Cells: The Working Units of Life

Chapter 5 Key Concepts

5.1 Cells Are the Fundamental Units of Life

5.2 Prokaryotic Cells Are the Simplest Cells

5.3 Eukaryotic Cells Contain Organelles

5.4 Extracellular Structures Have Important Roles

5.5 Eukaryotic Cells Evolved in Several Steps

Key Concepts 5.1 Focus Your Learning

- **Cell theory** states that the cell is the smallest unit of life, that cells make up all living organisms, and that cells come from existing cells.
- Membranes provide a structural role in a cell and also allow the cell to maintain homeostasis and communicate with other cells.

5.1 Cells Are the Fundamental Units of Life

Cell theory is an important unifying theory of biology.

- Cells are the fundamental units of life.
- All organisms are composed of cells.
- All cells come from preexisting cells.
- Modern cells evolved from a common ancestor.

Implications of the cell theory:

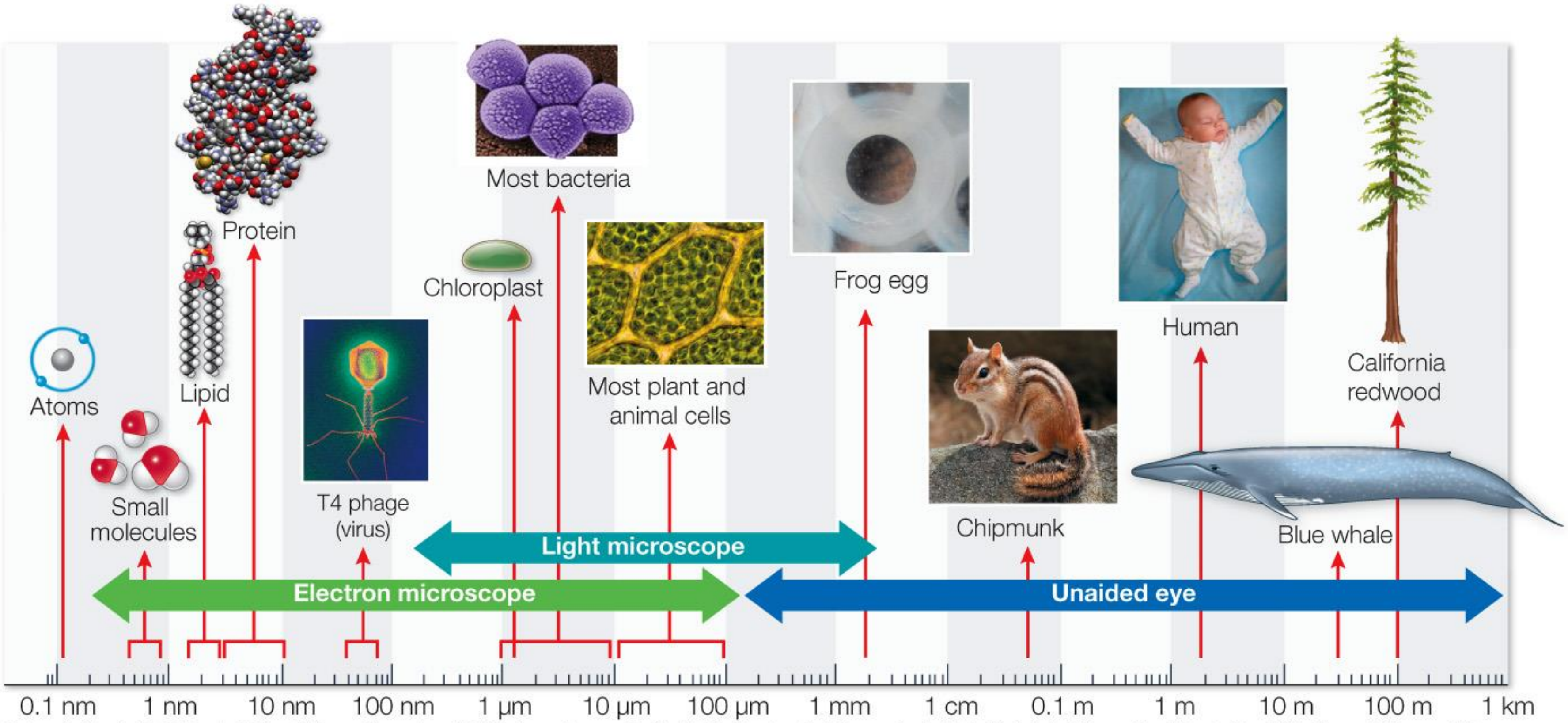
- Functions of all cells are similar.
- Life is continuous.
- Origin of life was the origin of cells.

5.1 Cells Are the Fundamental Units of Life

Cells are small (mostly).

- Exceptions: bird eggs, some algae and bacteria

Figure 5.1 The Scale of Life



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LIFE: THE SCIENCE OF BIOLOGY 11e, **Figure 5.1**

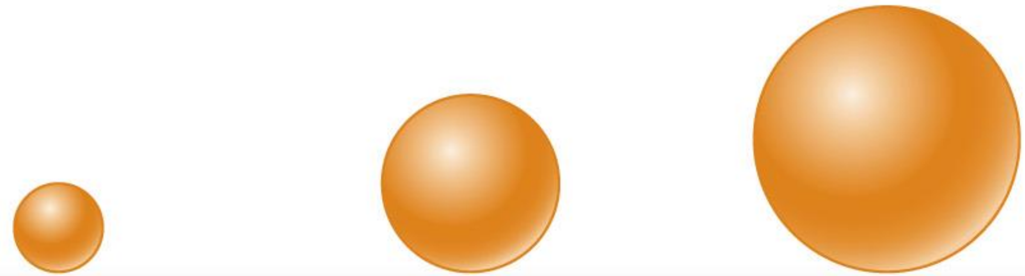
5.1 Cells Are the Fundamental Units of Life

Cells are small because a high surface area-to-volume ratio is essential.

As a cell volume increases, chemical activity increases, along with the need for resources and waste removal.

Surface area becomes limiting. Thus large organisms consist of many small cells.

Figure 5.2 Why Cells Are Small



Diameter	2 µm	20 µm	200 µm
Surface area $4 \pi r^2$	12.6 μm^2	1,260 μm^2	126,000 μm^2
Volume $4/3 \pi r^3$	4.2 μm^3	4,200 μm^3	4,200,000 μm^3
Surface area-to-volume ratio	3.0:1	0.3:1	0.003:1

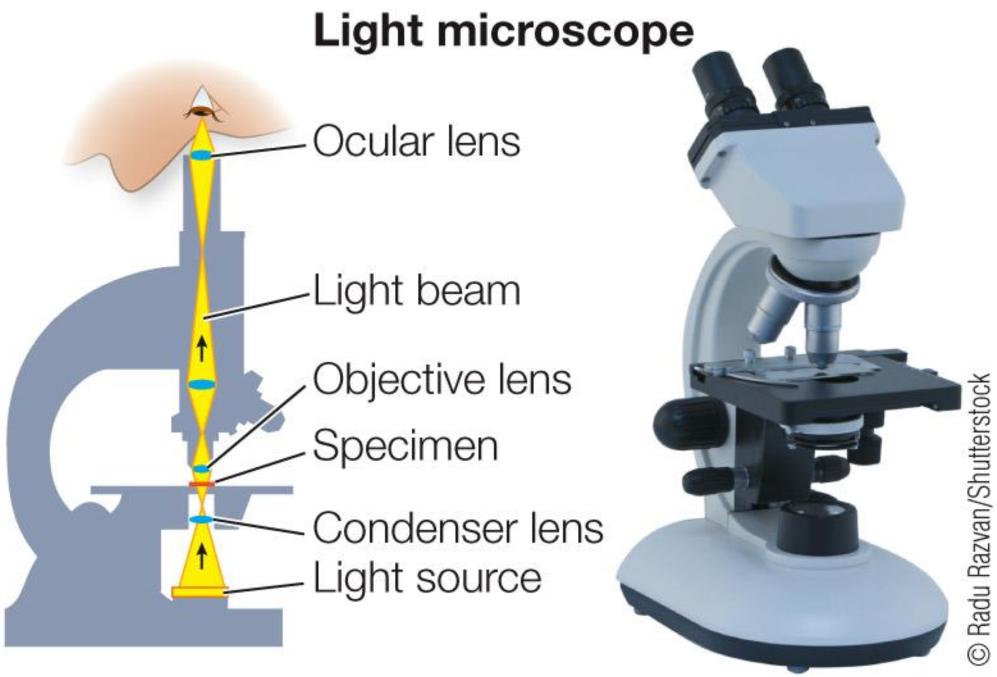
5.1 Cells Are the Fundamental Units of Life

To see most cells, we use microscopes:

Magnification: Increases apparent size.

Resolution: Clarity of magnified object—minimum distance two objects can be apart and still be seen as two objects.

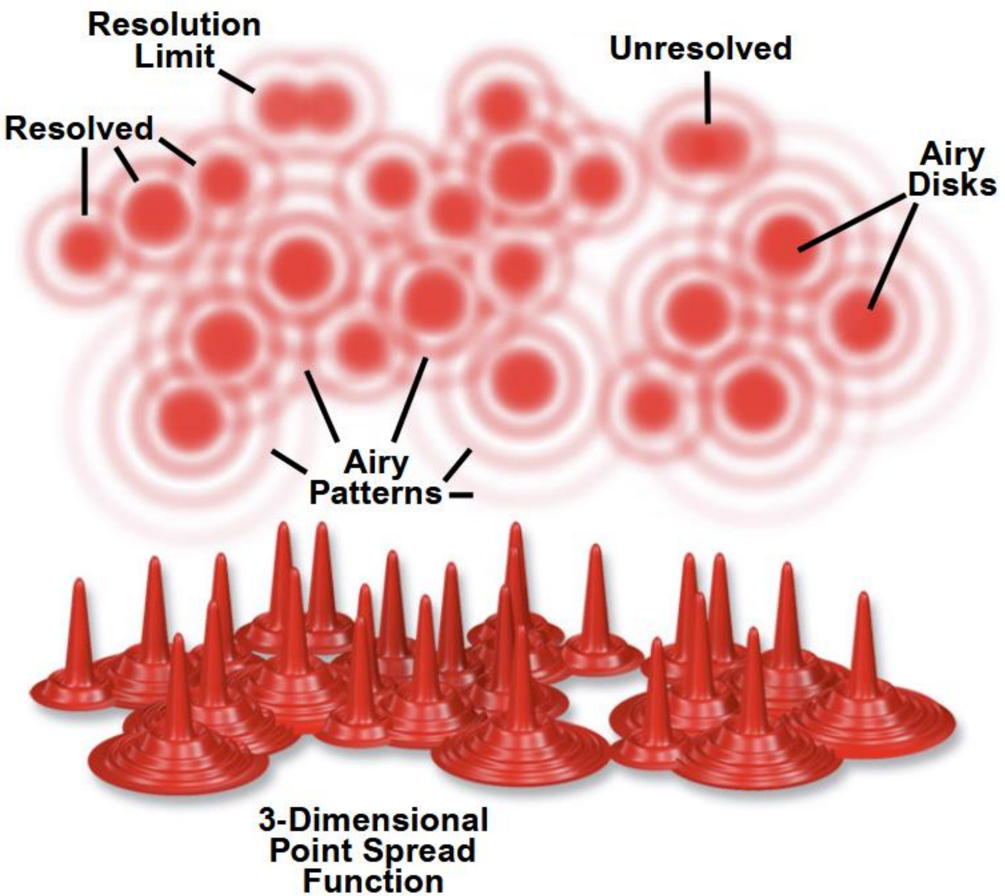
- Two basic types of microscopes:
  - Light microscopes: glass lenses and light; resolution = 0.2 µm
  - Electron microscopes: electromagnets focus an electron beam; resolution = 0.2 nm



In a *light microscope*, glass lenses and visible light are used to form an image. The resolution is about 0.2 µm, which is 1,000 times greater than that of the human eye. Light microscopy allows visualization of cell sizes and shapes and some internal cell structures. Internal structures are hard to see under visible light, so cells are often chemically treated and stained with various dyes to make certain structures stand out by increasing contrast.

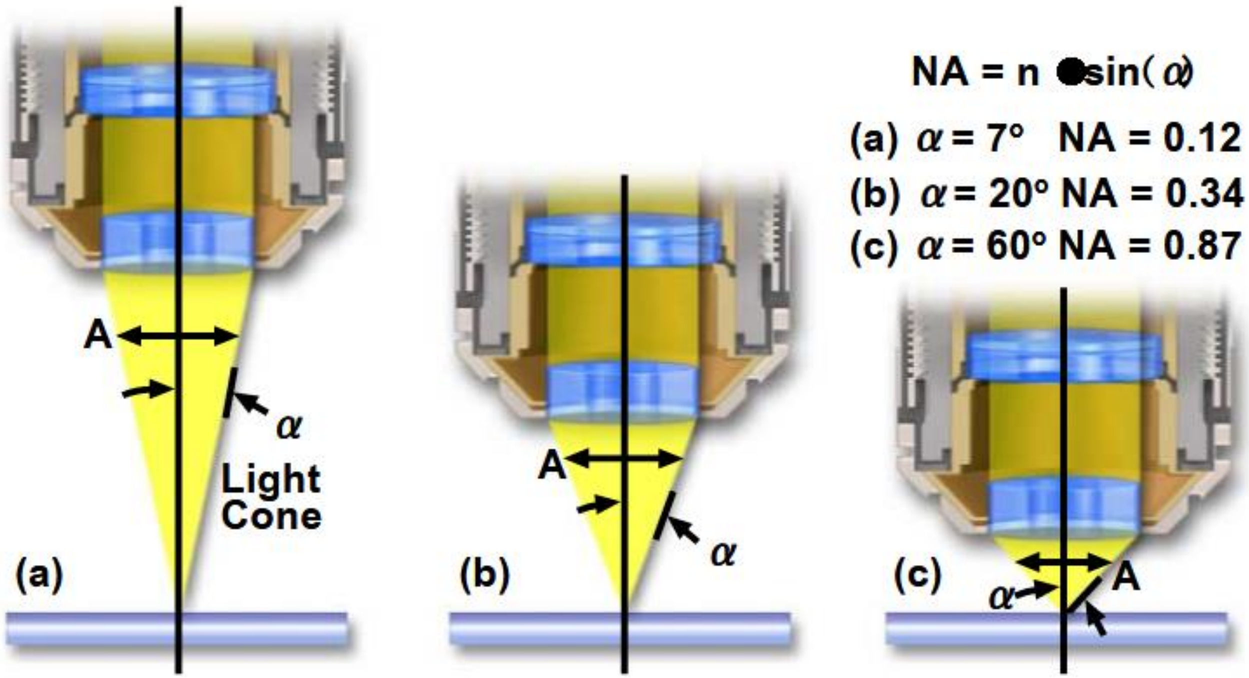
LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.3 (Part 1)

Figure 1 - Airy Patterns and the Limit of Resolution



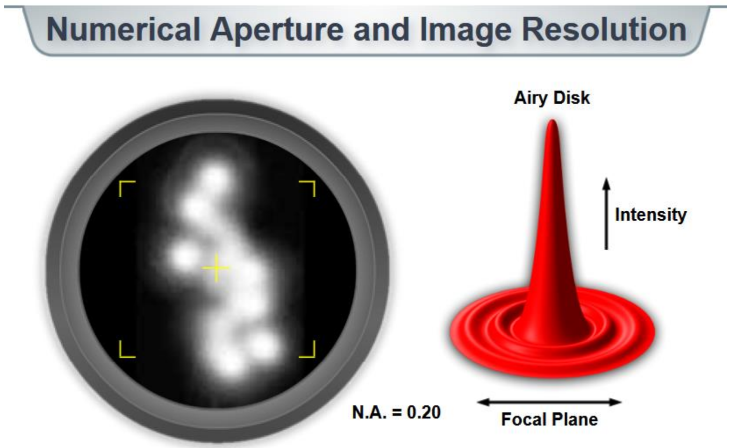
Resolution (r) = $0.61\lambda/NA$

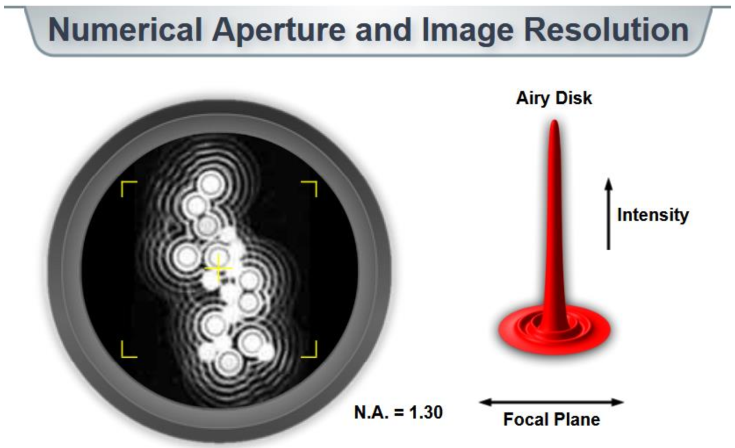
Numerical aperture



water (refractive index = 1.33),
glycerin (refractive index = 1.47),
immersion oil (refractive index = 1.51)

resolution


Numerical Aperture and Image Resolution
Airy Disk
Intensity
N.A. = 0.20
Focal Plane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Intensity
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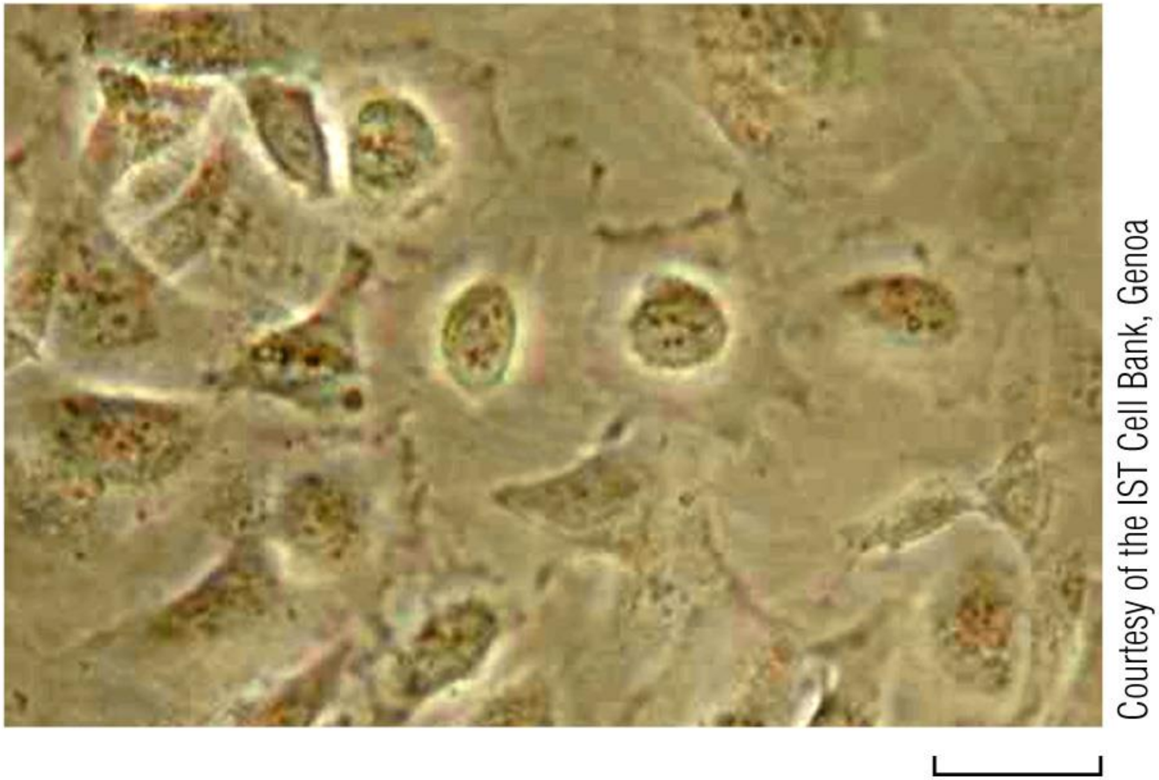
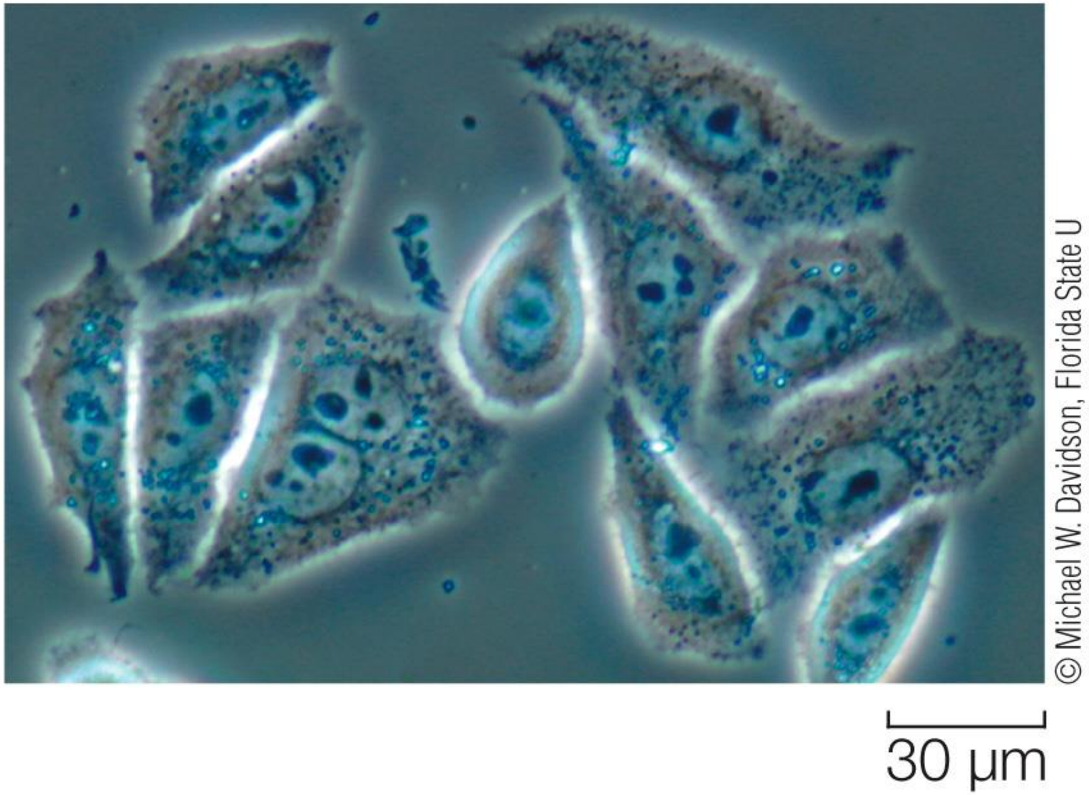


In **bright-field microscopy**, light passes directly through these human cells. Unless natural pigments are present, there is little contrast and details are not distinguished.



In **phase-contrast microscopy**, contrast in the image is increased by emphasizing differences in refractive index (the capacity to bend light), thereby enhancing light and dark regions in the cell.

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Differential interference-contrast microscopy uses two beams of polarized light. The combined images look as if the cell is casting a shadow on one side.

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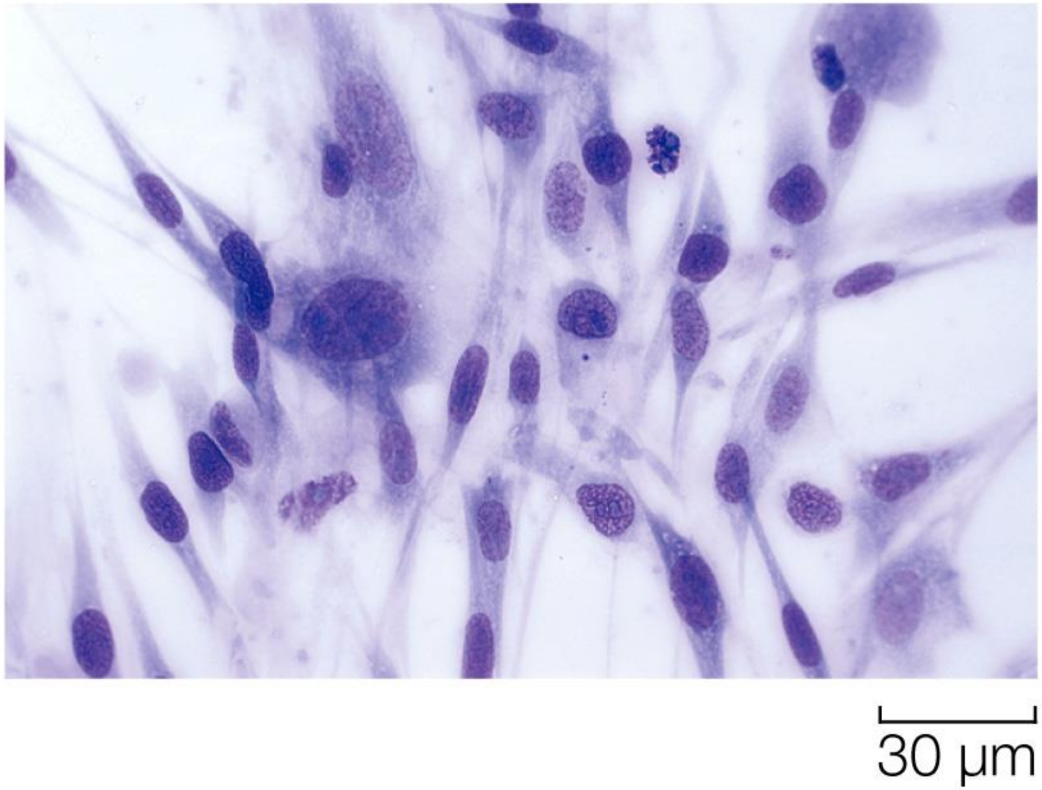
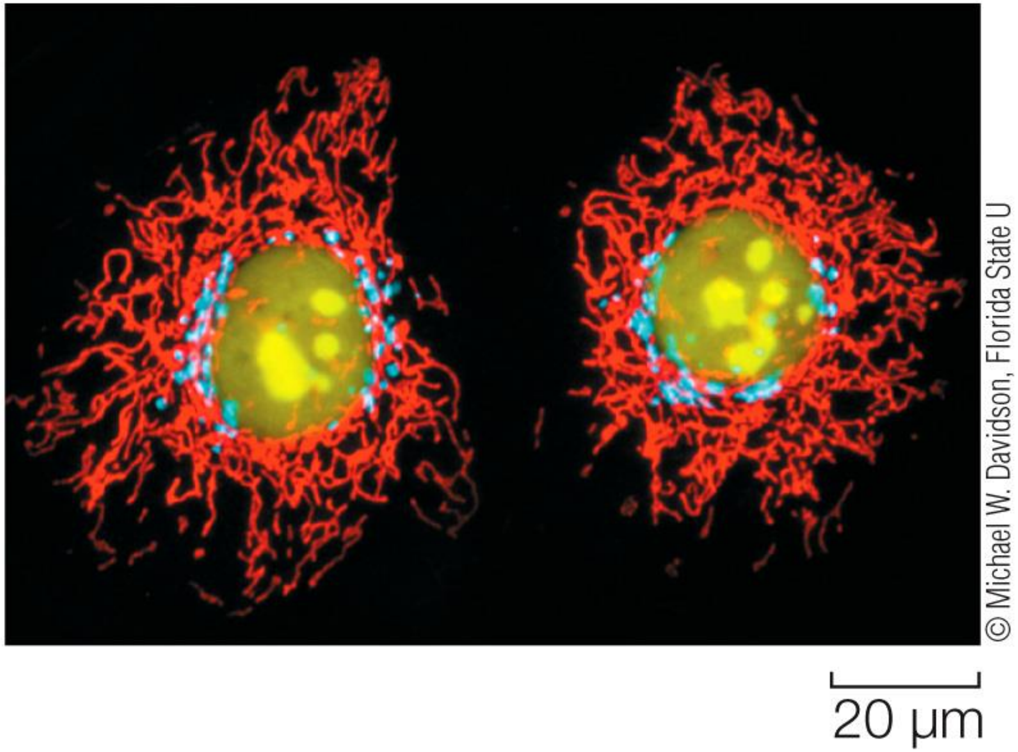
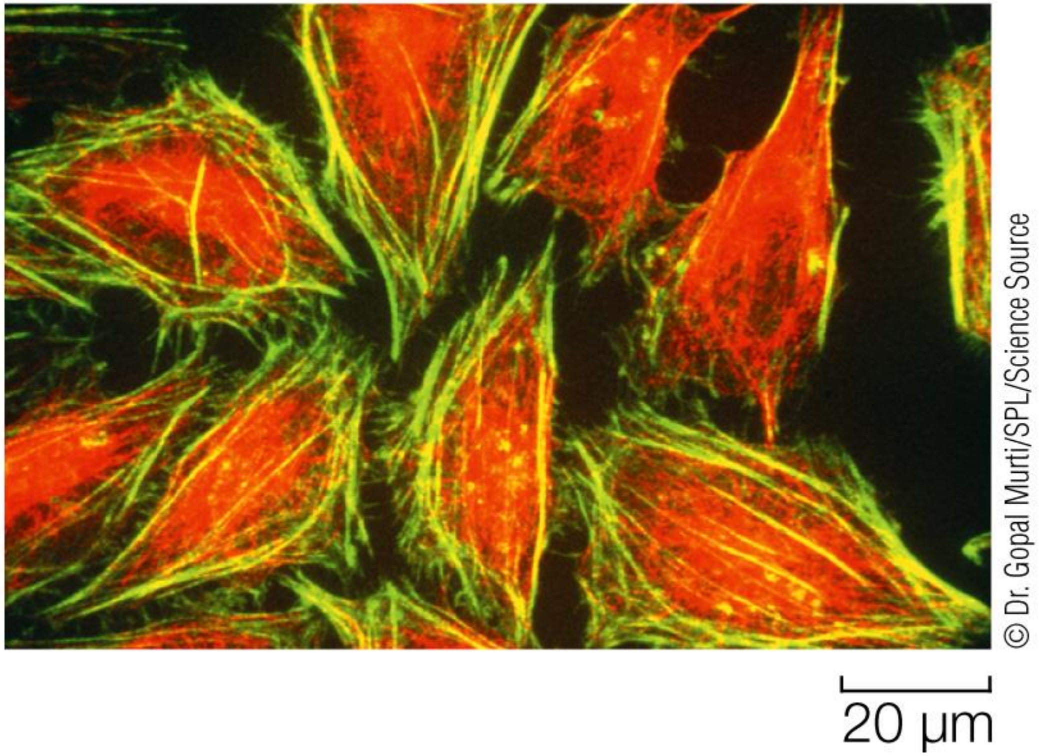


In **stained bright-field microscopy**, a stain enhances contrast and reveals details not otherwise visible. Stains differ greatly in their chemistry and their capacity to bind to cell materials, so many choices are available.

Figure 5.3 Looking at Cells (Part 6)



In **fluorescence microscopy**, a natural substance in the cell or a fluorescent dye that binds to a specific cell material is stimulated by a beam of light, and the longer-wavelength fluorescent light is observed coming directly from the dye.



Confocal microscopy uses fluorescent materials but adds a system of focusing both the stimulating and emitted light so that a single plane through the cell is seen. The result is a sharper two-dimensional image than with standard fluorescence microscopy.

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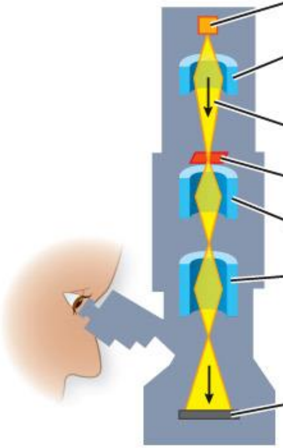
Transmission electron microscope



In an *electron microscope*, electromagnets are used to focus an electron beam, much as a light microscope uses glass lenses to focus a beam of light. Since we cannot see electrons, the electron microscope directs them through a vacuum at a fluorescent screen or digital camera to create a visible image. The resolution of electron microscopes is about 2 nm, which is about 100,000 times greater than that of the human eye. This resolution permits the details of many subcellular structures to be distinguished.

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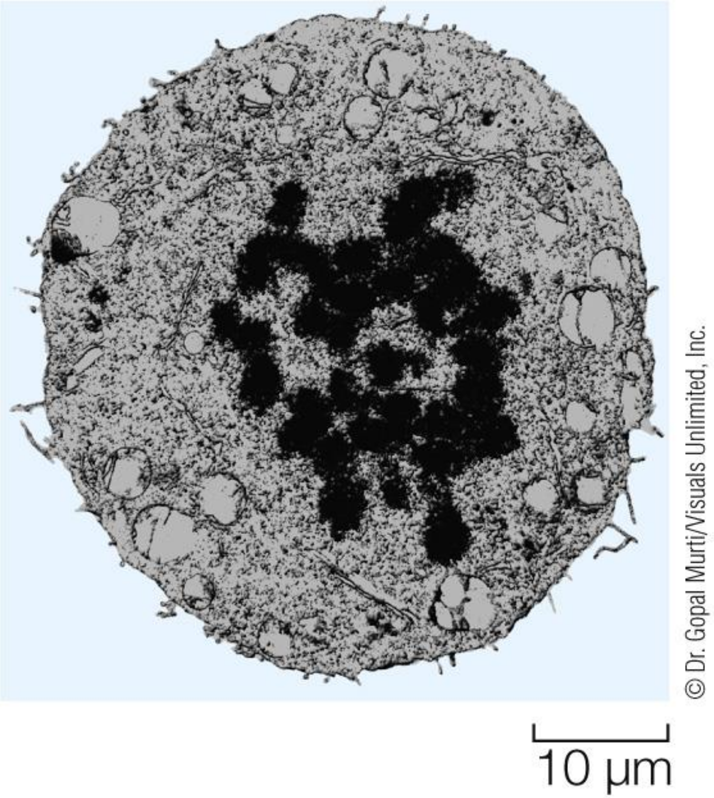

In **transmission electron microscopy** (TEM), a beam of electrons is focused on the object by magnets. Objects appear darker if they absorb the electrons. If the electrons pass through they are detected on a fluorescent screen.

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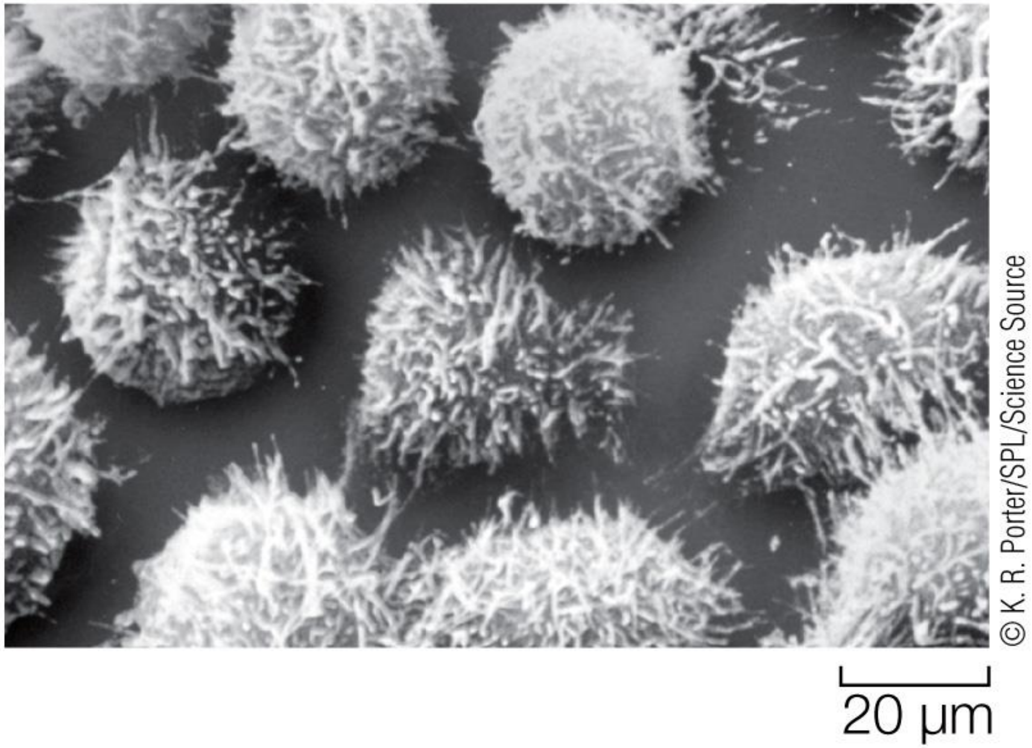

Scanning electron microscopy (SEM) directs electrons to the surface of the sample, where they cause other electrons to be emitted. These electrons are viewed on a screen. The three-dimensional surface of the sample can be visualized.

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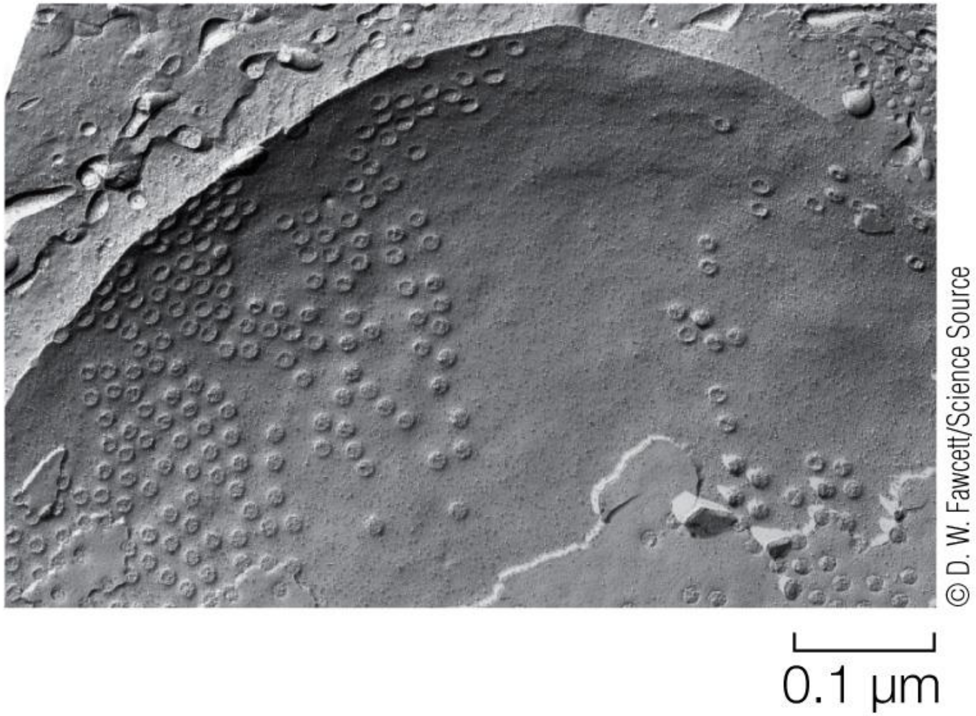


In **freeze-fracture microscopy**, cells are frozen and then a knife is used to crack them open. The crack often passes through the interior of cell and internal membranes. The "bumps" that appear are usually large proteins or aggregates embedded in the interior of the membrane.

The **cell membrane** is the outer boundary of every cell and has similar structure in all cells.

The membrane is a phospholipid bilayer with embedded proteins.

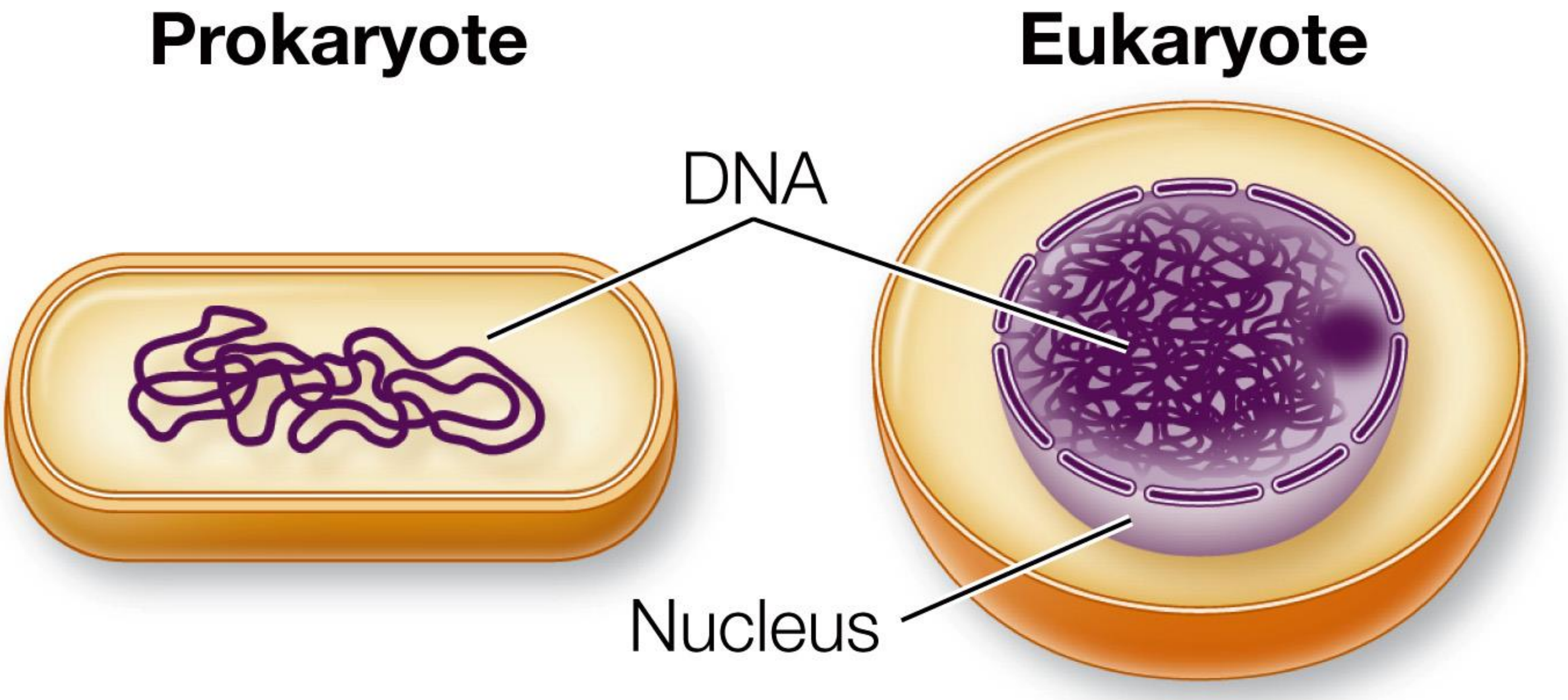
The cell membrane:

- is a selectively permeable barrier
- allows cells to maintain a constant internal environment
- is important in communication and receiving signals
- often has proteins for binding and adhering to adjacent cells

5.1 Cells Are the Fundamental Units of Life

Two types of cells:

- **Prokaryotic** (Bacteria and Archaea) have no membrane-enclosed internal compartments.
- **Eukaryotic** (Eukarya) have membrane-enclosed organelles in which different functions occur.



LIFE: THE SCIENCE OF BIOLOGY 11e, In-Text Art, Ch. 5, p. 85

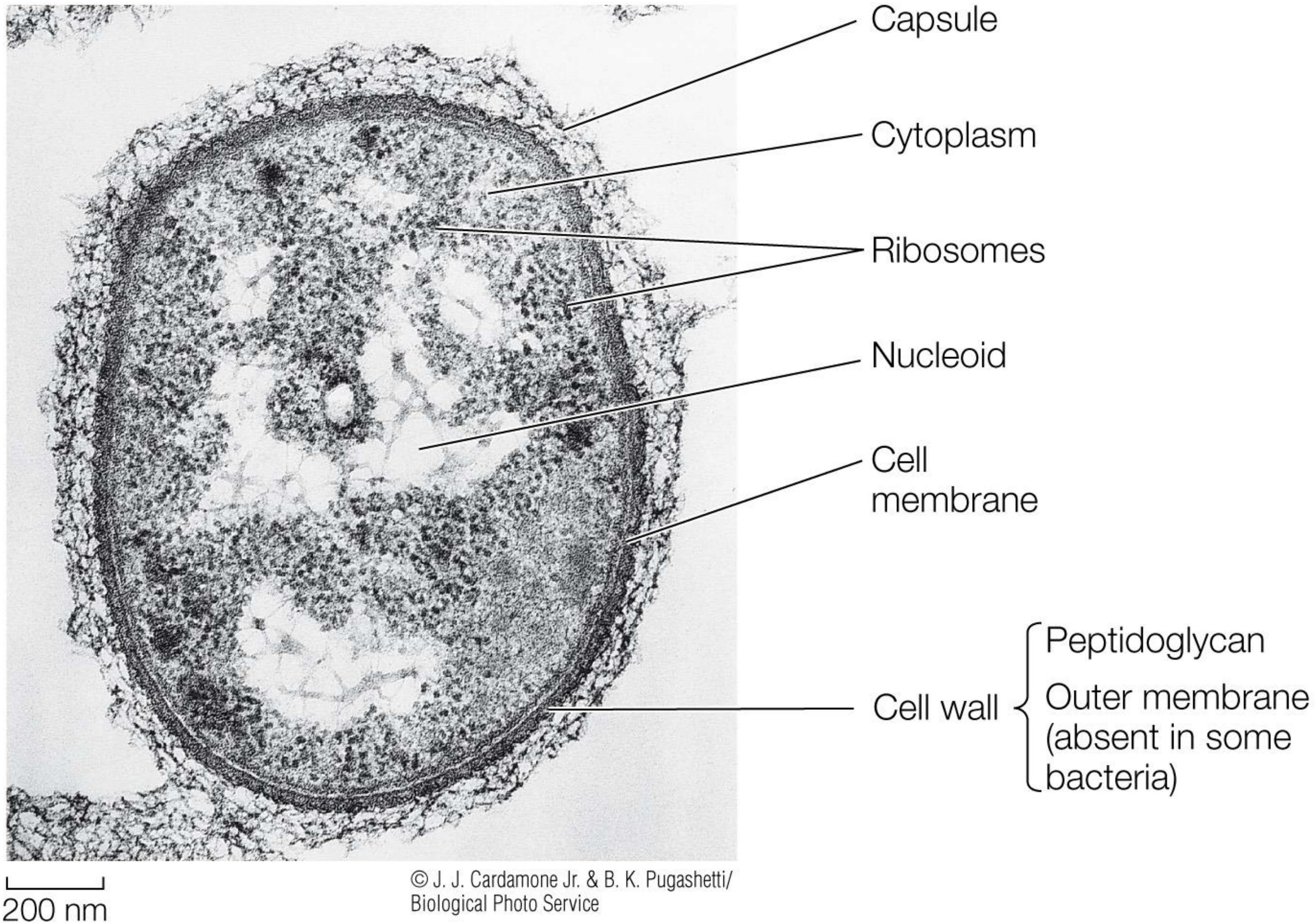
Key Concept 5.2 Focus Your Learning

- All prokaryotic cells contain a cell membrane, nucleoid with DNA, cytoplasm, and ribosomes.

Characteristics of prokaryotic cells:

- Enclosed by a cell membrane
- DNA located in a region called the **nucleoid**
- **Cytoplasm**: the rest of the cell contents
- **Ribosomes**: sites of protein synthesis

Figure 5.4 A Prokaryotic Cell (Part 1)



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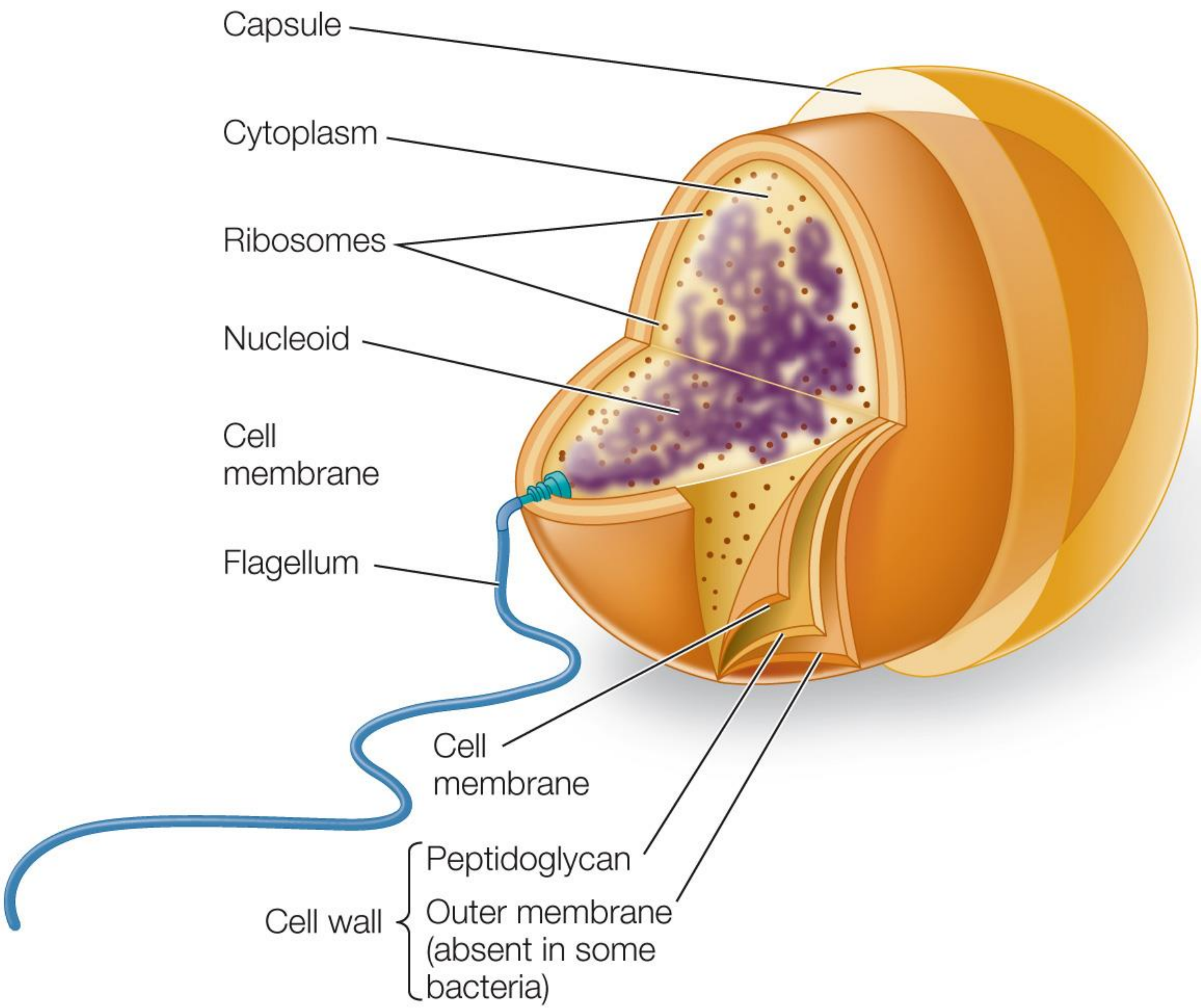

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Most prokaryotes have a rigid **cell wall** outside the cell membrane.

Bacterial cell walls contain peptidoglycan.

Some bacteria have an additional **outer membrane**.

Some bacteria have a slimy **capsule** of polysaccharides.

Some prokaryotes swim using **flagella**, made of the protein flagellin.

Pili are hairlike structures projecting from the cell surface. They help bacteria adhere to other cells.

Fimbriae are shorter; they help cells adhere to surfaces such as animal cells.

Figure 5.5 Prokaryotic Flagella (Part 1)

(A) Flagella of a prokaryotic cell

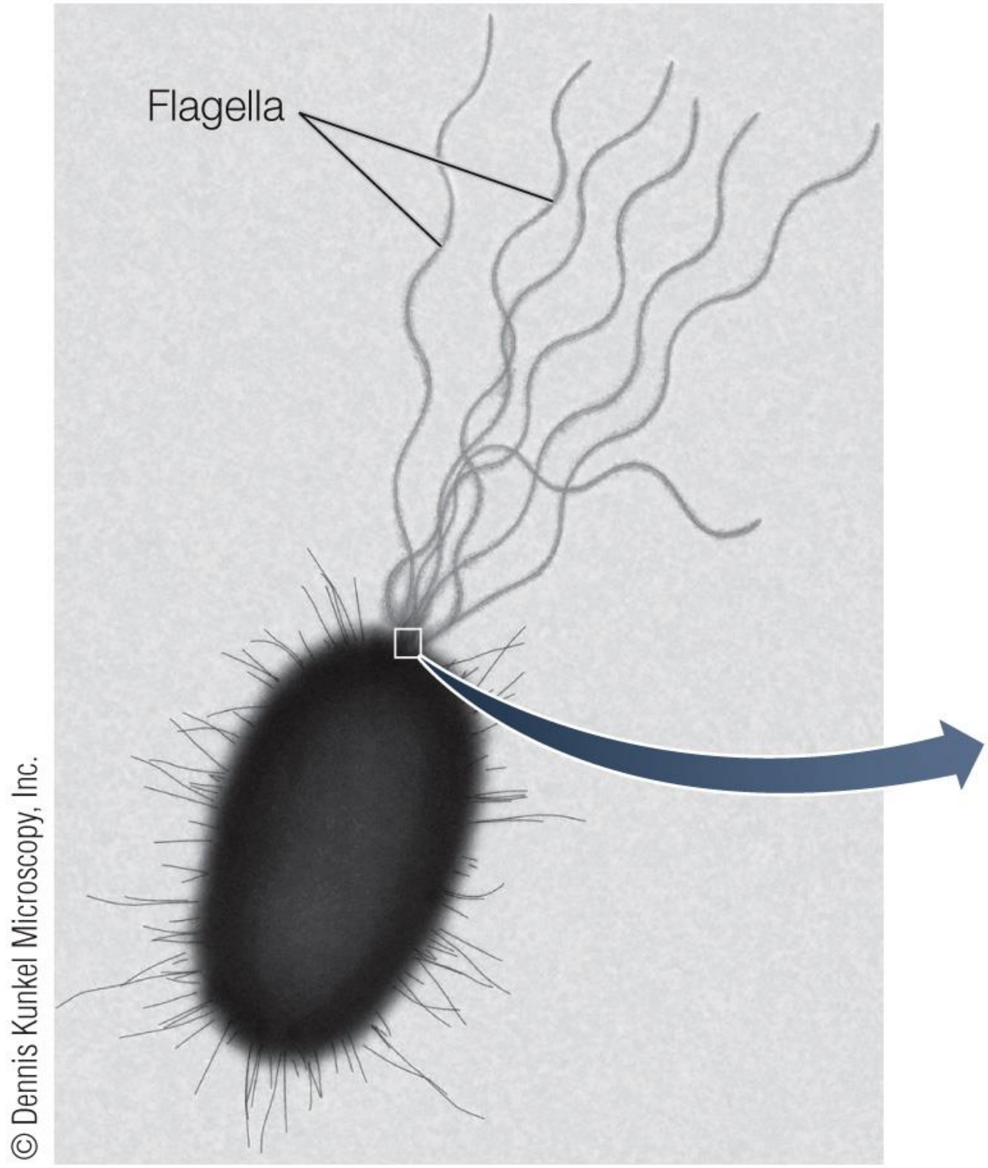

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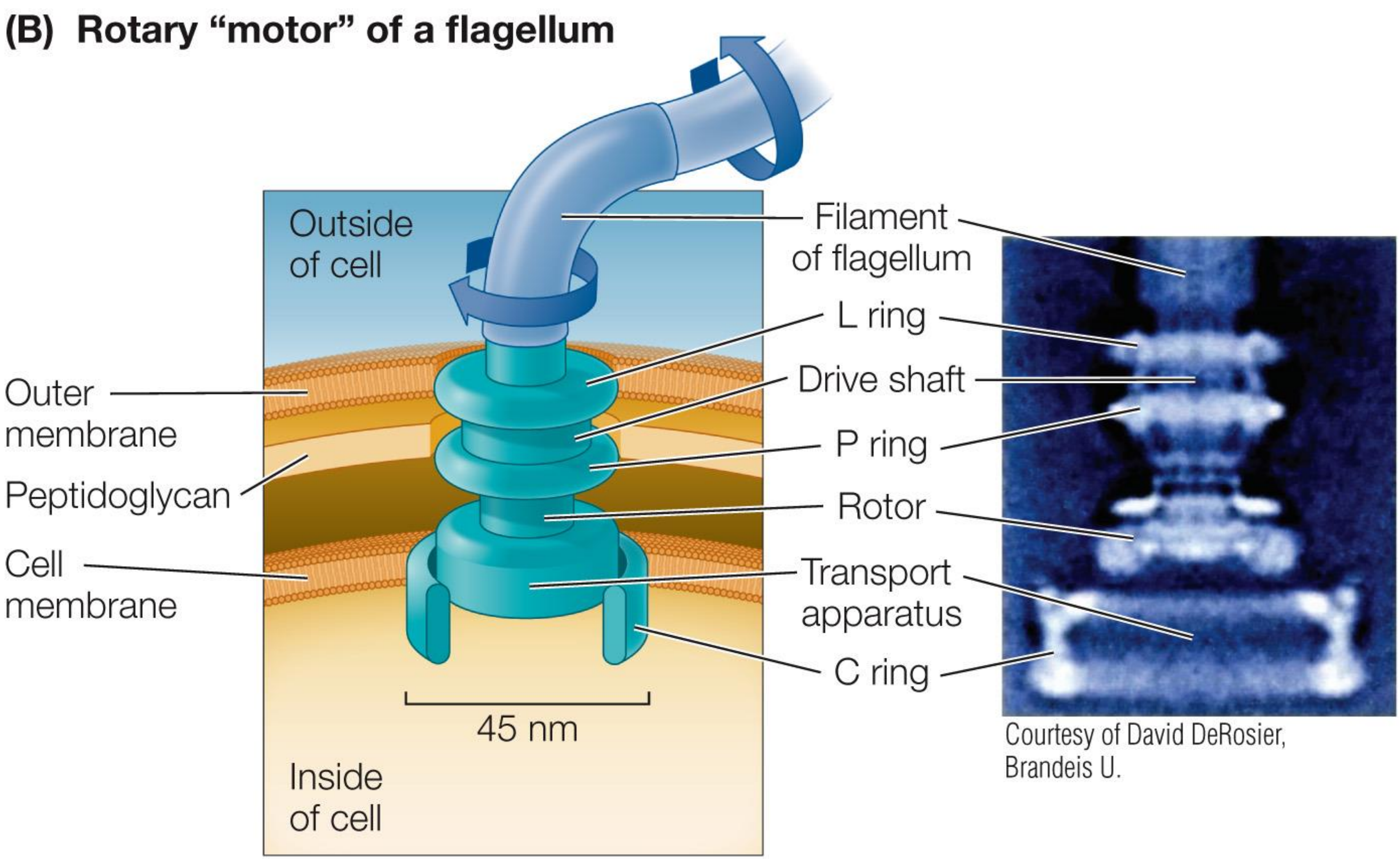
Figure 5.5 Prokaryotic Flagella (Part 2)



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Bacteria are important for us

There are approximately 39 trillion bacterial cells in the human microbiota as personified by a "reference" 70 kg male 170 cm tall, whereas there are 30 trillion human cells in the body.

Cytoskeleton: System of protein filaments that maintain cell shape and play roles in cell movement and cell division.

Key Concepts 5.3 Focus Your Learning

- Eukaryotic cells differ from prokaryotic cells in that they contain membrane-bound structures known as organelles.
- Each organelle carries out a different specific function that, when combined with others, allows the cell to function as a whole.

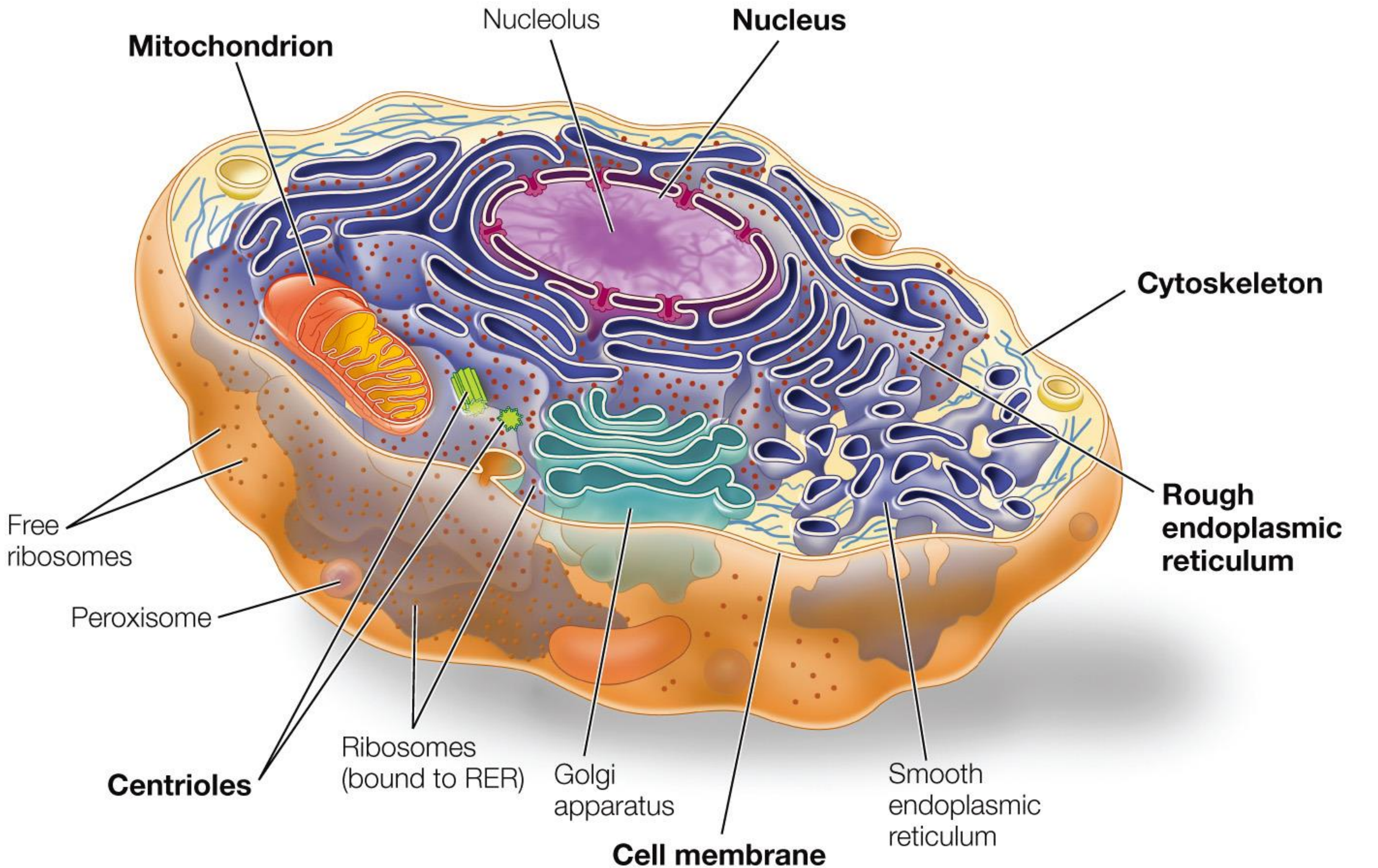
5.3 Eukaryotic Cells Contain Organelles

Eukaryotic cells are about 10 times larger than those of prokaryotes.

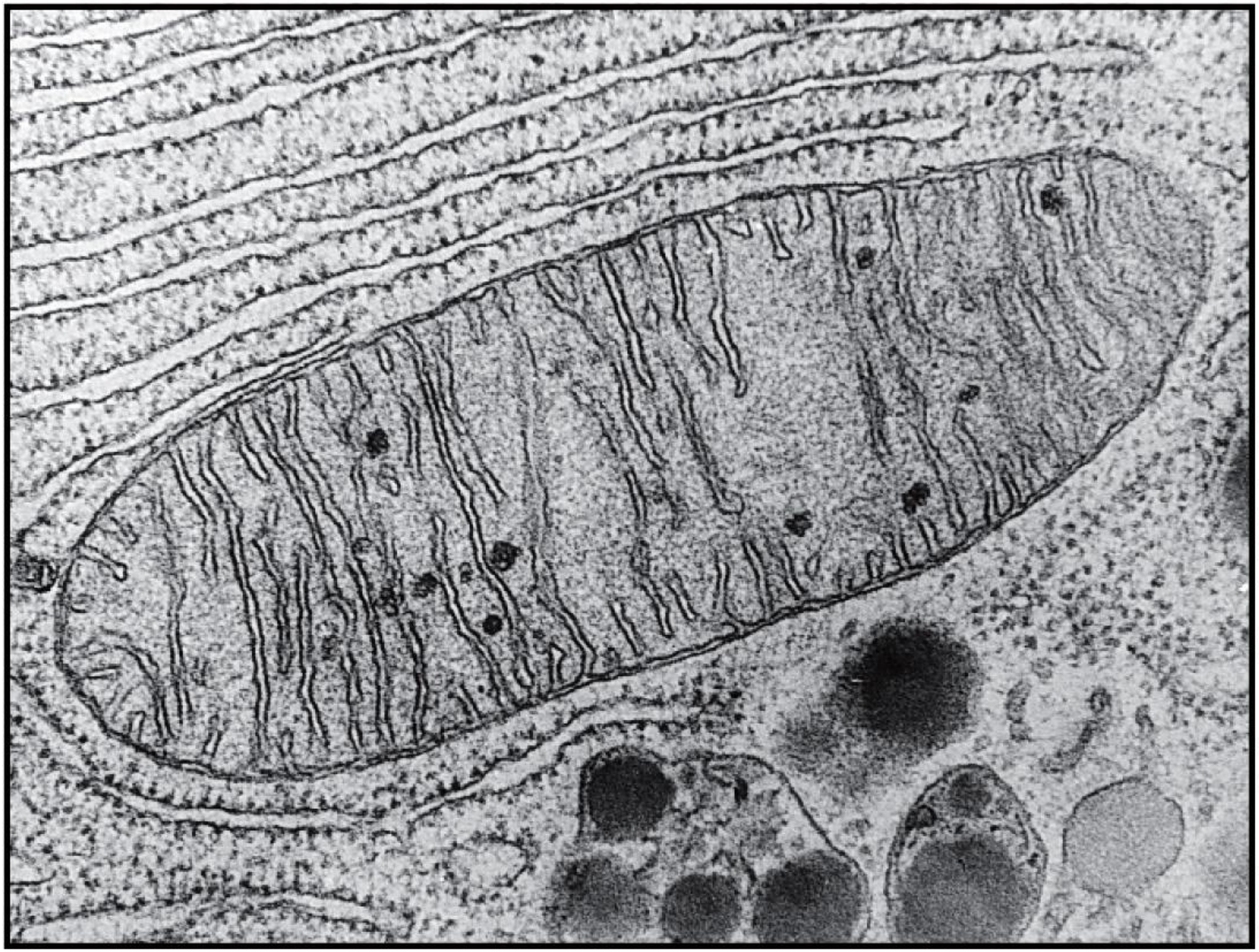
They have membrane-enclosed organelles.

Most eukaryotic cells have similar organelles, but there are some differences.

Figure 5.7 Eukaryotic Cells (Part 1)



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.7 (Part 1)



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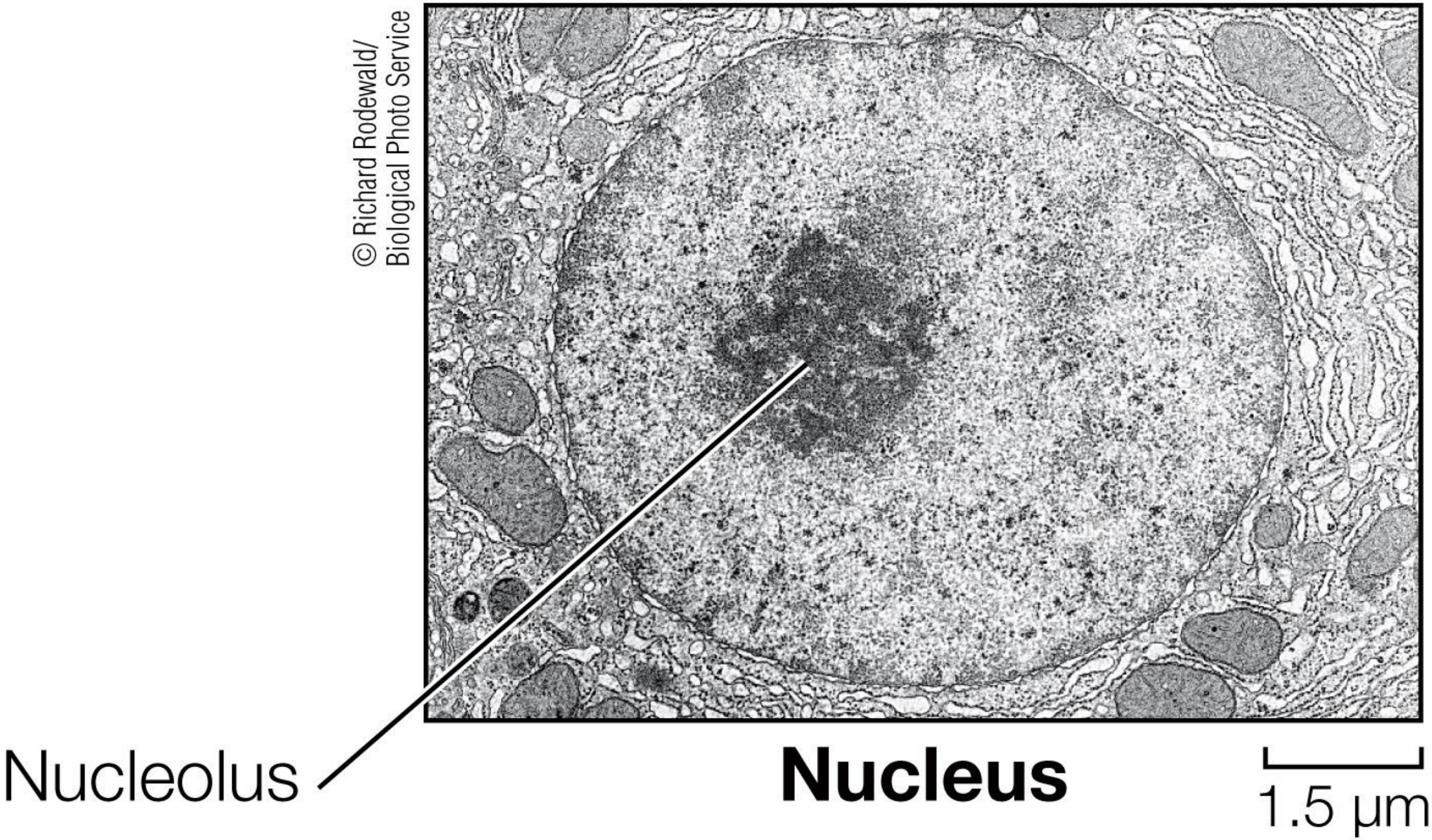
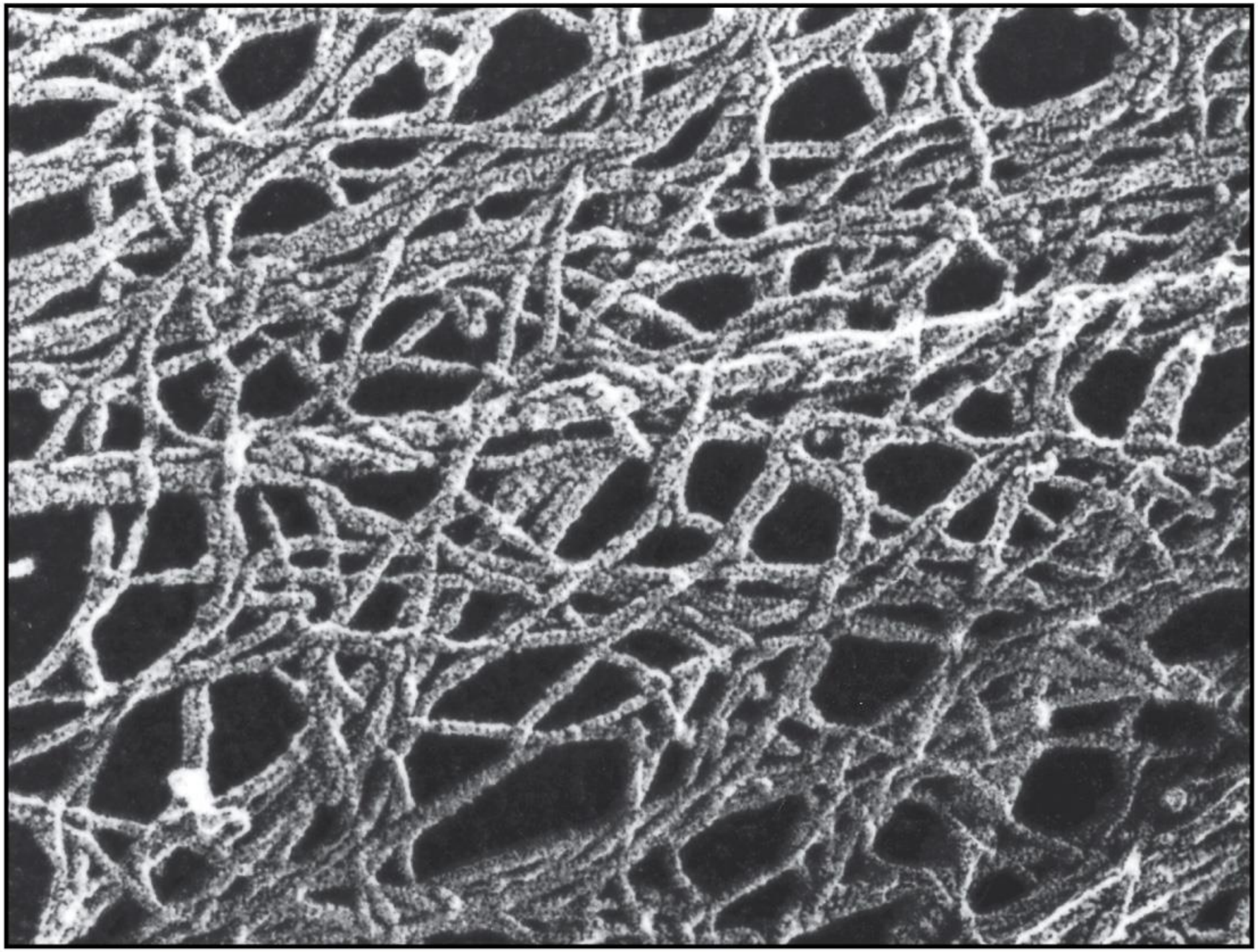
Mitochondrion

0.8 μm

Figure 5.7 Eukaryotic Cells (Part 3)

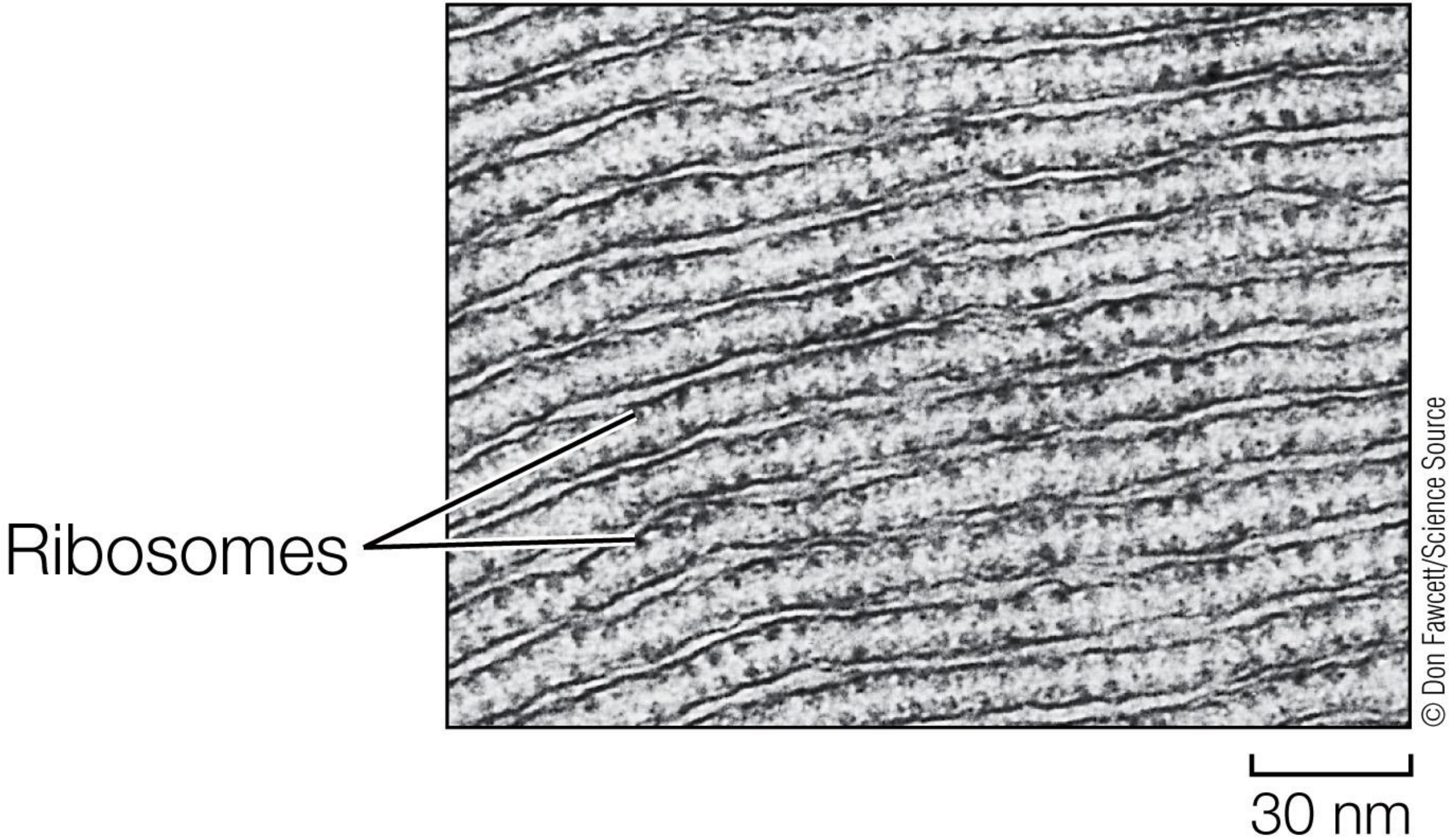




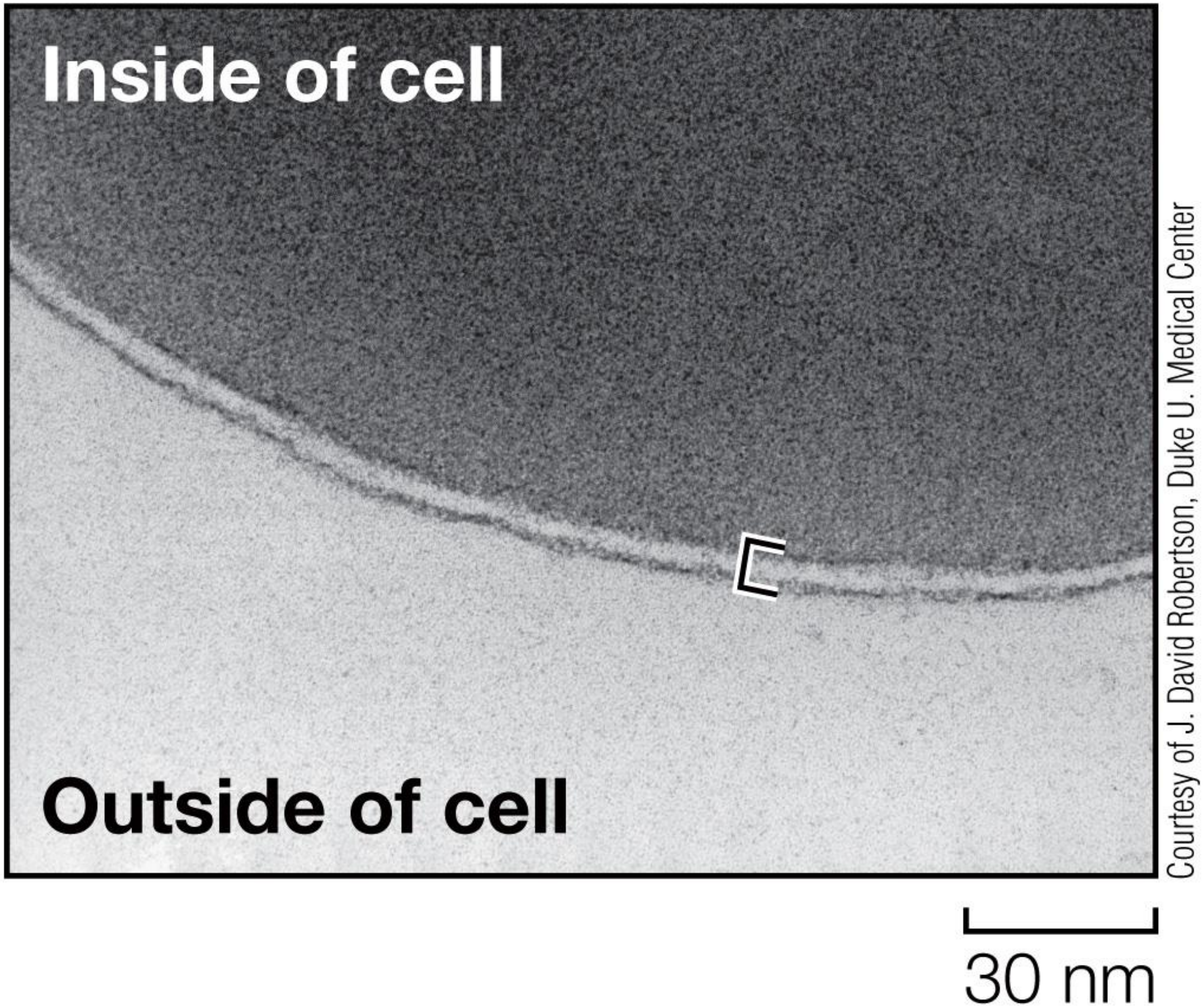
Cytoskeleton

25 nm

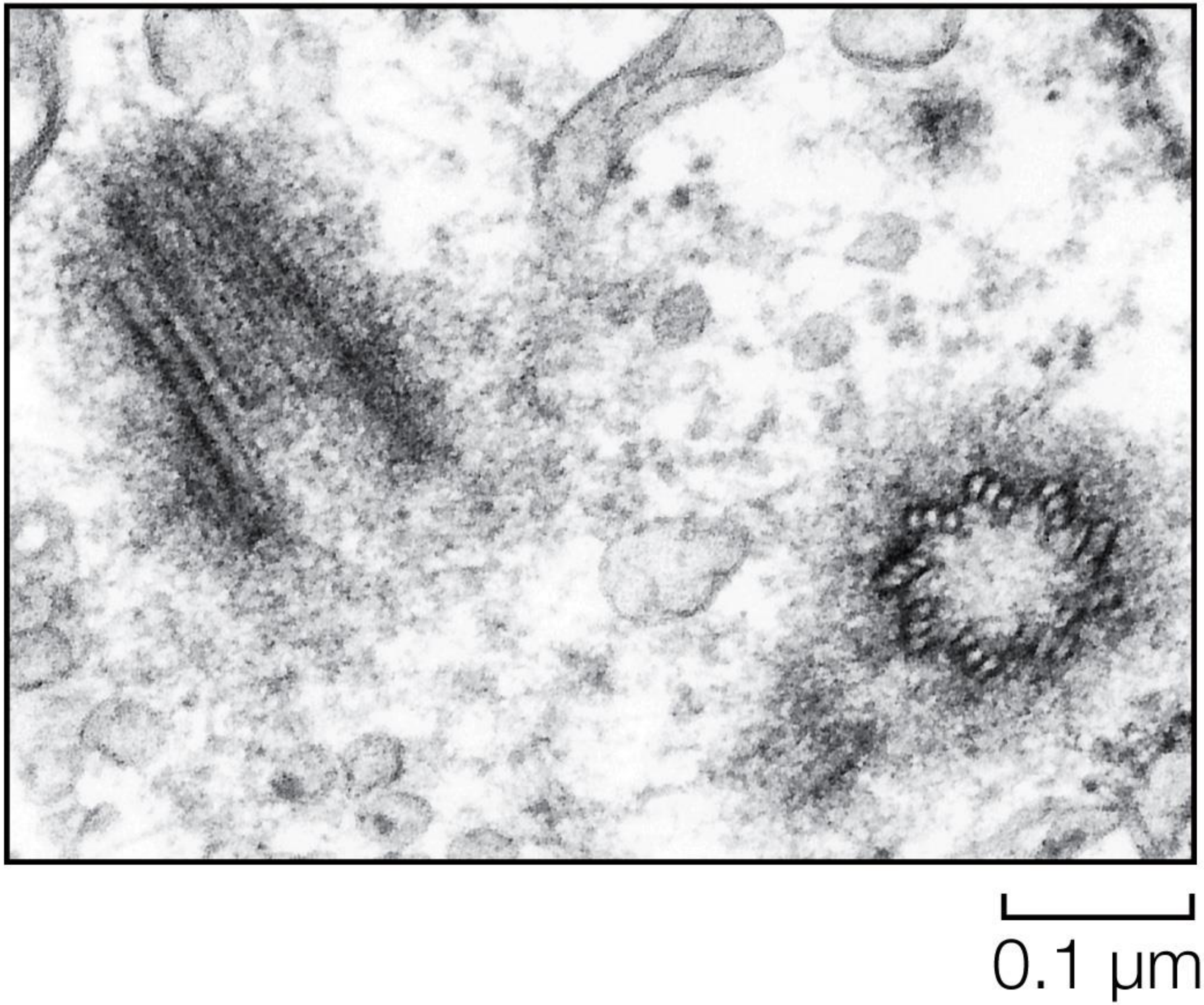
Rough endoplasmic reticulum

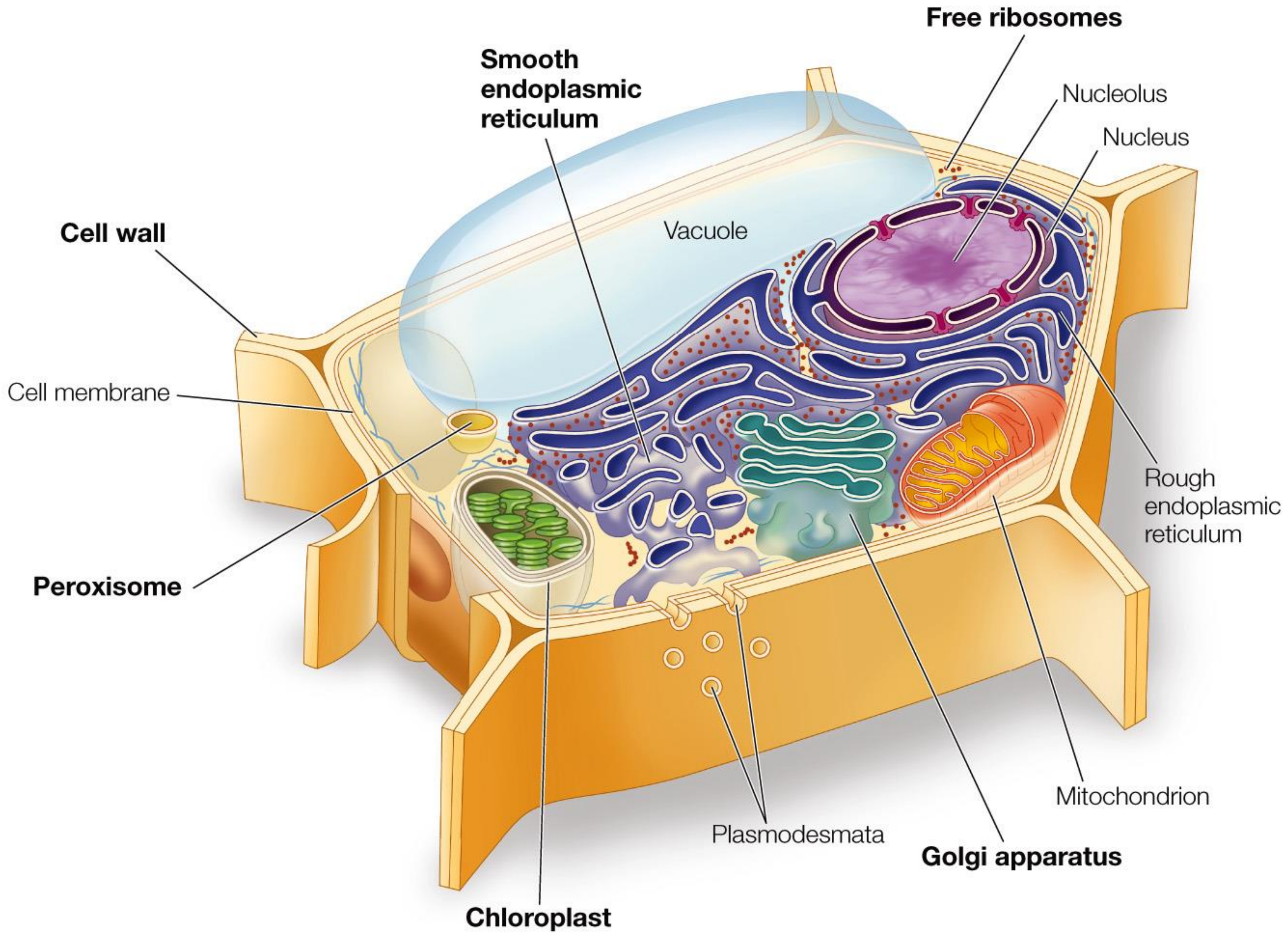


Cell membrane



Centrioles





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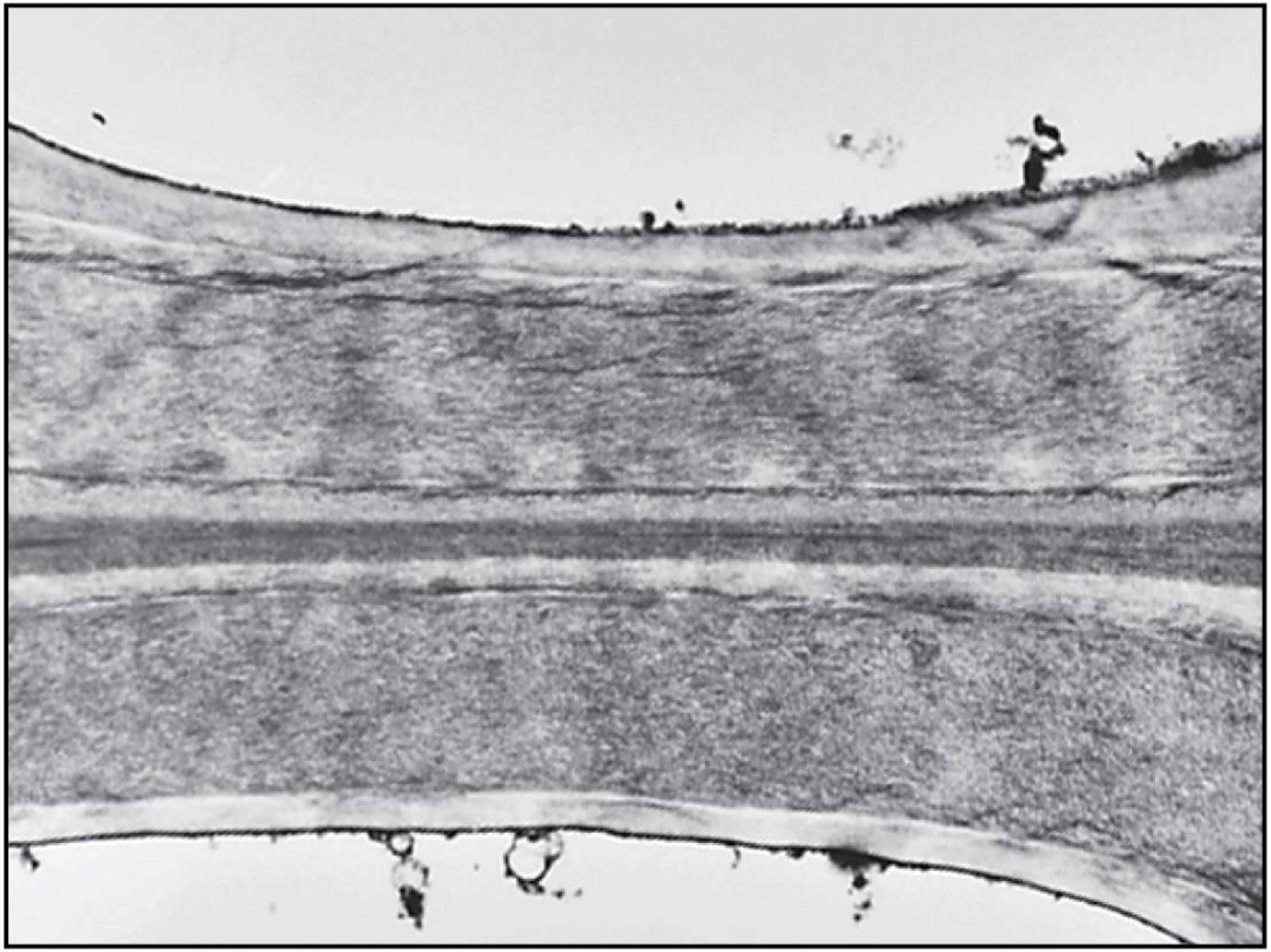

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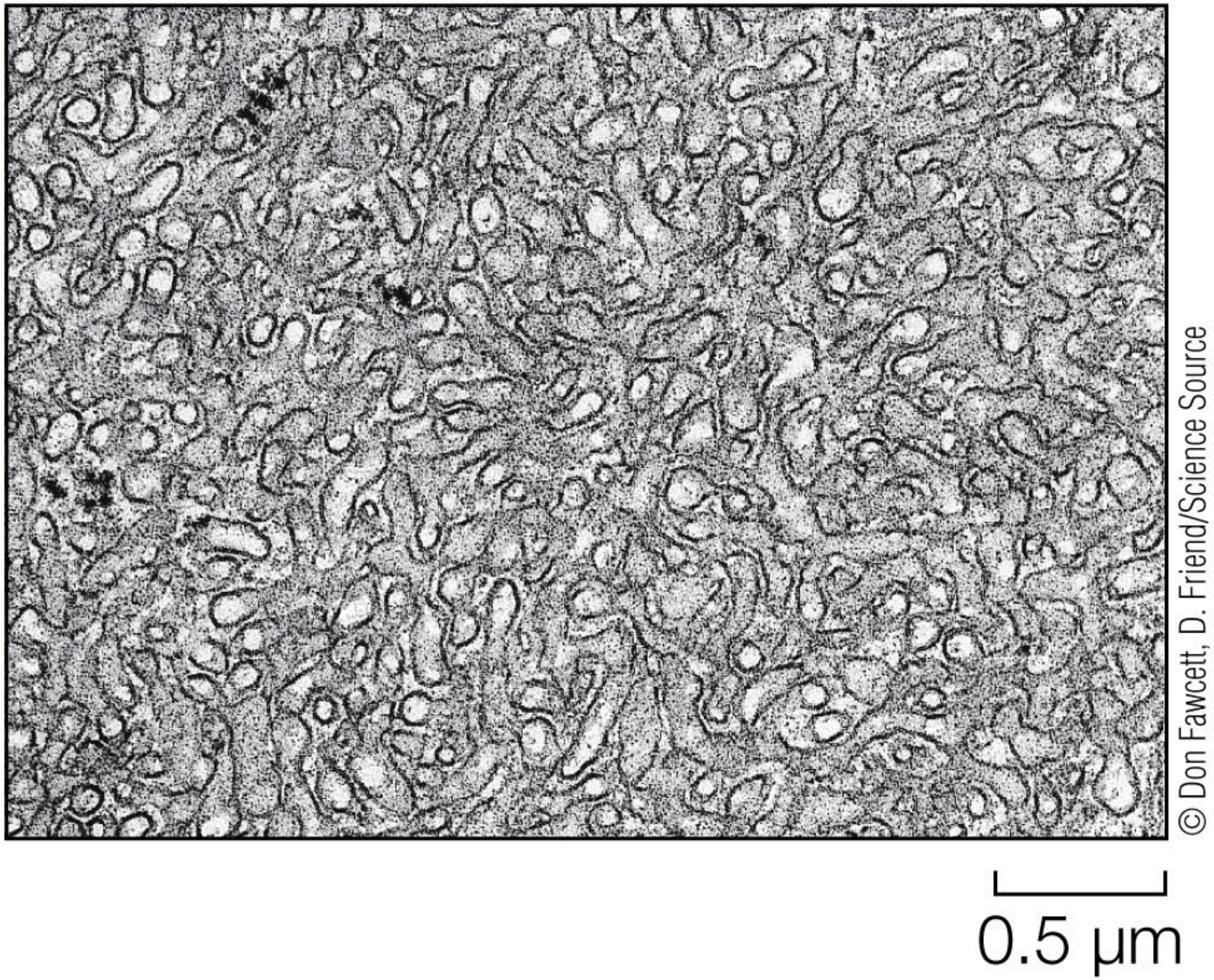
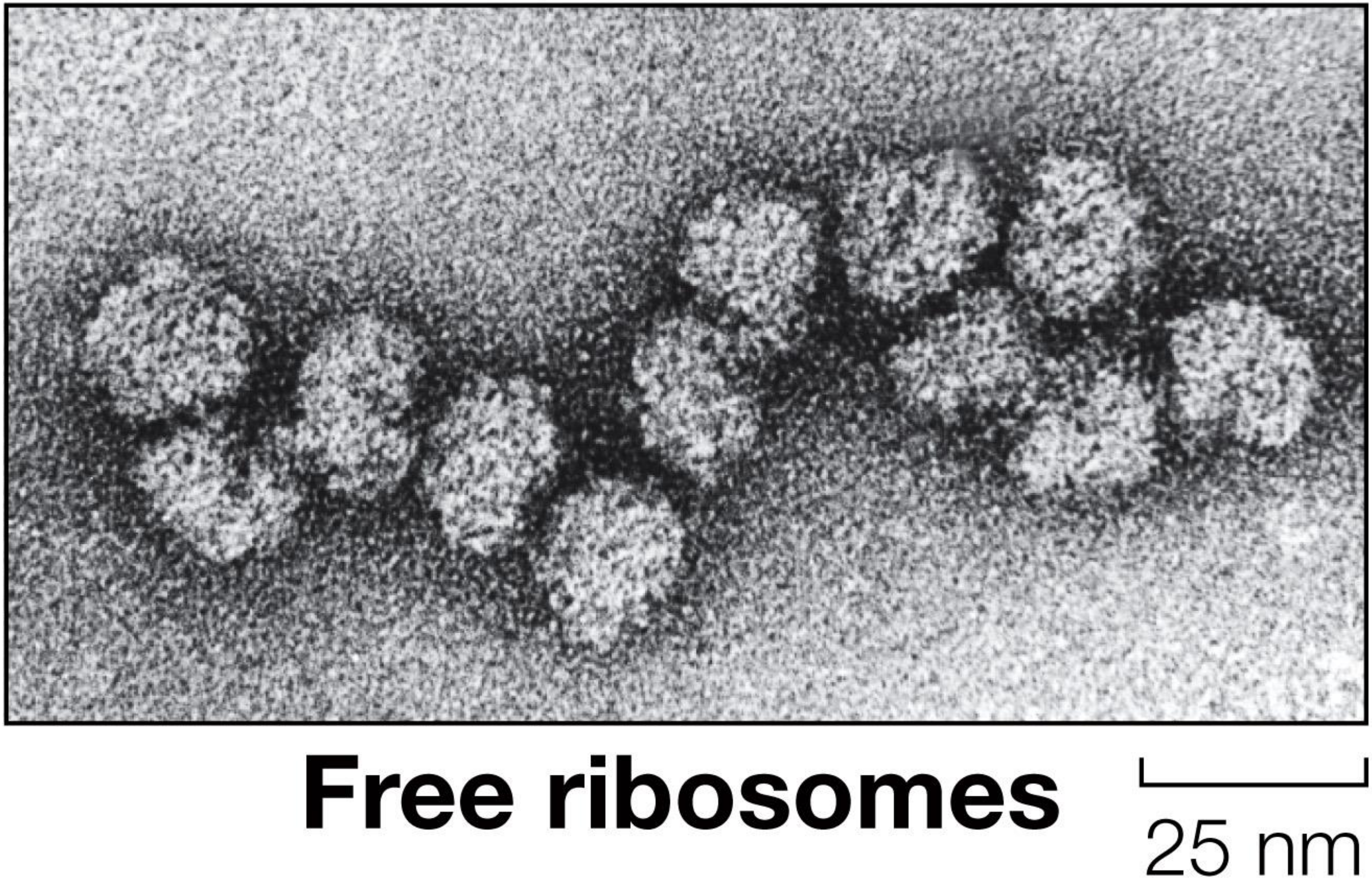
Cell wall

0.75 µm

Smooth endoplasmic reticulum



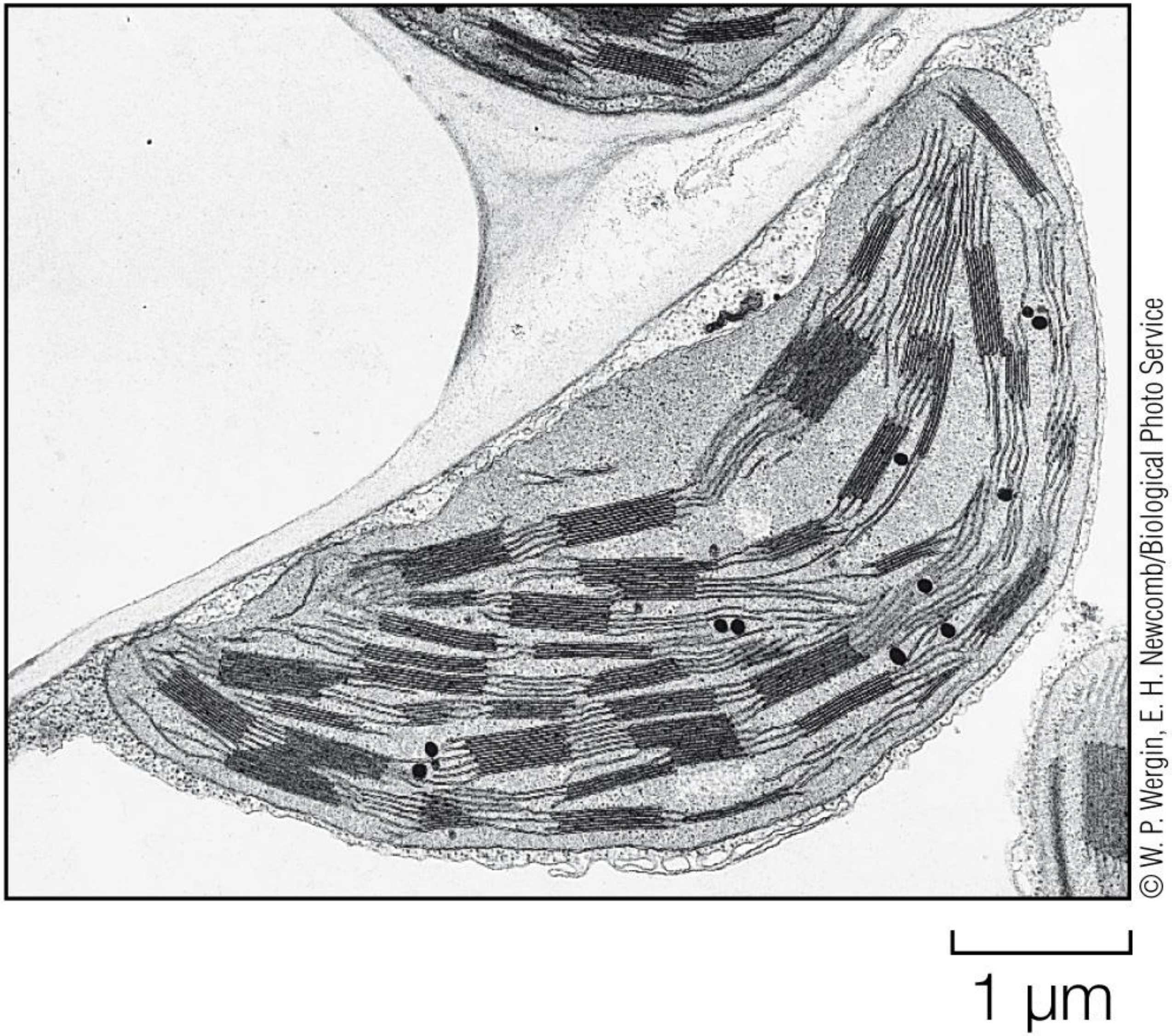


From M. Boublik et al., 1990. *The Ribosome*, p. 177. Courtesy of American Society for Microbiology

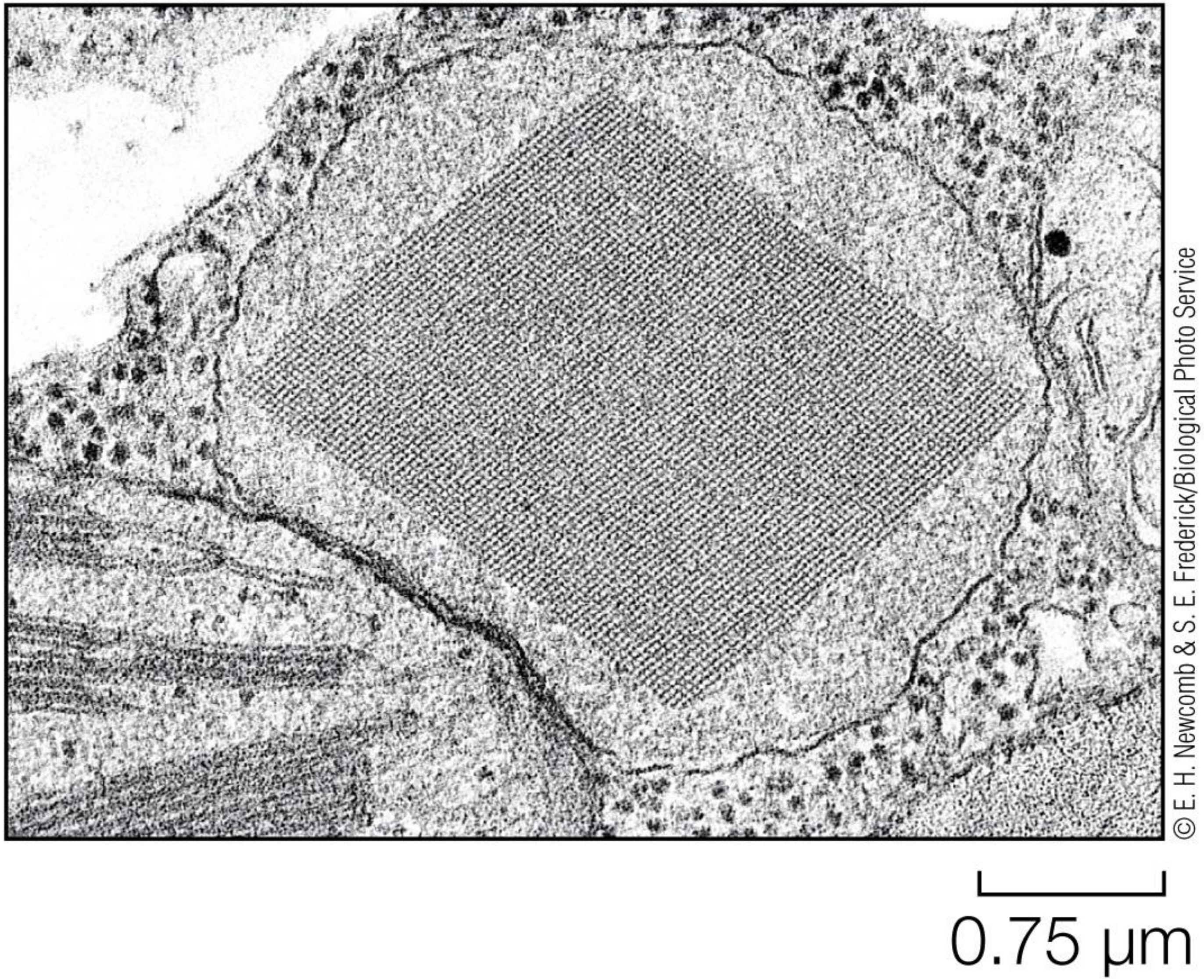
Free ribosomes

Golgi apparatus

Chloroplast



Peroxisome



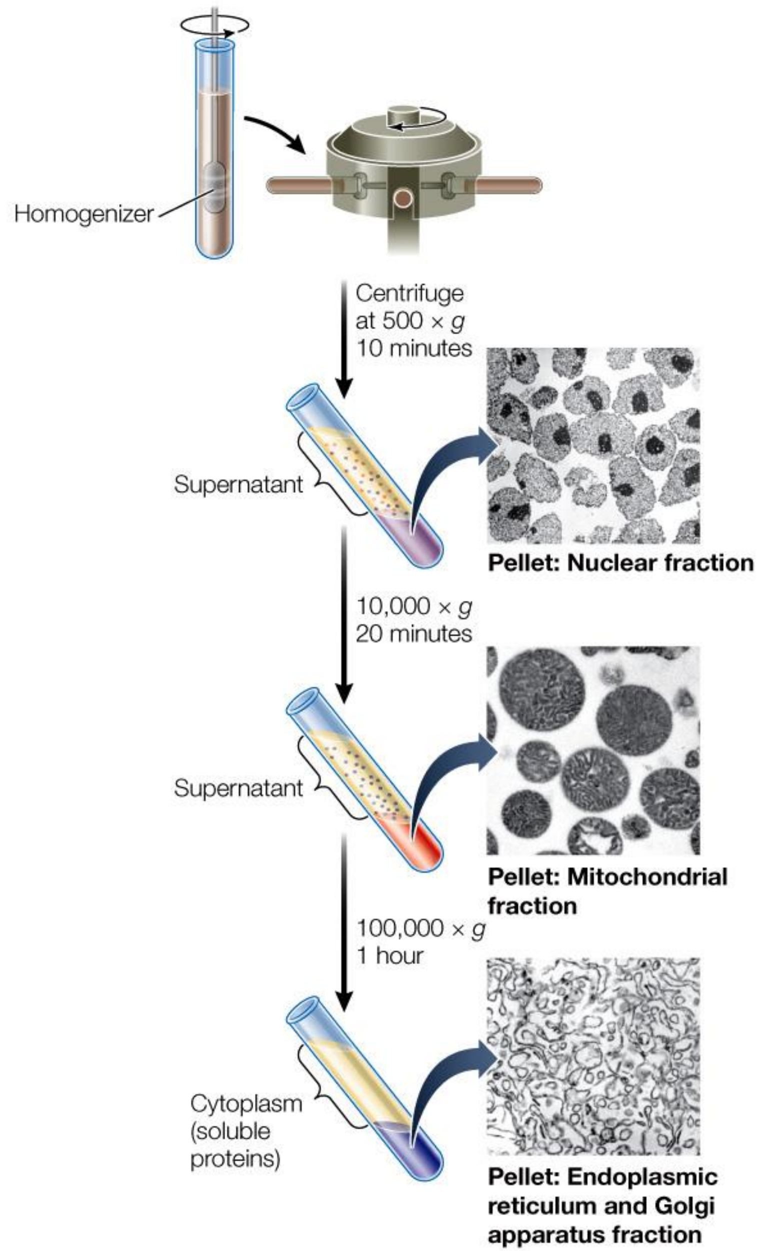
5.3 Eukaryotic Cells Contain Organelles

Organelles were first studied using light microscopy and then electron microscopy.

Stains targeted to specific molecules helped determine chemical composition of organelles.

Cell fractionation separates organelles by size or density for study.

Figure 5.6 Cell Fractionation



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LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.6

Ribosomes: Sites of protein synthesis.

- Have similar structure in prokaryotes and eukaryotes.
- Consist of ribosomal RNA (rRNA) and more than 50 different protein molecules.

Nucleus—usually the largest organelle

- Contains most of the DNA
- Site of DNA replication
- Site where gene transcription is turned on or off
- Assembly of ribosomes begins in a region called the **nucleolus**

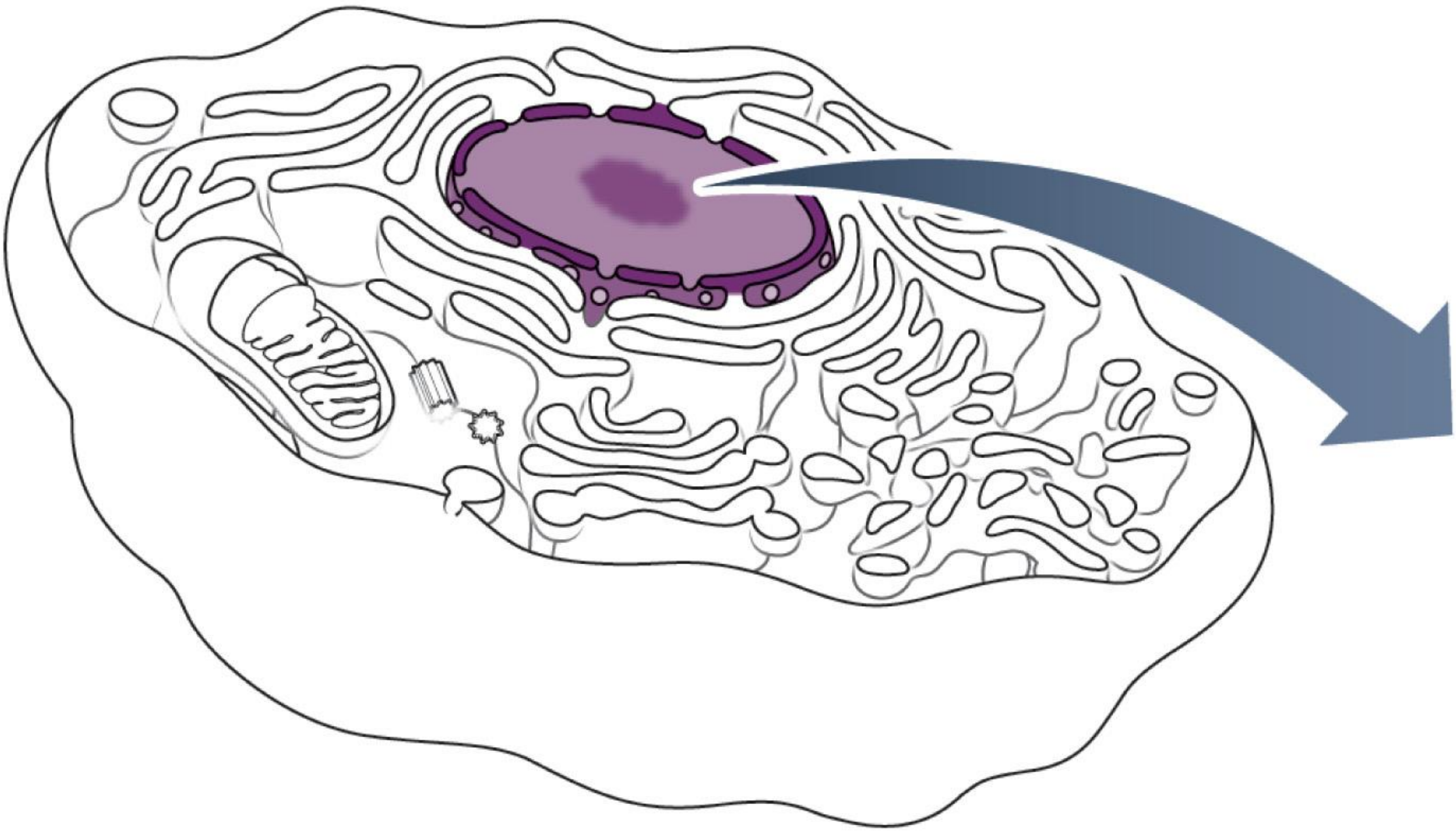
- Surrounded by the **nuclear envelope**, a double membrane
  - Nuclear pores in the envelope control movement of molecules across the envelope.

5.3 Eukaryotic Cells Contain Organelles

DNA combines with proteins to form **chromatin** in long, thin threads called **chromosomes**.

Before cell division, chromatin condenses, and individual chromosomes are visible in the light microscope.

Figure 5.8 The Nucleus, Chromatin, and Chromosomes (Part 1)



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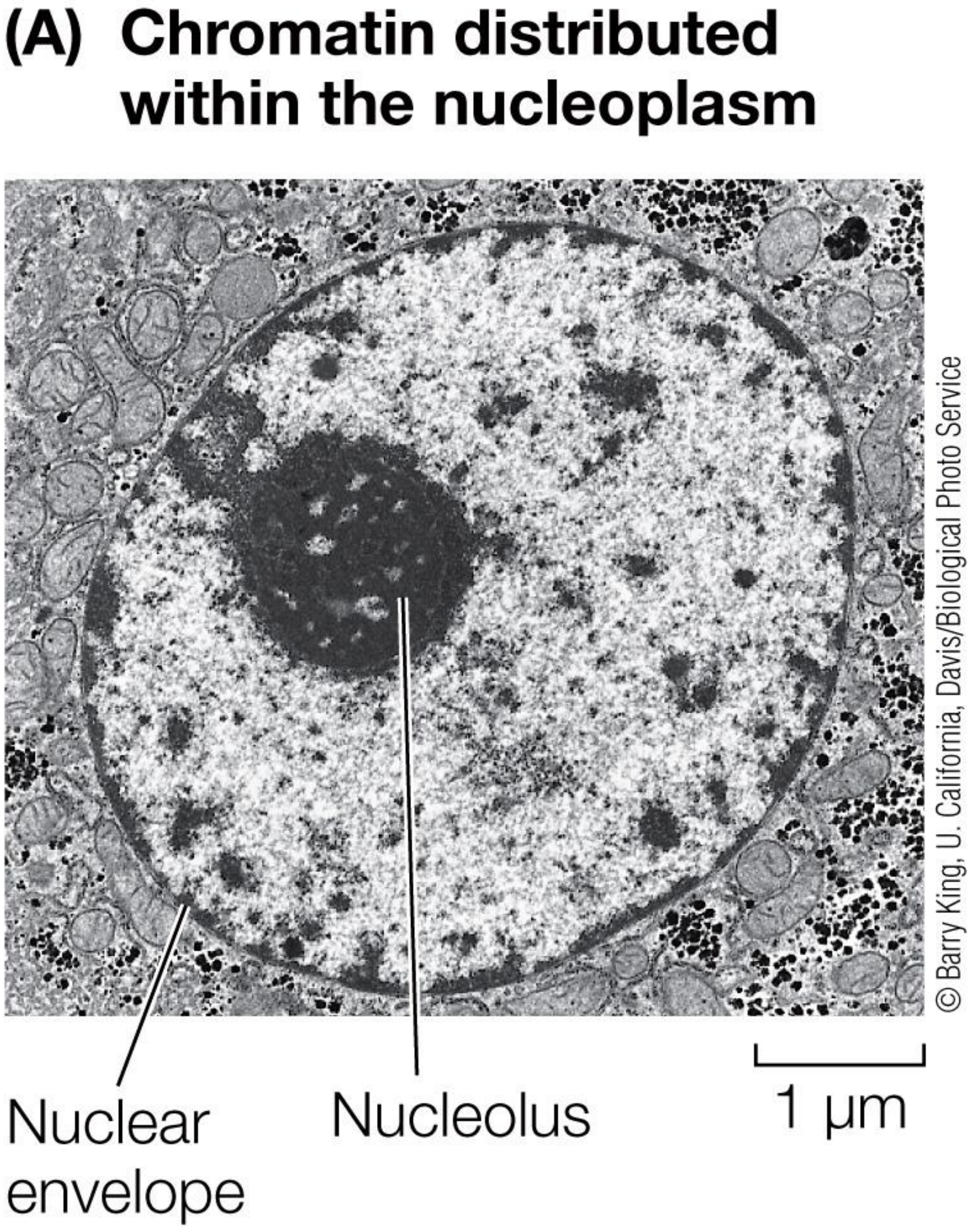

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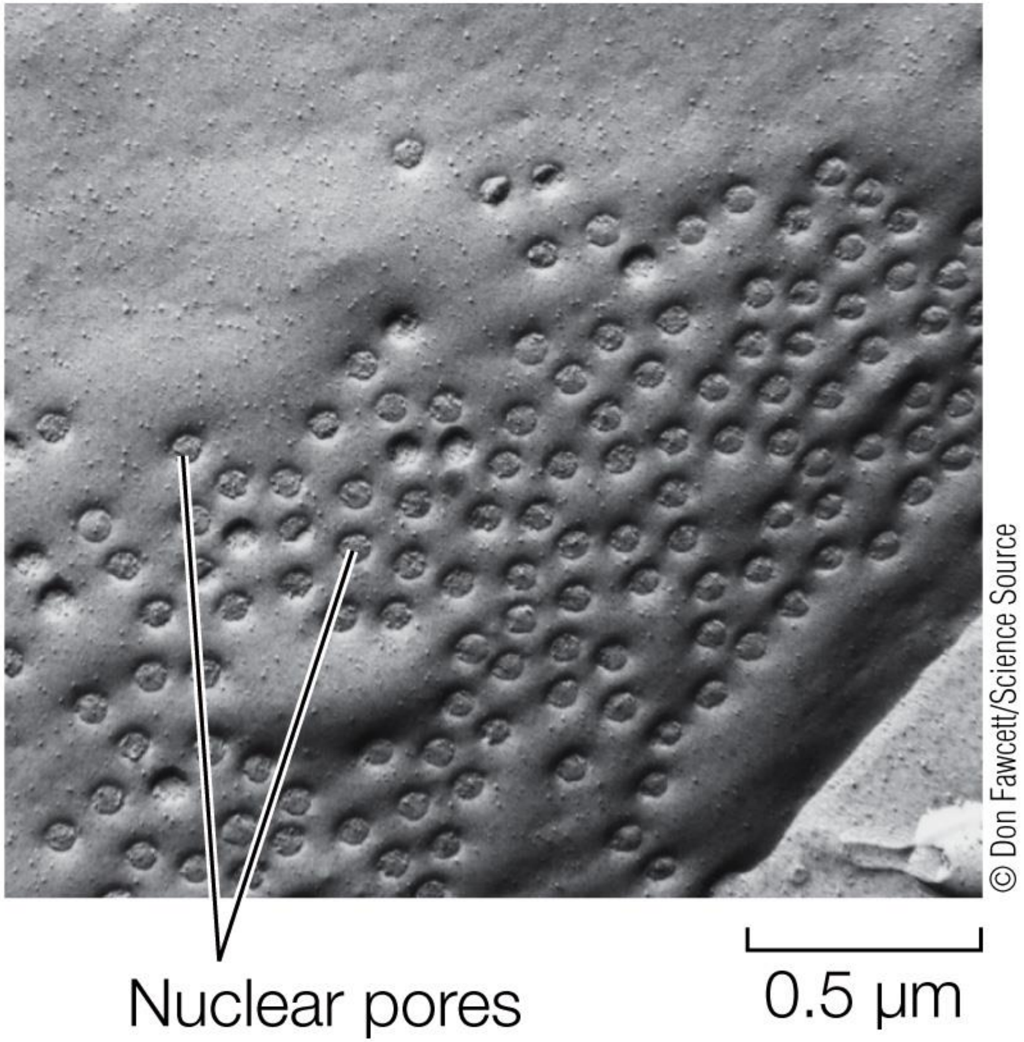
(B) Nuclear pores of the nuclear envelope



(C) Chromatin fibers highly condensed into chromosomes

1.4 μm

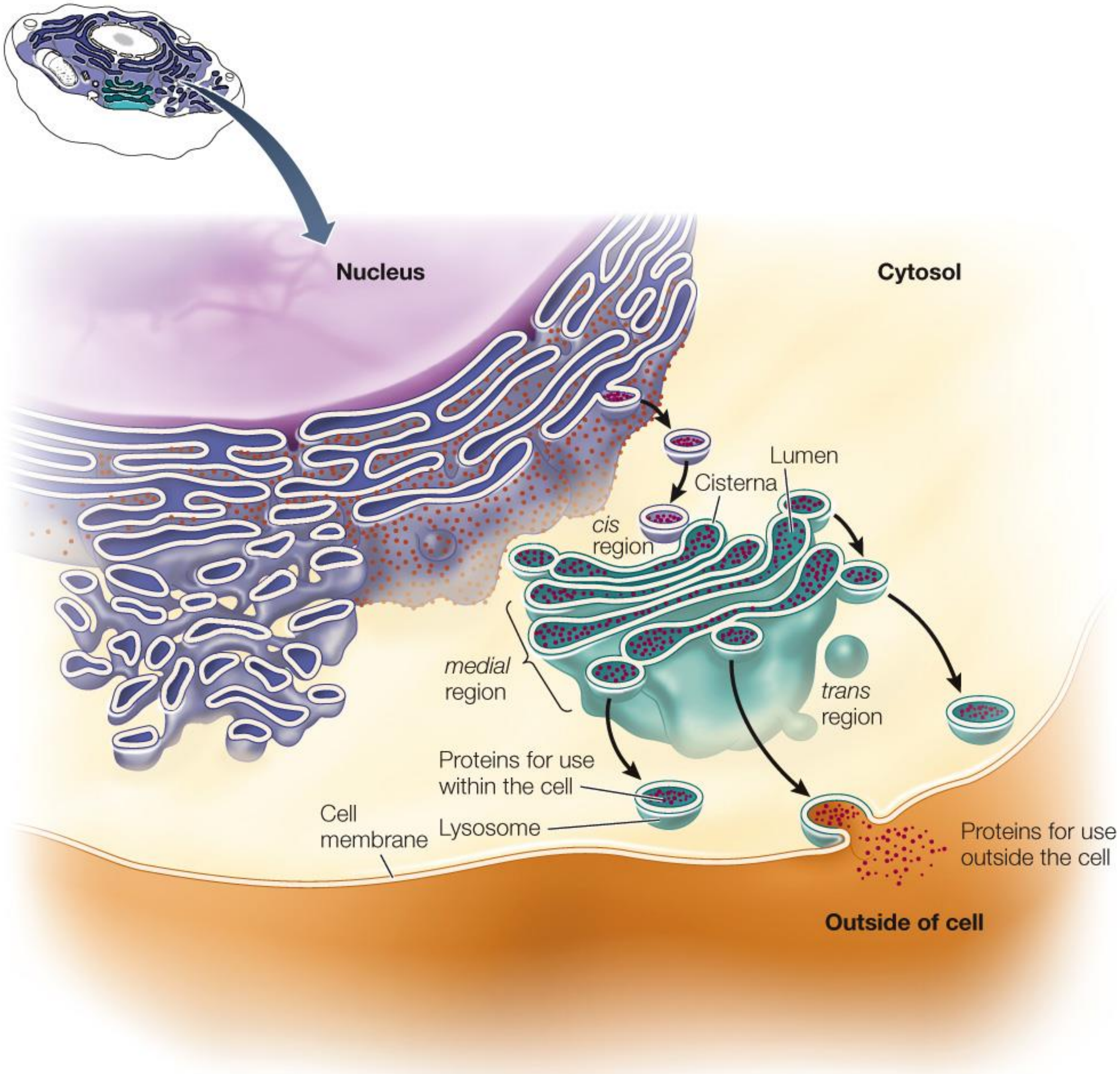
LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.8 (Part 4)

Endomembrane system: Interconnected system of membrane-enclosed compartments.

- Tiny, membrane-surrounded vesicles shuttle substances between the various components.

- **Endoplasmic reticulum (ER)**: Network of membranes in the cytoplasm; large surface area.
  - **Rough endoplasmic reticulum (RER)**: Ribosomes are attached.
    - Newly made proteins enter the RER lumen and are modified, folded, and transported to other regions.

Figure 5.9 The Endomembrane System (Part 1)



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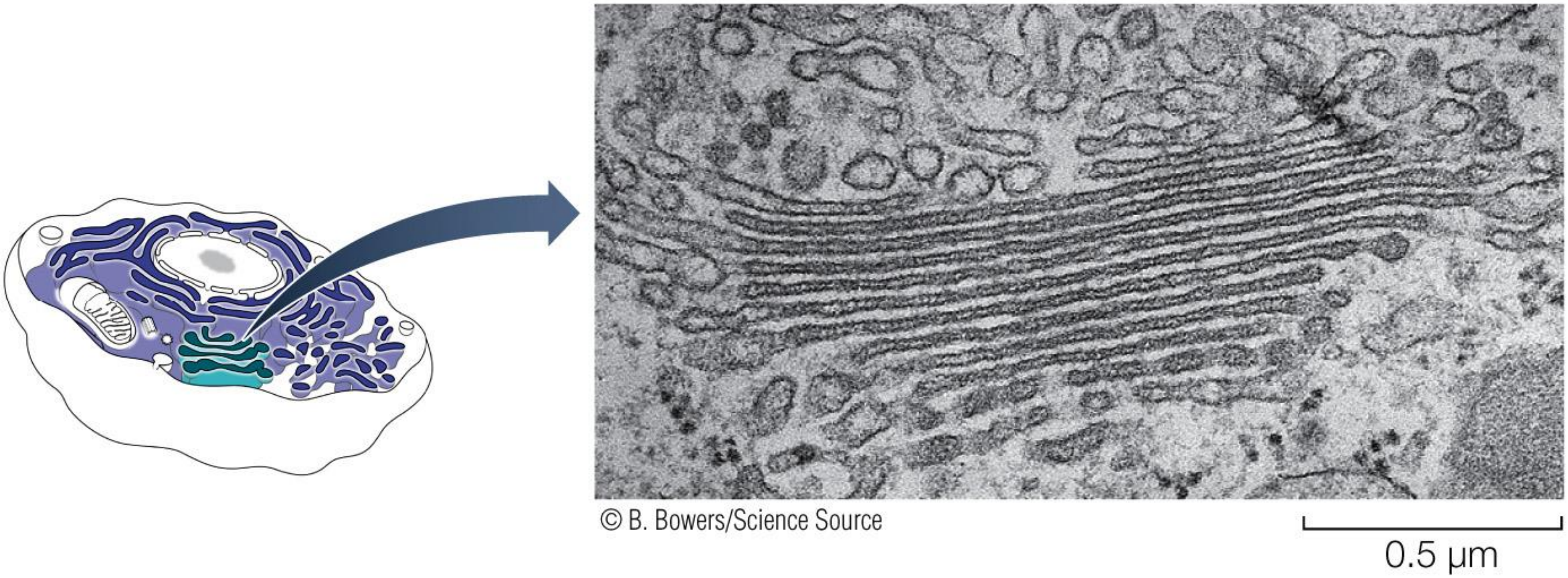


LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.9 (Part 2)

- **Smooth endoplasmic reticulum** (**SER**): No ribosomes.
  - Chemically modifies small molecules such as drugs and pesticides
  - Site of glycogen degradation in animal cells
  - Synthesis of lipids and steroids

Golgi apparatus: Flattened sacs (cisternae) and small vesicles.

- Receives proteins from the RER—can further modify them
- Concentrates, packages, sorts proteins
- In plant cells, polysaccharides for cell walls are synthesized here

Lysosomes: Contain digestive enzymes that hydrolyze macromolecules into monomers.

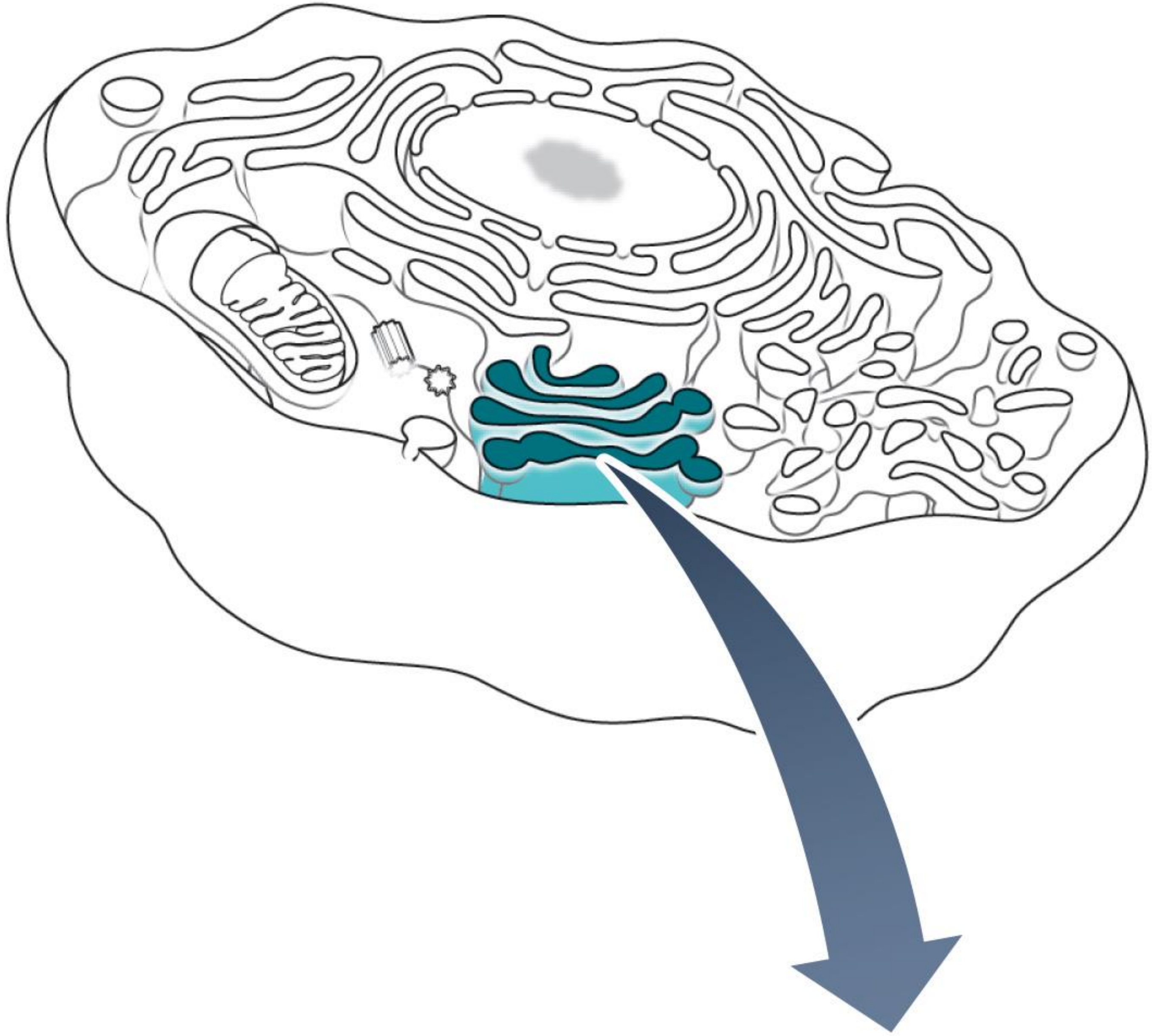
- **Primary lysosomes** originate from the Golgi apparatus.

Food molecules enter the cell by **phagocytosis**—a phagosome is formed.

Phagosomes fuse with primary lysosomes to form **secondary lysosomes**. Enzymes hydrolyze the food molecules.

Wastes are ejected by **exocytosis**.

Figure 5.10 Lysosomes Isolate Digestive Enzymes from the Cytoplasm (Part 1)



LIFE: THE SCIENCE OF BIOLOGY 11e, Figure 5.10 (Part 1)

Figure 5.10 Lysosomes Isolate Digestive Enzymes from the Cytoplasm (Part 2)

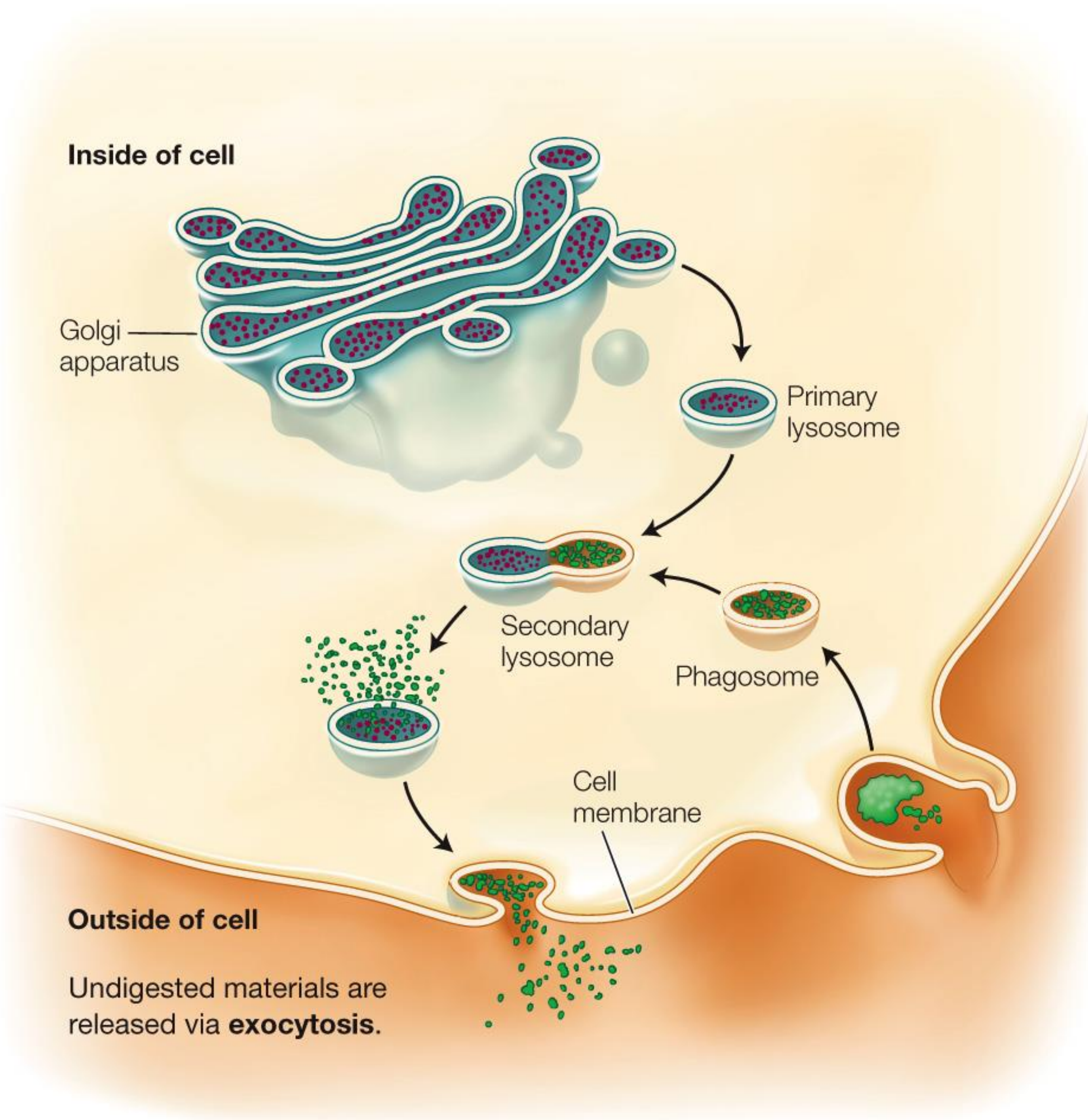


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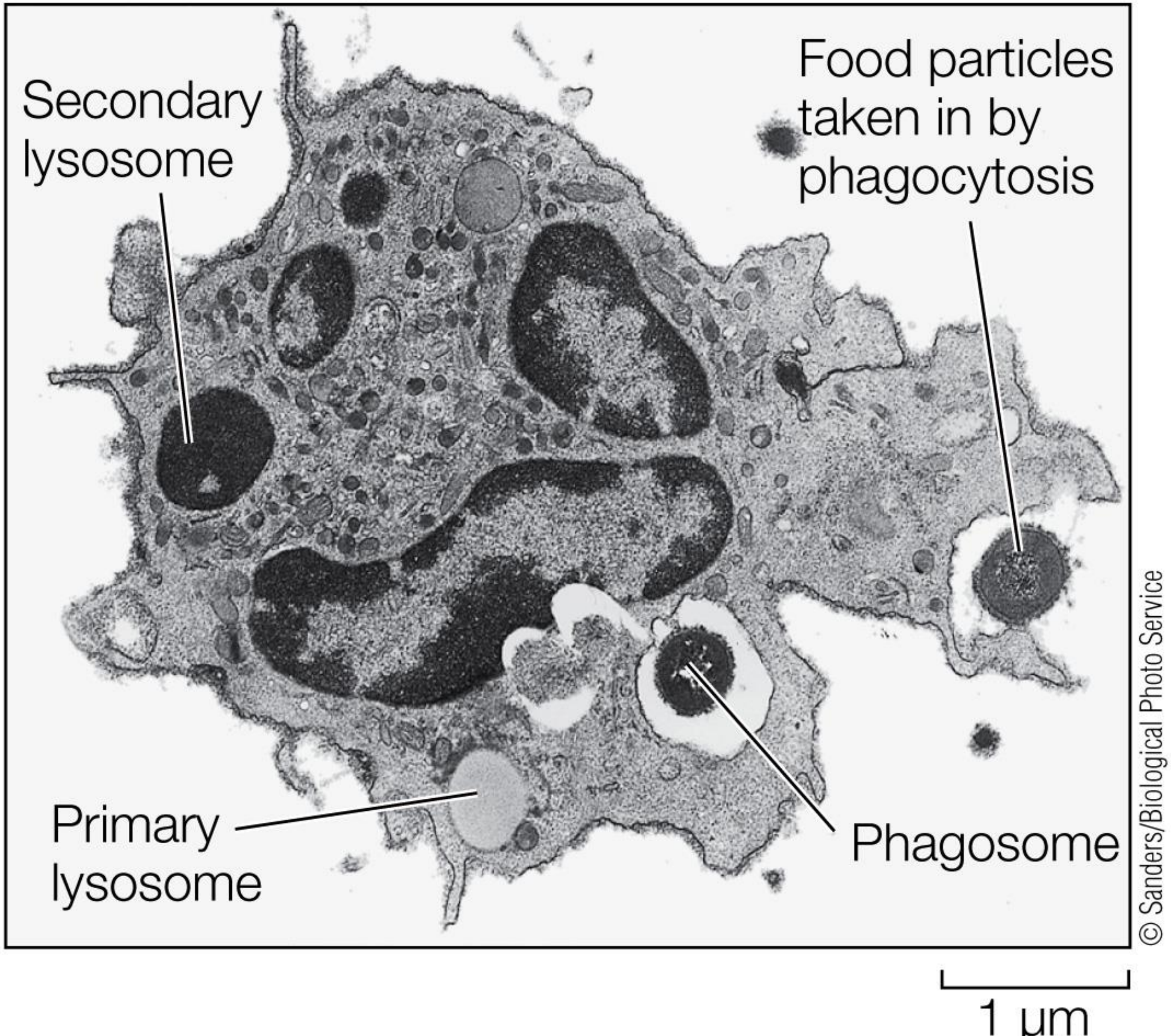
Figure 5.10 Lysosomes Isolate Digestive Enzymes from the Cytoplasm (Part 3)



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Mitochondria: Energy in fuel molecules is transformed to the bonds of energy-rich ATP (**cellular respiration**).

- Cells that require a lot of energy have many mitochondria.