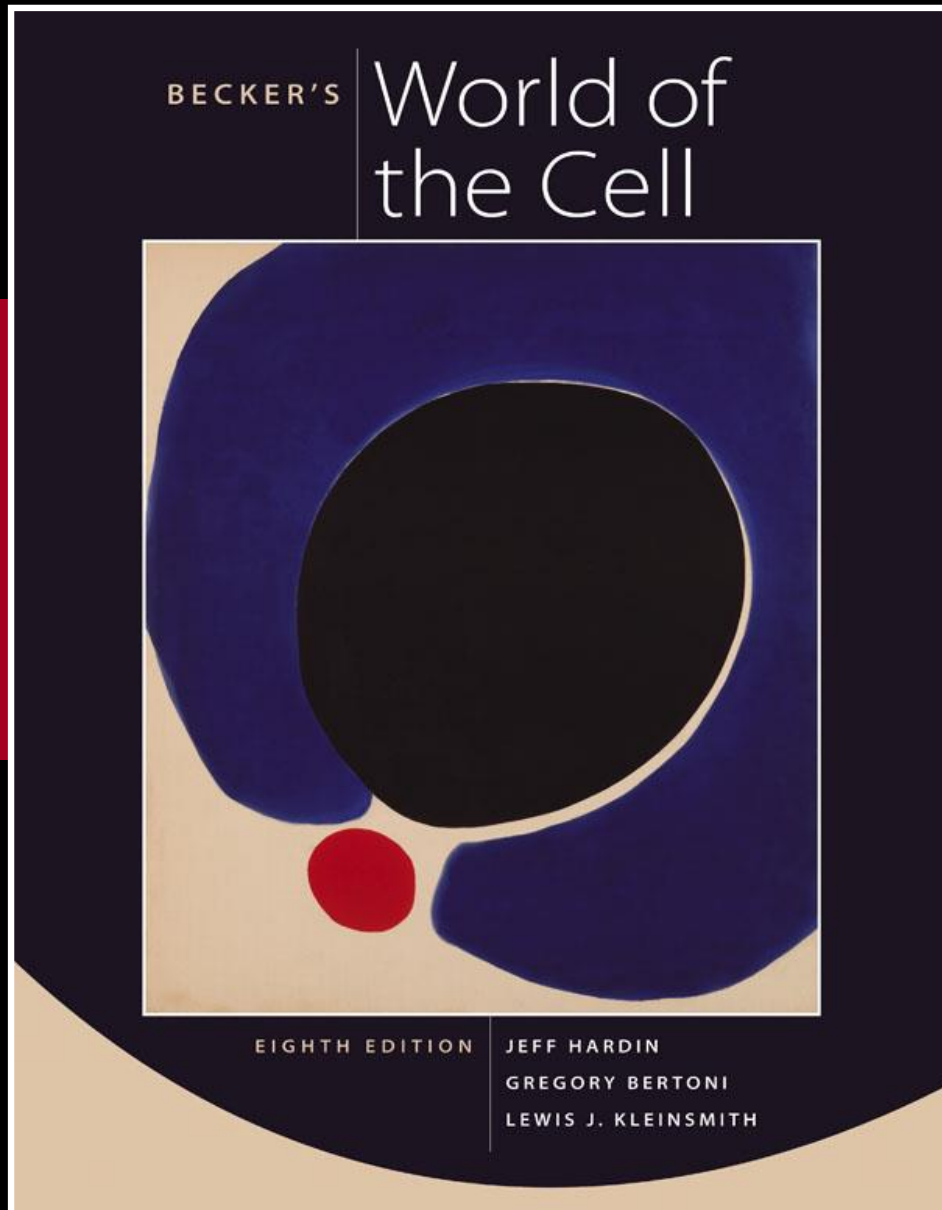


Chapter 4

Cells and Organelles



Lectures by
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Simon Fraser University

All Organisms Are Bacteria, Archaea, or Eukaryotes

- Two types of cells
- The simpler type is characteristic of bacteria (**prokaryotes**) and the more complex type characteristic of plants, animals, fungi, algae and protozoa (**eukaryotes**)
- The main distinction between the two cells types is the membrane-bounded nucleus of eukaryotic cells

A changing view of prokaryotes

- Recently, the term *prokaryote* is unsatisfactory in describing the non-nucleated cells
- Sharing of a gross structural feature is not necessarily evidence of relatedness
- Based on rRNA sequence analysis, prokaryotic cells can be divided into the widely divergent **bacteria** and **archaea**

Three domains

- Bacteria and archaea are as divergent from one another as humans and bacteria are
- Biologists now recognize three domains, the archaea, bacteria and **eukarya** (*eukaryotes*)

Bacteria

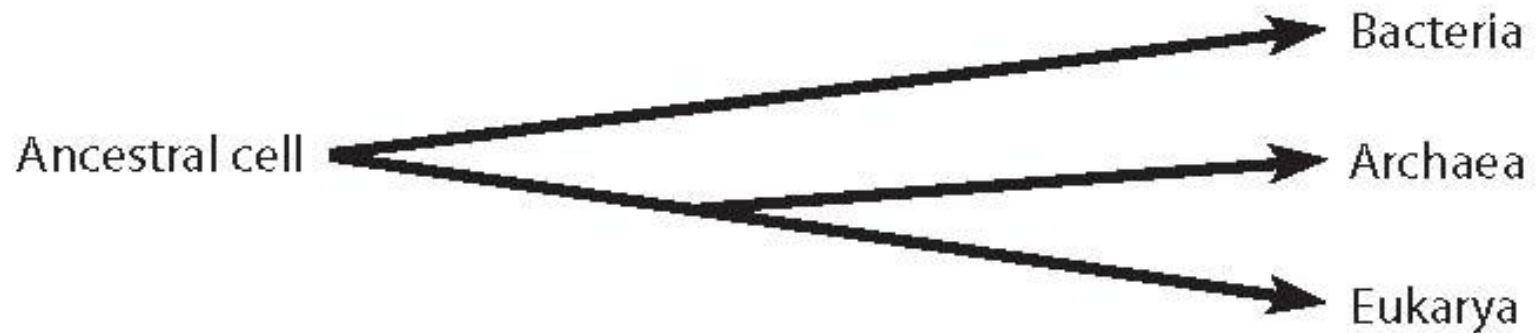
- These include most of the commonly encountered single-celled, non-nucleated organisms traditionally called bacteria
- Examples include:
 - *Escherichia coli*
 - *Pseudomonas*
 - *Streptococcus*

Archaea

- Archaea were originally called *archebacteria* before they were discovered to be so different from bacteria
- They include many species that live in extreme habitats and have diverse metabolic strategies
- Types of archaea include:
 - *methanogens* - obtain energy from hydrogen and convert CO₂ into methane
 - *halophiles* - occupy extremely salty environments
 - *thermacidophiles* - thrive in acidic hot springs

Archaea (continued)

- They are considered to have descended from a common ancestor that also gave rise to eukaryotes long after diverging from bacteria



Limitations on Cell Size

- Cells come in various sizes and shapes
- Some of the smallest bacteria are about 0.2 - 0.3 μm in diameter (*mycoplasma*)
- Some highly elongated nerve cells may extend a meter or more
- Despite the extremes, cells in general fall into predictable size ranges

Size ranges

- Bacteria cells normally range from 1 to 5 μm in diameter
- Animal cells have dimensions in the range of 10 - 100 μm
- Cells are usually very small
- There are 3 main limitations on cell size

Limitations on cell size

- Cell size is limited by:
 - The need for **adequate surface area relative to volume**
 - The **rates at which molecules can diffuse**
 - The need to maintain **adequate local concentrations of substances** required for necessary cellular functions

Surface area/volume ratio

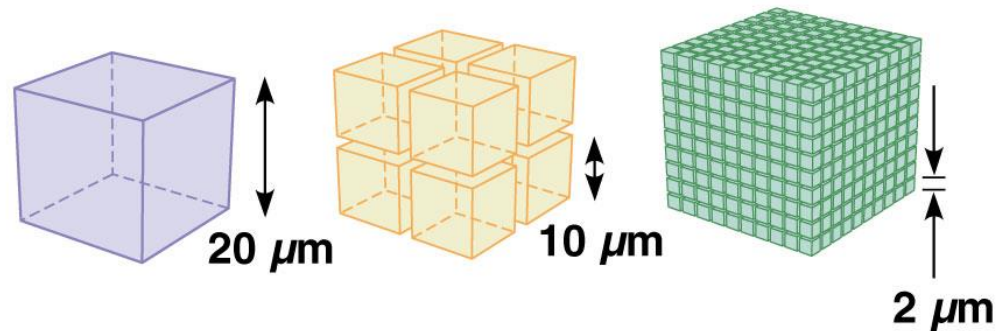
- In most cases, the major limit on cell size is set by the need to maintain an adequate surface area/volume ratio
- Surface area is important because *exchanges between the cell and its surrounding* take place there
- The cell's volume determines the amount of exchange that must take place, across the available surface area

The problem of maintaining adequate surface area/volume ratio

- The volume of a cell increases with the **cube** of its length
- But the surface area of the cell increases with the **square** of its length, *so larger cells have proportionately smaller surface areas*
- Beyond a certain threshold a large cell would not have a large enough surface area to allow for intake of enough nutrients and release of enough wastes

Figure 4-1

Volume stays the same, but surface area increases*



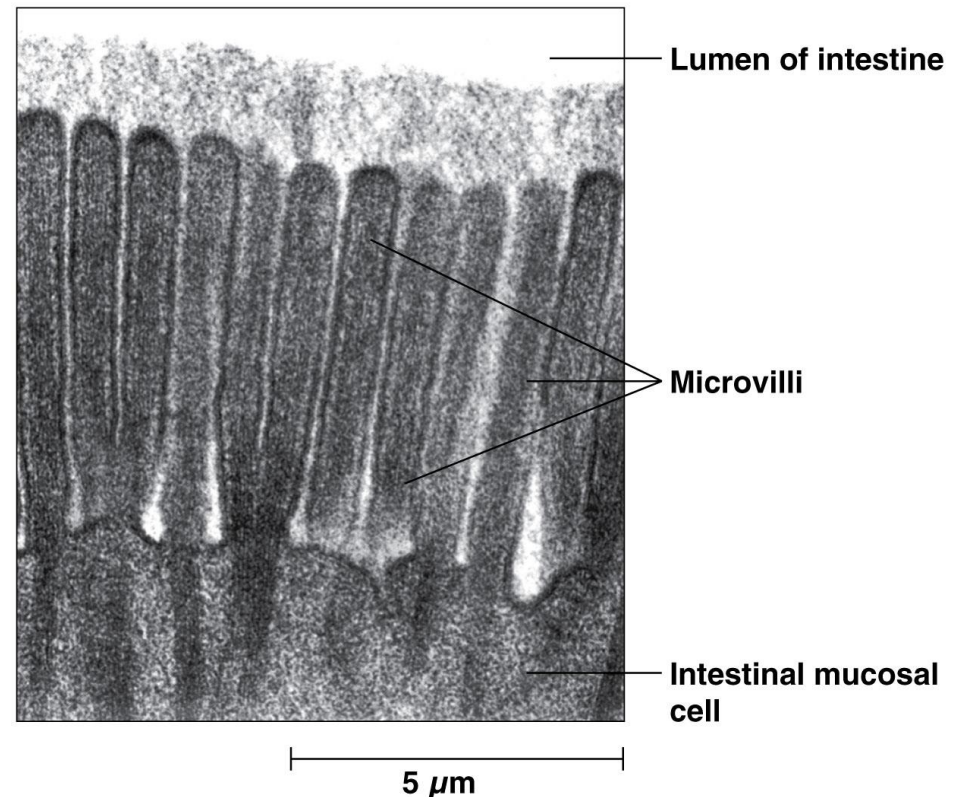
Number of cells	1	8	1000
Length of one side	20 μm	10 μm	2 μm
Total volume	8000 μm ³	8000 μm ³	8000 μm ³
Total surface area	2400 μm ²	4800 μm ²	24,000 μm ²
Surface area to volume ratio	0.3	0.6	3.0

*For a cube having a side with length s , volume = s^3 and surface area = $6s^2$.

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Cells specialized for absorption

- Cells that are specialized for absorption have characteristics to maximize surface area/volume ratio
- E.g., cells lining the small intestine have *microvilli*, fingerlike projections that increase the surface area



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Diffusion Rates of Molecules

- Many molecules move through the cell by **diffusion**, the unassisted movement of a substance from a region of high concentration to a region of low concentration
- *The rate of diffusion of molecules decreases as the size of the molecule increases*, so the limitation is most important for macromolecules like proteins and nucleic acids

Avoiding limitations of rates of diffusion

- Eukaryotic cells can avoid the problem of slow diffusion rates by using carrier proteins to actively transport materials through the cytoplasm
- Some cells use **cytoplasmic streaming** (**cyclosis** in plants) to actively move cytoplasmic contents
- Other cells move molecules through the cell in vesicles that are transported along microtubules

The Need for Adequate Concentrations of Reactants and Catalysts

- For a reaction to occur, the appropriate reactants must collide with and bind to a particular enzyme
- The frequency of such collisions is greatly increased by higher concentrations of enzymes and reactants
- $\uparrow$ cell vol $\downarrow$ concentration of molecules $\rightarrow$ need to produce more molecules to get the same amount of reactions

Eukaryotic Cells Use Organelles to Compartmentalize Cellular Function

- A solution to the concentration problem is the *compartmentalization of activities* within specific regions of the cell
- Most eukaryotic cells have a variety of **organelles**, membrane-bounded compartments that are specialized for specific functions
- e.g. cells in a plant leaf have most of the materials needed for photosynthesis compartmentalized into structures called *chloroplasts*

Bacteria, Archaea, and Eukaryotes Differ from Each Other in Many Ways

- There are shared characteristics among cells of each of the domains, bacteria, archaea and eukarya
- However, each type of cell has a unique set of distinguishing properties

Prokaryotes vs. Eukaryotes

- Membrane-bound nucleus
- Internal membranes to segregate function
- Tubules and filaments
- Exocytosis and endocytosis
- DNA organization
- Segregation of genetic information
- Expression of DNA

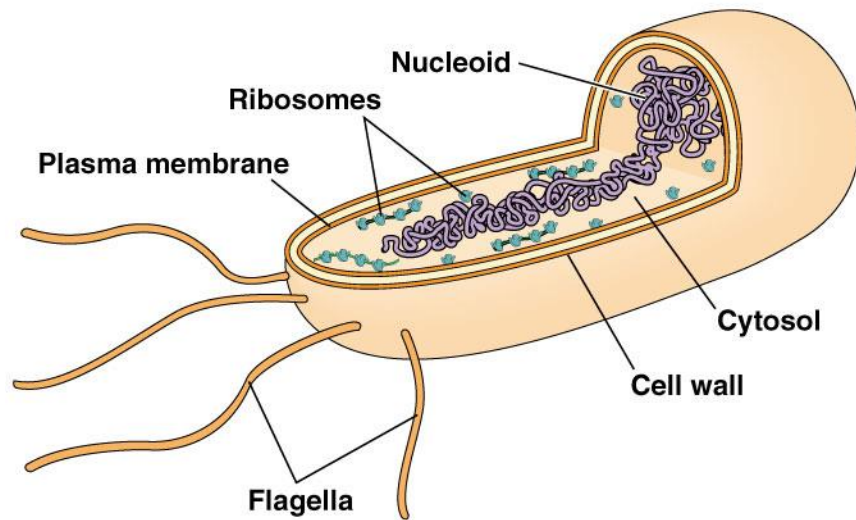
Table 4-1**Table 4-1****A Comparison of Some Properties of Bacterial, Archaeal, and Eukaryotic Cells***

Property	Prokaryotes		Eukaryotes	Refer to:
	Bacteria	Archaea		
Typical size	Small (1–5 μm)	Small (1–5 μm)	Large (10–100 μm)	—
Nucleus and organelles	No	No	Yes	Table 4-2
Microtubules and microfilaments	Actin-like and tubulin-like proteins	Actin-like and tubulin-like proteins	Actin and tubulin proteins	Chapter 15
Exocytosis and endocytosis	No	No	Yes	Chapter 12
Cell wall	Peptidoglycan	Varies from proteinaceous to peptidoglycan-like	Cellulose in plants, fungi; none in animals, protozoa	Chapter 17
Mode of cell division	Binary fission	Binary fission	Mitosis or meiosis plus cytokinesis	Chapter 19
Typical form of chromosomal DNA	Circular, few associated proteins	Circular, associated with histone-like proteins	Linear, associated with histone proteins	Chapter 18
RNA processing	Minimal	Moderate	Extensive	Chapter 21
Transcription initiation	Bacterial type	Eukaryotic type	Eukaryotic type	Chapter 21
RNA polymerase	Bacterial type	Some features of both bacterial, eukaryotic types	Eukaryotic type	Chapter 21
Ribosome size and number of proteins	70S with 55 proteins	70S with 65 proteins	80S with 78 proteins	Chapter 22
Ribosomal RNAs	Bacterial type	Archaeal type	Eukaryotic type	Chapter 21
Translation initiation	Bacterial type	Eukaryotic type	Eukaryotic type	Chapter 22
Membrane phospholipids	Glycerol-3-phosphate + linear fatty acids	Glycerol-1-phosphate + branched polyisoprenoids	Glycerol-3-phosphate + linear fatty acids	Chapter 7

*This table lists many features that we have not yet discussed in detail. Its main purpose is to point out that, despite some sharing of characteristics, each of the three main cell types has a unique set of properties.

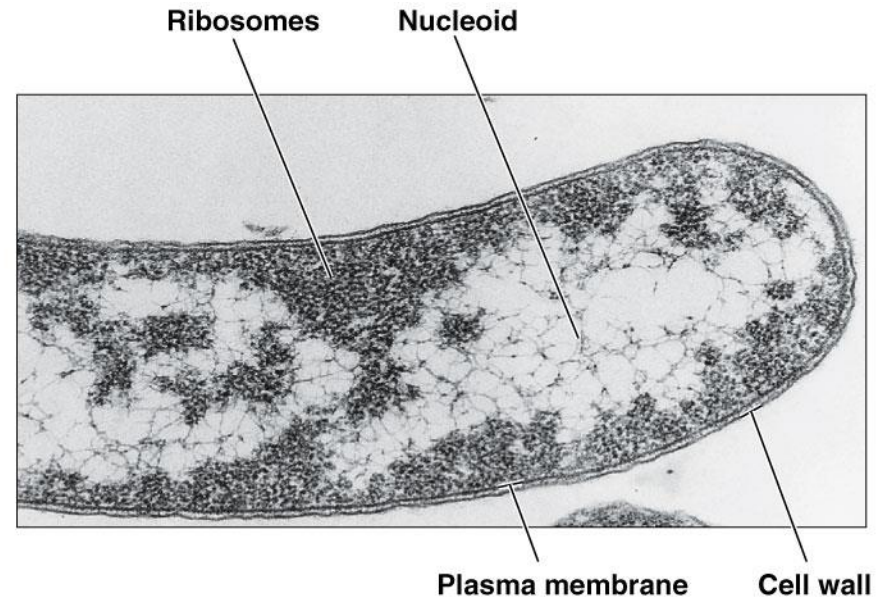
Presence of a Membrane-Bounded Nucleus

- A eukaryotic cell has a true, membrane bounded nucleus
- The *nuclear envelope* consists of two membranes
- The nucleus also includes the *nucleolus*, the site of ribosomal RNA synthesis and ribosome assembly
- The genetic information of a bacterial or archaeal cell is folded into a compact structure called the *nucleoid* and is attached to the cell membrane

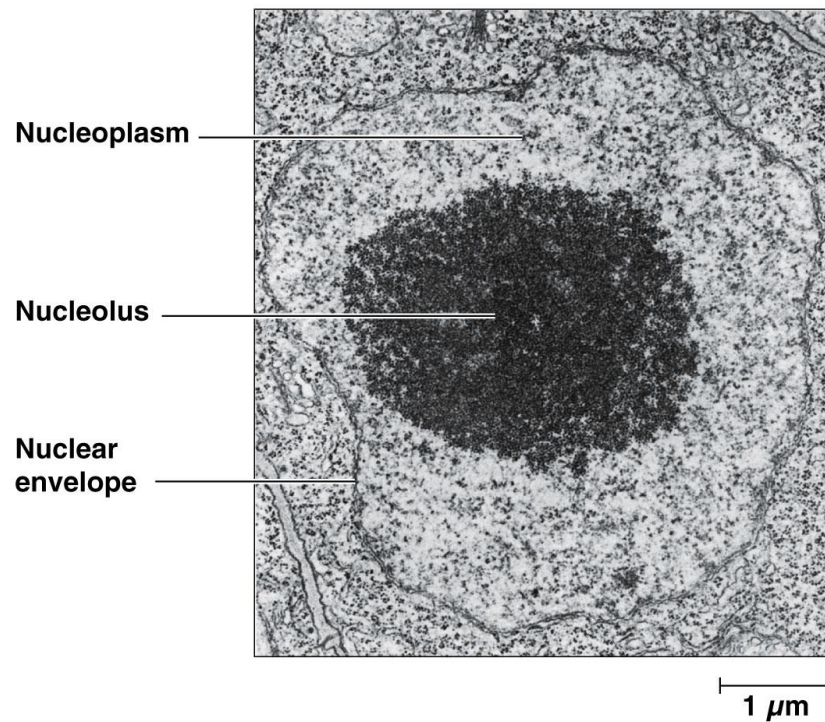


(a)

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(b)

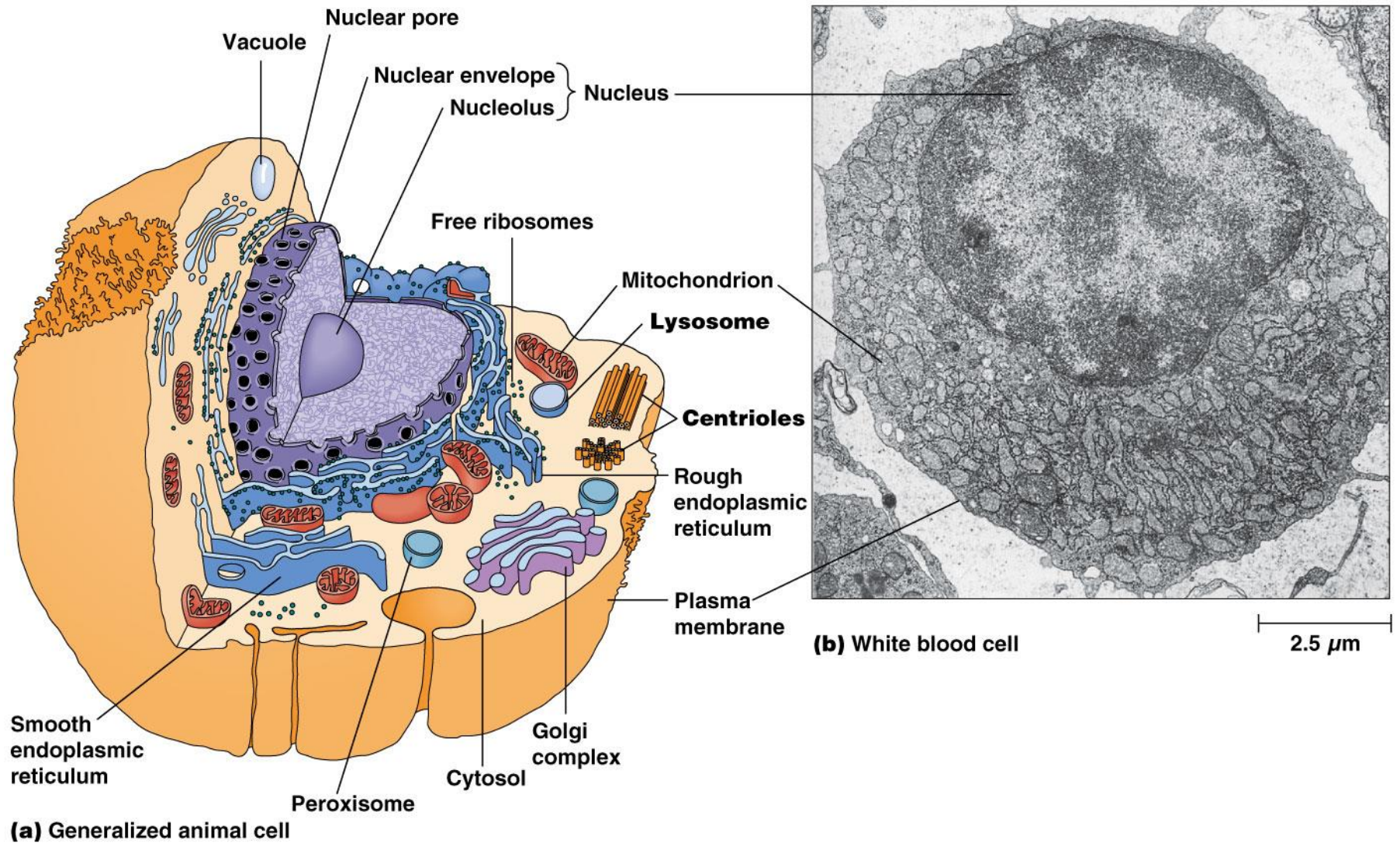


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Eukaryote organelles

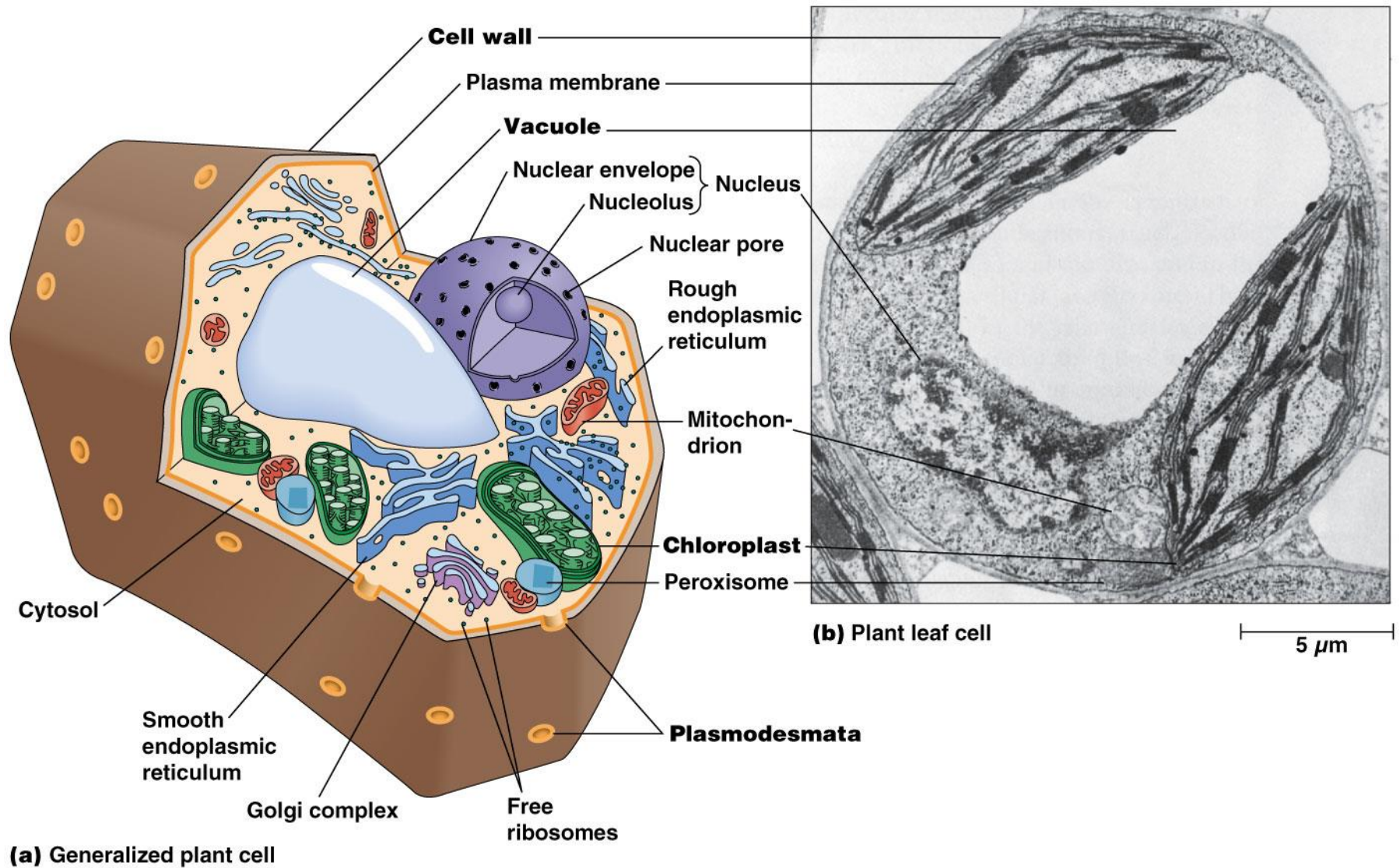
- Nearly all eukaryotes make extensive use of internal membranes to compartmentalize specific functions and have numerous organelles
- E.g., *endoplasmic reticulum, Golgi complex, mitochondria, chloroplasts, lysosomes, peroxisomes and various types of vacuoles and vesicles*
- Each organelle contains the materials and molecular machinery needed to carry out the functions for which the structure is specialized

Figure 4-5



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Figure 4-6



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The Cytoskeleton

- Several nonmembranous, proteinaceous structures for cellular contraction, motility and support are found in the cytoplasm of eukaryotic cells
- These include: *microtubules*, *microfilaments*, and *intermediate filaments*, all key components of the *cytoskeleton*, which imparts structure and elasticity to most eukaryotic cells
- The cytoskeleton also provides scaffolding for transport of vesicles within the cell

Exocytosis and Endocytosis

- Eukaryotic cells are able to exchange materials between compartments within the cell and the exterior of the cell
- This is possible through *exocytosis* and *endocytosis*, processes involving membrane fusion events unique to eukaryotic cells

Organization of DNA

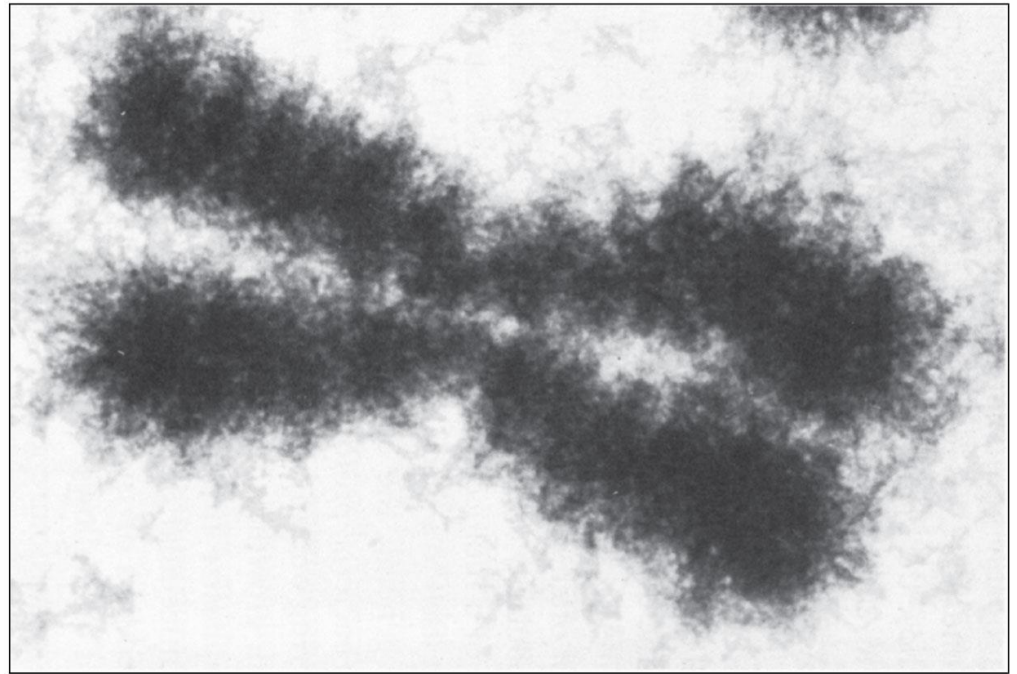
- Bacterial DNA is present in the cell as a circular molecule associated with few proteins
- Eukaryotic DNA is organized into linear molecules complexed with large amounts of proteins called *histones*
- Archaeal DNA is circular and complexes with proteins similar to eukaryotic histone proteins

DNA packaging

- The circular DNA of bacteria or archaea is much longer than the cell itself and so must be folded and packed tightly, equivalent to packing about 60 feet of thread into a thimble
- Most eukaryotic cells have **more than 1000 times more DNA** than prokaryotes and encode only **5-10 times more proteins**
- The excess noncoding DNA has been referred to as junk DNA but may have important functions in gene regulation and evolution

Chromosomes

- The problem of DNA packaging is solved among eukaryotes by organizing the DNA into **chromosomes**
- Chromosomes contain equal amounts of histones and DNA



1 μm

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Segregation of Genetic Information

- Prokaryotes and eukaryotes differ in how genetic information is allocated to daughter cells upon division
- Bacterial and archaeal cells replicate their DNA and divide by *binary fission* with one molecule of the replicated DNA and the cytoplasm going into each daughter cell
- Eukaryotic cells replicate DNA and then distribute their chromosomes into daughter cells by *mitosis* and *meiosis*, followed by *cytokinesis*, division of the cytoplasm

Expression of DNA

- Eukaryotic cells transcribe genetic information in the nucleus into large RNA molecules which are processed and transported into the cytoplasm for protein synthesis
- Each RNA molecule typically encodes one polypeptide
- Ribosome size: large (80S)
- Bacteria transcribe genetic information into RNA, and the RNA molecules produced may contain information for several polypeptides
- In both bacteria and archaea, RNA molecules become involved in protein synthesis before transcription is complete
- Ribosome size: small (70S)

The Eukaryotic Cell in Overview: Pictures at an Exhibition

- The structural complexity of eukaryotic cells is illustrated by the typical animal and plant cells
- A typical eukaryotic cell has: a *plasma membrane*, a *nucleus*, *membrane bounded organelles* and the *cytosol* interlaced by a *cytoskeleton*
- In addition, plant and fungal cells have a rigid cell wall, surrounded by an *extracellular matrix*

The Plasma Membrane Defines Cell Boundaries and Retains Contents

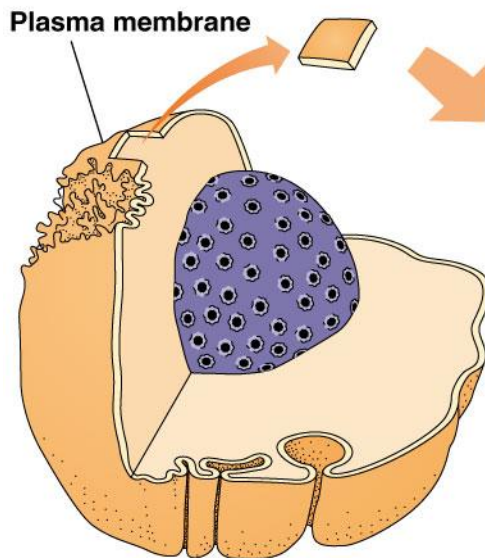
- The plasma membrane surrounds every cell
- It ensures that the cells contents are retained
- It consists of lipids, including phospholipids and proteins and is organized into two layers

Amphipathic membrane components

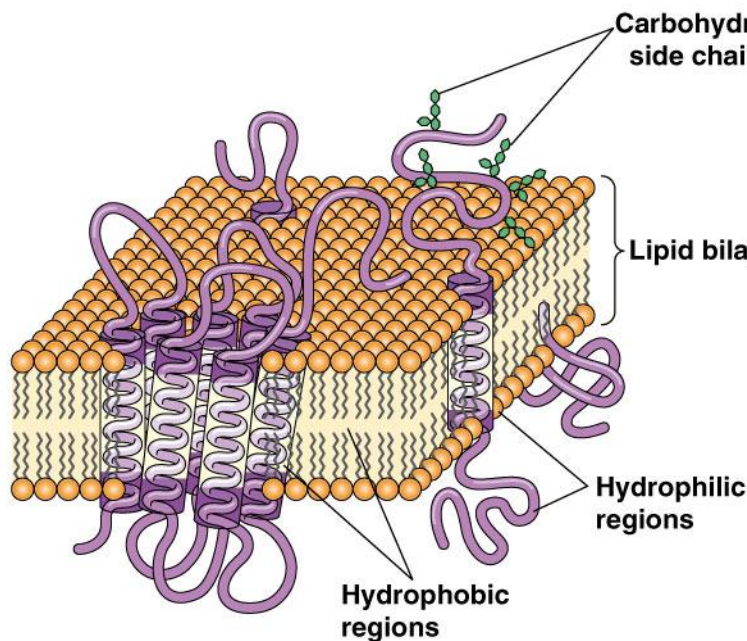
- Each phospholipid molecule consists of two hydrophobic “tails” and a hydrophilic “head” and is therefore an ***amphipathic molecule***
- The **lipid bilayer** is formed when the hydrophilic heads face outward and the tails face inward
- Membrane proteins are also amphipathic, some, with polysaccharides attached to them, are called *glycoproteins*

Figure 4-10

(a) A cell. A cutaway view of an animal cell, showing the orientation of the piece of membrane shown in part b.

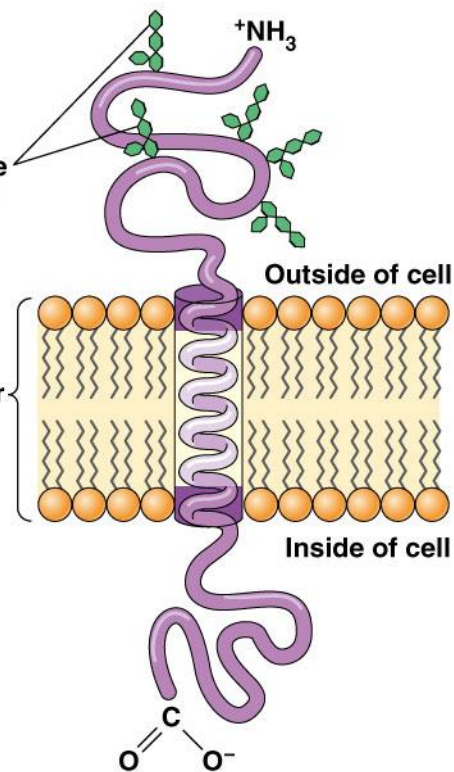


(b) Plasma membrane with membrane proteins. The plasma membrane consists of a lipid bilayer with membrane proteins suspended in it. Their hydrophobic regions are associated with the interior of the bilayer and their hydrophilic regions protrude from the membrane on one or both sides of the bilayer.



(c) Lipid bilayer with a glycoprotein.

Most membrane proteins have at least one hydrophobic membrane-spanning domain. Proteins in the plasma membrane are typically glycoproteins with short carbohydrate side chains attached to the protein on the external side of the membrane.



The Nucleus is the Information Center of the Eukaryotic Cell

- The most prominent structure in the eukaryotic cell is the **nucleus**
- It contains the DNA and is surrounded by the **nuclear envelope**, composed of inner and outer membranes
- The nuclear envelope has numerous openings called *pores*, each of which is a transport channel, lined with a *nuclear pore complex* that regulates movement of macromolecules

The nucleus

- The number of chromosomes in the nucleus is a species-specific characteristic
- Chromosomes are most easily visualized during mitosis, whereas during *interphase*, they are dispersed as **chromatin** and difficult to visualize
- **Nucleoli** are also present in the nucleus

Intracellular Membranes and Organelles Define Compartments

- The internal volume of the cell outside the nucleus is called the *cytoplasm* and is occupied by *organelles* and the semifluid *cytosol*
- A number of heritable human disorders are caused by malfunctions of specific organelles

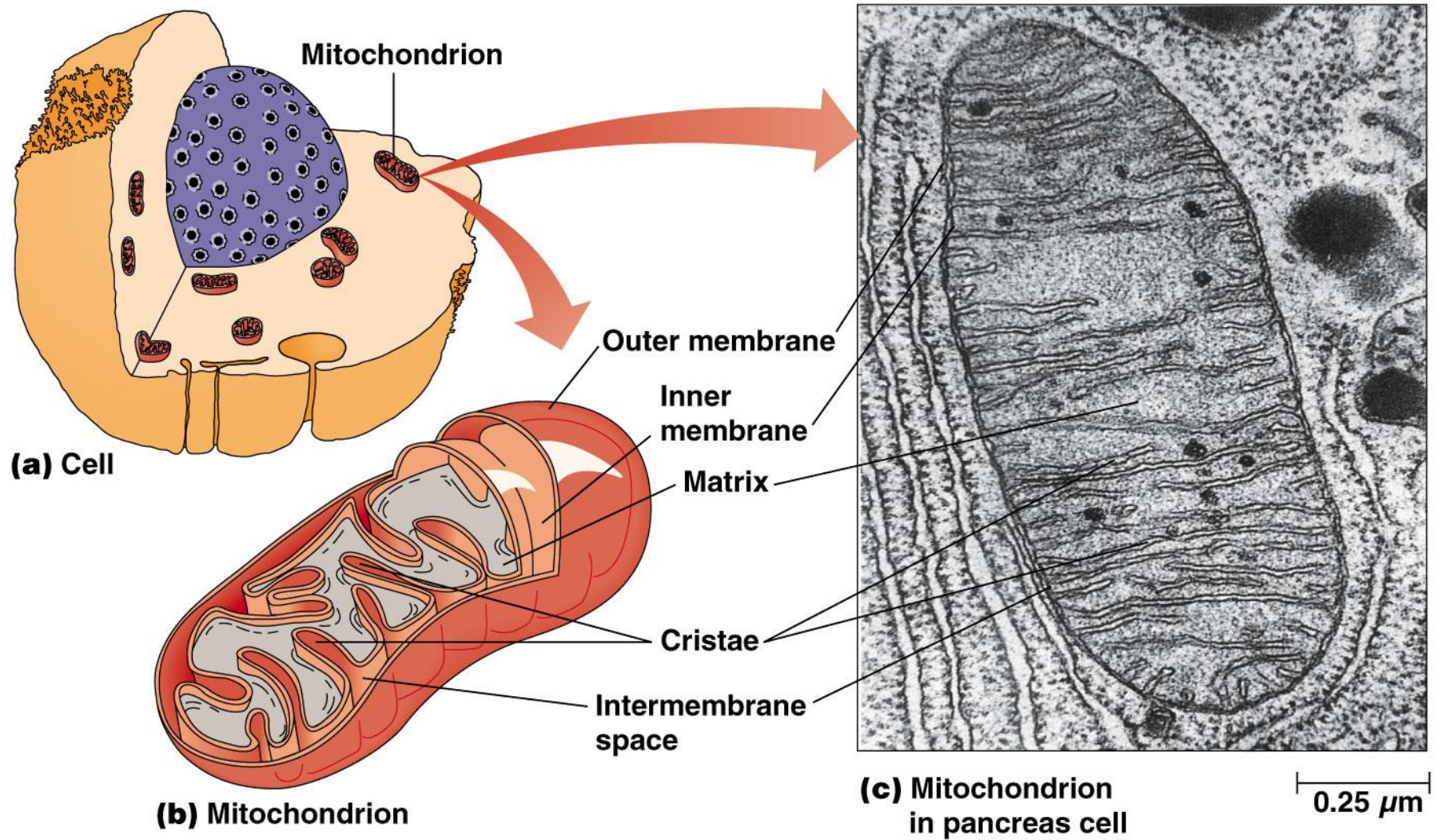
The Mitochondrion

- **Mitochondria**, found in all eukaryotic cells, are the site of aerobic respiration
- They are comparable in size to bacteria
- Most eukaryotic cells contain hundreds of mitochondria, each of which is surrounded by a *mitochondrial inner and outer membrane*

Mitochondrial similarity to bacterial cells

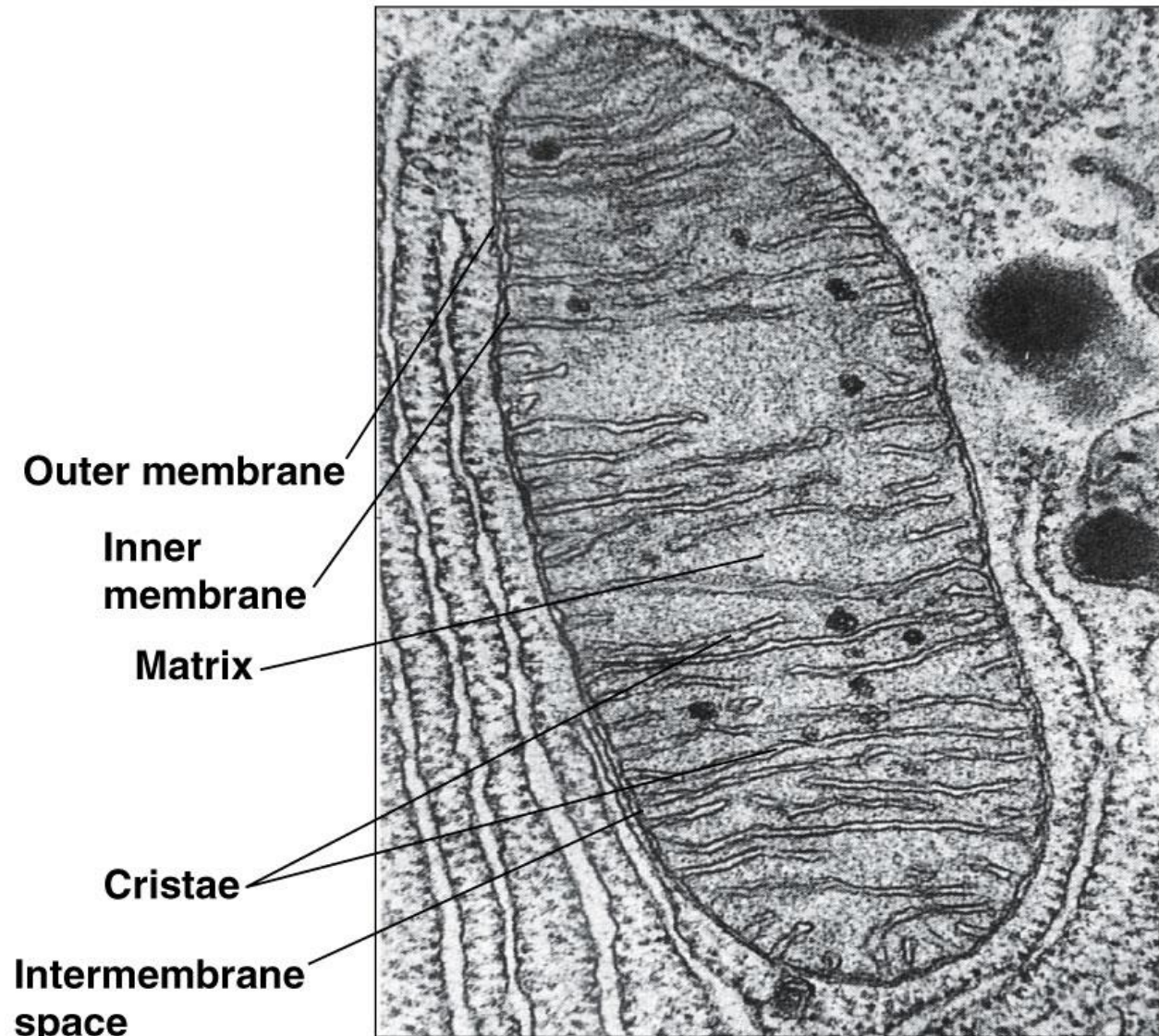
- Mitochondria contain small circular molecules of DNA
- The mitochondrial chromosome encodes some RNAs and proteins needed for mitochondrial function
- They also have their own ribosomes, to carry out protein synthesis

Figure 4-11



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Figure 4-11C



**(c) Mitochondrion
in pancreas cell**

0.25 μm

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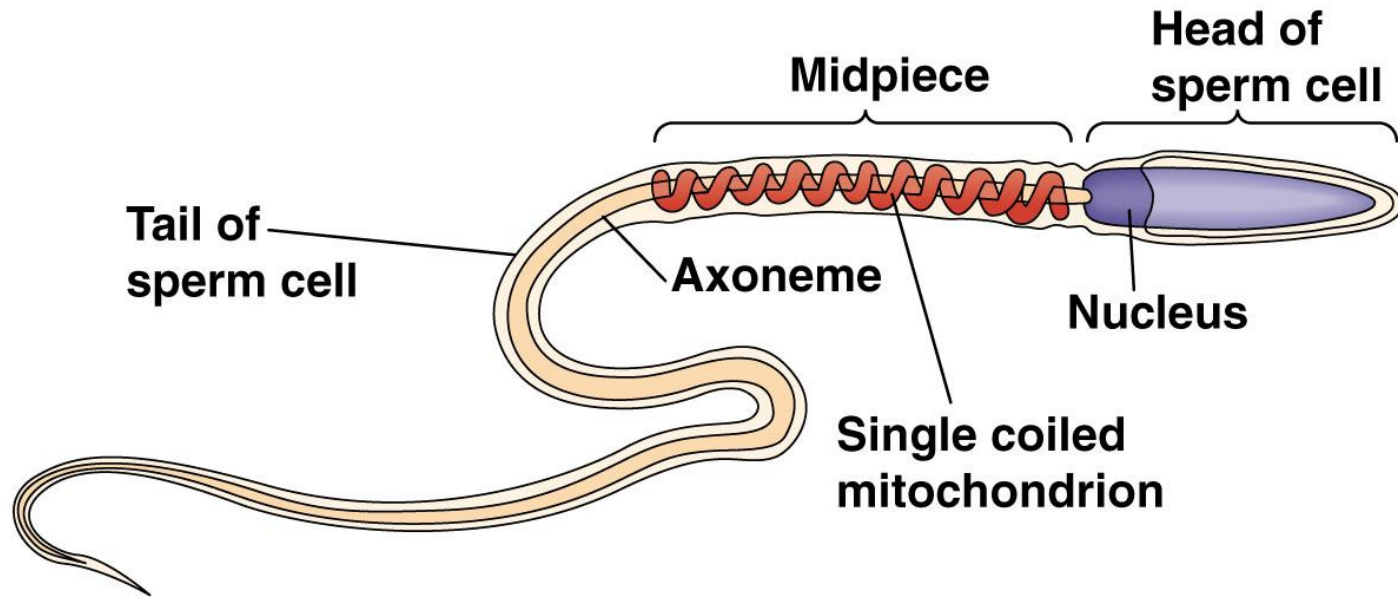
Mitochondrial function

- Oxidation of sugars and other fuel molecules in mitochondria extracts energy from food and stores it in *ATP* (*adenosine triphosphate*)
- Most molecules for mitochondrial function are localized on the **cristae** (infoldings of the inner mitochondrial membrane) or the **matrix** (fluid that fills the inside of the mitochondrion)

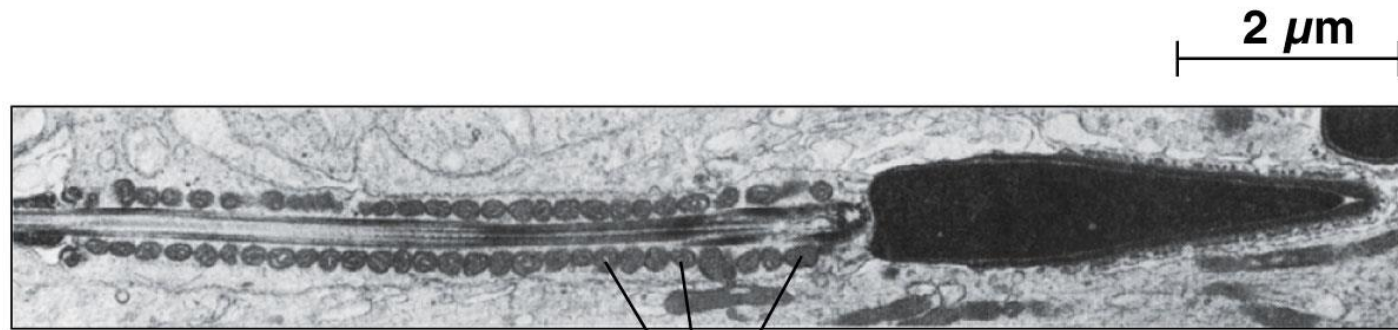
Varied number and location of mitochondria

- Number and location of mitochondria varies among cells according to their role in that cell type
- Tissues with high demand for ATP have many mitochondria, located within the cell at the site of greatest energy needs
- E.g., sperm and muscle cells

Figure 4-13



(a)



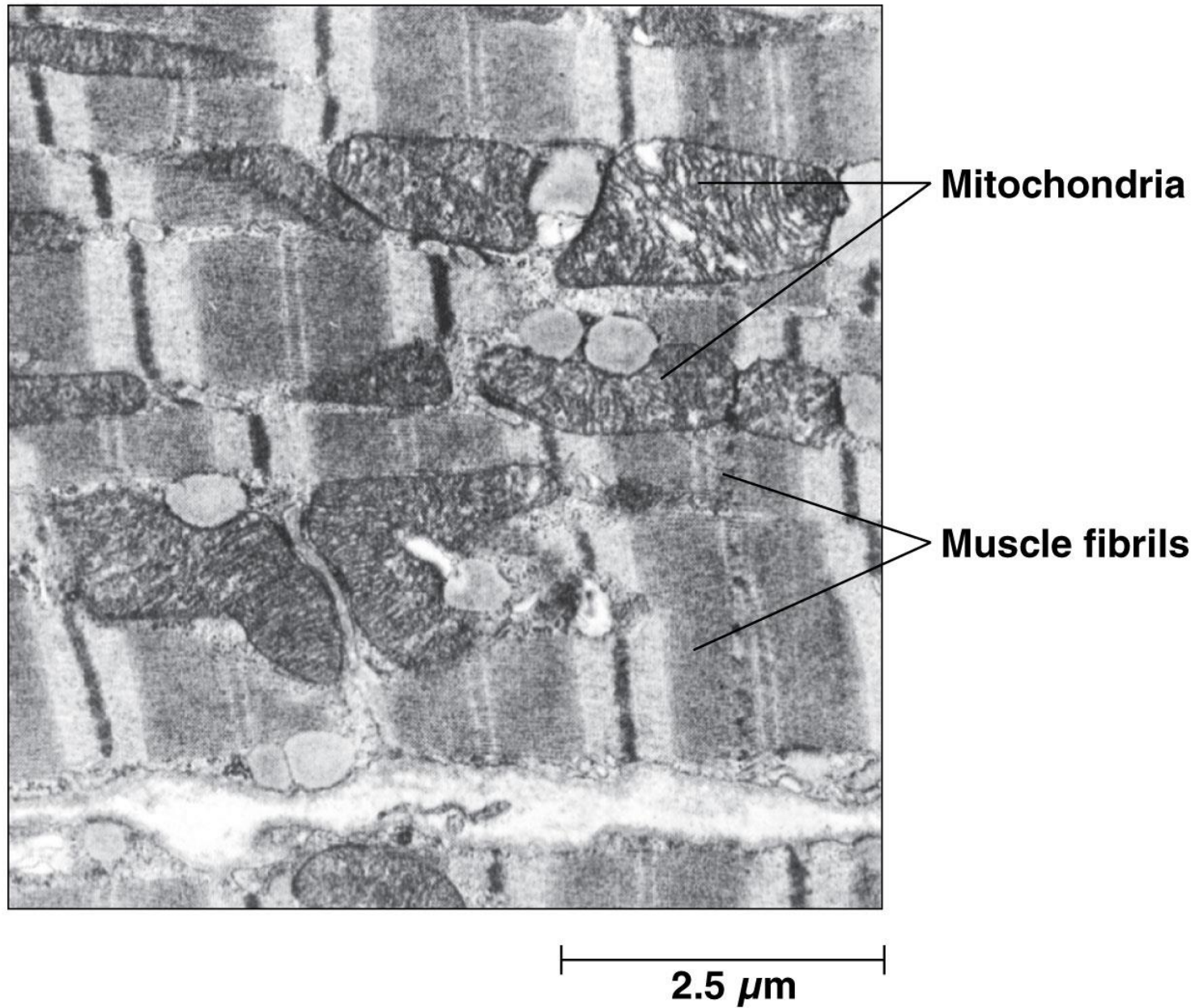
(b)

Midpiece

**Head of
sperm cell**

**Cross-sectional views
of coiled mitochondrion**

Figure 4-13

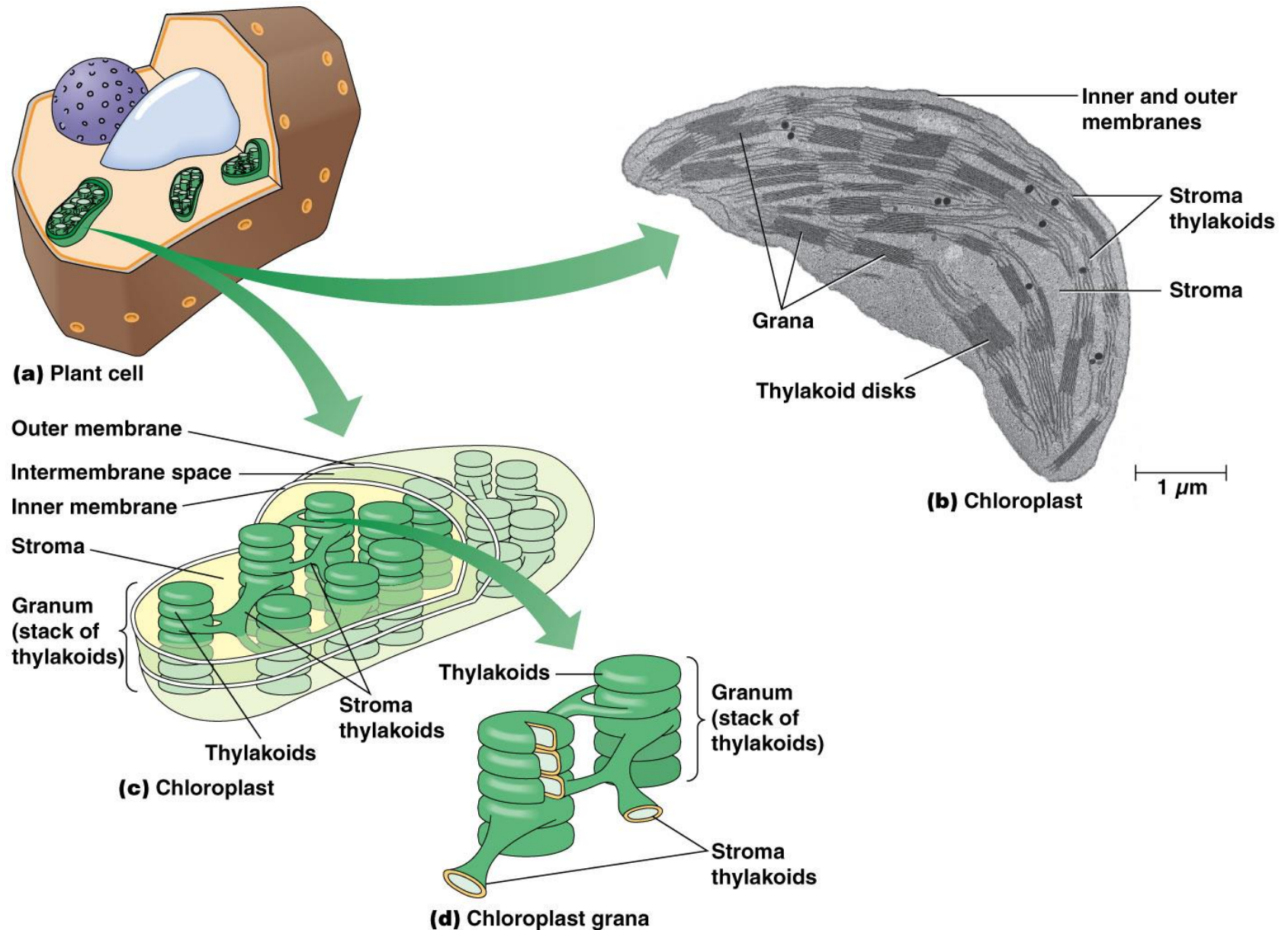


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The Chloroplast

- The chloroplast is the site of photosynthesis in plants and algae
- They are large, and can be quite numerous in the cells of green plants
- They are surrounded both inner and outer membranes and contain a system of flattened membranous sacs called **thylakoids**, stacked into **grana**

Figure 4-14



Chloroplast function

- Chloroplasts are the site of *photosynthesis*, a process that uses solar energy and CO_2 to produce sugars and other organic compounds
- This process is the reverse of the mitochondrial reactions that oxidize glucose into CO_2
- Chloroplasts are found in photosynthetic cells and contain most of the enzymes needed for photosynthesis

Chloroplast function (continued)

- Reactions that depend on solar energy, take place in or on the thylakoid membranes
- Reactions involved in the reduction of CO₂ to sugar occur within the **stroma**, a semifluid in the interior of the chloroplast
- Like mitochondria, chloroplasts contain their own ribosomes, and a small circular DNA molecule that encodes some RNAs and proteins needed in the chloroplast

The Endosymbiont Theory: Did Mitochondria and Chloroplasts Evolve from Ancient Bacteria?

- Both mitochondria and chloroplasts have their own DNA and ribosomes and can produce some of their own proteins
- However, most of the proteins needed in these organelles are encoded by nuclear genes
- Overall there are many similarities between processes in mitochondria and chloroplasts and those in bacteria

Similarities between mitochondria and chloroplasts and bacteria

- All three have circular DNA molecules without associated histones
- rRNA sequences, ribosome size, sensitivities to inhibitors of RNA and protein synthesis and type of protein factors used in protein synthesis are all similar
- Both resemble bacteria in size and shape and are surrounded by double membranes, the inner of which has bacterial-type lipids

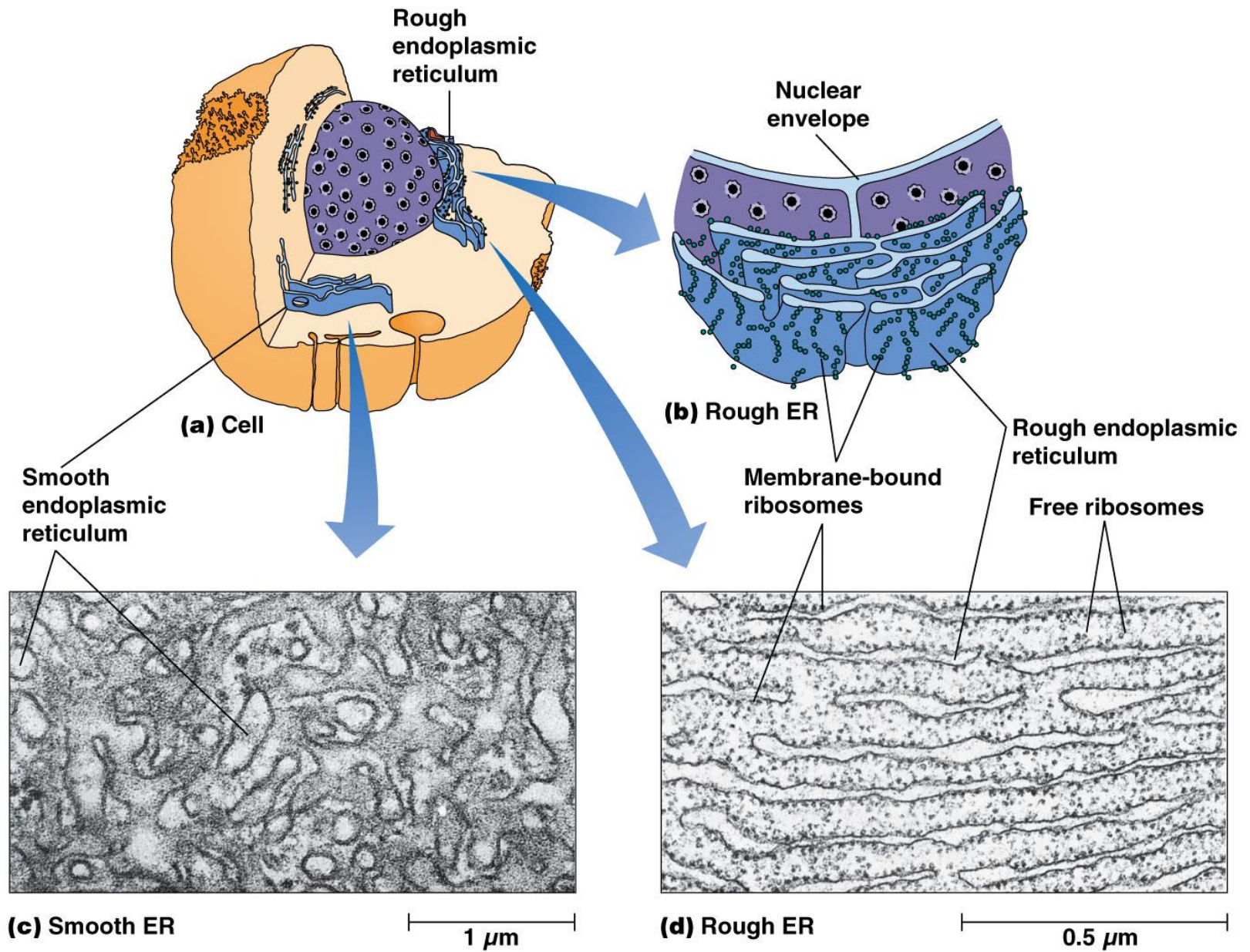
The endosymbiont theory

- The **endosymbiont theory** suggests that mitochondria and chloroplasts originated from prokaryotes
- These gained entry into single-celled organisms called *protoeukaryotes*
- Protoeukaryotes may have ingested bacteria by *phagocytosis* without then digesting them, allowing a symbiotic relationship to develop

The Endoplasmic Reticulum

- Almost every eukaryotic cell has a network of membranes in the cytoplasm, called the **endoplasmic reticulum (ER)**
- It consists of tubular membranes and flattened sacs called **cisternae**
- The internal space of the ER is called the **lumen**
- The ER is continuous with the other membranes in the cell

Figure 4-15



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Rough endoplasmic reticulum

- ER can be *rough* or *smooth* in appearance
- **Rough ER** is studded with ribosomes on the cytoplasmic side of the membrane
- These ribosomes synthesize polypeptides that accumulate within the membrane or are transported across it to the lumen
- Free ribosomes are not associated with the ER

Smooth endoplasmic reticulum

- **Smooth ER** has no role in protein synthesis
- It is involved in the synthesis of lipids and steroids such as cholesterol and its derivatives
- Smooth ER is responsible for inactivating and detoxifying potentially harmful substances
- *Sarcoplasmic reticulum* has critical functions in contraction

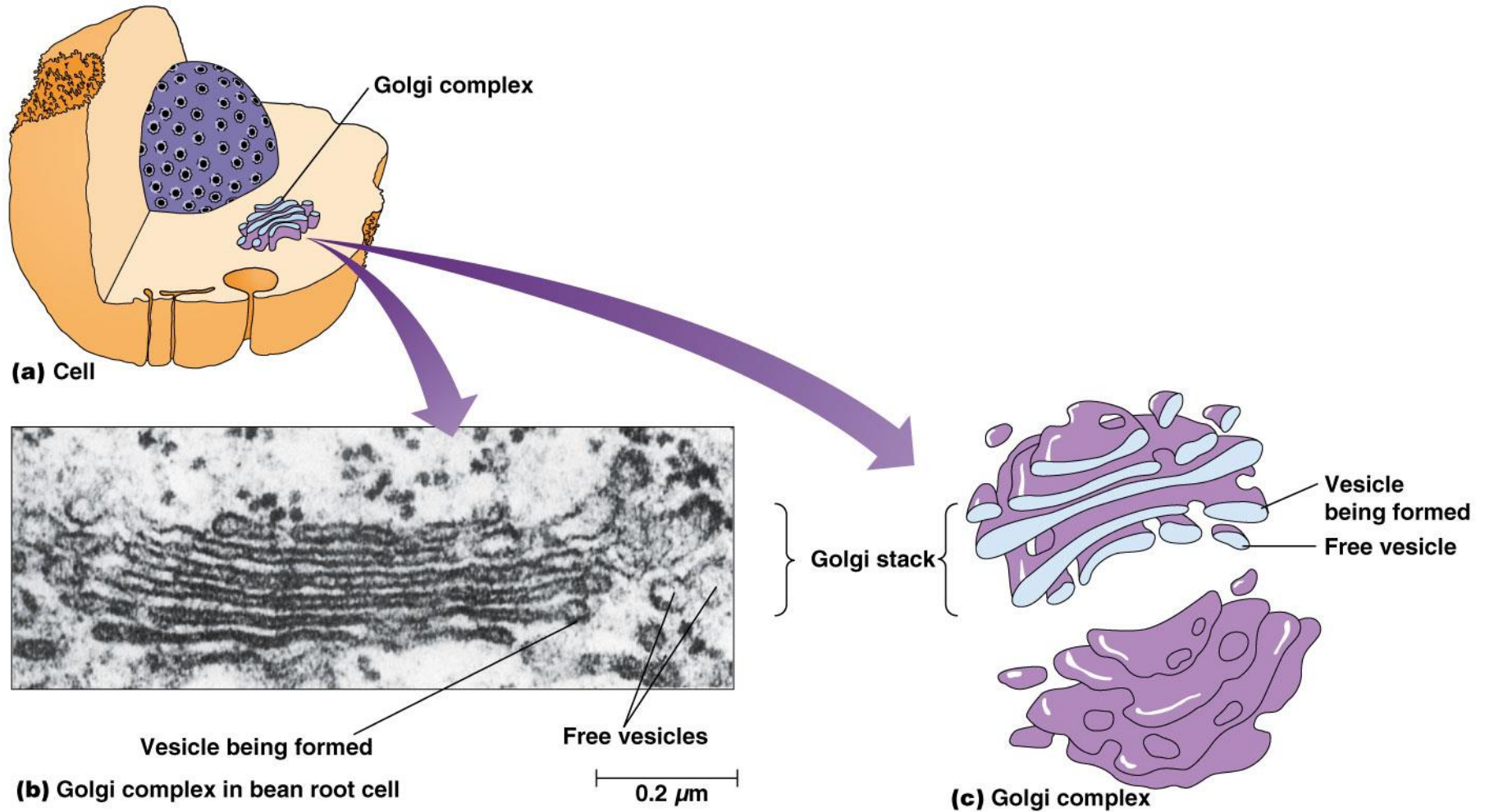
The Golgi Complex

- The **Golgi complex**, closely related to the ER in proximity and function, consists of a stack of flattened vesicles known as *cisternae*
- It plays an important role in processing and packaging secretory proteins, and in complex polysaccharide synthesis
- It accepts vesicles that bud off of the ER

The Golgi complex is like a processing station

- The contents of vesicles from the ER are modified and processed in the Golgi complex
- E.g., secretory and membrane proteins are mainly *glycosylated* (the addition of short-chain carbohydrates), a process that begins in the ER and is completed in the Golgi complex
- The processed substances then move to other locations in the cell through vesicles that bud off of the Golgi complex

Figure 4-16

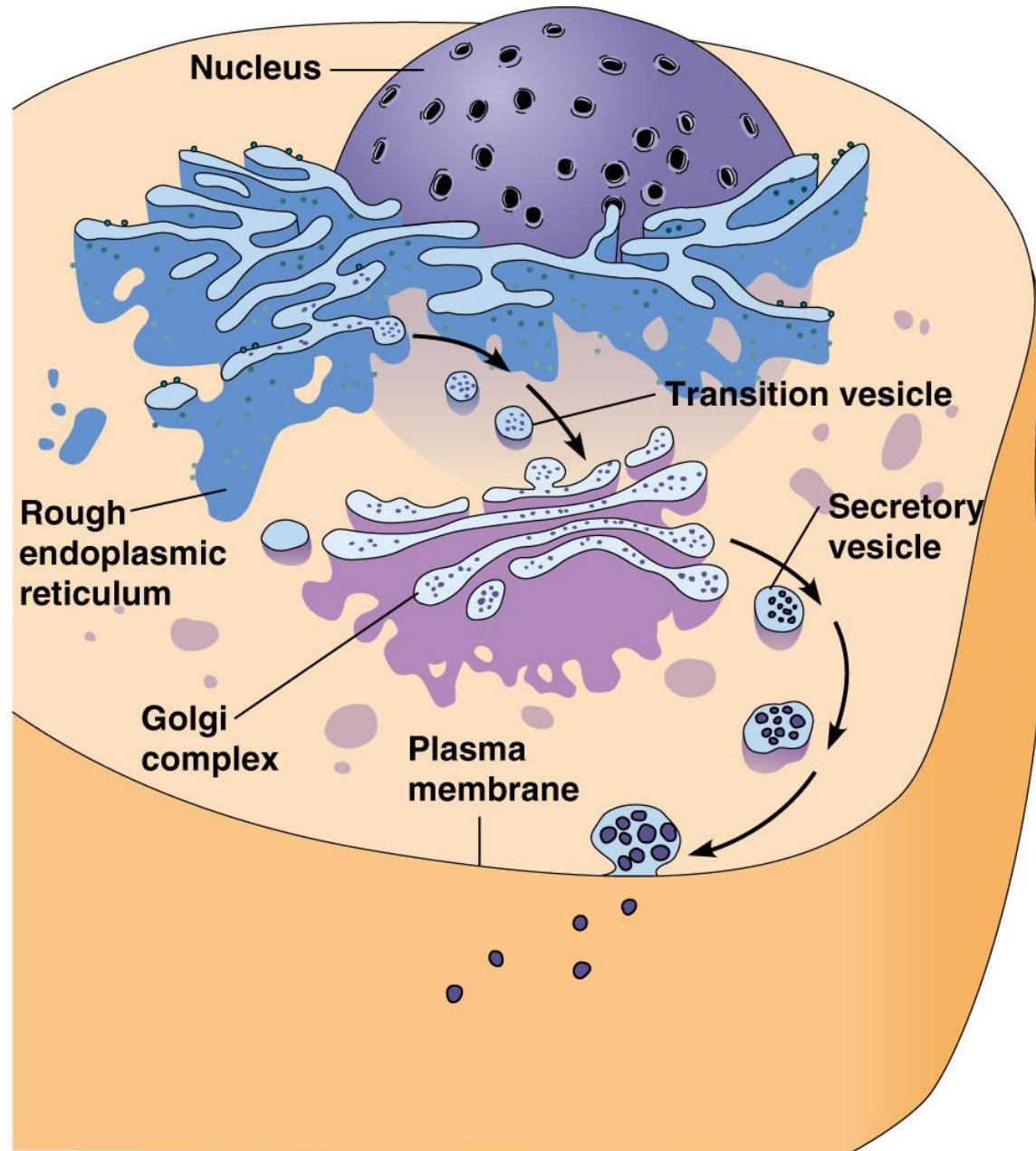


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Secretory Vesicles

- Once processed by the Golgi complex, materials to be exported from the cell are packaged into **secretory vesicles**
- These move to the plasma membrane and fuse with it, releasing their contents outside the cell
- The ER, Golgi, secretory vesicles and lysosomes make up the *endomembrane system* of the cell, responsible for *trafficking* substances through the cell

Figure 4-17

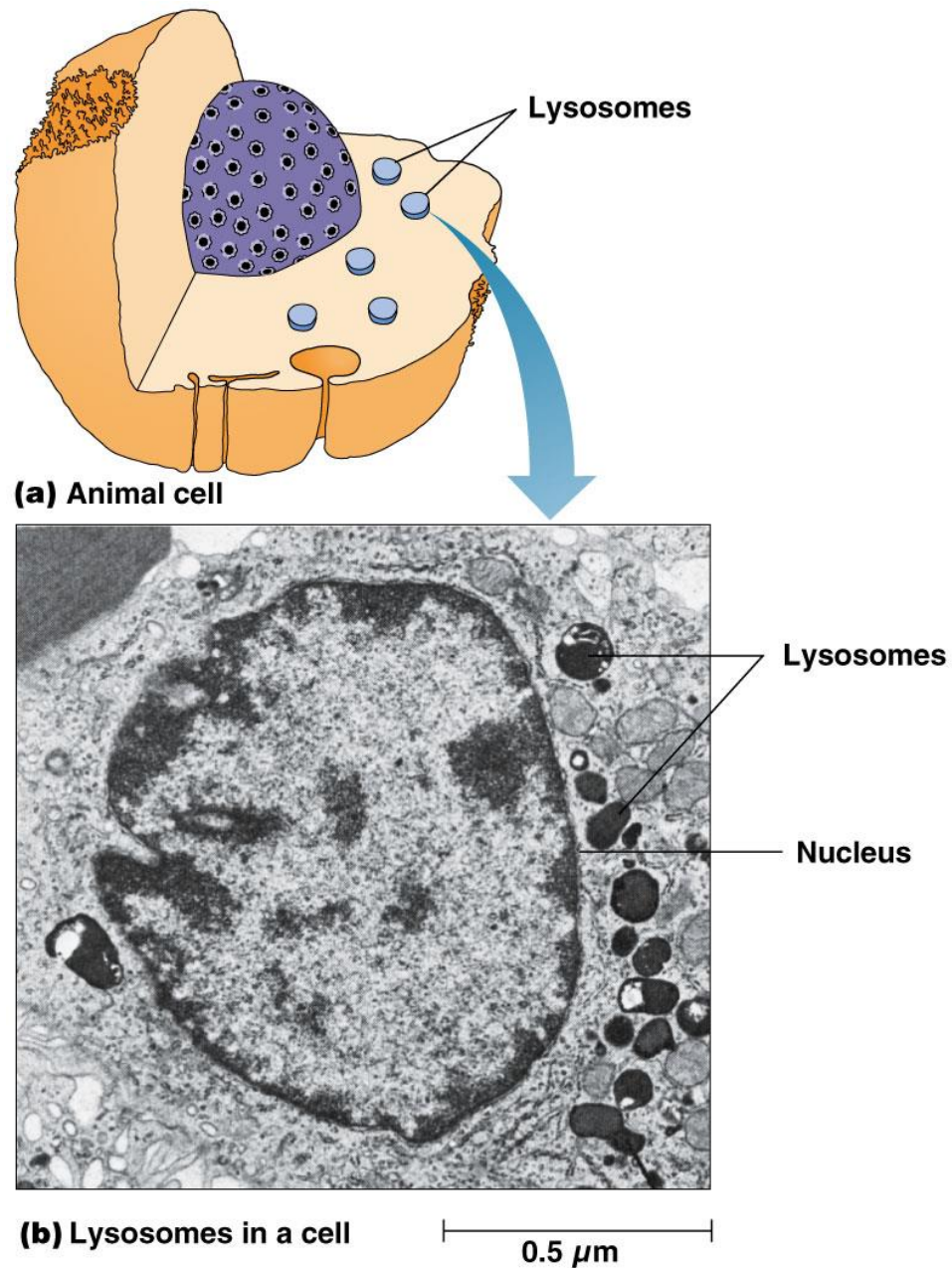


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The Lysosome

- **Lysosomes** are single membrane organelles that store *hydrolases*, enzymes that can digest any kind of biological molecule
- These enzymes are sequestered to prevent them from digesting the contents of the cell
- A special carbohydrate coating on the inner lysosome membrane protects it from digestion

Figure 4-18



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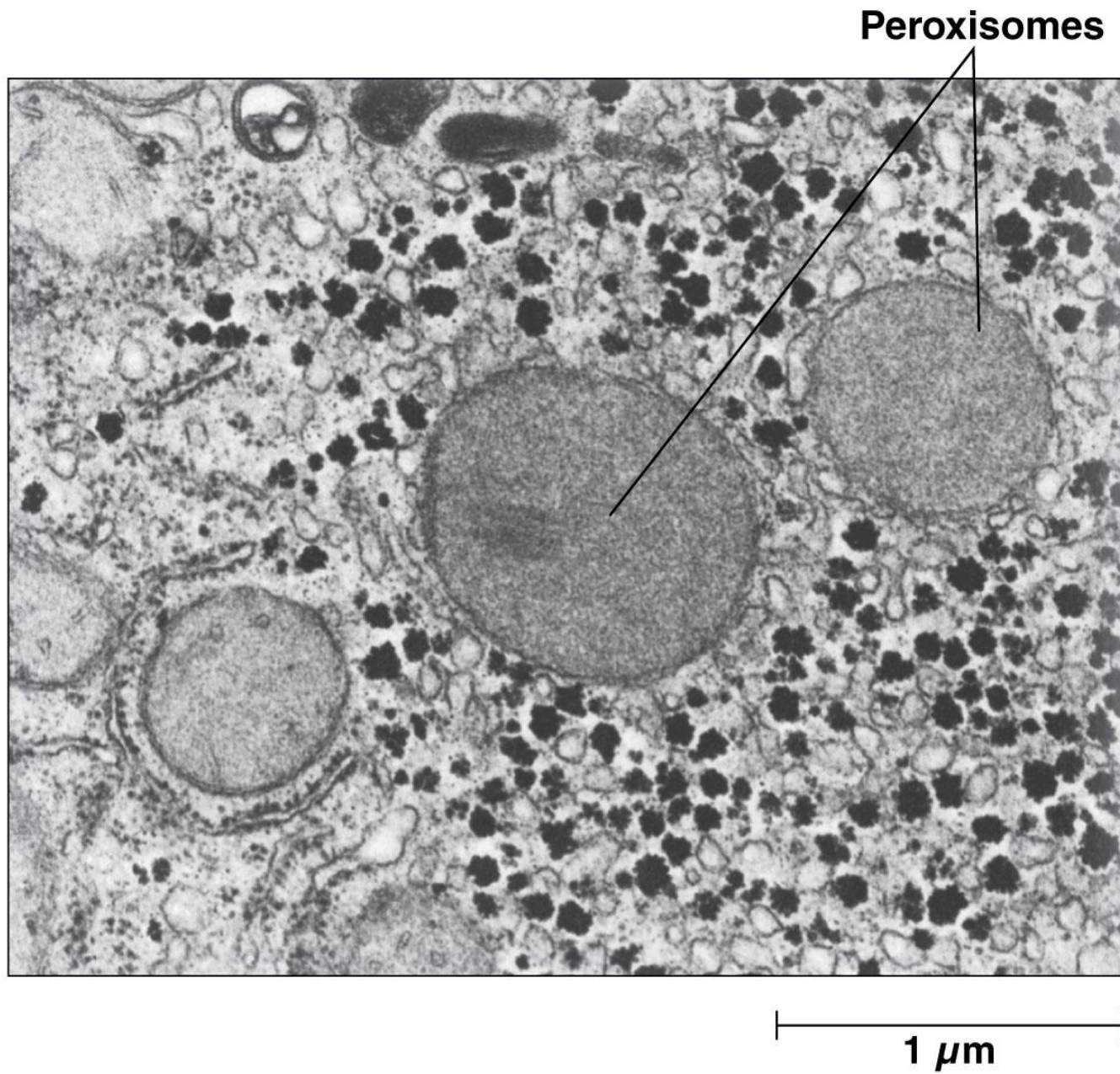
The Peroxisome

- **Peroxisomes** resemble lysosomes in size and appearance
- They are surrounded by a single membrane and perform several functions depending on cell type
- Peroxisomes are especially prominent in the liver and kidney cells of animals

Hydrogen peroxide

- H_2O_2 is highly toxic to cells but can be formed into water and oxygen by the enzyme *catalase*
- Eukaryotic cells have metabolic processes that produce H_2O_2
- These reactions are confined to peroxisomes that contain catalase, so that cells are protected from the harmful effects of peroxide

Figure 4-19



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Other functions of peroxisomes

- Peroxisomes detoxify other harmful compounds, and catabolize unusual substances
- In animals, they play roles in oxidative breakdown of fatty acids, especially longer chain fatty acids (up to 22 carbon atoms)
- Some serious human diseases result from defects in one or more peroxisomal enzymes, normally involved in degrading long-chain fatty acids

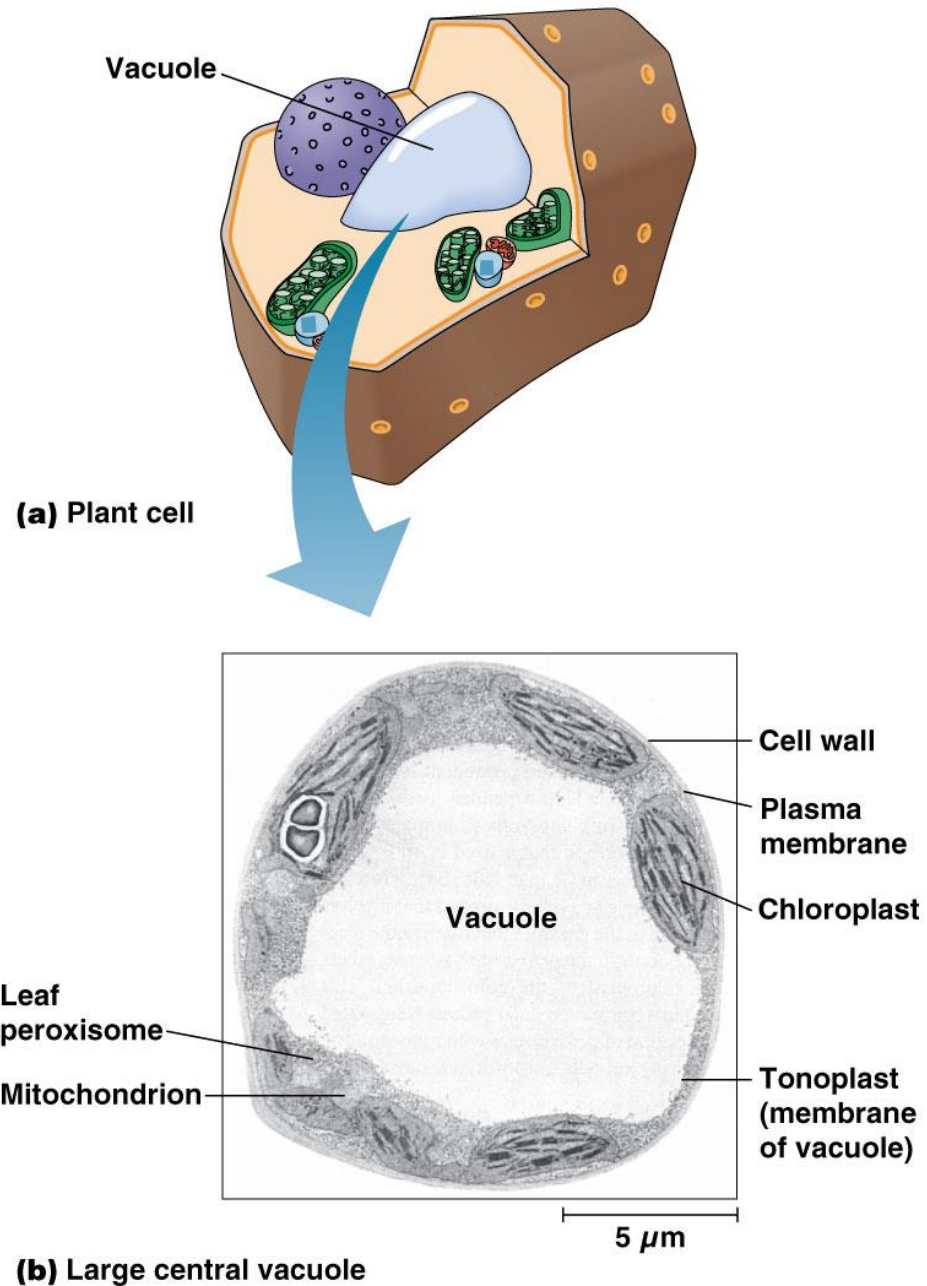
Vacuoles

- Some cells contain a membrane-bounded vacuole
- In animal and yeast cells they are used to temporary storage or transport
- Phagocytosis leads to the formation of a membrane bound particle, called a phagosome
- When this type of vacuole fuses with a lysosome, the contents are hydrolyzed to provide nutrients to a cell

Plant vacuoles

- Most mature plant cells contain a single large vacuole called a **central vacuole**
- The main function of the central vacuole is to maintain the *turgor pressure* that keeps the plant from wilting
- Tissues wilt when the central vacuole no longer presses against the cell contents (fails to provide adequate pressure)

Figure 4-21



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Ribosomes

- **Ribosomes** are not really organelles because they are not enclosed by a membrane
- They are found in all cells but differ slightly in bacteria, archaea and eukarya in their size and composition
- Each cell type has a unique type of ribosomal RNA

Ribosomes are very small

- Ribosomes can only be seen under the electron microscope
- They have **sedimentation coefficients** in keeping with their small size
- Sedimentation coefficient: a measure of how rapidly a particle sediments in an ultracentrifuge, expressed in *Svedberg units (S)*
- Ribosomes have values of 80S (eukaryotes) or 70S (bacteria and archaea)

Ribosome subunits

- Ribosomes have two subunits, the **large** and **small subunits**, with sedimentation coefficients of 60S and 40S respectively in eukaryotic cells
- Bacteria and archaea have large and small subunits of 50S and 30S, respectively
- The S values of large and small subunits does not add up to the value for the complete ribosome, because S values depend on both size and shape

Ribosome are numerous and ubiquitous

- Ribosomes are much more numerous than most other cellular structures (prokaryote cells contain thousands, eukaryote cells may contain millions)
- Ribosomes in mitochondria and chloroplasts are similar size and composition to those of bacteria

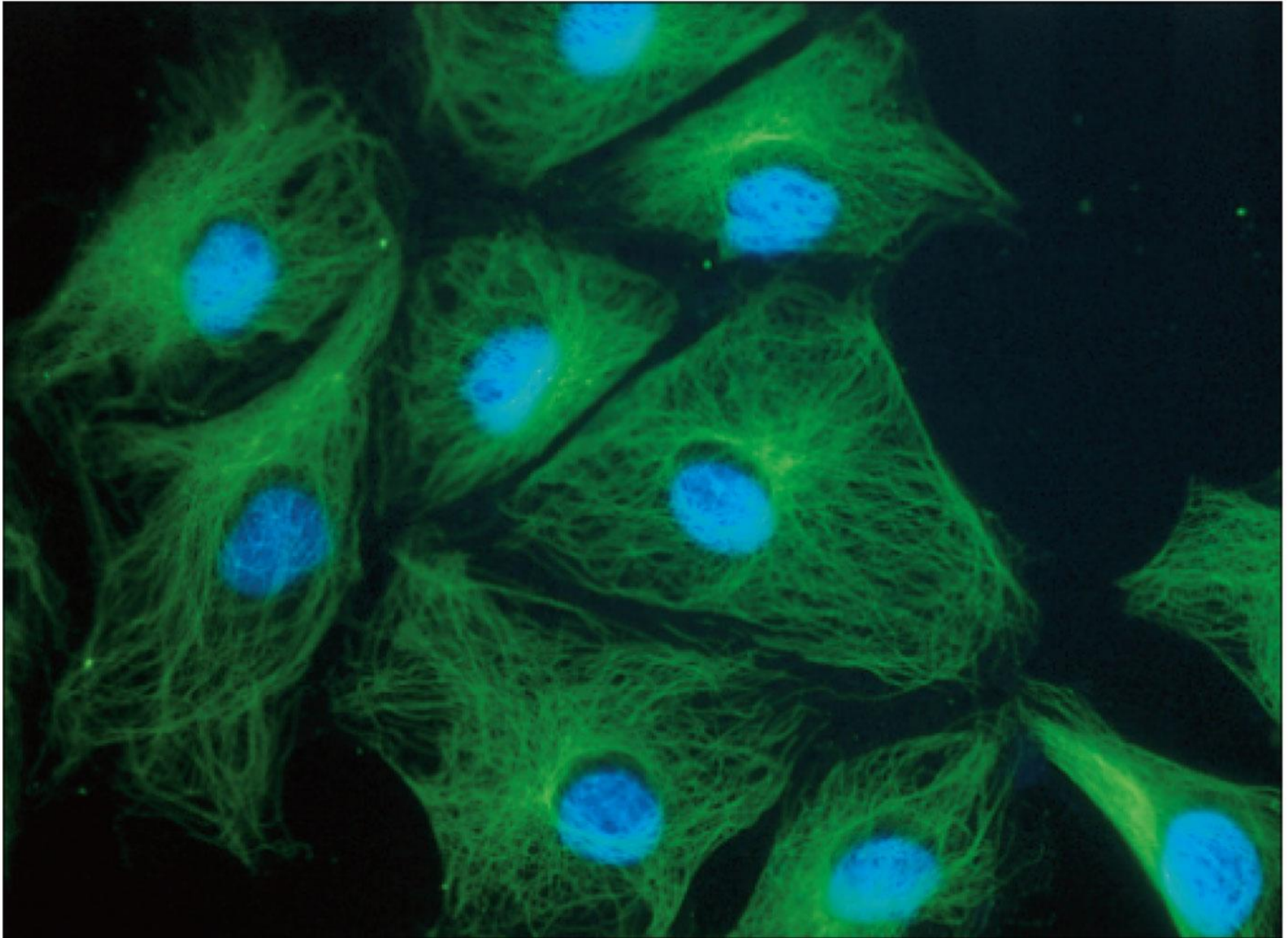
The Cytoplasm of Eukaryotic Cells Contains the Cytosol and Cytoskeleton

- The **cytoplasm** of a eukaryotic cell is the interior of the cell not occupied by the nucleus
- The **cytosol** is the semifluid substance in which the organelles are suspended
- The synthesis of fats and proteins and the initial steps in releasing energy from sugars takes place in the cytosol
- The cytosol is permeated by the **cytoskeleton**

The cytoskeleton

- The cytoskeleton is a three-dimensional array of interconnected microfilaments, microtubules and intermediate filaments
- It gives a cell its distinctive shape and internal organization
- It also plays a role in cell movement and cell division

Figure 4-23



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The cytoskeleton (continued)

- The cytoskeleton serves as a framework for positioning and moving organelles and macromolecules within the cell
- It may do the same for ribosomes and enzymes
- Even some of the water within the cell (20-40%) may be bound to microfilaments and microtubules

The Extracellular Matrix and the Cell Wall Are “Outside” the Cell

- Most cells are characterized by extracellular structures
- For many animal cells these structures are called the **extracellular matrix (ECM)** and consist mainly of collagen fibers and proteoglycans
- For plant and fungal cells, these are **cell walls**, consisting mainly of *cellulose microfibrils*

Motility and the ECM

- Plant cells are *nonmotile* and thus suited to the rigidity that cell walls confer on an organism
- Animal cells are *motile* and therefore are surrounded by a strong but elastic network of collagen fibers
- Bacteria and archaea may be motile or not; their cell walls provide protection from bursting due to osmotic differences between the cell and the surrounding environment

The ECM

- The primary function of the ECM is support but the types of materials and patterns in which they are deposited regulate a variety of processes
- In animal cells, a network of proteoglyans surrounds the collagen fibers
- In vertebrates, collagen is the most abundant protein in the animal body, as it is also found in tendons, cartilage and bone

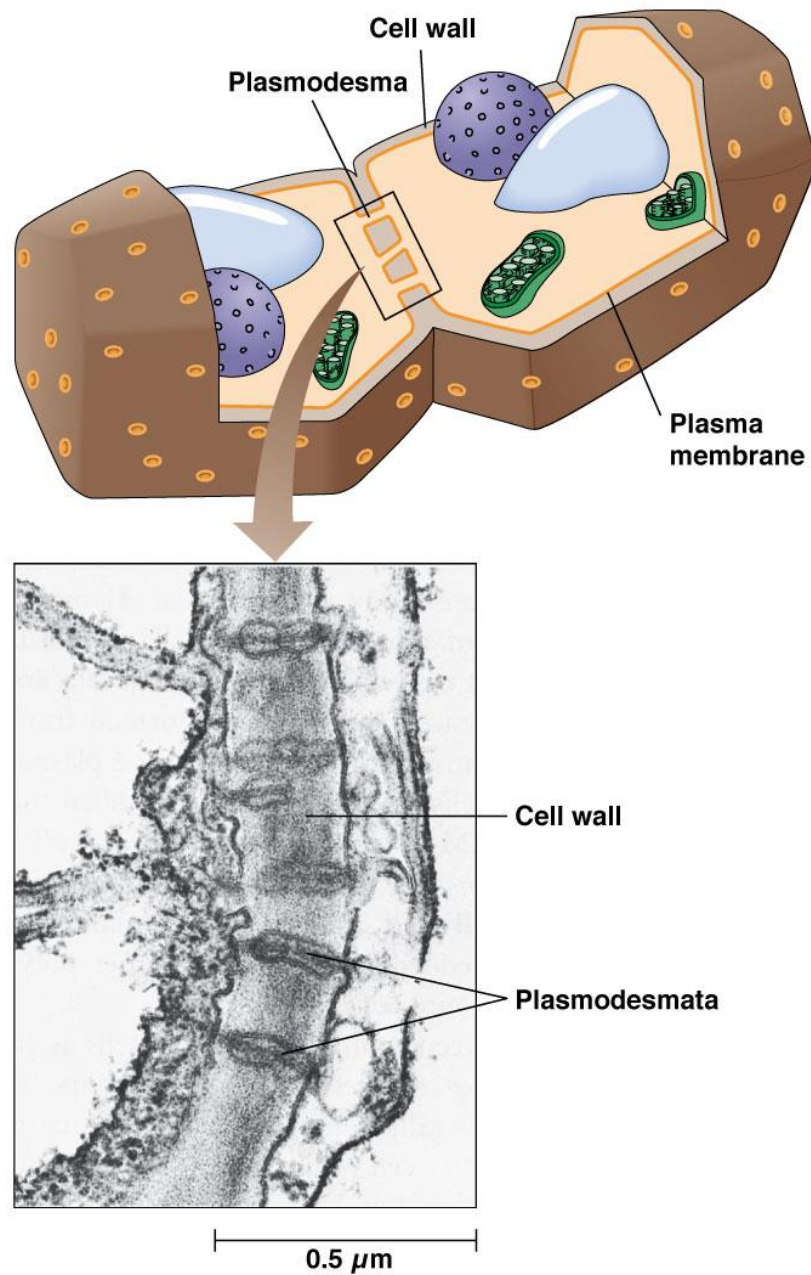
Additional functions of the ECM

- Processes regulated by the ECM may include:
 - Cell motility and migration
 - Cell division
 - Cell recognition and adhesion
 - Cell differentiation during embryonic development

Cell communication

- Plant cells are connected to neighboring cells by cytoplasmic bridges called **plasmodesmata**, which pass through the cell wall
- Plasmodesmata are large enough to allow the passage of water and small solutes from cell to cell
- Animal cells also communicate with one another through intercellular connections called *gap junctions*
- *Tight junctions* and *adhesion junctions* also connect animal cells

Figure 4-25



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