ring-shaped) diaphragm. The diaphragm allows direct light to pass through the condenser, focusing light on the specimen and a diffraction plate in the objective lens. Direct and reflected or diffracted light rays are brought together to produce the image. No staining required.		To facilitate detailed examination of the internal structures of living specimens.
Differential interference contrast (DIC)	Like phase-contrast, uses differences in refractive indexes to produce images. Uses two beams of light separated by prisms; the specimen appears colored as a result of the prism effect. No staining required.		To provide three-dimensional images.
Fluorescence	Uses an ultraviolet or near-ultraviolet source of illumination that causes fluorescent microbes (green-colored) in a specimen to emit light.		For fluorescent-antibody techniques (immunofluorescence) to rapidly detect and identify microbes in tissues or clinical specimens.

TABLE 3.2 A Summary of Various Types of Microscopes (continued)

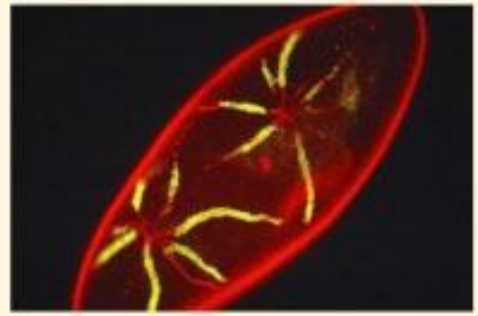
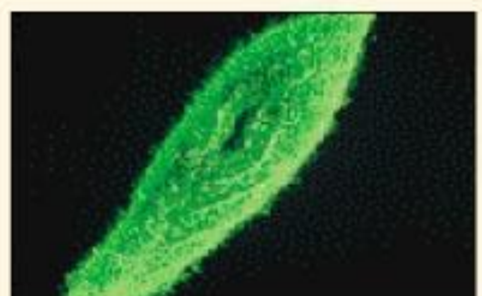
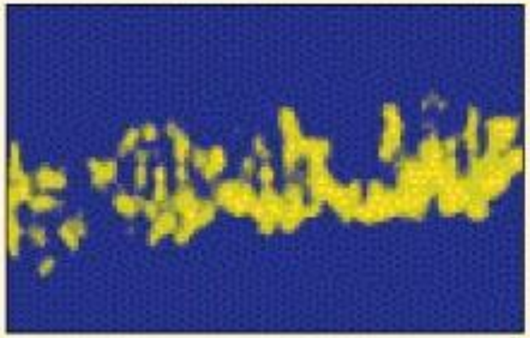
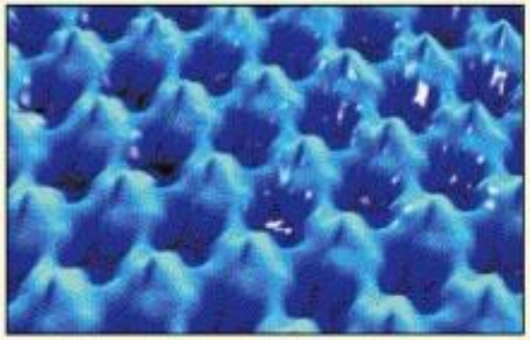
Microscope Type	Distinguishing Features	Typical Image	Principal Uses
Confocal	Uses laser light to illuminate one plane of a specimen at a time.		To obtain two- and three-dimensional images of cells for biomedical applications.
Electron Transmission	Uses a beam of electrons instead of light; electrons pass through the specimen; because of the shorter wavelength of electrons, structures smaller than 0.2 μm can be resolved. The image produced is two-dimensional.		To examine viruses or the internal ultrastructure in thin sections of cells (usually magnified 10,000–100,000×).
Scanning	Uses a beam of electrons instead of light; electrons are reflected from the specimen; because of the shorter wavelength of electrons, structures smaller than 0.2 μm can be resolved. The image produced appears three-dimensional.		To study the surface features of cells and viruses (usually magnified 1000–10,000×).

TABLE 3.2 A Summary of Various Types of Microscopes (continued)

Microscope Type	Distinguishing Features	Typical Image	Principal Uses
Scanned-probe			
Scanning tunneling	Uses a thin metal probe that scans a specimen and produces an image revealing the bumps and depressions of the atoms on the surface of the specimen. Resolving power is much greater than that of an electron microscope. No special preparation required.		Provides very detailed views of molecules inside cells.
Atomic force	Uses a metal-and-diamond probe gently forced down along the surface of the specimen. Produces a three-dimensional image. No special preparation required.		Provides images of biological molecules in nearly atomic detail and molecular processes.

Comparing Two Basic Types of Cells

Prokaryotic Cells

- Genetic material (DNA) ***not*** inside a membrane-enclosed **nucleus** (the term prokaryote comes from the Greek word for ***pre-nucleus***)
- DNA **not** associated with histones
- **Do not** have complex membrane-bound organelles
- Unique cell wall of **peptidoglycan** (protein-carbohydrate molecules) in most bacteria. Cell walls of archaea made of other chemicals.
- **Smaller** than eukaryotic cells
- Single-celled microorganisms that form groups called colonies:
  - **Bacteria**
  - **Archaea** (similar to bacteria in external features)

Eukaryotic Cells

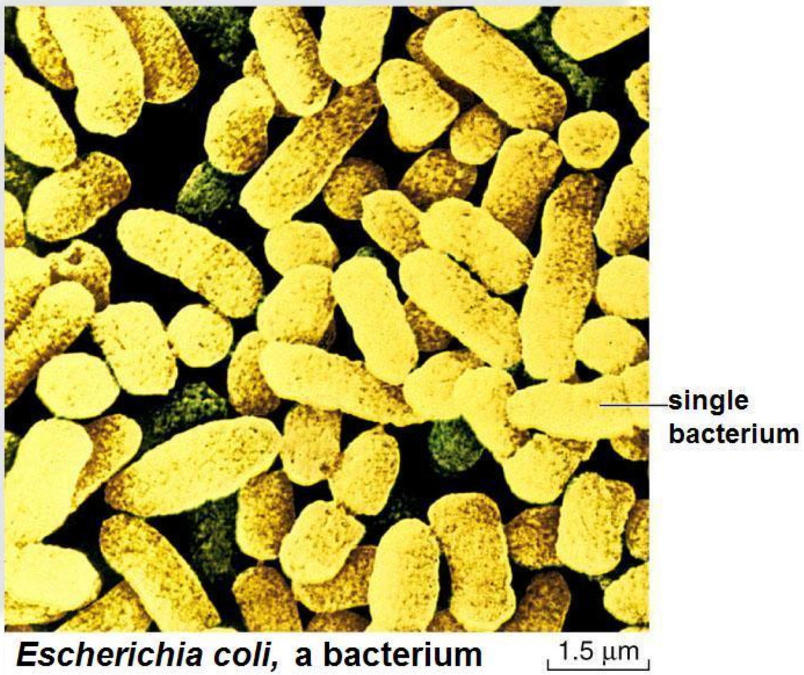
- Genetic material (DNA) inside a membrane-bound **nucleus** (eukaryote = ***true nucleus***)
- DNA around special proteins called **histones**
- Membrane-bound **organelles** (cell structures with specific functions)
- ***Some*** have simple cell walls (algae, fungi and plants), made up of other **polysaccharides** (carbohydrates).
- **Larger** than prokaryotic cells
- Eukaryotic organisms are single-celled and multicellular, and many are visible:
  - **Protists** (protozoa, algae), **fungi** (molds, mushrooms and yeasts), **plants** and **animals**

PROKARYOTIC MICROORGANISMS

FIGURE 1.7. Domain Archaea.

***Methanosarcina mazei*, an archaeon**

FIGURE 1.8. Domain Bacteria.



***Escherichia coli*, a bacterium**

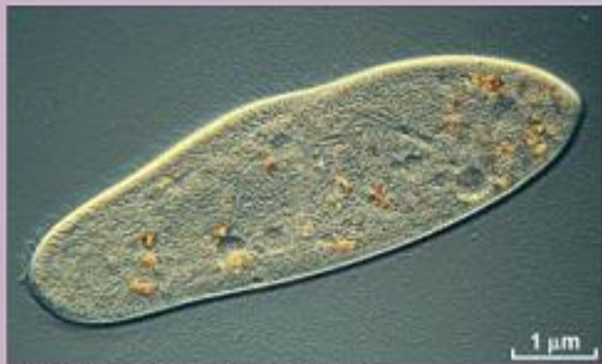
Archaea are prokaryotes that are often found in extreme environments (too salty, too hot, too cold, or too acidic for other organisms).

Bacteria are metabolically diverse prokaryotes widely distributed everywhere.

FIGURE 1.9. The four kingdoms in domain Eukarya.

DOMAIN EUKARYA

KINGDOM PROTISTA (protists)



Paramecium, a unicellular organism

- Algae, protozoans, slime molds, and water molds
- Complex single cell (sometimes filaments, colonies, or even multicellular)
- Absorb, photosynthesize, or ingest food

KINGDOM PLANTAE (plants)

Passiflora, passion flower, a flowering plant

- Mosses, ferns, conifers, and flowering plants (both woody and nonwoody)
- Multicellular with specialized tissues containing complex cells
- Photosynthesize food

KINGDOM FUNGI

Coprinus, a shaggy mane mushroom

- Molds, mushrooms, yeasts, and ringworms
- Mostly multicellular filaments with specialized, complex cells
- Absorb food

KINGDOM ANIMALIA (animals)

Vulpes, a red fox

- Sponges, worms, insects, fishes, frogs, turtles, birds, and mammals
- Multicellular with specialized tissues containing complex cells
- Ingest food

EUKARYOTIC ORGANISMS

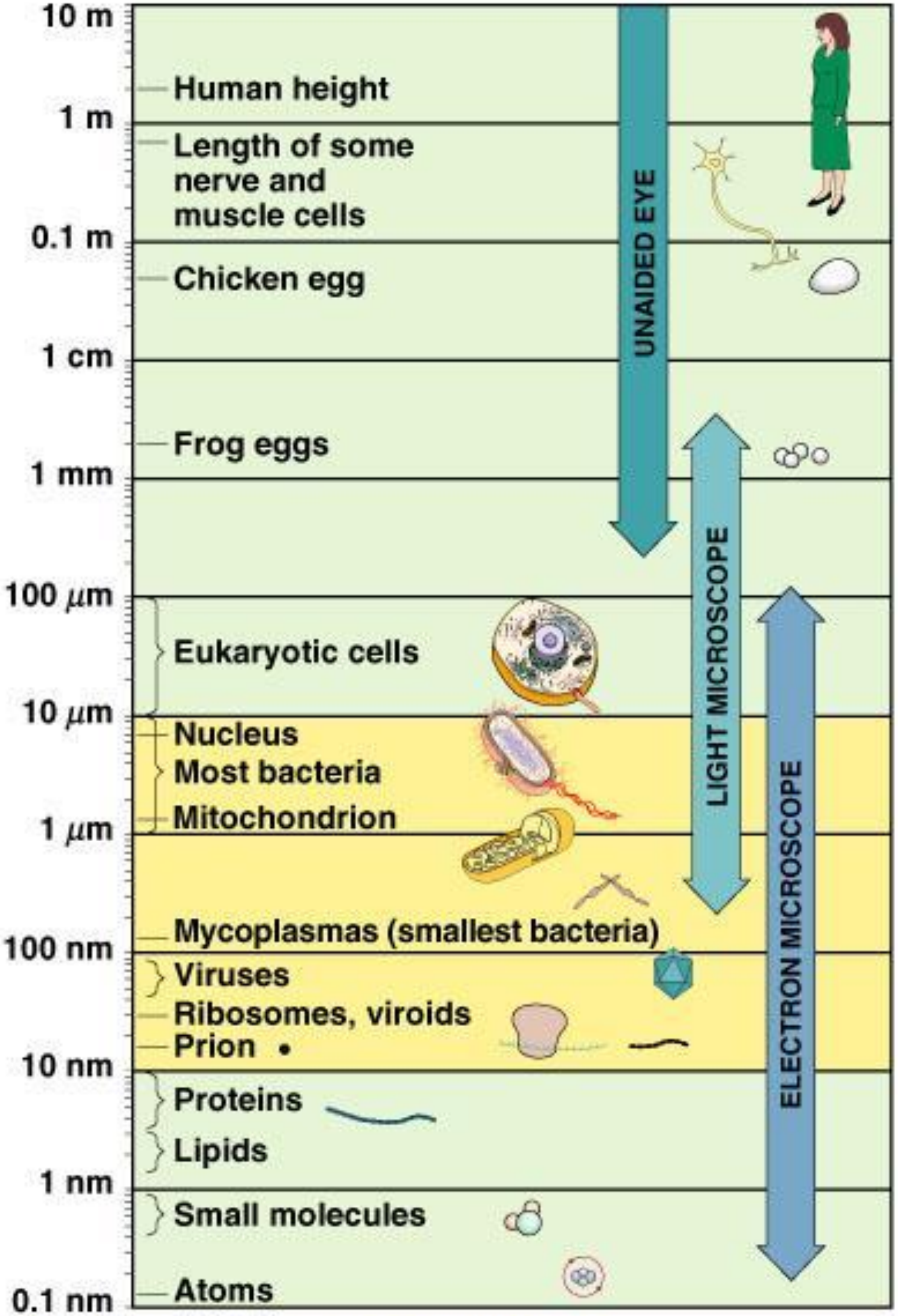


FIGURE 3.2 - Size relationships

FIGURE 3.2

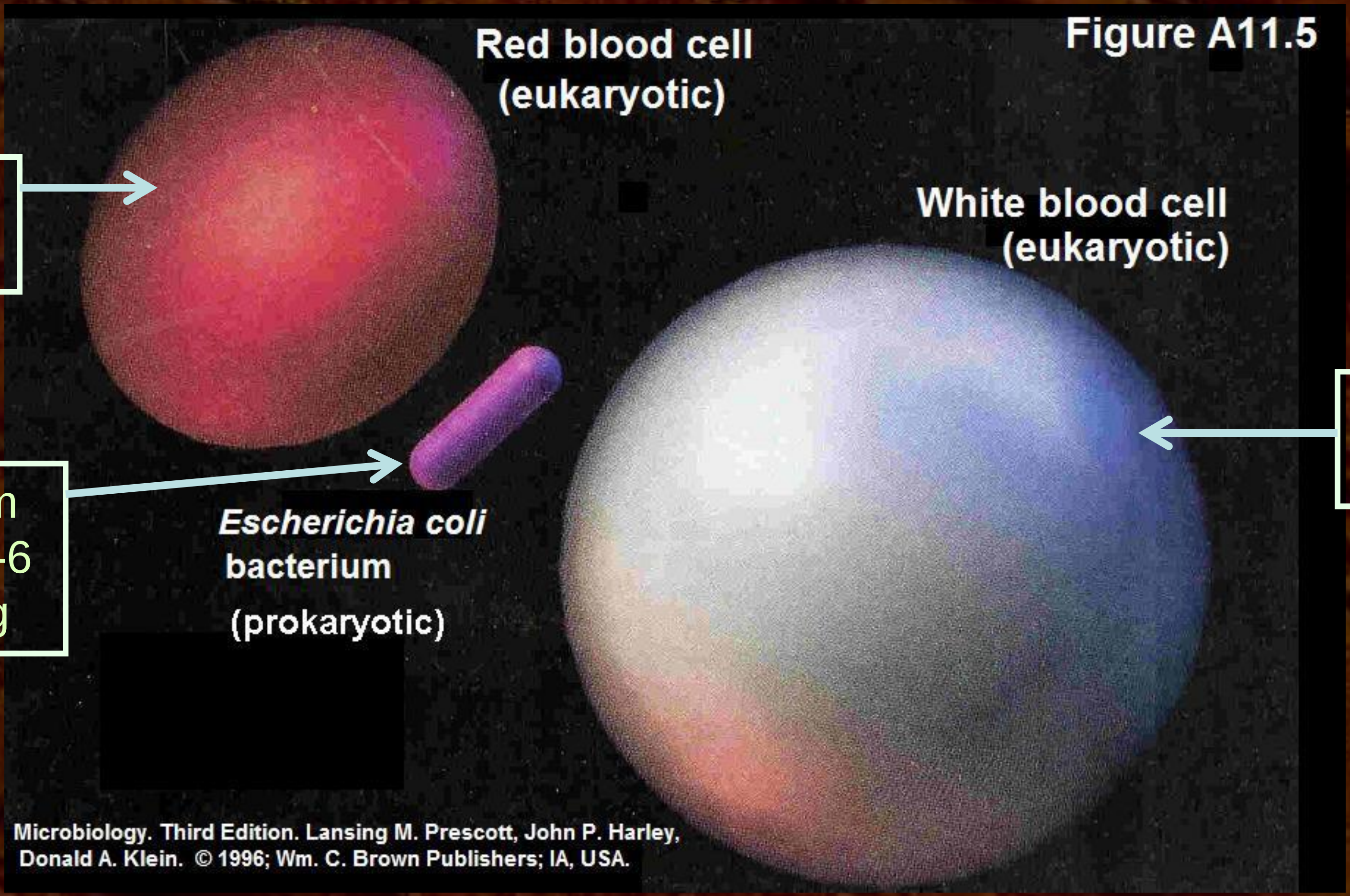
Relationships between the sizes of various specimens and the resolution of the human eye, light microscope, and electron microscope.

It takes a microscope to see most cells and lower levels of biological organization. Cells are visible with the light microscope, but not in much detail. An electron microscope is necessary to see eukaryotic cell organelles (such as the mitochondrion and the nucleus) in detail and to observe viruses (noncellular parasitic agents) and molecules.

In the metric system, each higher unit is ten times greater than the preceding unit. **Measurements:** 1 centimeter (cm) = 10^{-2} meter (m) = 0.4 inch; 1 millimeter (mm) = 10^{-3} m; 1 micrometer (µm) = 10^{-3} mm = 10^{-6} m; 1 nanometer = 10^{-3} µm = 10^{-9} m.

Comparing the Size of Prokaryotic and Eukaryotic Cells

7 μm diameter



~ 1.5 μm wide x 2-6 μm long

~ 10 μm diameter

Eukaryotic cells are almost always larger than prokaryotic cells such as *E. coli*. In this illustration *E. coli* is surrounded by highly stylized representations of two typical human cells, a small white blood cell or leukocyte (about 10 μm or 10,000 nm in diameter) and an average size red blood cell or erythrocyte (7 μm in diameter).

Comparing the Size of Prokaryotic and Eukaryotic Cells

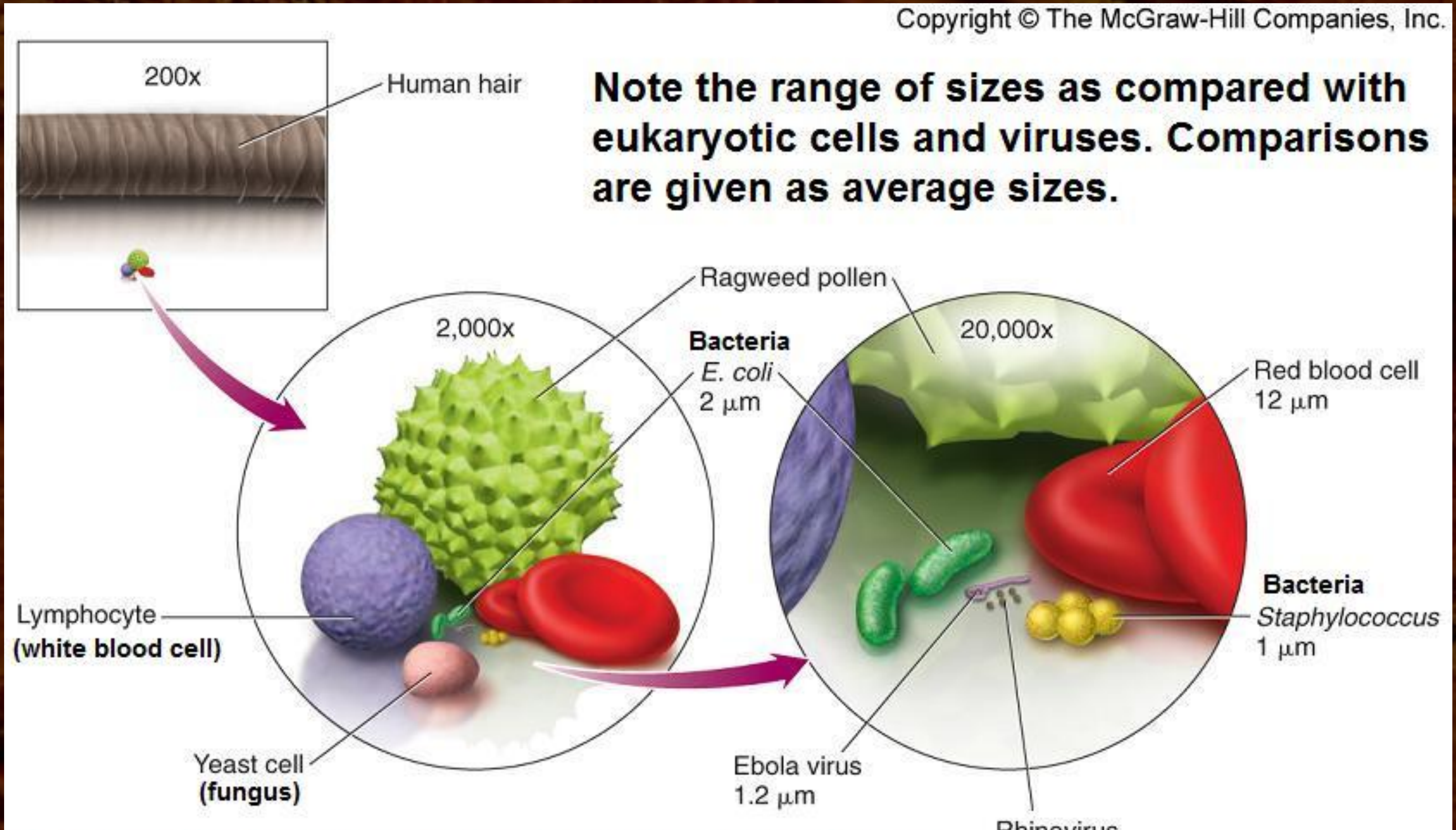
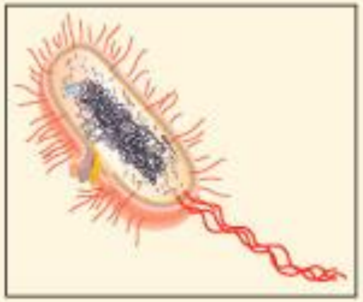


Figure 4.25. The dimensions of bacteria.

Prokaryotic cells (bacteria) are smaller than eukaryotic cells. The sizes of bacteria range from those just barely visible with light microscopy (0.2 µm) to those measuring over a thousand times that size.

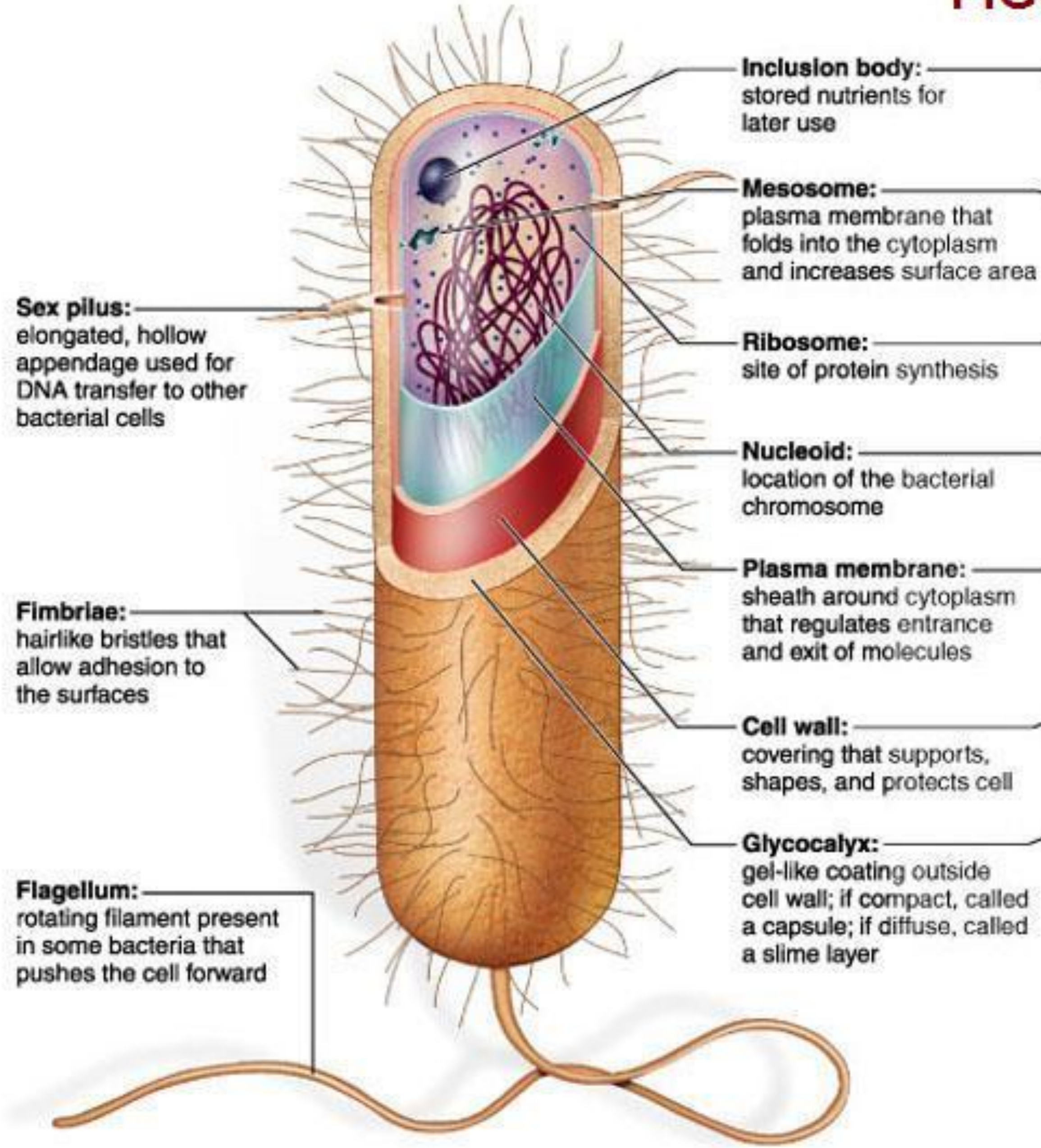
TABLE 4.2 **Principal Differences Between Prokaryotic and Eukaryotic Cells**

Characteristic	Prokaryotic	Eukaryotic
		
Size of cell	Typically 0.2–2.0 μm in diameter	Typically 10–100 μm in diameter
Nucleus	No nuclear membrane or nucleoli	True nucleus, consisting of nuclear membrane and nucleoli
Membrane-enclosed organelles	Absent	Present; examples include lysosomes, Golgi complex, endoplasmic reticulum, mitochondria, and chloroplasts
Flagella	Consist of two protein building blocks	Complex; consist of multiple microtubules
Glycocalyx	Present as a capsule or slime layer	Present in some cells that lack a cell wall
Cell wall	Usually present; chemically complex (typical bacterial cell wall includes peptidoglycan)	When present, chemically simple
Plasma membrane	No carbohydrates and generally lacks sterols	Sterols and carbohydrates that serve as receptors present
Cytoplasm	No cytoskeleton or cytoplasmic streaming	Cytoskeleton; cytoplasmic streaming
Ribosomes	Smaller size (70S)	Larger size (80S); smaller size (70S) in organelles
Chromosome (DNA)	Single circular chromosome; lacks histones	Multiple linear chromosomes with histones arrangement
Cell division	Binary fission	Mitosis
Sexual reproduction	No meiosis; transfer of DNA fragments only	Involves meiosis

Cellular Structures and Organelles

- * REMEMBER:
  - **Prokaryotic** organisms are:
    - **Archaea** and **Bacteria**.
    - They ***do not*** have a true nucleus or membrane-bound organelles like the eukaryotic organisms.
  - *** We will focus on the **eukaryotic** organisms:
    - **Protists, Fungi, Plants, Animals.**

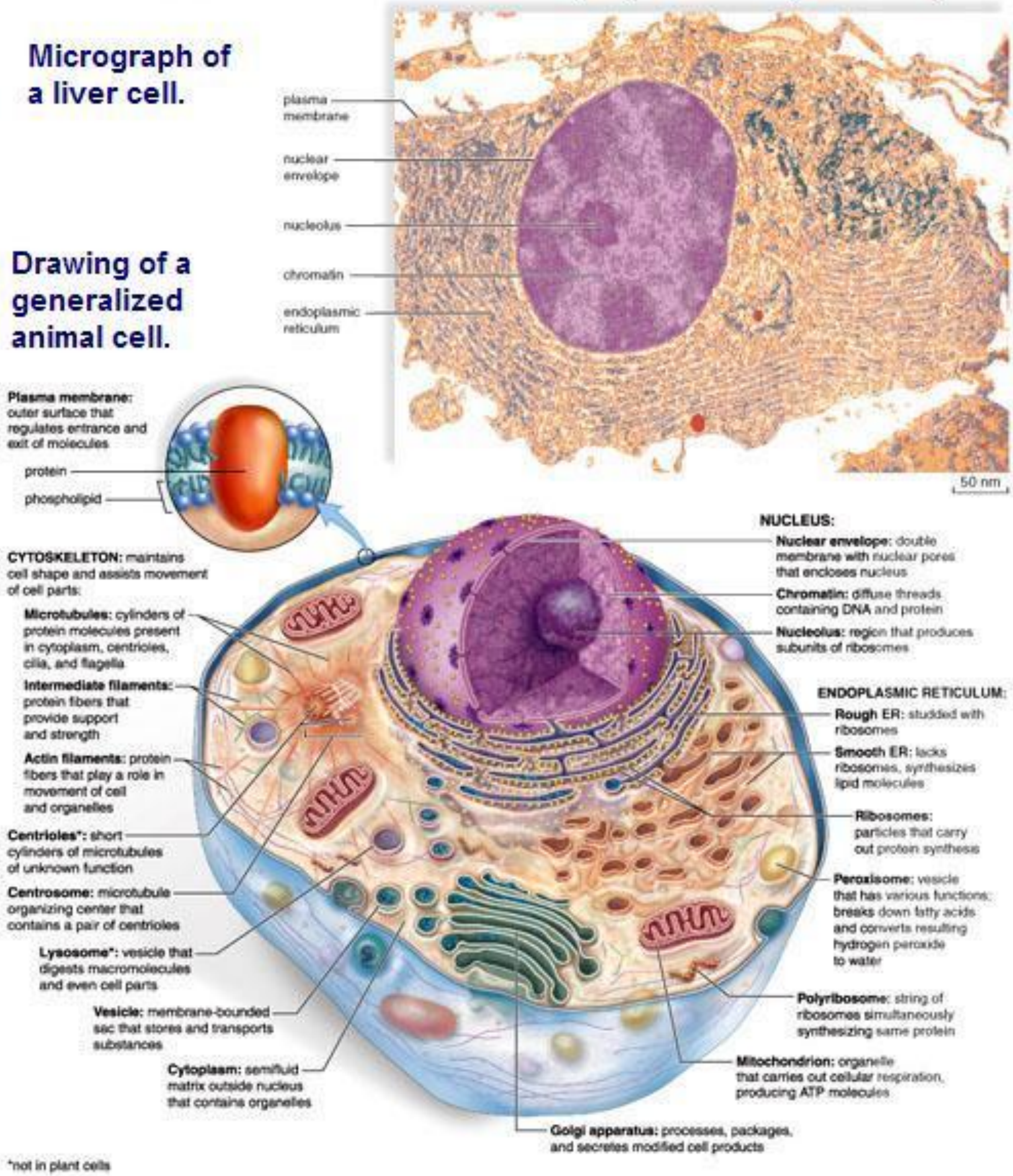
FIGURE 4.4. Prokaryotic cell.



Prokaryotic cells lack membrane-bounded organelles, as well as a nucleus, but they possess a nucleoid region that houses DNA.

ANIMAL CELL

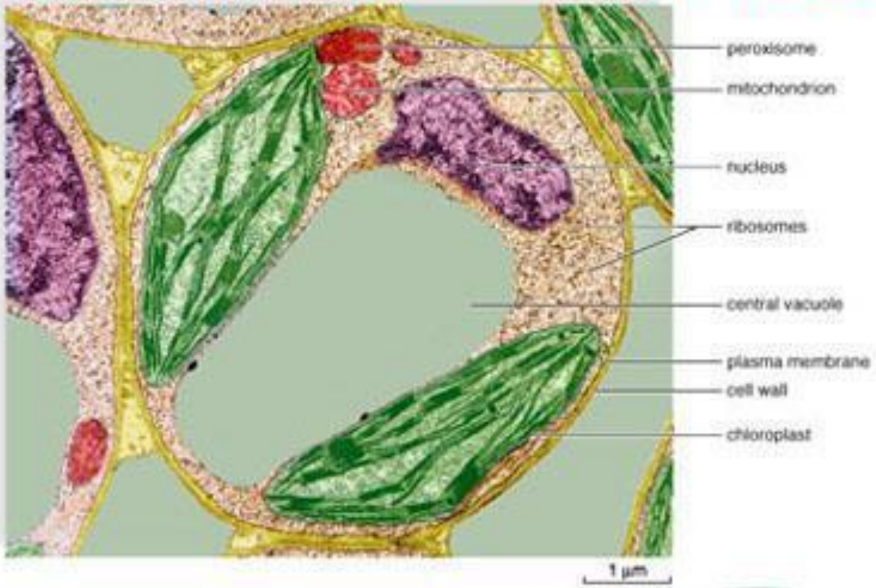
FIGURE 4.6. Animal Cell Anatomy. (An Eukaryotic Cell)



EUKARYOTIC CELL

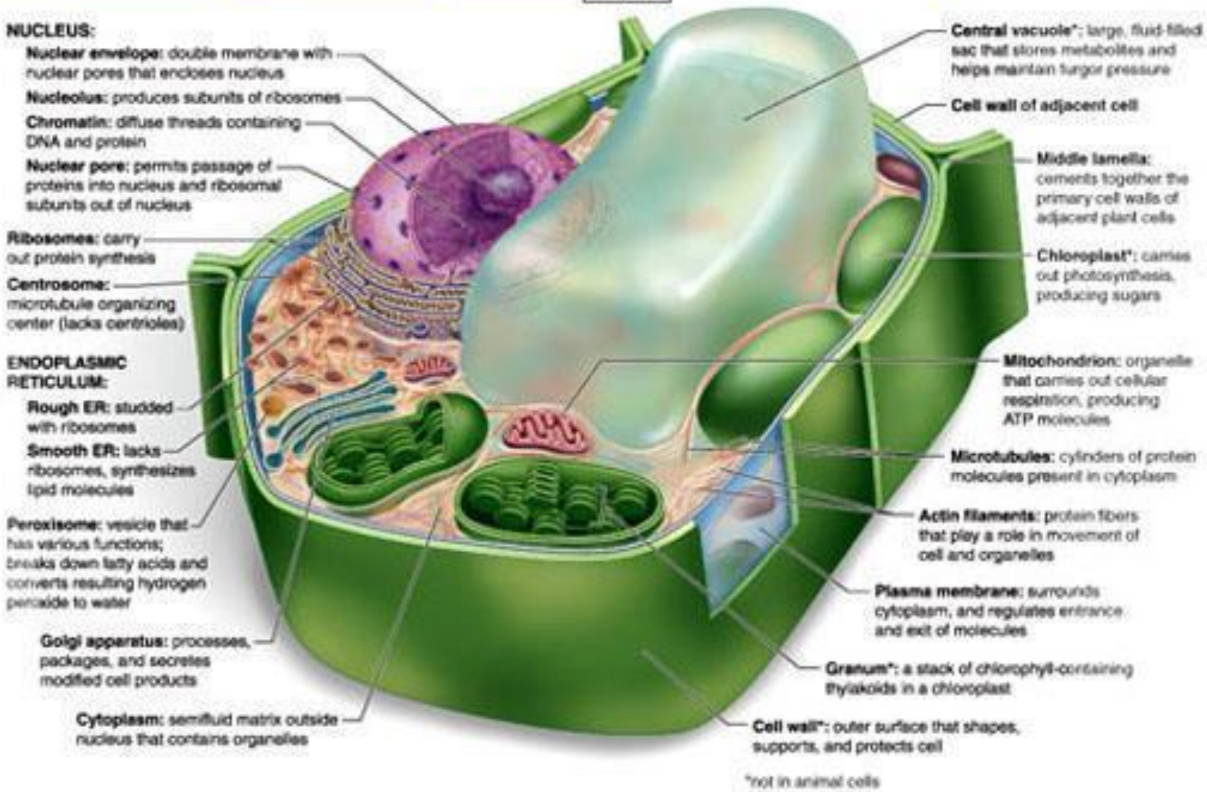
FIGURE 4.7. Plant Cell Anatomy. (An Eukaryotic Cell)

P L A N T C E L L



False-colored micrograph of a young plant cell.

Drawing of a generalized plant cell.



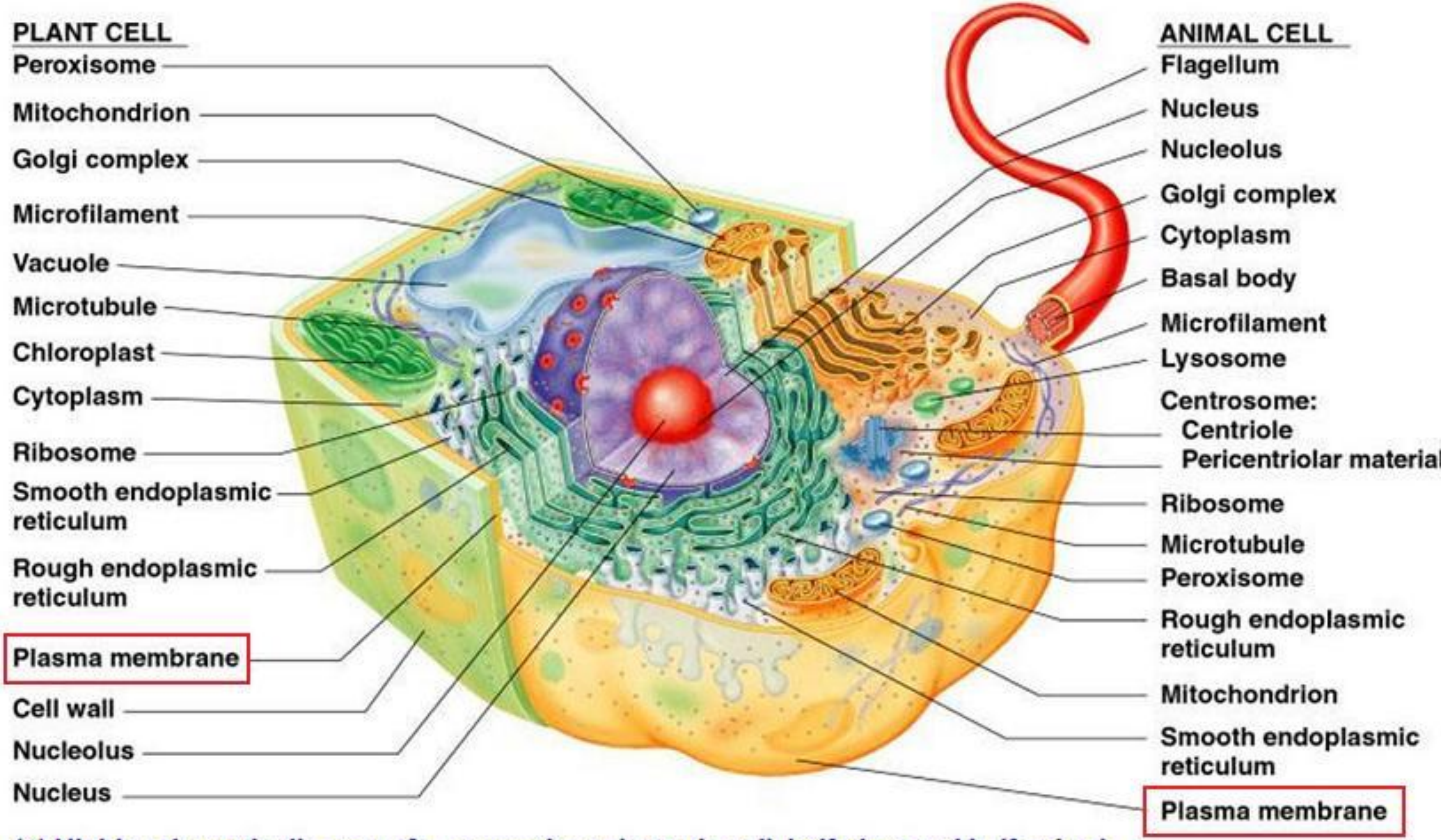
E U K A R Y O T I C C E L L

Cell Structures:
Plasma Membrane (Cell Membrane, Cytoplasmic Membrane)

- The plasma membrane is the cell's flexible outer limiting barrier that separates the cell's internal environment from the external (extracellular) environment.
- A cell membrane is present in ***prokaryotes*** and ***eukaryotes***.
- Main functions of the cell membrane:
  1. ***Regulation of exchange with the environment*.** It is a **selective barrier** that regulates the flow of **nutrients** into the cell and discharge of **wastes** out of the cell.
  2. ***Sensitivity to the Environment*.** It **detects changes** in the surroundings and plays a role in **communication**, transmitting signals both among cells and between cells and their external environment.
  3. It is involved in **energy transfer** and **chemical reactions**.
  4. ***Structural Support*.** Specialized connections between plasma membranes, or between plasma membranes and extracellular materials, give tissues stability.

Fluid Mosaic Model of the Plasma Membrane

- The **"Fluid Mosaic Model"** describes the **structure** of the plasma membrane as a mosaic formed by a **phospholipid bilayer** with **proteins** and **carbohydrates**. The proteins can move laterally, giving **fluidity** to the plasma membrane.
- The **phospholipid** molecules (made up of two *fatty acids* joined to *glycerol* and a *phosphate group*) are arranged in two layers (a *bilayer)* or parallel sheets, and are ***amphipathic*** **molecules**—they have a **hydrophilic** region and a **hydrophobic** region.
    - The **hydrophilic** ("water-loving") "heads" (phosphate group and glycerol) face outward, and the **hydrophobic** (water-fearing) "tails" (fatty acids) face inward.
- The cell membrane also has ***glycolipids*** (carbohydrate-lipids) and ***glycoproteins*** (carbohydrate-proteins).



(a) Highly schematic diagram of a composite eukaryotic cell, half plant and half animal

FIGURE 4.22a - Eukaryotic cell showing typical structures.

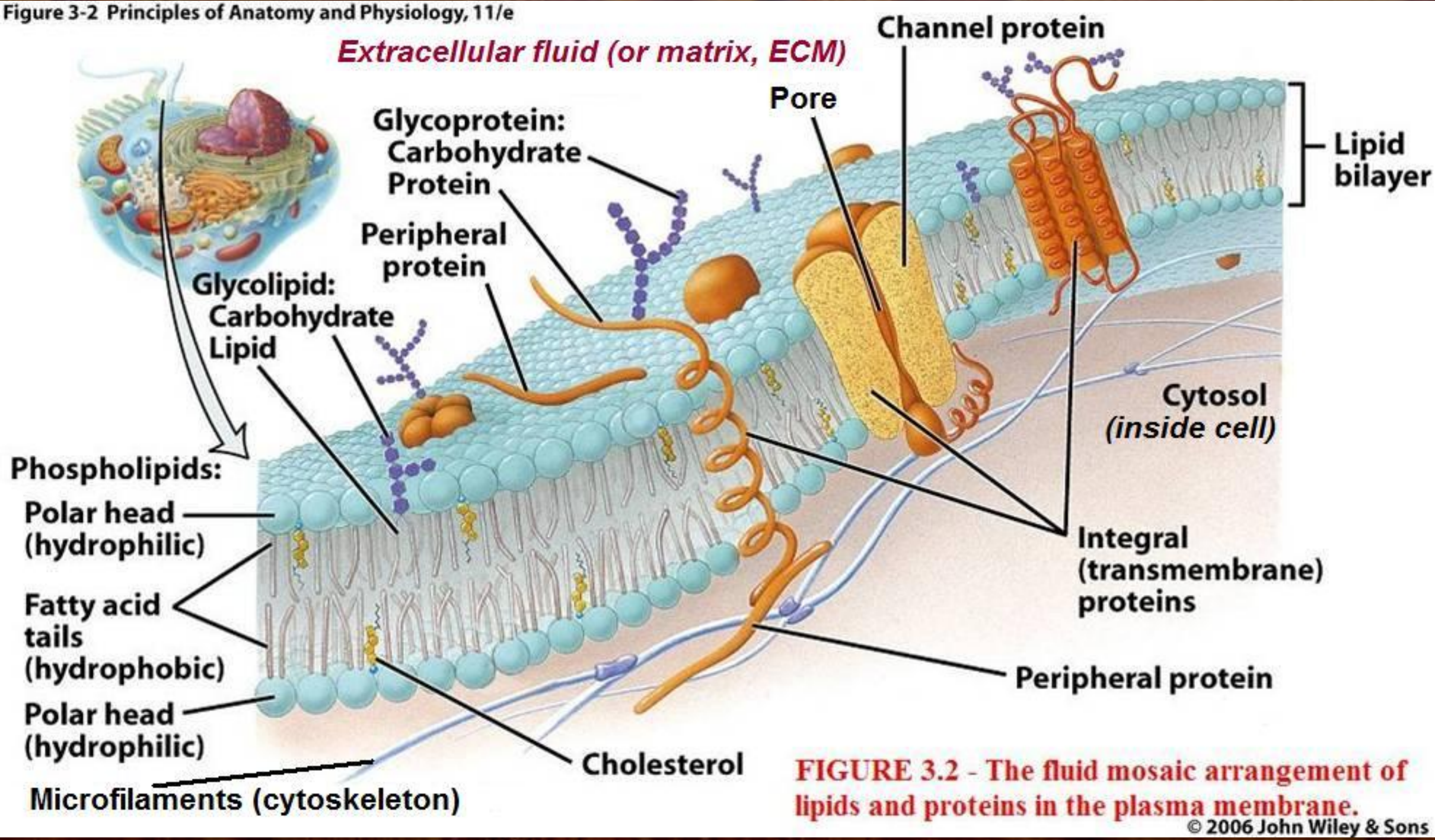


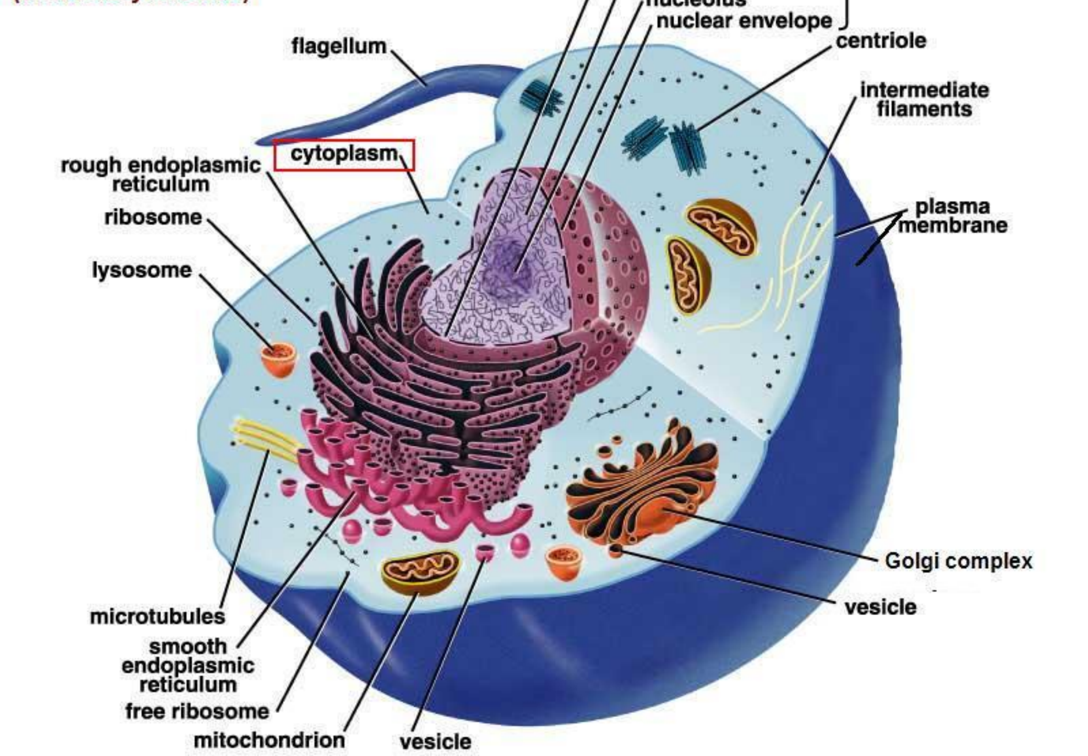
FIGURE 3.2 - The fluid mosaic arrangement of lipids and proteins in the plasma membrane.

- The eukaryotic plasma membrane has a greater variety of lipids than the prokaryotic membrane. It contains **sterols** (such as **cholesterol**) which adds rigidity to the membrane. Because of their larger size, eukaryotic cells have a much lower surface-to-volume ratio than prokaryotic cells. As the volume of cytoplasm enclosed by a membrane increases, the membrane is placed under greater stress. The sterols in the membrane may help it withstand the stress.

Cell Structures: **Cytoplasm**

- The thick, aqueous, semitransparent, and gelatinous substance or contents of the cell inside the plasma membrane, excluding the nucleus; **site of metabolic processes**.
- It is more complex than that of prokaryotes.
- **Cytosol:** The *fluid portion* of the cytoplasm.
- About 70-80% **water** and contains substances such as carbohydrates, proteins (such as enzymes), lipids, ions, and wastes.

FIGURE 5-3 - A generalized animal cell (an eukaryotic cell)



Eukaryotic Cell Organelles:
The Nucleus

- Organelle enclosed by a nuclear membrane that contains the **genetic material (DNA)** in eukaryotic organisms.
- It is the **control center** of the cell: all activities are regulated by it.
- **Nucleolus** (pl. nucleoli): spherical body in the nucleus that produces ribosomal subunits and rRNA (ribosomal RNA).
- The nucleus contain the **chromosomes:** the structures that carry the genetic material, or **genes** (segments of DNA).
- **Chromatin:** threadlike, uncondensed chromosomes.

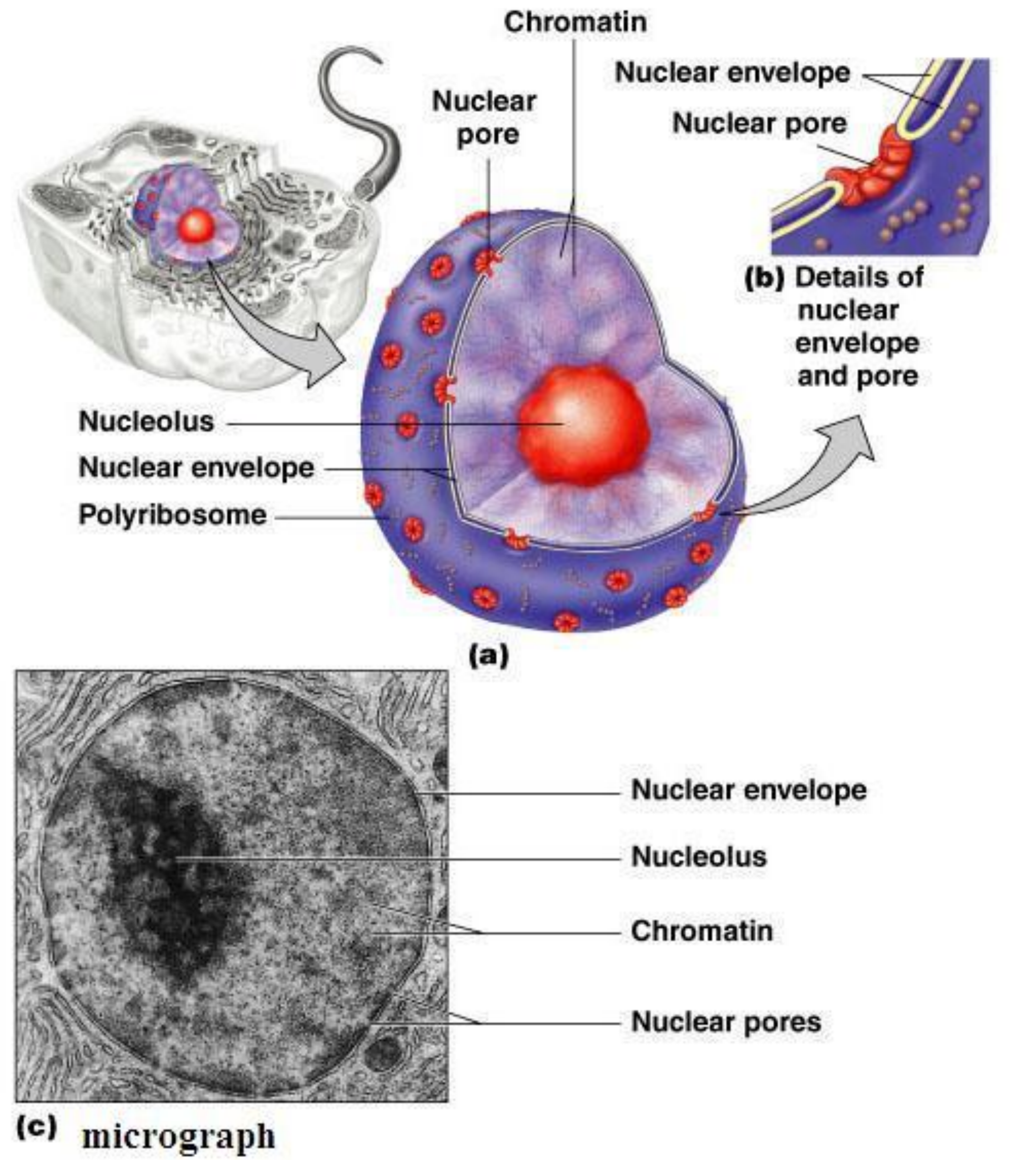
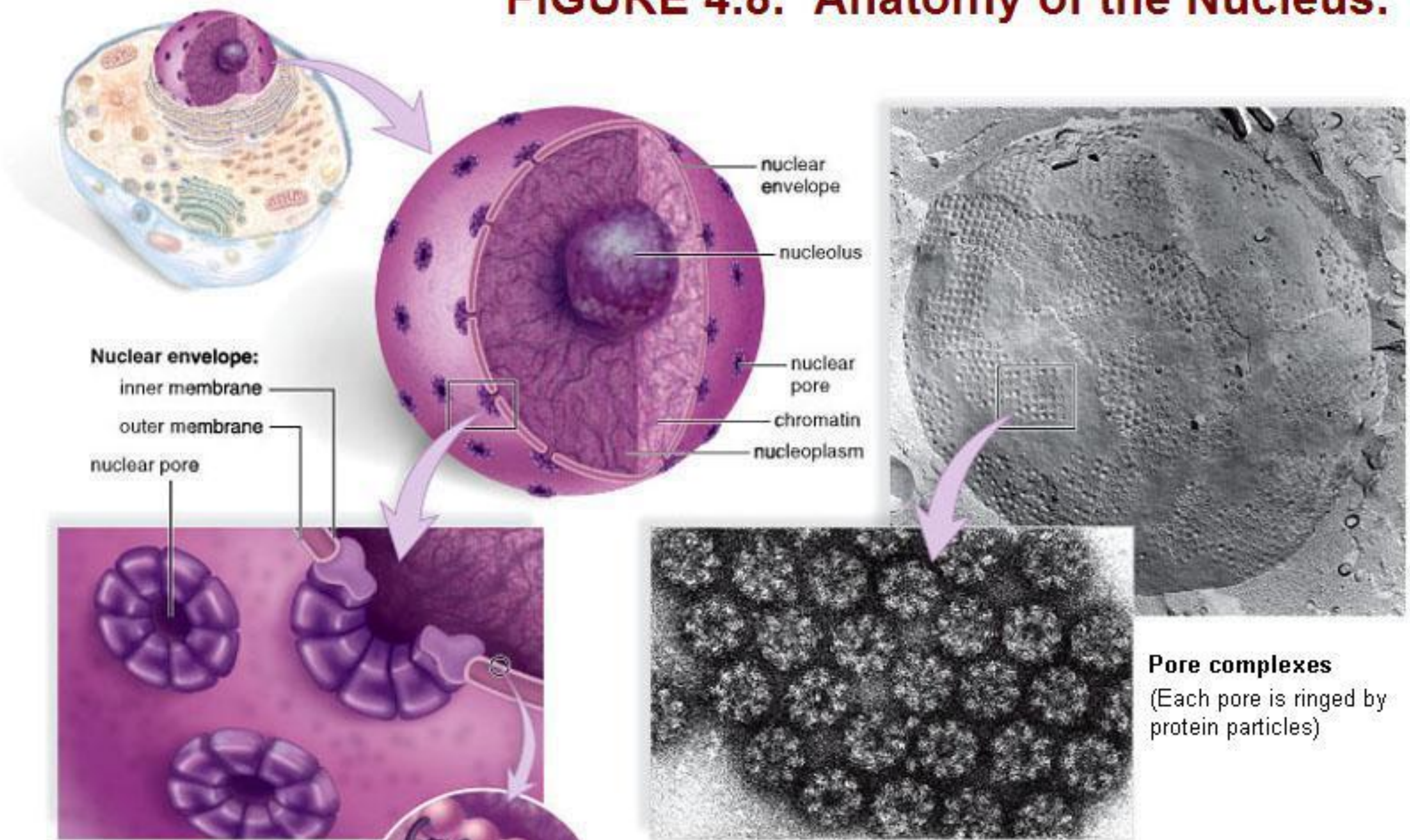
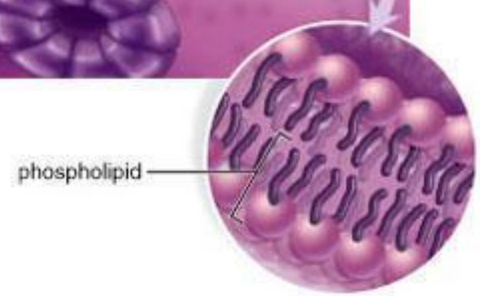


FIGURE 4.24 - The eukaryotic nucleus.

Eukaryotic Cell Organelles: **THE NUCLEUS**

FIGURE 4.8. Anatomy of the Nucleus.





The nucleus is the control center of the cell, containing the genetic information. It contains chromatin, a network of fibrils of DNA and associated proteins. The nucleolus is a region of chromatin where rRNA is produced, and ribosomal subunits are assembled.

Cell Structures: **Ribosomes**

- Nearly spherical, non-membranous structure, site of **protein synthesis** in cells (eukaryotic and prokaryotic). It is composed of RNA and protein.
- This electron micrograph of part of a pancreas cell shows many ribosomes, both free (in the cytosol) and bound (to the endoplasmic reticulum). The simplified diagram of a ribosome shows its two subunits.

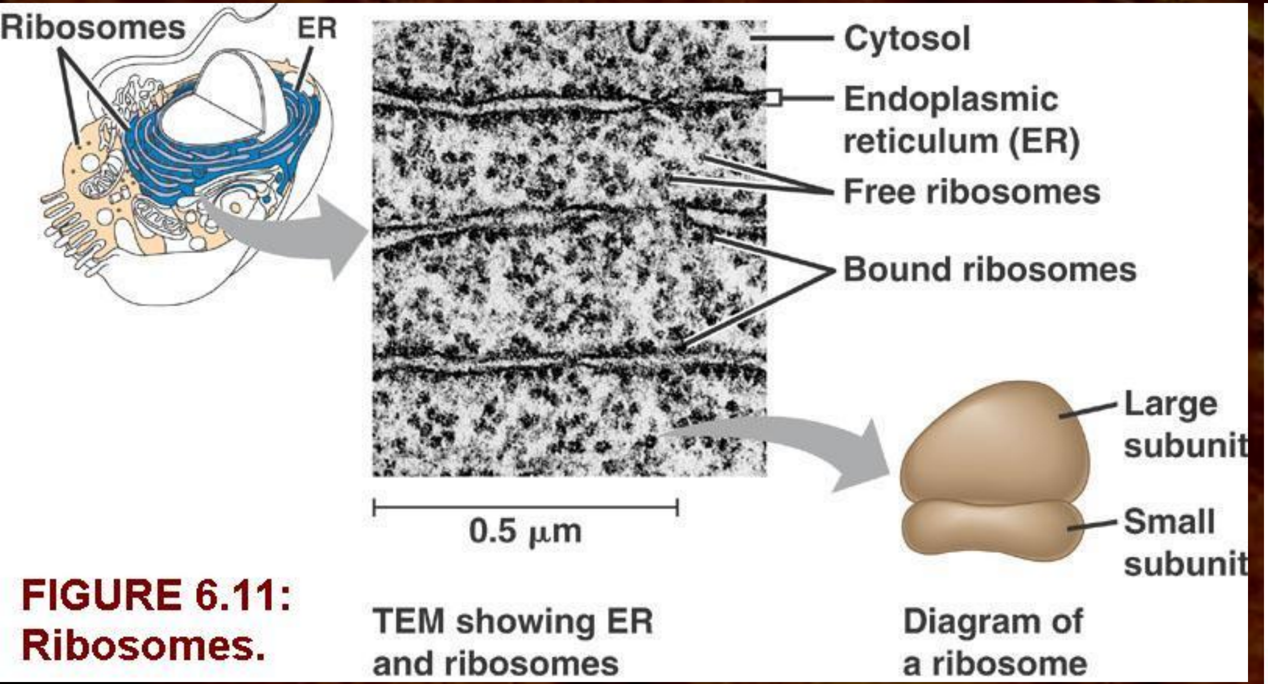


FIGURE 6.11: Ribosomes.

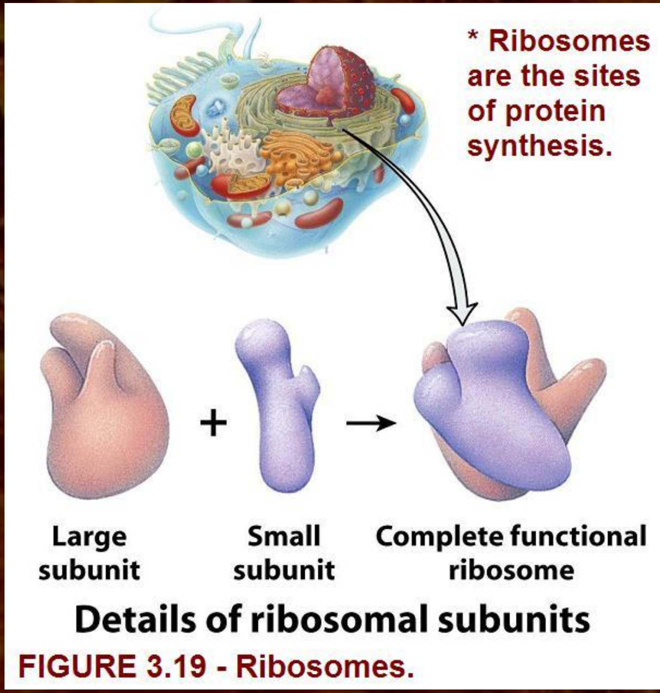
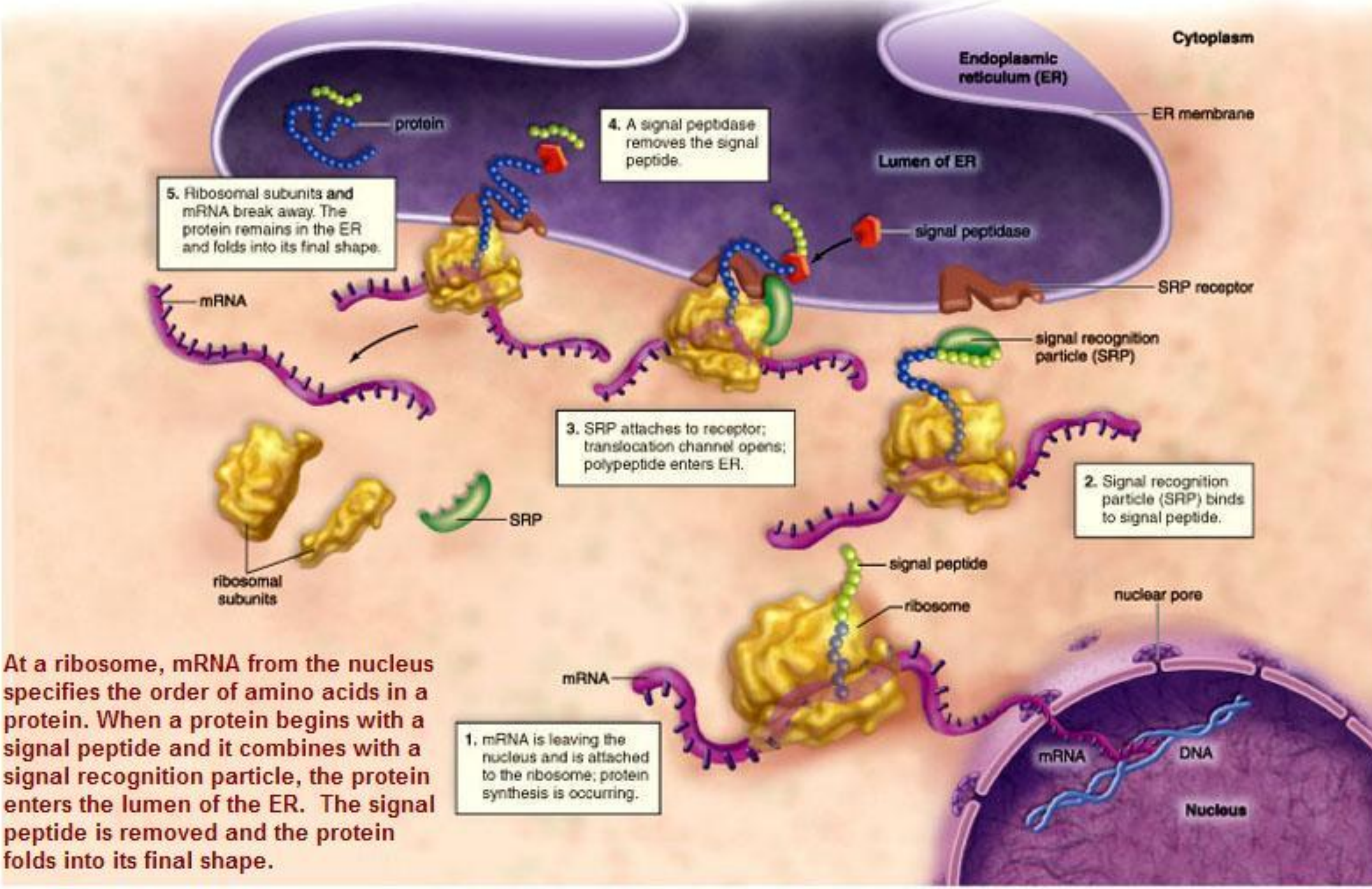


FIGURE 3.19 - Ribosomes.

FIGURE 4.9. Function of Ribosomes.

Ribosomes are sites of protein synthesis.



At a ribosome, mRNA from the nucleus specifies the order of amino acids in a protein. When a protein begins with a signal peptide and it combines with a signal recognition particle, the protein enters the lumen of the ER. The signal peptide is removed and the protein folds into its final shape.

The Eukaryotic Endomembrane System

- The **endomembrane system** regulates protein traffic and performs metabolic functions in the cell.
  - Synthesis of proteins and their transport into membranes and organelles or out of the cell.
  - Metabolism and movement of lipids and carbohydrates.
  - Detoxification of drugs and poisons.
- The endomembrane system includes:
  - The nuclear envelope, endoplasmic reticulum, Golgi apparatus, lysosomes, various kinds of vacuoles, and the plasma membrane.

Eukaryotic Cell Organelles:
The Endoplasmic Reticulum (ER)

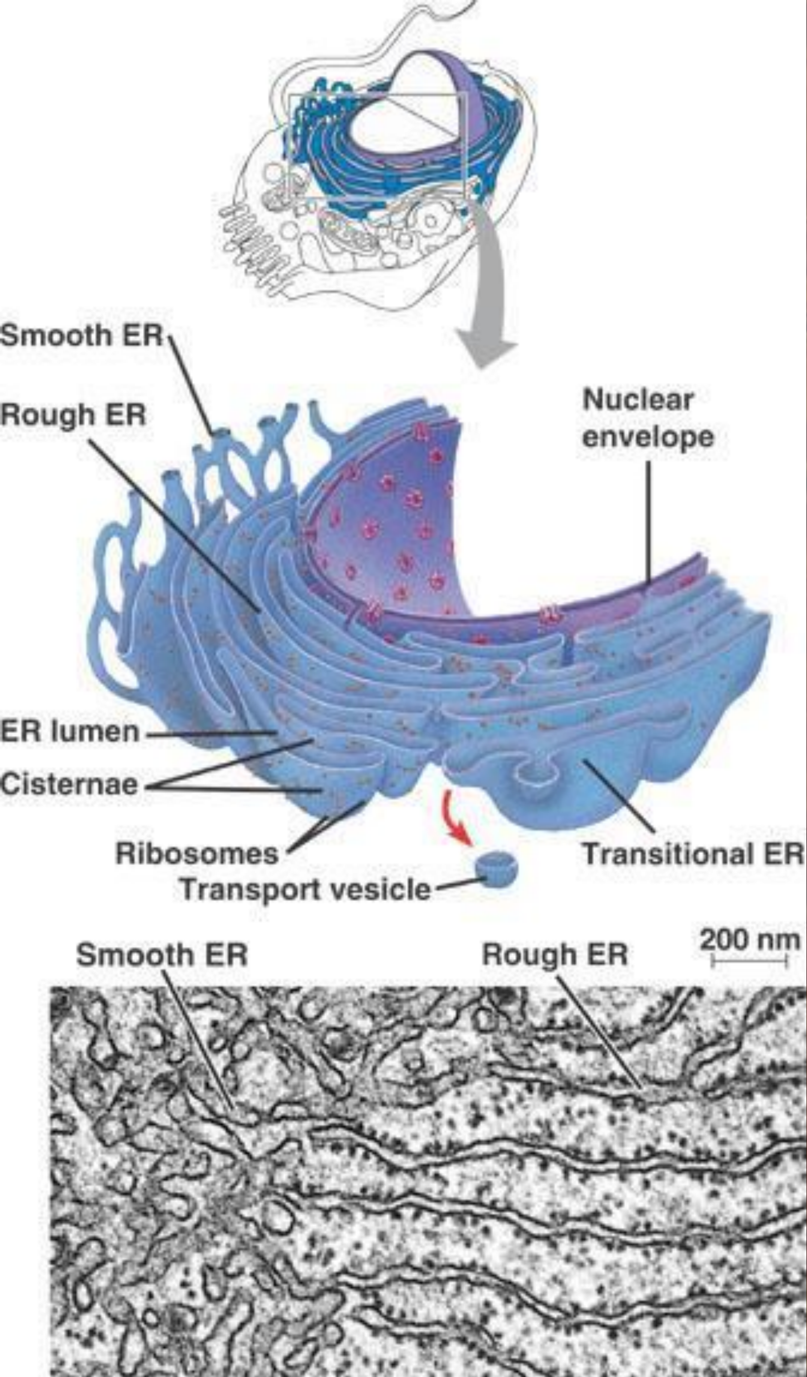
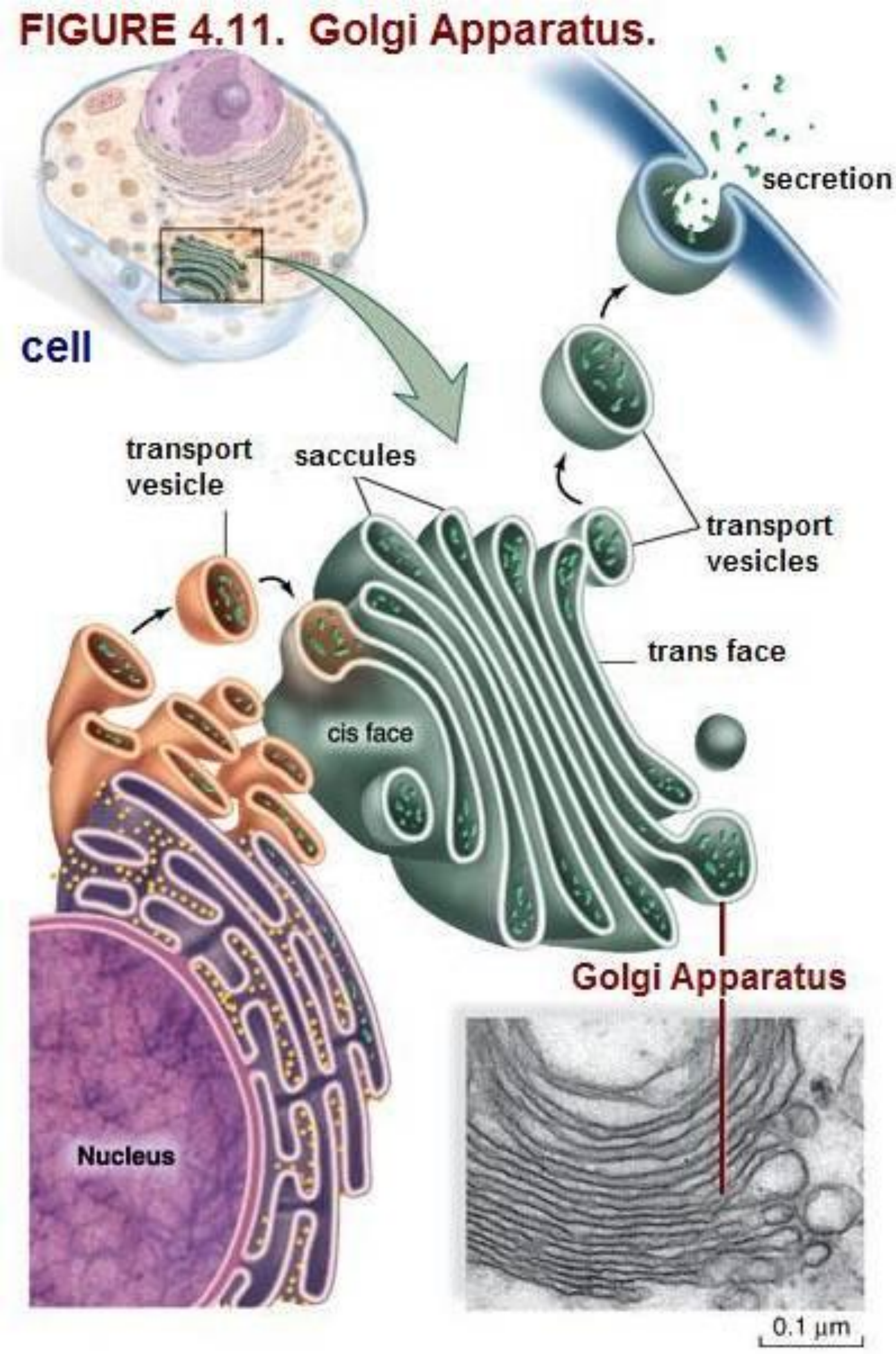


Figure 6.12. Endoplasmic Reticulum (ER)

- A system of **membranous** tubules and flattened sacs (***cisternae***) in the cytoplasmic matrix of eukaryotic cells.
- **Site of synthesis of lipids and proteins, and metabolism of carbohydrates.**
- **Rough or granular endoplasmic reticulum (RER or GER)** bears ribosomes on its surface; synthesizes secretory proteins and is the membrane factory for the cell.
- **Smooth or agranular endoplasmic reticulum (SER or AER)** lacks ribosomes; site of lipid synthesis, metabolism of carbohydrates, and detoxification of drugs and poisons.
- The ER is continuous with the nuclear envelope.
- Transport vesicles bud off from a region of the rough ER called transitional ER and travel to the Golgi apparatus and other destinations.



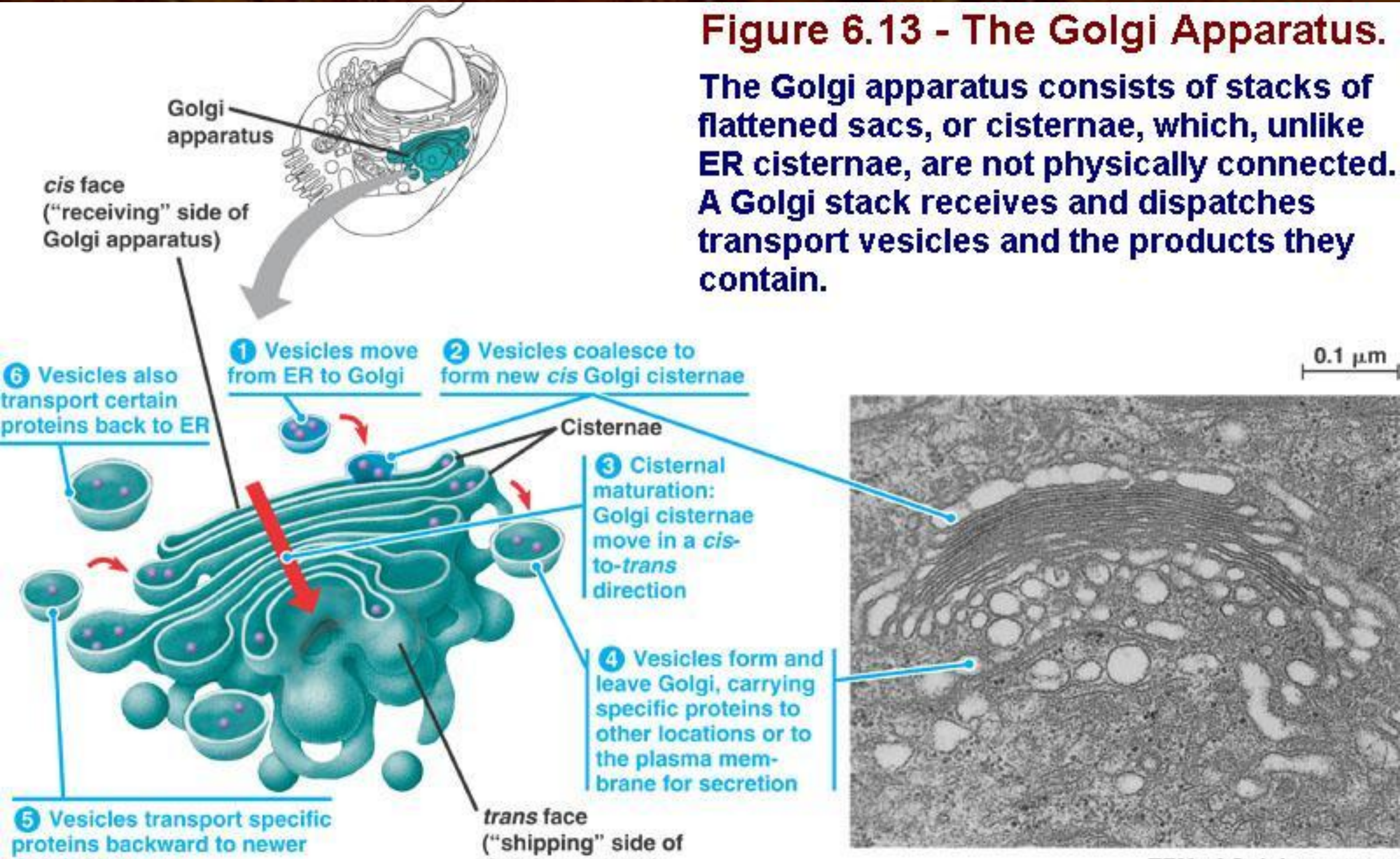
Eukaryotic Cell Organelles: **The Golgi Apparatus (Golgi Complex)**

- A membranous eukaryotic organelle composed of stacks of flattened sacs (**cisternae**), which is involved in ***modifying and packaging materials*** (such as lipids and proteins) for **secretion** out of the cell and for many other cell processes.
- It is like a **"sorting, shipping and receiving center"**. After leaving the ER, many transport vesicles travel to the Golgi apparatus.

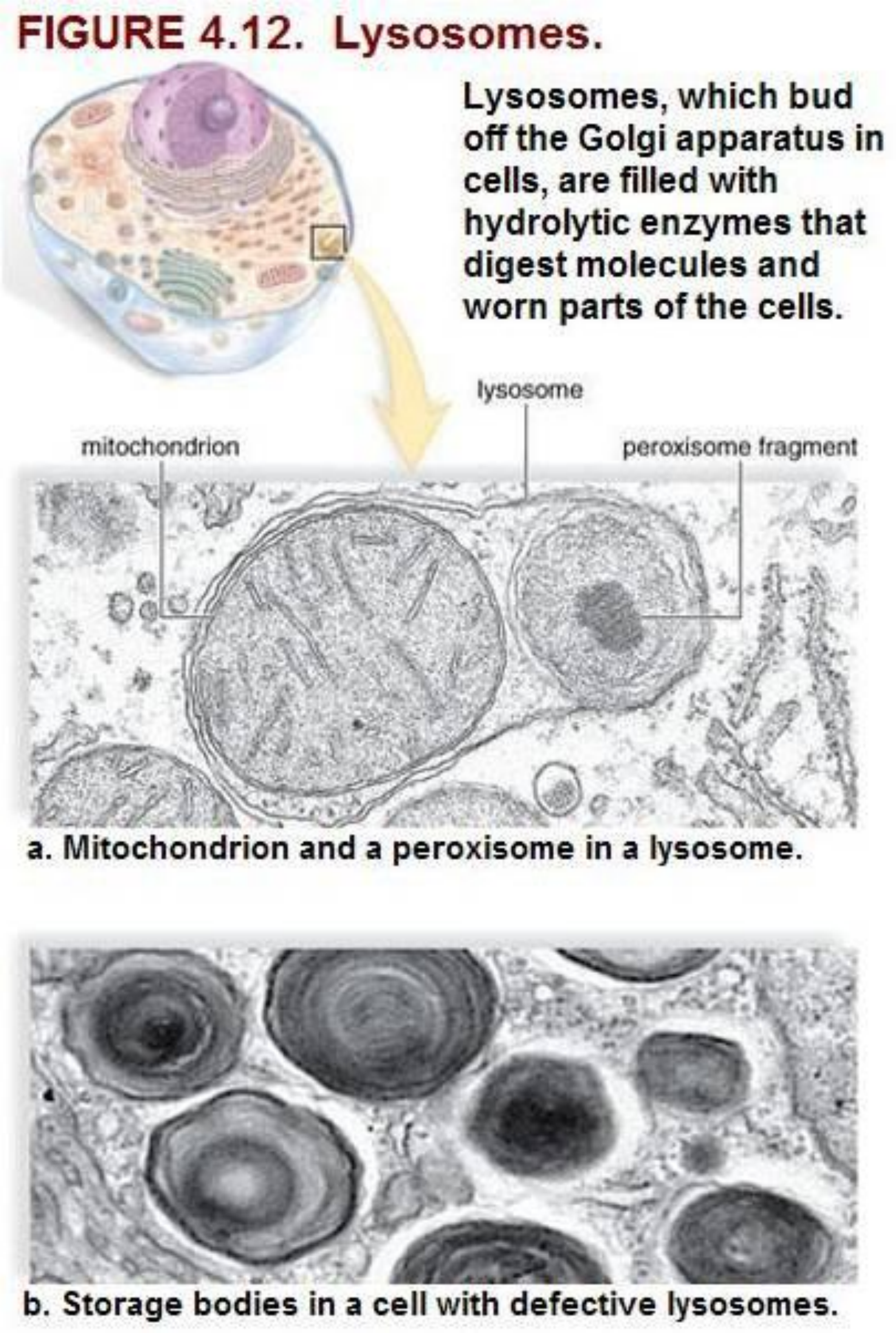
Eukaryotic Cell Organelles: **The Golgi Apparatus**

Figure 6.13 - The Golgi Apparatus.

The Golgi apparatus consists of stacks of flattened sacs, or cisternae, which, unlike ER cisternae, are not physically connected. A Golgi stack receives and dispatches transport vesicles and the products they contain.



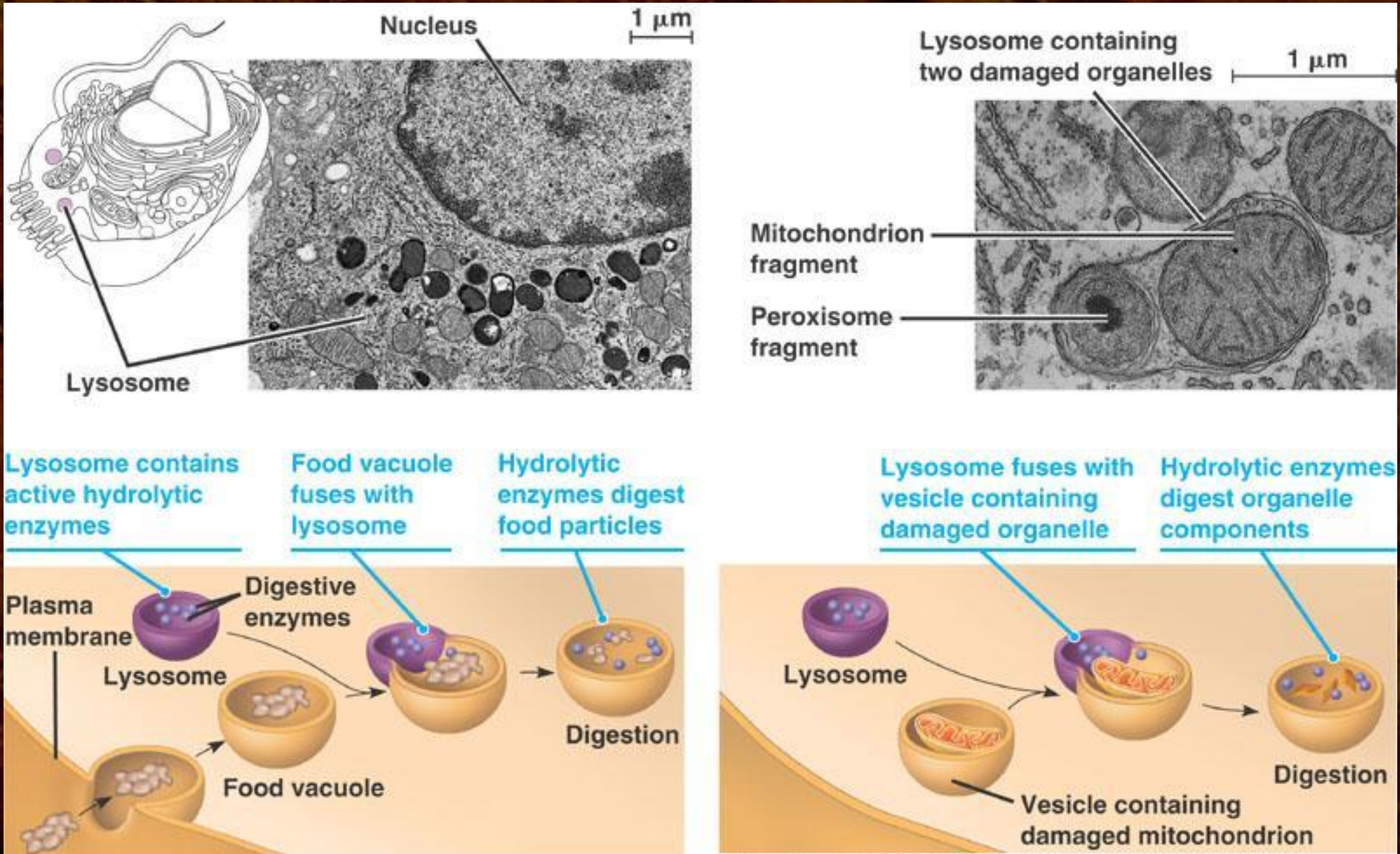
TEM of Golgi apparatus



Eukaryotic Cell Organelles: **Lysosomes**

- Lysosomes are **membrane-bounded vesicles** produced by the Golgi apparatus.
- They function in recycling cellular material, and destroying nonfunctional organelles and portions of cytoplasm.
- They contain **hydrolytic digestive enzymes** that digest molecules and worn parts of the cell.
- * Plants cell do not have lysosomes.

Eukaryotic Cell Organelles: **Lysosomes**



(a) Phagocytosis: lysosome digesting food

(b) Autophagy: lysosome breaking down damaged organelle

Fig. 6.14 - Lysosomes

Eukaryotic Cell Organelles: **Vacuoles**

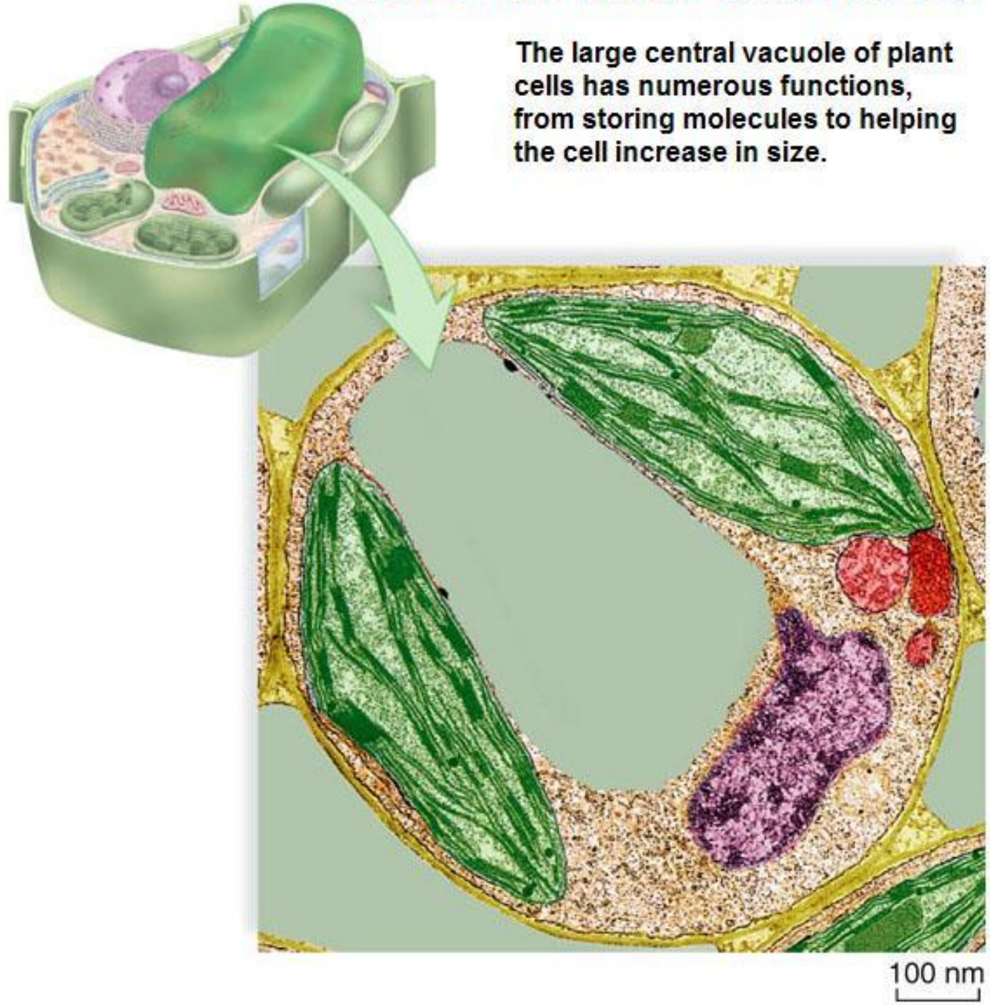
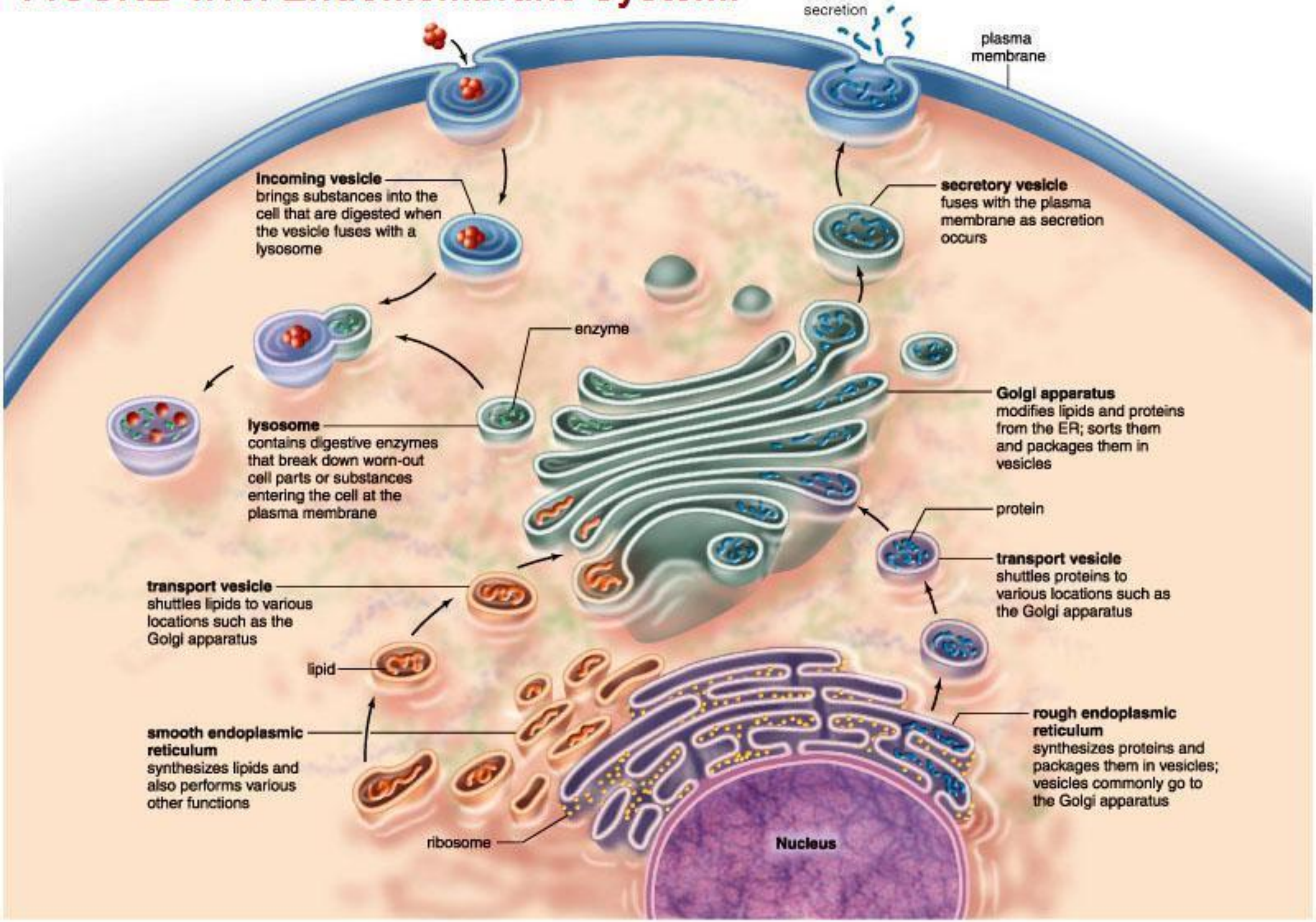


FIGURE 4.15. Plant Cell Central Vacuole.

The large central vacuole of plant cells has numerous functions, from storing molecules to helping the cell increase in size.

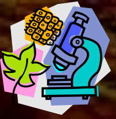
- Membrane-enclosed sacs that **store materials** such as starch, glycogen, or fat to be used for energy; they also break down substances (like lysosomes).
- Specialized vacuoles include:
  - ***Contractile vacuoles:*** get rid of excess water.
  - ***Digestive vacuoles:*** break down nutrients.
  - ***Central vacuole*:** for storage of materials in plants, surrounded by a membrane called the tonoplast.

FIGURE 4.13. Endomembrane System.



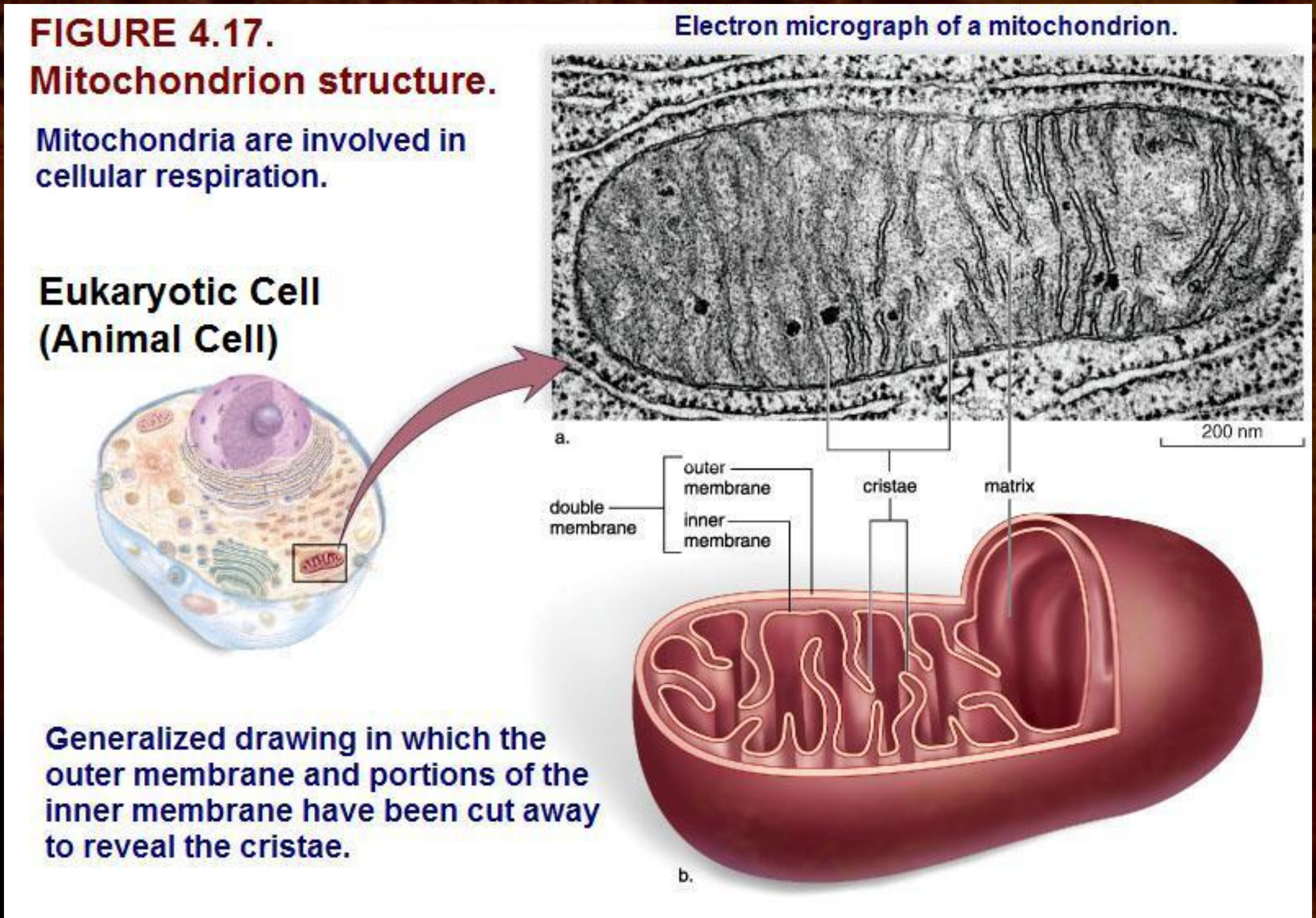
Eukaryotic Cell Organelles: **Mitochondria and Chloroplasts**

- In eukaryotic organisms, mitochondria and chloroplasts are the organelles that convert **energy** to forms that cells can use for work.
  - **Mitochondria** (singular: **mitochondrion**) are the sites of cellular respiration, the metabolic process that generates ATP by extracting energy from sugars, fats, and other fuels with the help of oxygen.
  - **Chloroplasts**, found only in **plants** and **algae**, are the sites of *photosynthesis*, the process of converting solar energy to chemical energy by absorbing sunlight and using it to drive the synthesis of organic compounds, such as sugars, from carbon dioxide and water.



Eukaryotic Cell Organelles: **The Mitochondrion**

- Membrane-bounded organelle in which **energy as ATP** (adenosine triphosphate, a nucleotide molecule) is produced during **cellular respiration**. It is the **"powerhouse"** of the cell.
- The ***cristae*** are infoldings of the inner membrane that increase the surface area.
- Free **ribosomes** are seen in the **matrix**, along with **DNA** molecules.



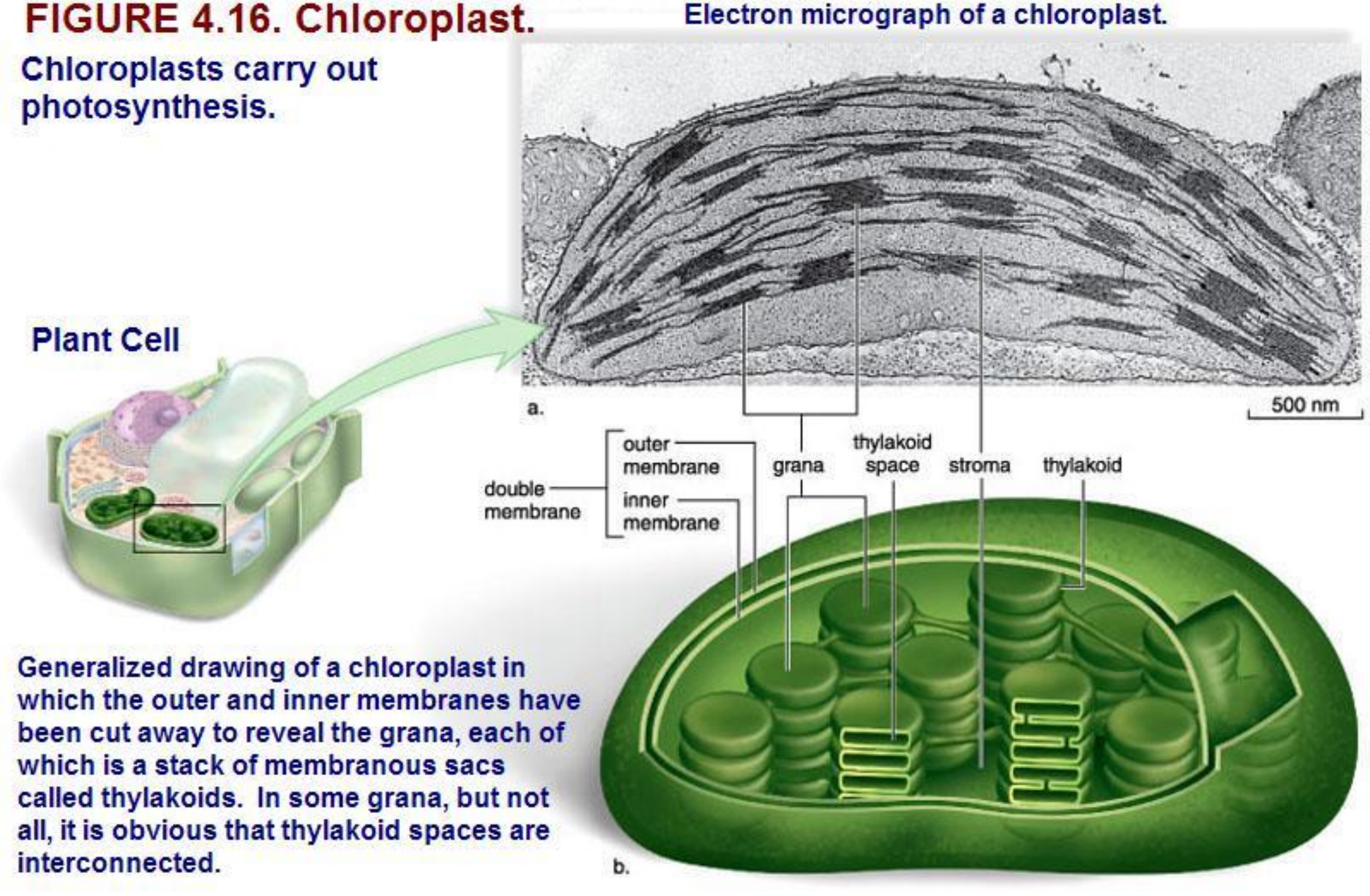
A **mitochondrion** is bounded by a double membrane with an intermembrane space. The inner membrane invaginates to form the shelflike ***cristae***.

Eukaryotic Cell Organelles: **The Chloroplast in Plants and Algae**

- The membranous organelle that performs **photosynthesis** (capture of sun light energy to convert it into chemical energy in carbohydrates), in *algae* and *plants*.
- It has internal membranes called ***thylakoids*** that contain the photosynthetic pigment ***chlorophyll***. The fluid outside the thylakoids is the **stroma**.

FIGURE 4.16. Chloroplast.

Chloroplasts carry out photosynthesis.



Generalized drawing of a chloroplast in which the outer and inner membranes have been cut away to reveal the grana, each of which is a stack of membranous sacs called thylakoids. In some grana, but not all, it is obvious that thylakoid spaces are interconnected.

Eukaryotic Cell Organelles: **Peroxisomes**

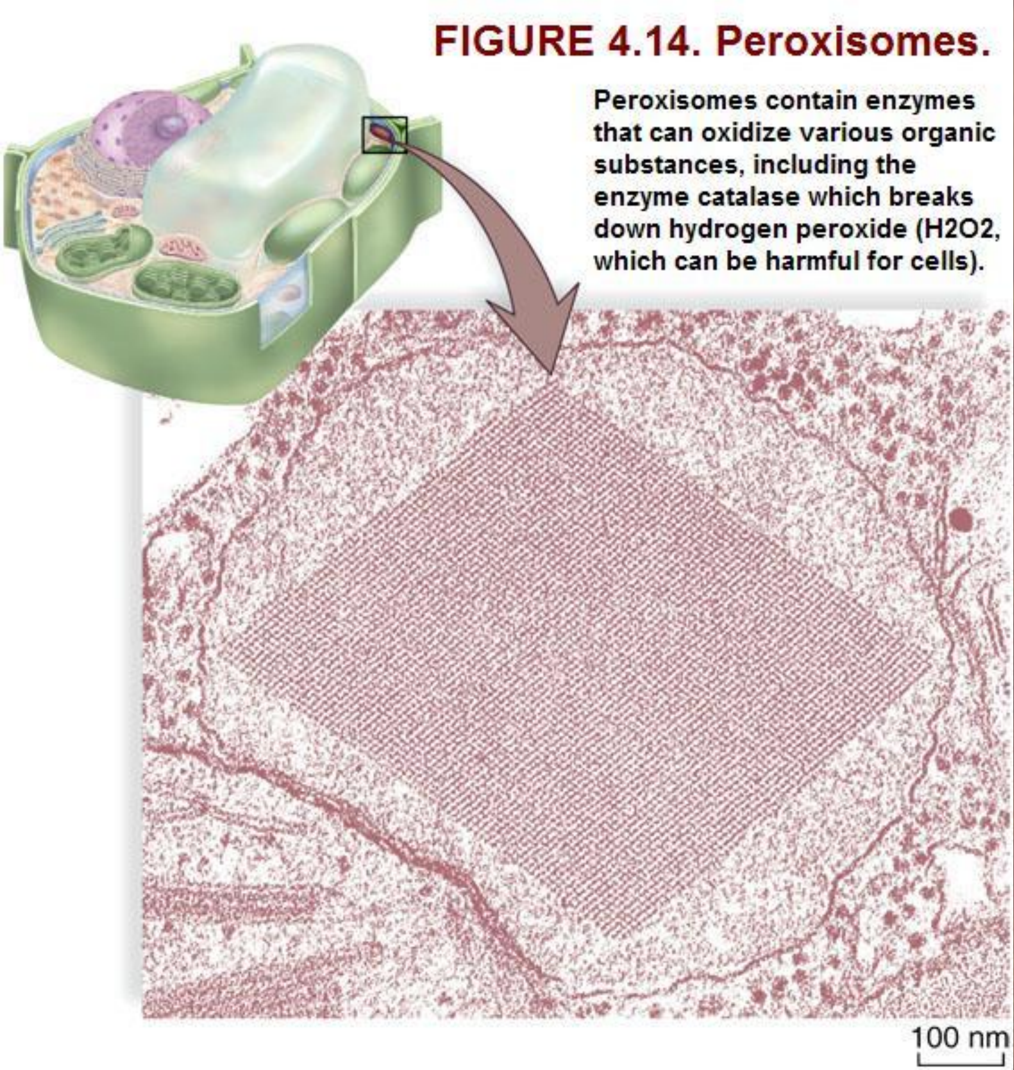


FIGURE 4.14. Peroxisomes.

Peroxisomes contain enzymes that can oxidize various organic substances, including the enzyme catalase which breaks down hydrogen peroxide (H2O2, which can be harmful for cells).

- These are membrane-bounded vesicles (similar to lysosomes) containing **enzymes** that oxidize various organic substances.
- One of those enzymes is **catalase**; it breaks down **hydrogen peroxide (H_2O_2)**, which can be harmful for cells if it accumulates in excess.
- Peroxisomes in the liver **detoxify alcohol and other harmful compounds** by transferring hydrogen from the poisons to oxygen (forming the H_2O_2) that is then converted to water.

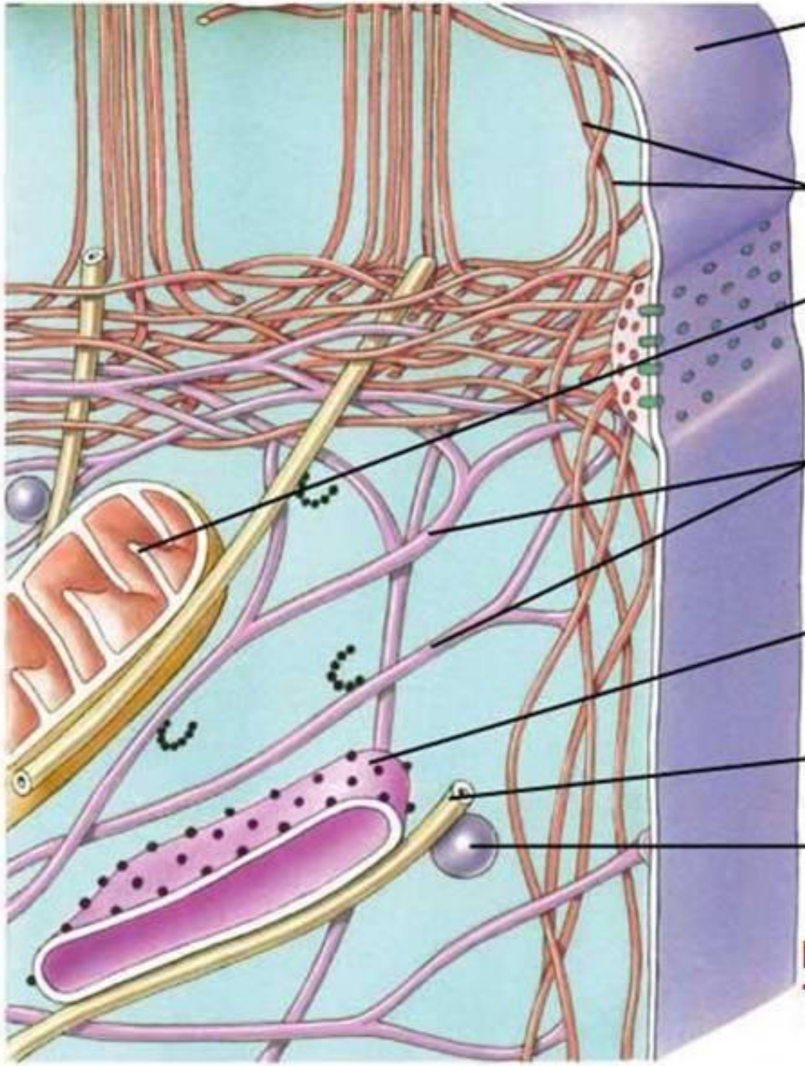
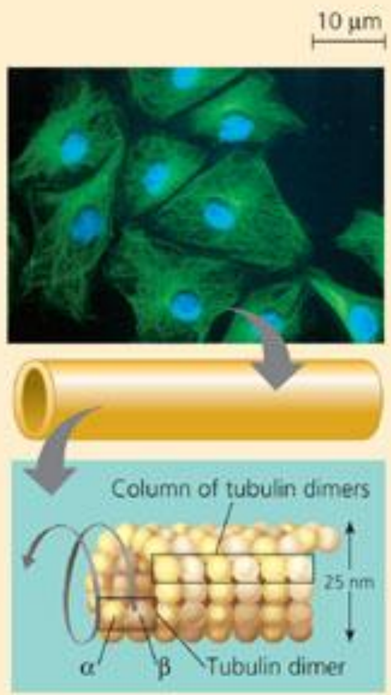
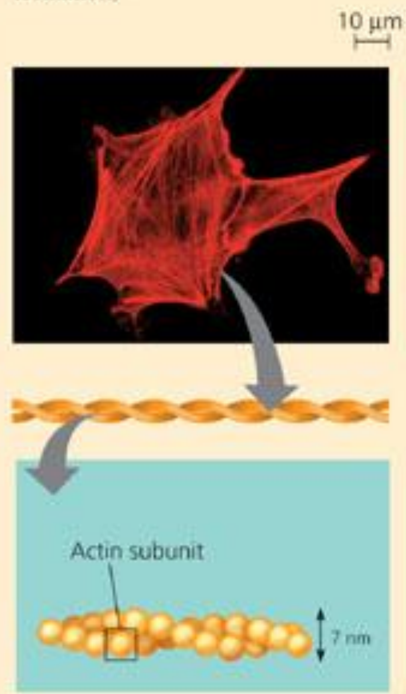
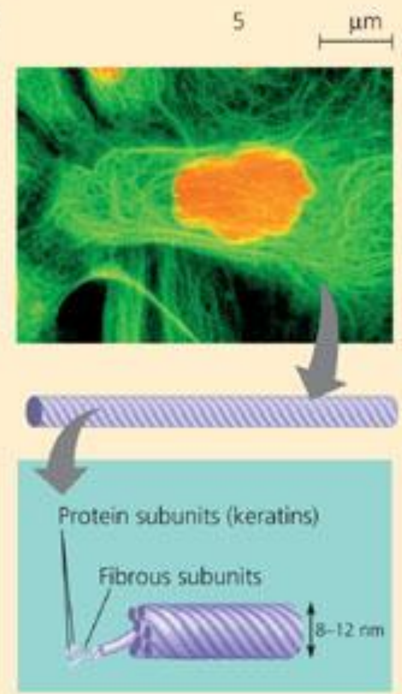


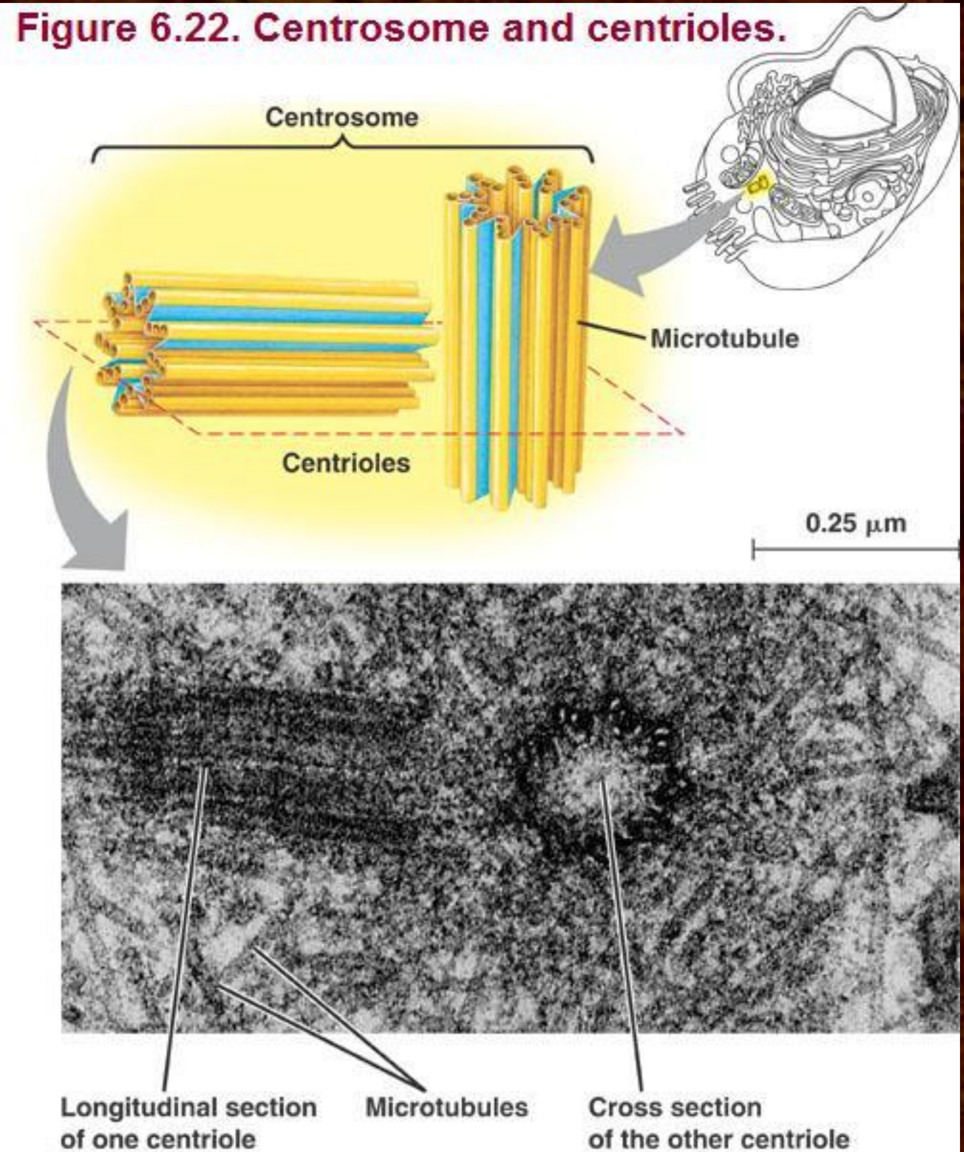
FIGURE 5-16.
The cytoskeleton.

Cell Structures:
Cytoskeleton

- Internal framework of protein fibers, made of **microtubules** (hollow tubes) and **microfilaments** (filamentous actin tubes).
- Supports, protects, and gives rigidity and shape to a cell, enables movement of the cell and cellular structures, and is involved in cellular division and regulation of biochemical activities.

Table 6.1 The Structure and Function of the Cytoskeleton

Property	Microtubules (Tubulin Polymers)	Microfilaments (Actin Filaments)	Intermediate Filaments
Structure	Hollow tubes; wall consists of 13 columns of tubulin molecules	Two intertwined strands of actin, each a polymer of actin subunits	Fibrous proteins supercoiled into thicker cables
Diameter	25 nm with 15-nm lumen	7 nm	8–12 nm
Protein subunits	Tubulin, consisting of α-tubulin and β-tubulin	Actin	One of several different proteins of the keratin family, depending on cell type
Main functions	Maintenance of cell shape (compression-resisting "girders") Cell motility (as in cilia or flagella) Chromosome movements in cell division Organelle movements	Maintenance of cell shape (tension-bearing elements) Changes in cell shape Muscle contraction Cytoplasmic streaming Cell motility (as in pseudopodia) Cell division (cleavage furrow formation)	Maintenance of cell shape (tension-bearing elements) Anchorage of nucleus and certain other organelles Formation of nuclear lamina
Micrographs of fibroblasts, a favorite cell type for cell biology studies. Each has been experimentally treated to fluorescently tag the structure of interest.			



Cell Structures: **Cytoskeleton: Centrosomes and Centrioles**

- **Centrosome:** Region located near the nucleus in animal cells that functions as a "microtubule-organizing center". A centrosome has two centrioles.
- **Centrioles:** Pair of short cylinders with nine microtubule triplets, and none in the middle.
- These rings give rise to the microtubules of cilia and flagella, and are involved in spindle formation for chromosome movement during cell division.

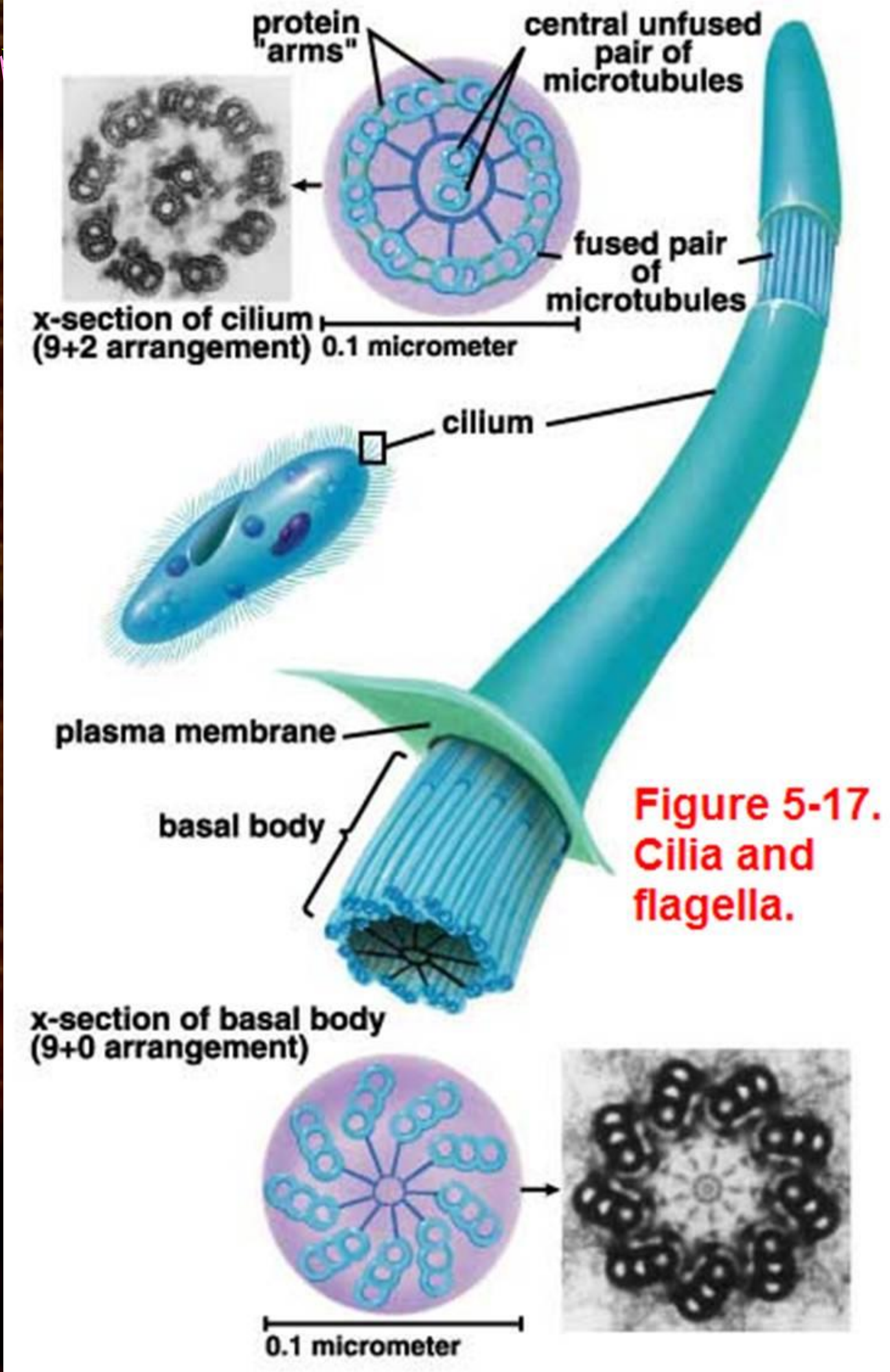


Figure 5-17. Cilia and flagella.

Other Cell Structures: **Cilia and Flagella**

- **Cilia** and **flagella** (in *singular*: cilium and flagellum) are hairlike projections from the plasma membrane that are involved in cell movement (locomotion) in some eukaryotic cells.
- Their construction in eukaryotes: nine protein microtubule doublets anchored to a central pair of microtubules.
- Cilia are shorter and more abundant than flagella.
- Prokaryotes (bacteria) may also have flagella that differ structurally and functionally.

Other Cell Structures: **Cilia and Flagella**

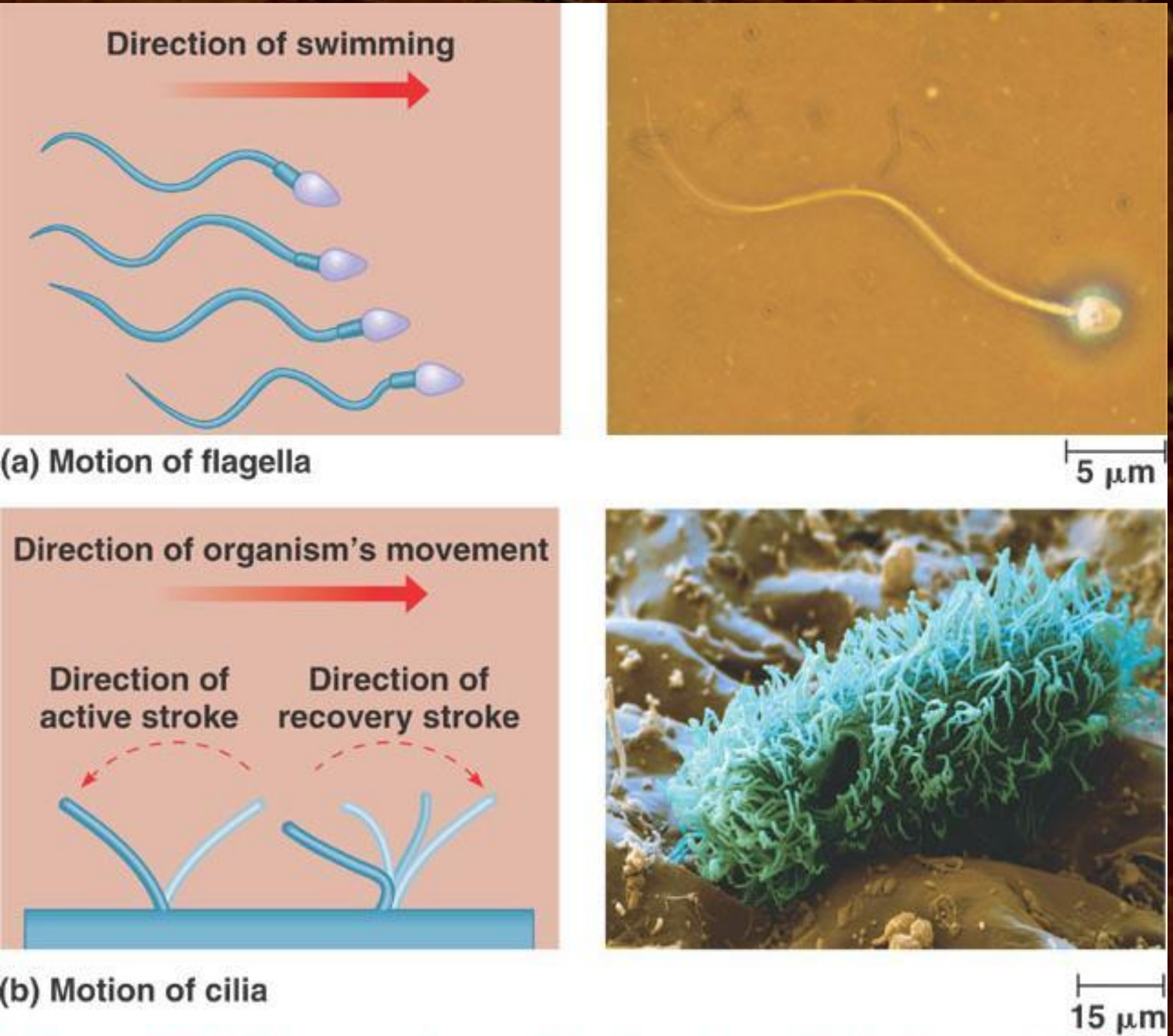
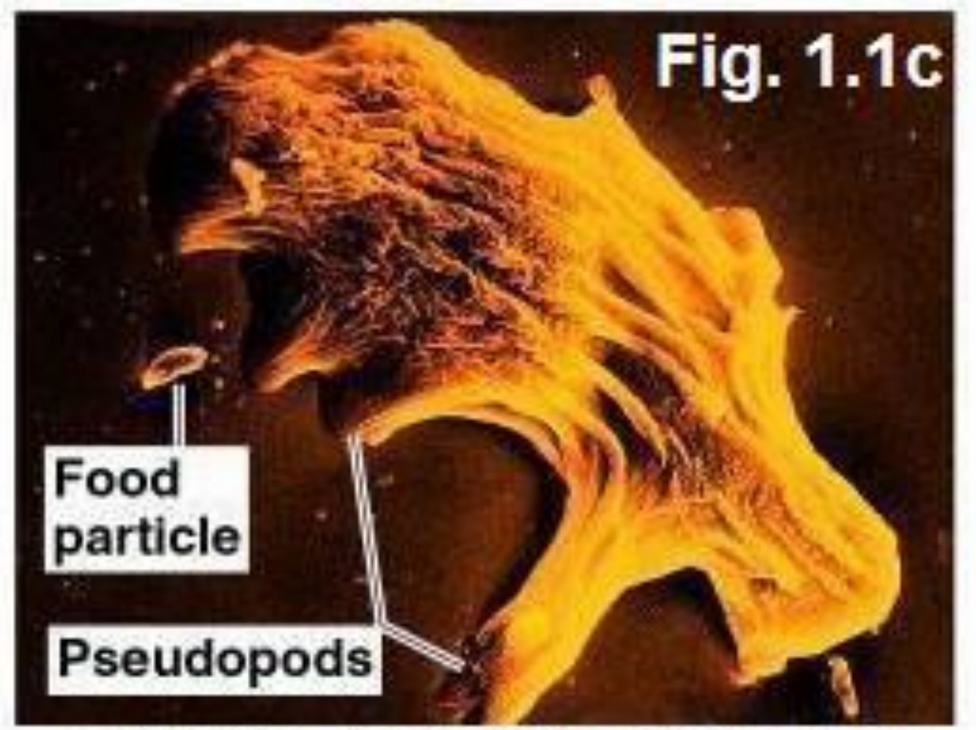


Figure 6.23. A comparison of the beating of flagella and cilia.

a) **Motion of flagella.** A flagellum usually undulates in a snakelike motion. Propulsion of a human sperm cell is an example of flagellar locomotion.

b) **Motion of cilia.** Cilia have a back-and-forth motion. This freshwater protozoan (*Colpidium*) has a dense nap of cilia.

Other Eukaryotic Cell Structures: **Pseudopods**



Protozoan (an amoeba)

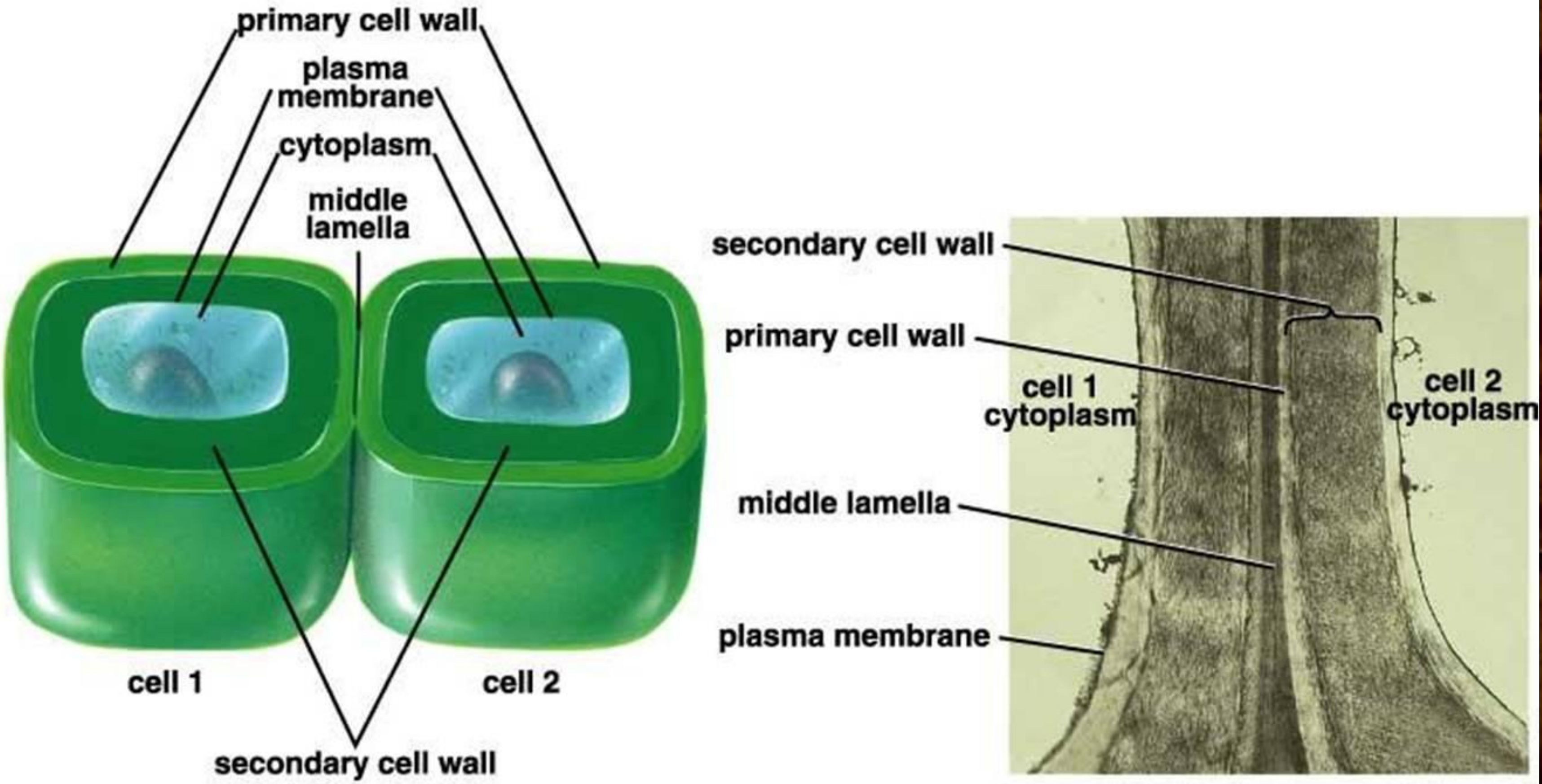
- Pseudopods or Pseudopodia
  - Extensions of a eukaryotic cell that aid in **moving** and **feeding**.
  - Pseudopodia are found, for example, in protists such as ***amoebas*** (which are microscopic eukaryotes).

Cell Structures: **Cell Wall**

- The ***outer covering*** of some eukaryotes (**algae** and some other **protists, plants, fungi**) and most prokaryotes, surrounding the plasma membrane.
- *** Functions:** It maintains the **shape** and provides **strength** and **protection** to the cell; it also prevents lysis (rupture) and excessive uptake of water.
- In *eukaryotes* the cell wall consists of polysaccharides such as **cellulose** in algae and plants, and **chitin** in fungi.
- Animal cells do not have a cell wall.

Eukaryotic Cell Wall (In Plant Cells)

FIGURE 4-12. Plant Cell Walls.



Each plant cell secretes cellulose and other carbohydrates to form a cell wall outside the plasma membrane. Many plant cells also produce secondary cell walls. The middle lamella separates adjacent plant cells.

Eukaryotic Cell Structures:
Extracellular Matrix (ECM) of Animal Cells

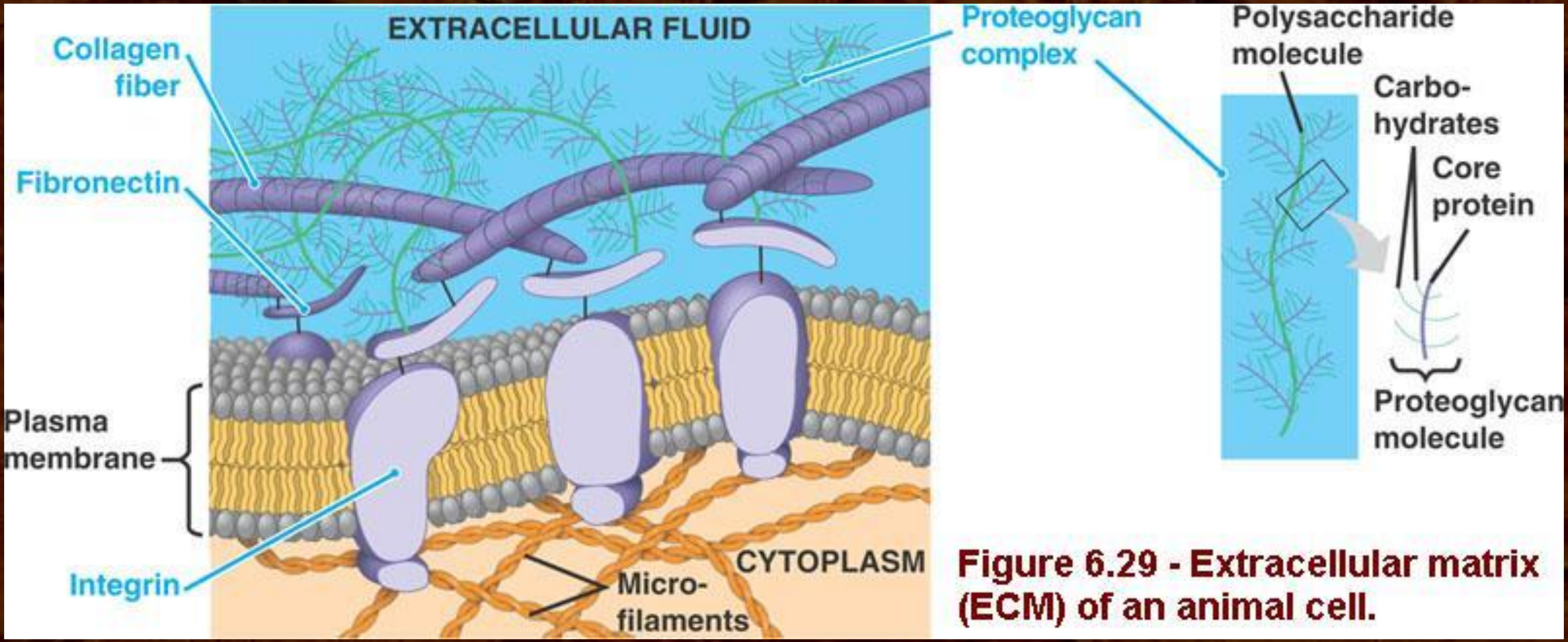


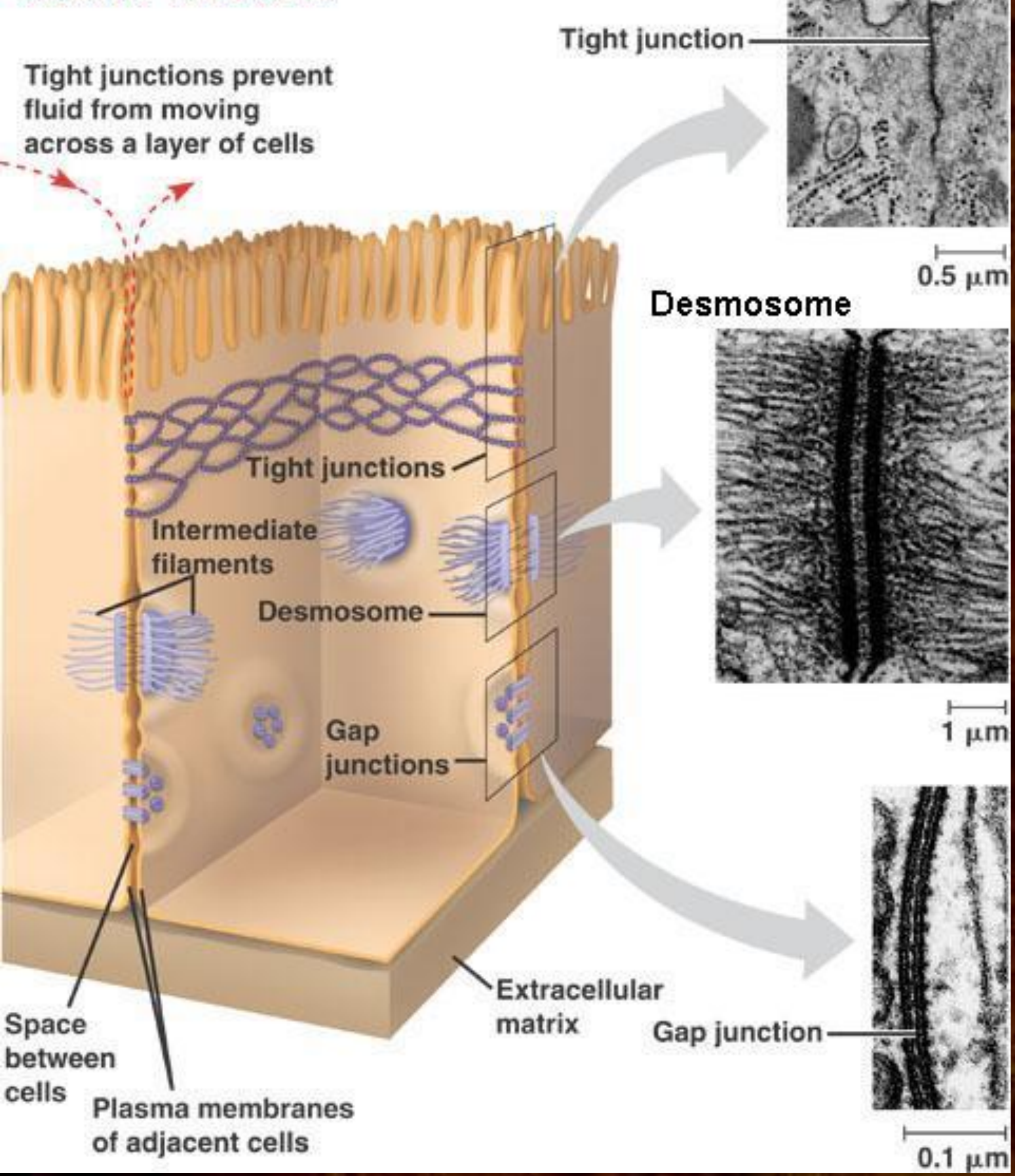
Figure 6.29 - Extracellular matrix (ECM) of an animal cell.

- Although animal cells do not have walls akin to those of plant cells, they do have an elaborate substance called the **extracellular matrix (ECM)**.
- The main ingredients of the ECM are **glycoproteins** (carbohydrate-protein).
  - Collagen, proteoglycans, fibronectin, integrins.

Eukaryotic Cell Structures: **Intercellular Junctions**

- The many cells of an animal or plant are organized into tissues, organs, and organ systems. Neighboring cells often adhere, interact, and communicate through special patches of direct physical contact called **intercellular junctions**.
- * In **plants:** **plasmodesmata** are channels in the cell walls that connect the chemical environments of adjacent cells; they are similar in function to gap junctions in animal cells.
- * In **animals:** the connections are called **tight junctions**, **desmosomes**, and **gap junctions**.

Figure 6.31 - Intercellular Junctions in Animal Tissues.



Eukaryotic Cell Structures: **Intercellular Junctions**

- At **tight junctions**, the membranes of neighboring cells are very tightly pressed against each other, bound together by specific proteins.
- **Desmosomes** (anchoring junctions) function like rivets, fastening cells together into strong sheets.
- **Gap junctions** (communicating junctions) provide cytoplasmic channels from one cell to an adjacent cell. Special membrane proteins surround a pore.

Table 5-2 Cell Structures, Their Functions, and Their Distribution in Living Cells

Structure	Function	Prokaryotes	Plants	Animals
Cell surface				
Cell wall	Protects, supports cell	Present	Present	Absent
Plasma membrane	Isolates cell contents from environment; regulates movement of materials into and out of cell; communicates with other cells	Present	Present	Present
Organization of genetic material				
Genetic material	Encodes information needed to construct cell and control cellular activity	DNA	DNA	DNA
Chromosomes	Contain and control use of DNA	Single, circular, no proteins	Many, linear, with proteins	Many, linear, with proteins
Nucleus	Membrane-bound container for chromosomes	Absent	Present	Present
Nuclear envelope	Encloses nucleus; regulates movement of materials into and out of nucleus	Absent	Present	Present
Nucleolus	Synthesizes ribosomes	Absent	Present	Present
Cytoplasmic structures				
Mitochondria	Produce energy by aerobic metabolism	Absent	Present	Present
Chloroplasts	Perform photosynthesis	Absent	Present	Absent
Ribosomes	Provide site of protein synthesis	Present	Present	Present
Endoplasmic reticulum	Synthesizes membrane components and lipids	Absent	Present	Present
Golgi complex	Modifies and packages proteins and lipids; synthesizes carbohydrates	Absent	Present	Present
Lysosomes	Contain intracellular digestive enzymes	Absent	Present	Present
Plastids	Store food, pigments	Absent	Present	Absent
Central vacuole	Contains water and wastes; provides turgor pressure to support cell	Absent	Present	Absent
Other vesicles and vacuoles	Contain food obtained through phagocytosis; contain secretory products	Absent	Present (some)	Present
Cytoskeleton	Gives shape and support to cell; positions and moves cell parts	Similar structures	Present	Present
Centrioles	Synthesize microtubules of cilia and flagella; may produce spindle in animal cells	Absent	Absent (in most)	Present
Cilia and flagella	Move cell through fluid or move fluid past cell surface	Present[a]	Absent (in most)	Present

[a] Many prokaryotes have structures called *flagella*, but these are not made of microtubules and move in a fundamentally different way than do eukaryotic cilia or flagella.

TABLE 3.2 Cell Parts and Their Functions

Part	Structure	Functions
Plasma Membrane	Fluid-mosaic lipid bilayer (phospholipids, cholesterol, and glycolipids) studded with proteins; surrounds cytoplasm.	Protects cellular contents; makes contact with other cells; contains channels, transporters, receptors, enzymes, cell-identity markers, and linker proteins; mediates the entry and exit of substances.
Cytoplasm	Cellular contents between the plasma membrane and nucleus—cytosol and organelles.	Site of all intracellular activities except those occurring in the nucleus.
Cytosol	Composed of water, solutes, suspended particles, lipid droplets, and glycogen granules.	Medium in which many of cell's metabolic reactions occur.
Organelles	Specialized structures with characteristic shapes.	Each organelle has specific functions.
Cytoskeleton	Network of three types of protein filaments: microfilaments, intermediate filaments, and microtubules.	Maintains shape and general organization of cellular contents; responsible for cellular movements.
Centrosome	A pair of centrioles plus pericentriolar material.	The pericentriolar material contains tubulins, which are used for growth of the mitotic spindle and microtubule formation.
Cilia and flagella	Motile cell surface projections that contain 20 microtubules and a basal body.	Cilia move fluids over a cell's surface; flagella move an entire cell.

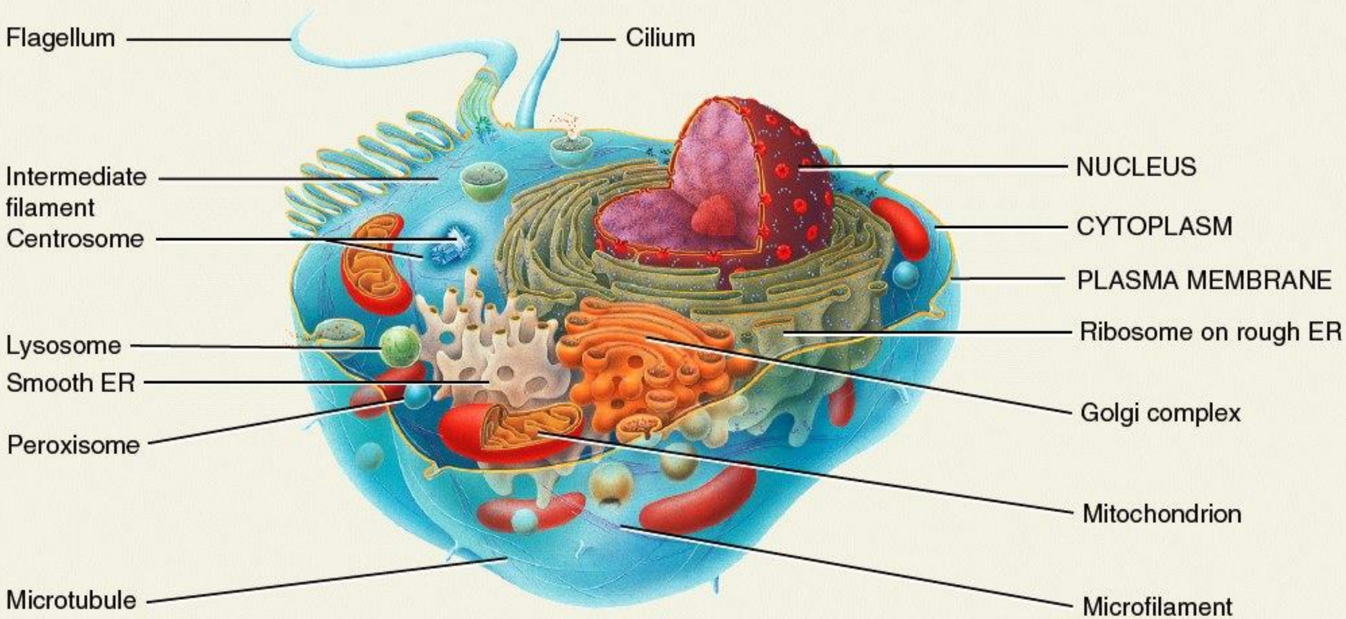


Table 3-2 part 1 Principles of Anatomy and Physiology, 11/e

TABLE 3.2 Cell Parts and Their Functions

Part	Structure	Functions
Ribosome	Composed of two subunits containing ribosomal RNA and proteins; may be free in cytosol or attached to rough ER.	Protein synthesis.
Endoplasmic reticulum (ER)	Membranous network of flattened sacs or tubules. Rough ER is covered by ribosomes and is attached to nuclear envelope; smooth ER lacks ribosomes.	Rough ER synthesizes glycoproteins and phospholipids that are transferred to cellular organelles, inserted into the plasma membrane, or secreted during exocytosis. Smooth ER synthesizes fatty acids and steroids; inactivates or detoxifies drugs; removes phosphate group from glucose-6-phosphate; and stores and releases calcium ions in muscle cells.
Golgi complex	Consists of 3–20 flattened membranous sacs called cisternae; structurally and functionally divided into entry (*cis*) face, medial cisternae, and exit (*trans*) face.	Entry *(cis)* face accepts proteins from rough ER; medial cisternae form glycoproteins, glycolipids, and lipoproteins; exit *(trans)* face modifies the molecules further, then sorts and packages them for transport to their destinations.
Lysosome	Vesicle formed from Golgi complex; contains digestive enzymes.	Fuses with and digests contents of endosomes, pinocytic vesicles, and phagosomes and transports final products of digestion into cytosol; digests worn-out organelles (autophagy), entire cells (autolysis), and extracellular materials.

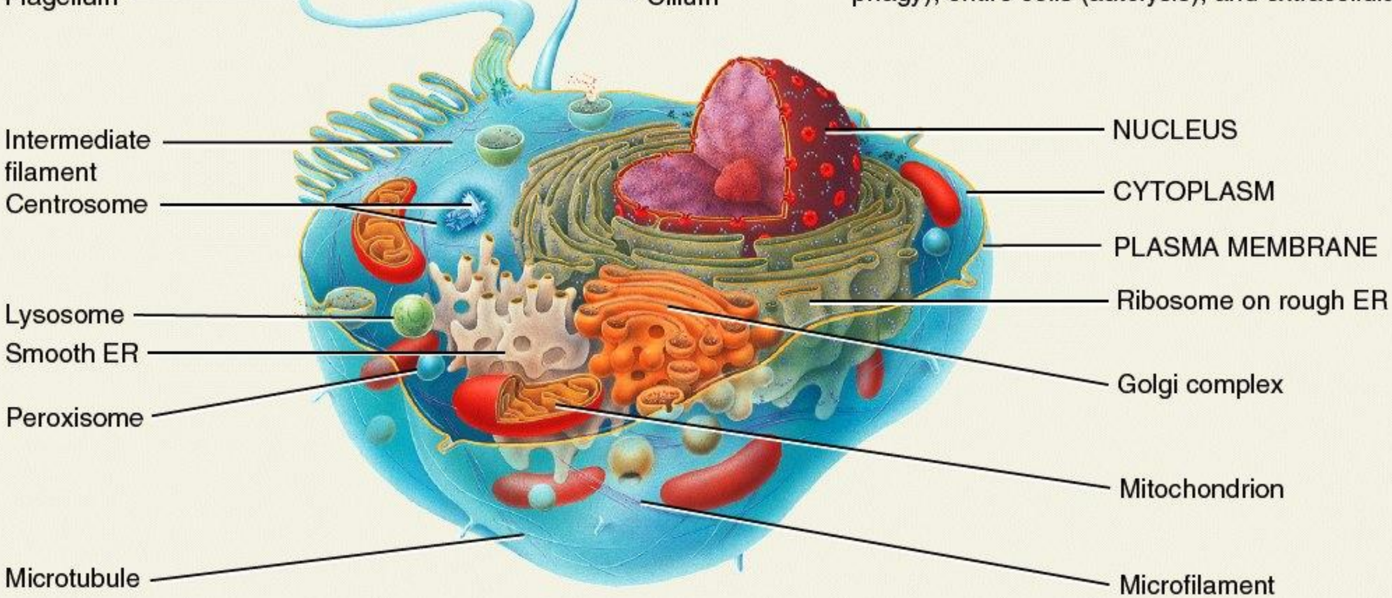


Table 3-2 part 2 Principles of Anatomy and Physiology, 11/e

TABLE 3.2 Cell Parts and Their Functions

Part	Structure	Functions
Peroxisome	Vesicle containing oxidases (oxidative enzymes) and catalase (decomposes hydrogen peroxide); new peroxisomes bud from preexisting ones.	Oxidizes amino acids and fatty acids; detoxifies harmful substances, such as alcohol; produces hydrogen peroxide.
Proteasome	Tiny structure that contains proteases (proteolytic enzymes).	Degrades unneeded, damaged, or faulty proteins by cutting them into small peptides.
Mitochondrion	Consists of outer and inner mitochondrial membranes, cristae, and matrix; new mitochondria form from preexisting ones.	Site of aerobic cellular respiration reactions that produce most of a cell's ATP.
Nucleus	Consists of nuclear envelope with pores, nucleoli, and chromosomes, which exist as a tangled mass of chromatin in interphase cells.	Nuclear pores control the movement of substances between the nucleus and cytoplasm, nucleoli produce ribosomes, and chromosomes consist of genes that control cellular structure and direct cellular functions.

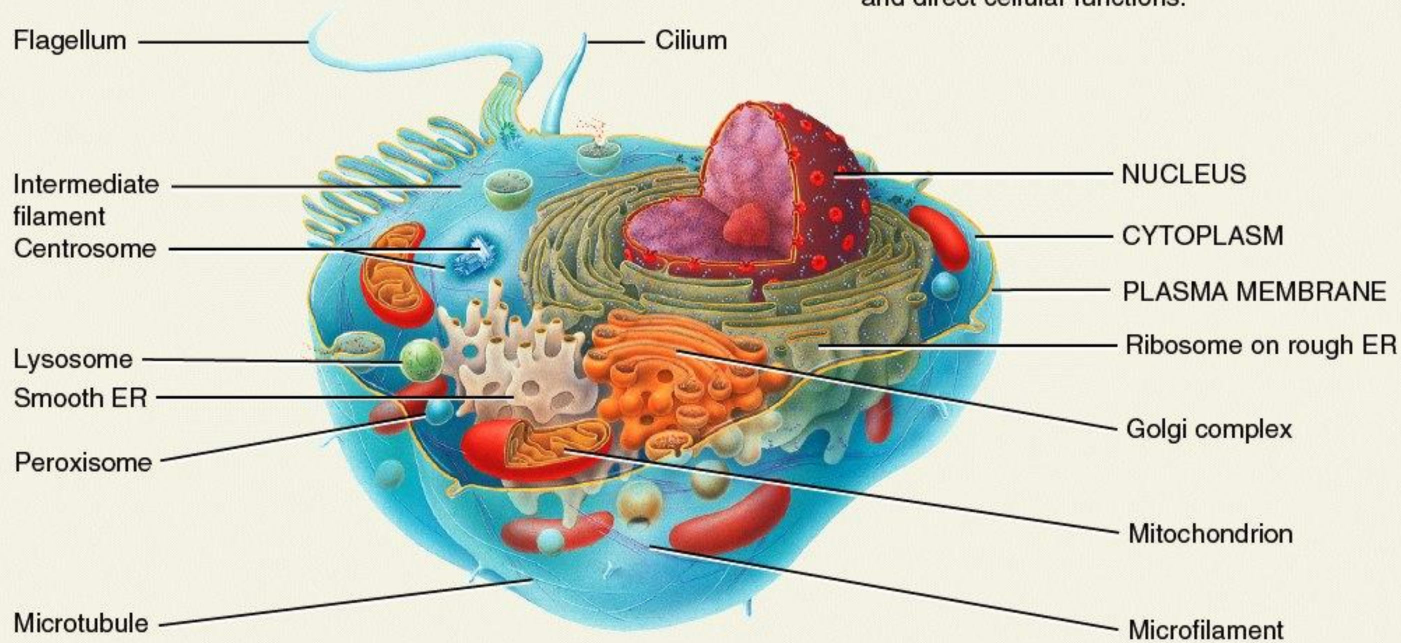
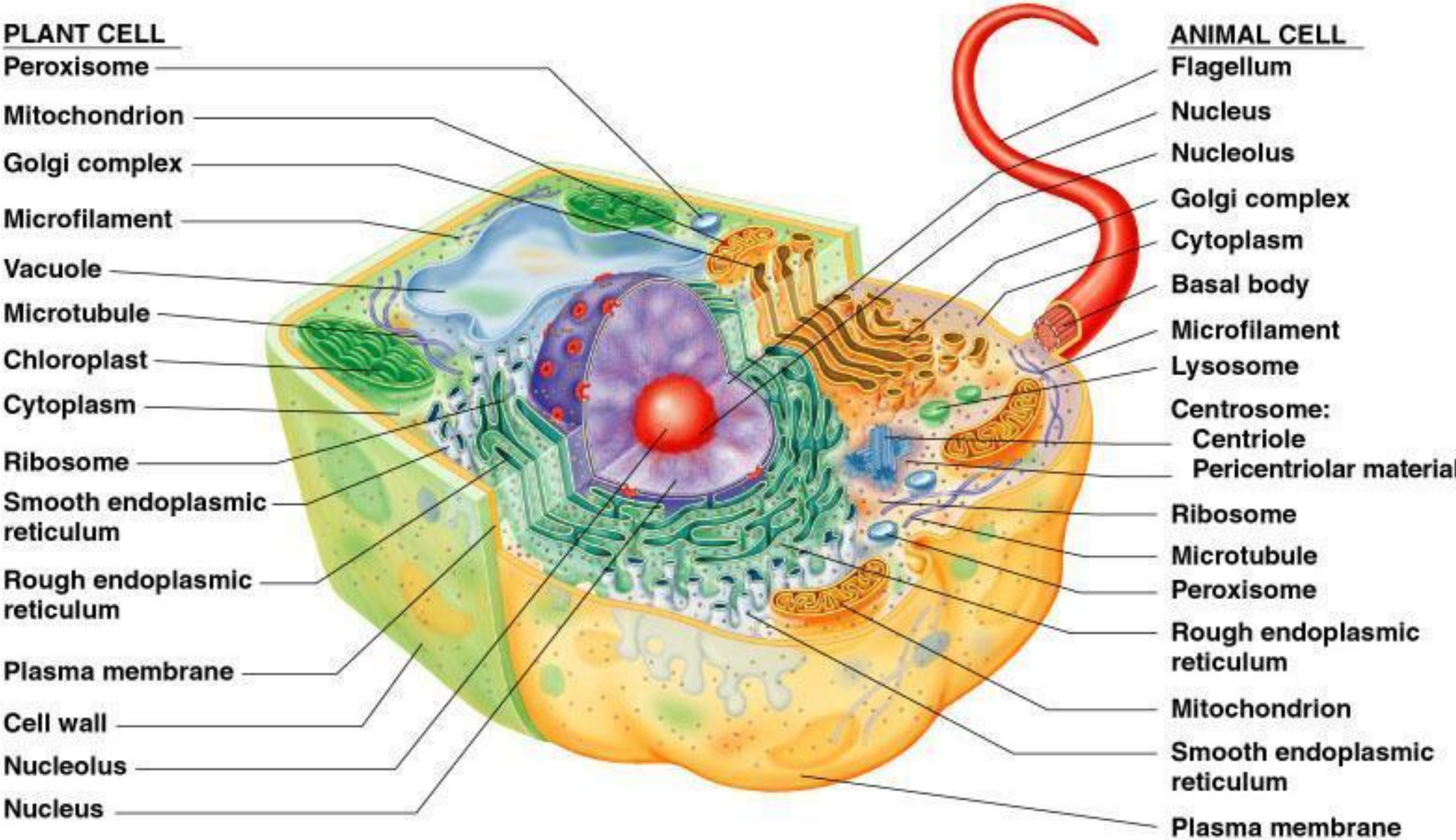


Table 3-2 part 3 Principles of Anatomy and Physiology, 11/e



(a) Highly schematic diagram of a composite eukaryotic cell, half plant and half animal

FIGURE 4.22a - Eukaryotic cell showing typical structures.

Animal Cell

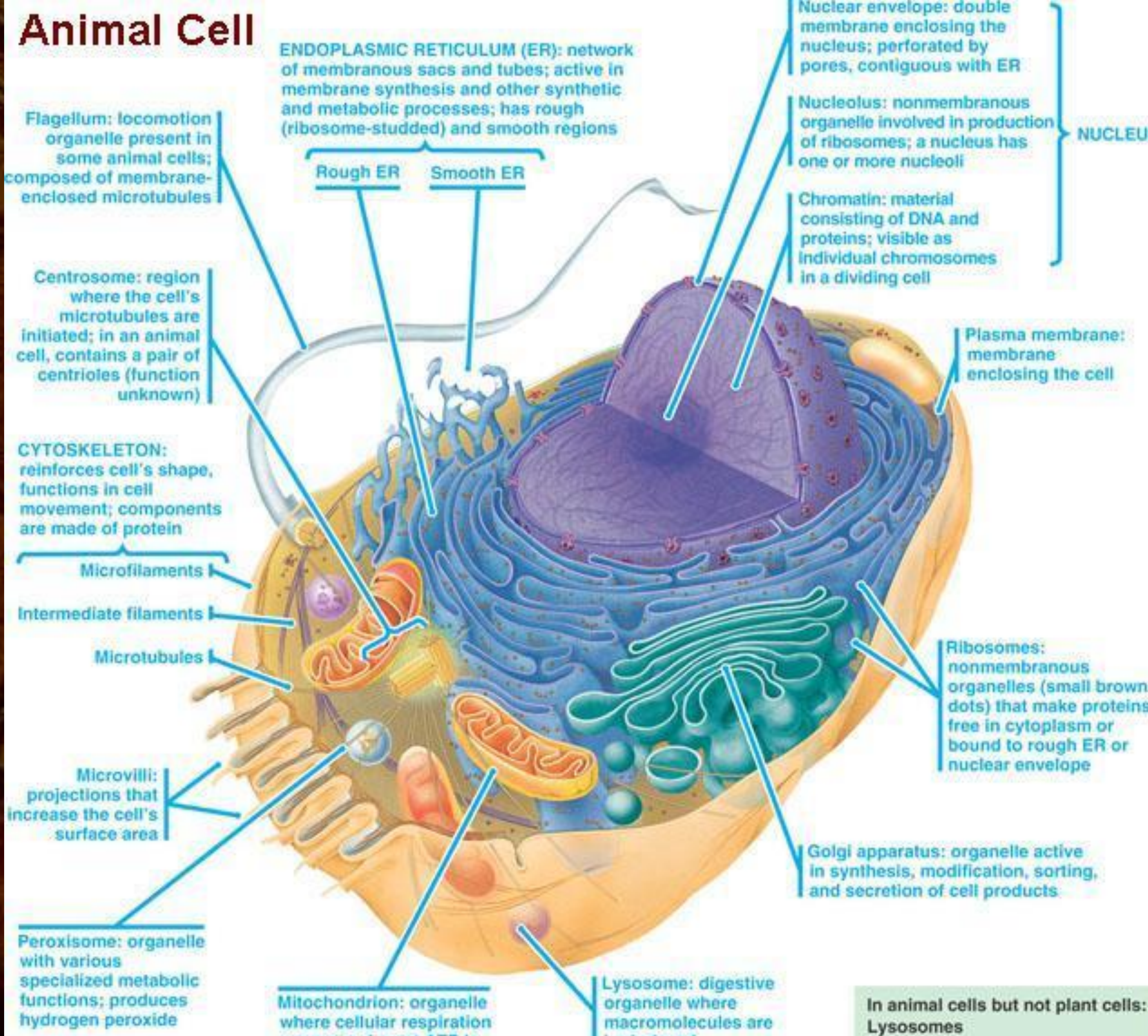
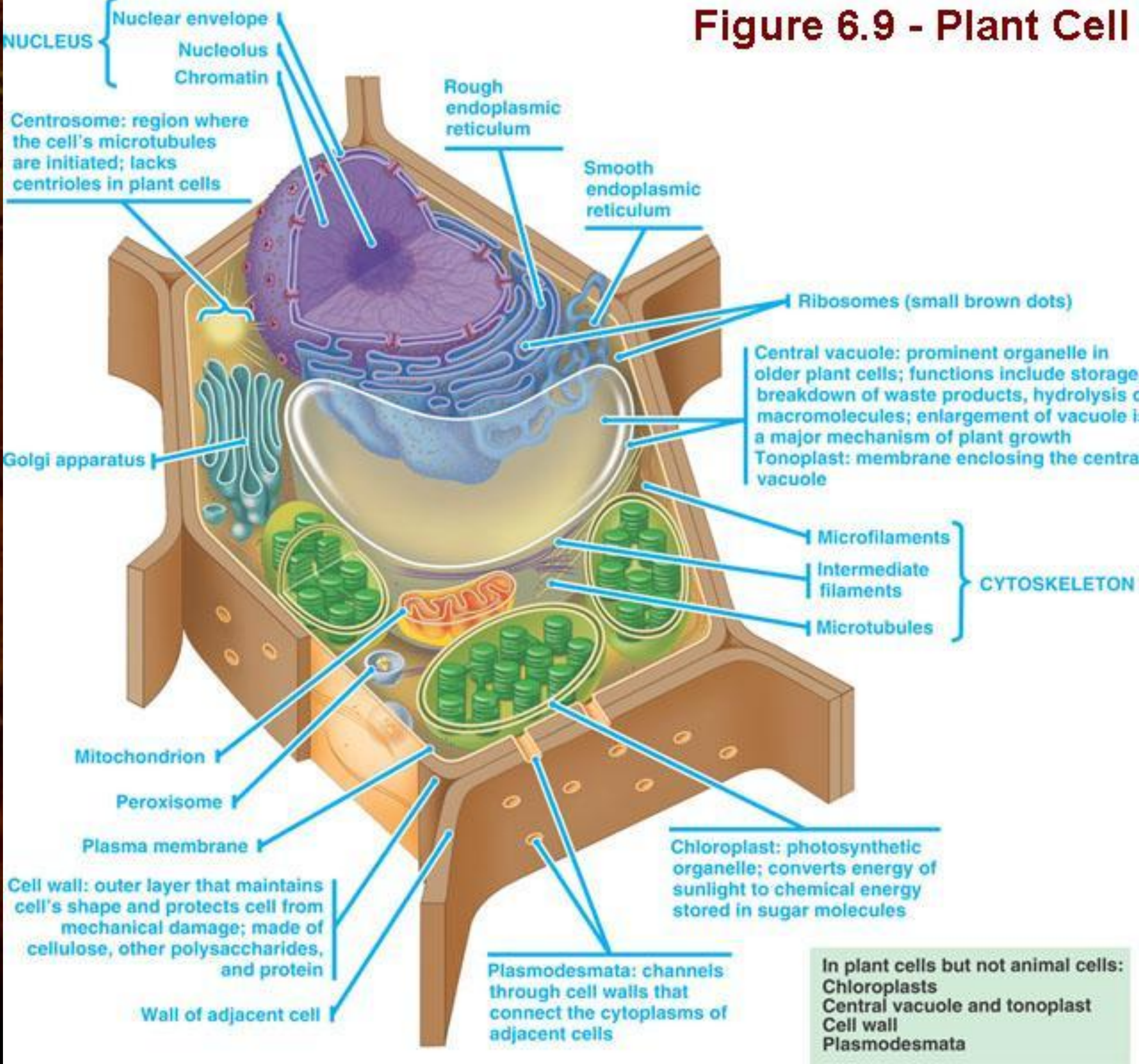


Figure 6.9

Figure 6.9 - Plant Cell



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