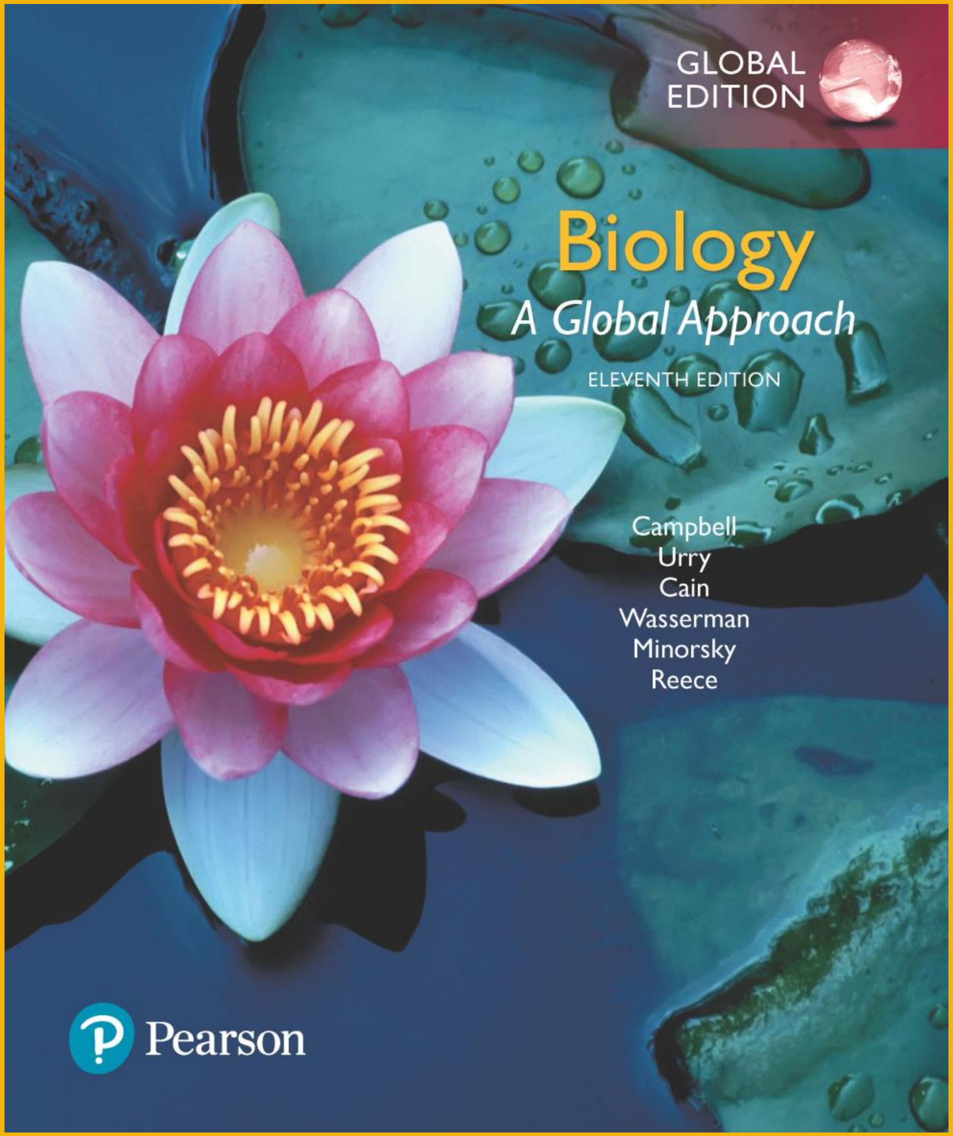


Chapter 7

Cell Structure and Function

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

The Fundamental Units of Life

- All organisms are made of cells
- The cell is the simplest collection of matter that can be alive
- All cells are related by their descent from earlier cells
- Cells can differ substantially from one another but share common features

Figure 7.1

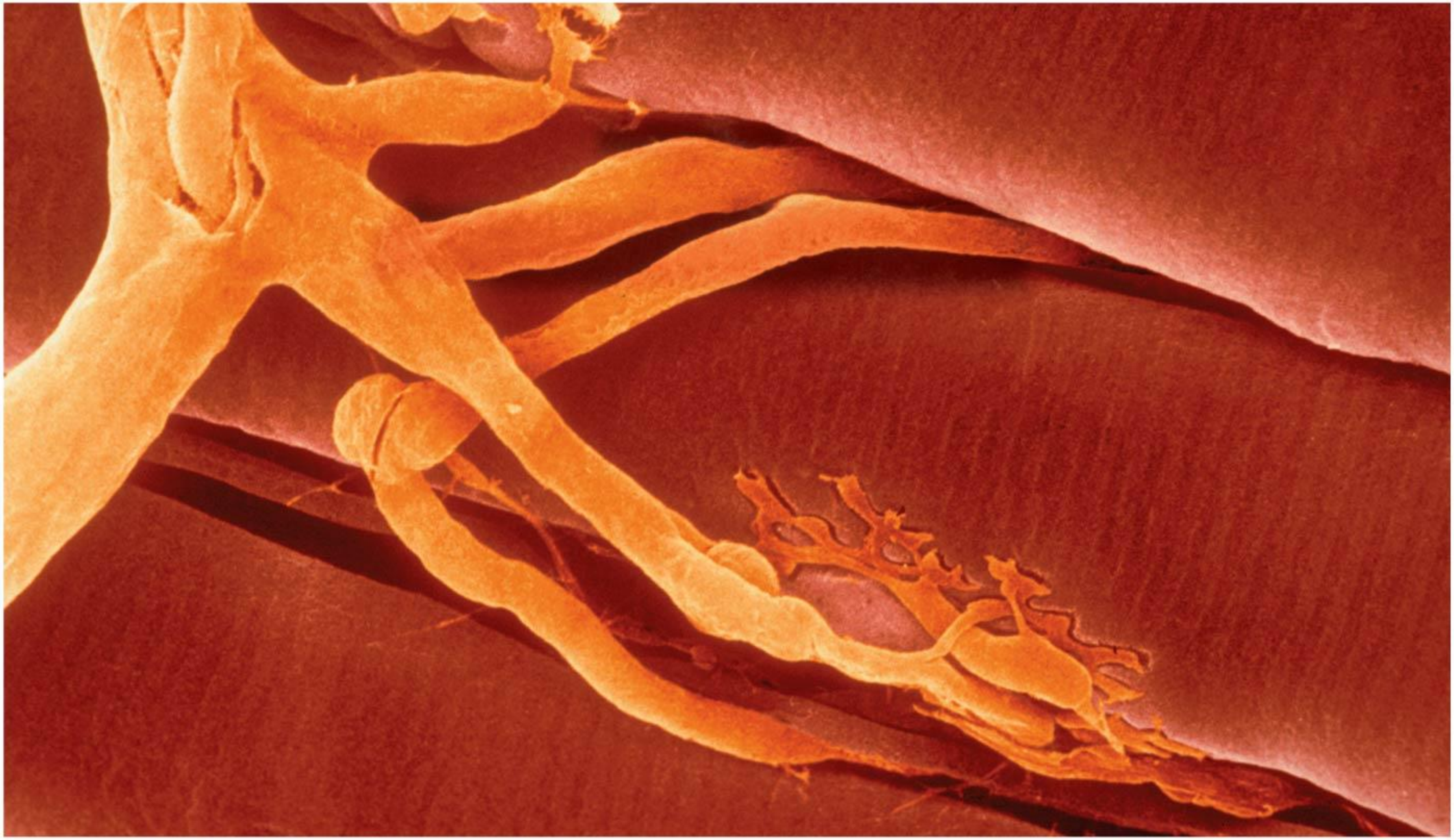
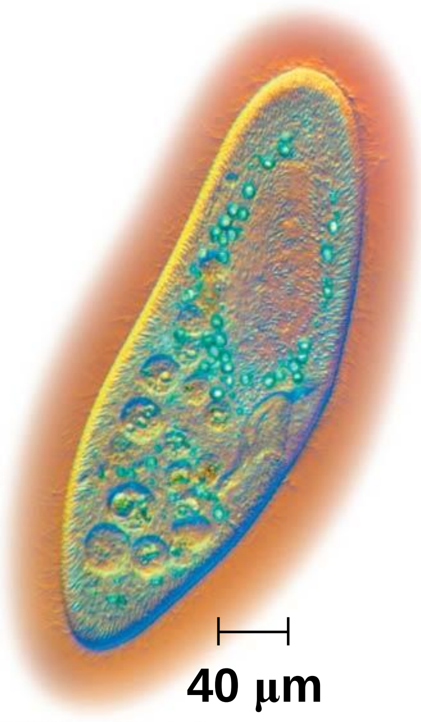


Figure 7.1a



Concept 7.1: Biologists use microscopes and the tools of biochemistry to study cells

- Cells are usually too small to be seen by the naked eye

Microscopy

- Microscopes are used to visualize cells
- In a **light microscope (LM)**, visible light is passed through a specimen and then through glass lenses
- Lenses refract (bend) the light so that the image is magnified

- Three important parameters of microscopy:
  - Magnification, the ratio of an object's image size to its real size
  - Resolution, the measure of the clarity of the image, or the minimum distance of two distinguishable points
  - Contrast, visible differences in brightness between parts of the sample

Figure 7.2

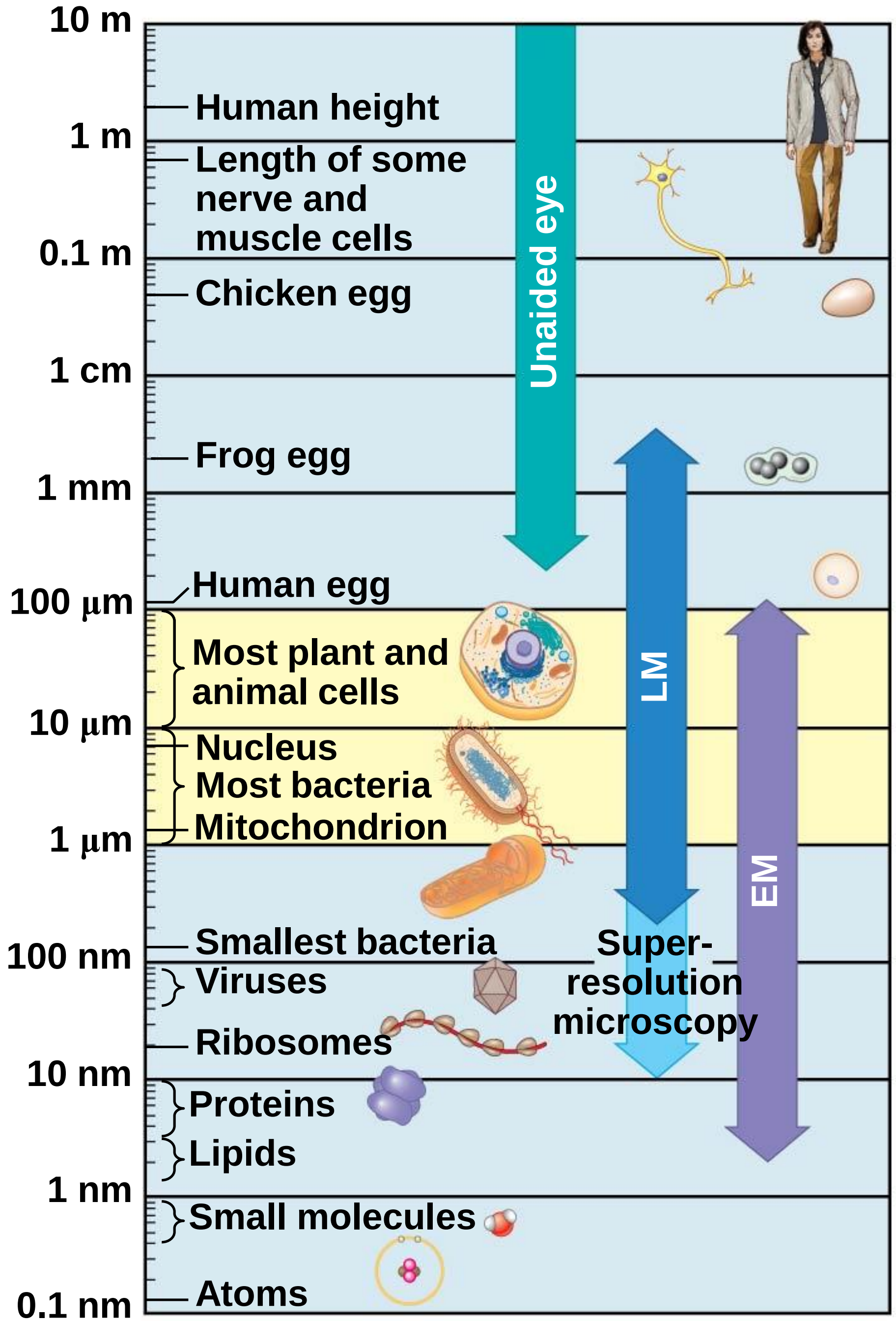
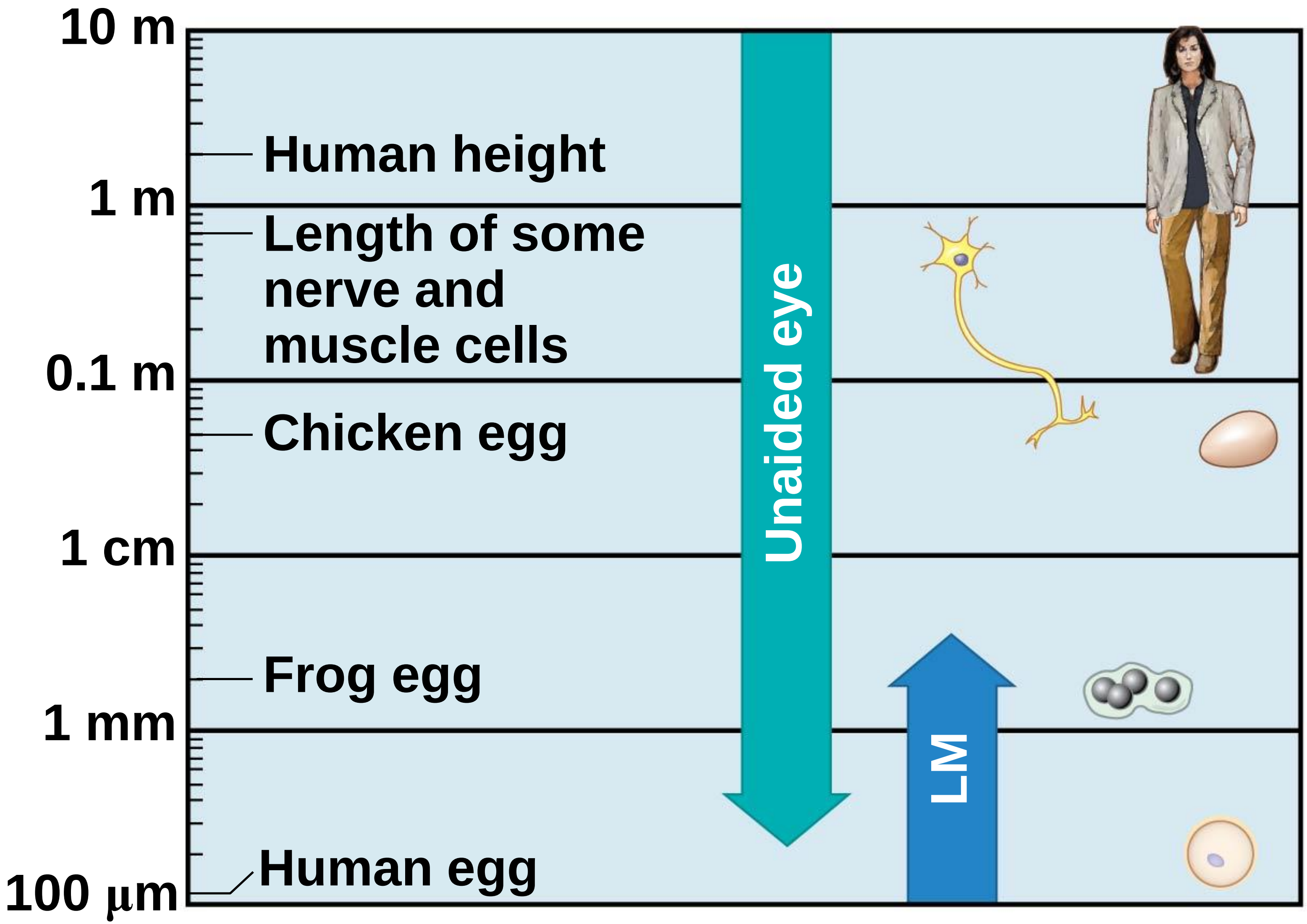

10 m
1 m
0.1 m
1 cm
1 mm
100 µm
10 µm
1 µm
100 nm
10 nm
1 nm
0.1 nm
Human height
Length of some nerve and muscle cells
Chicken egg
Frog egg
Human egg
Most plant and animal cells
Nucleus
Most bacteria
Mitochondrion
Smallest bacteria
Viruses
Ribosomes
Proteins
Lipids
Small molecules
Atoms
Unaided eye
LM
EM
Super-resolution microscopy

Figure 7.2a



10 m
Human height
1 m
Length of some nerve and muscle cells
0.1 m
Chicken egg
1 cm
Frog egg
1 mm
Human egg
100 µm
Unaided eye
LM

Figure 7.2b

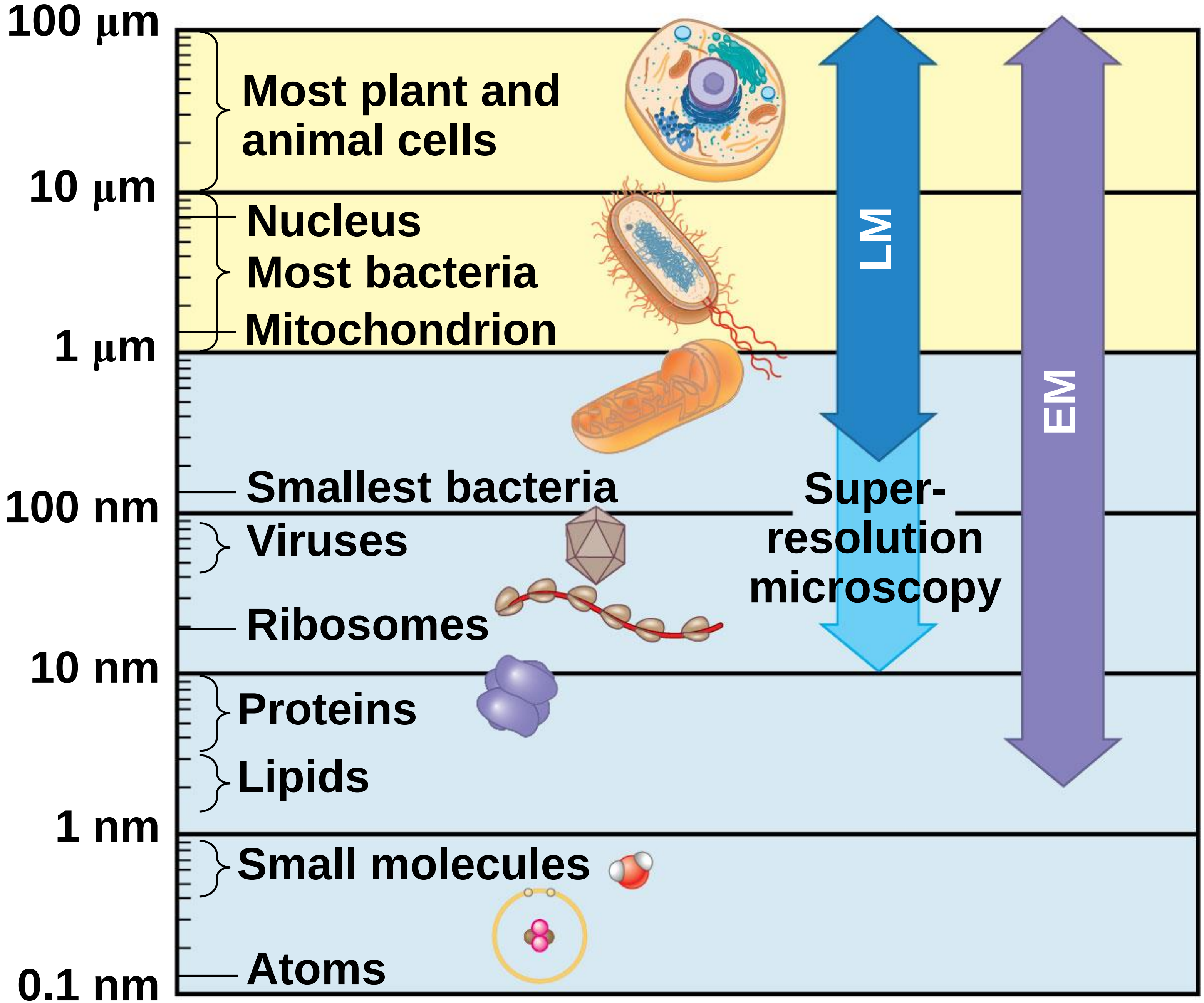
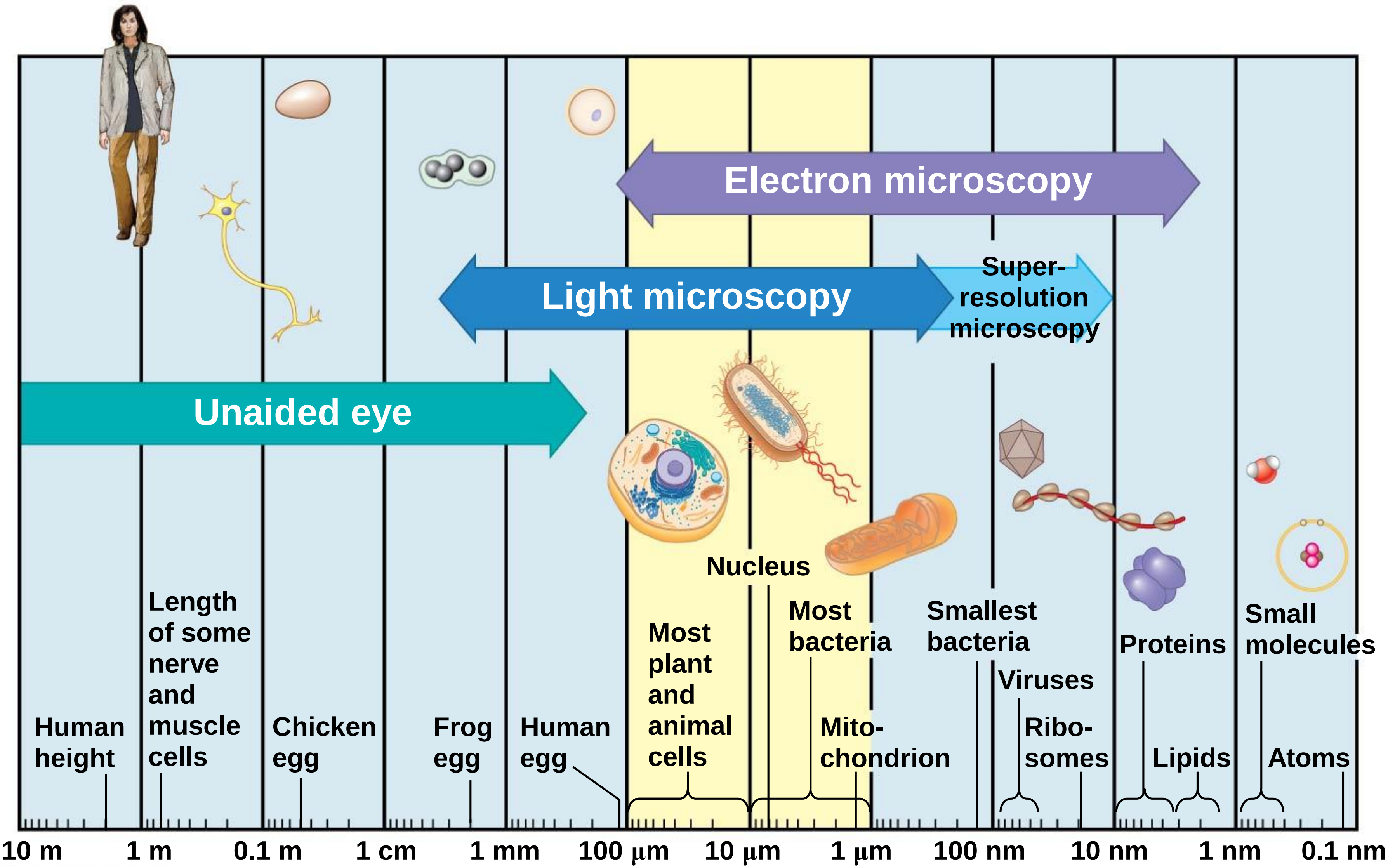
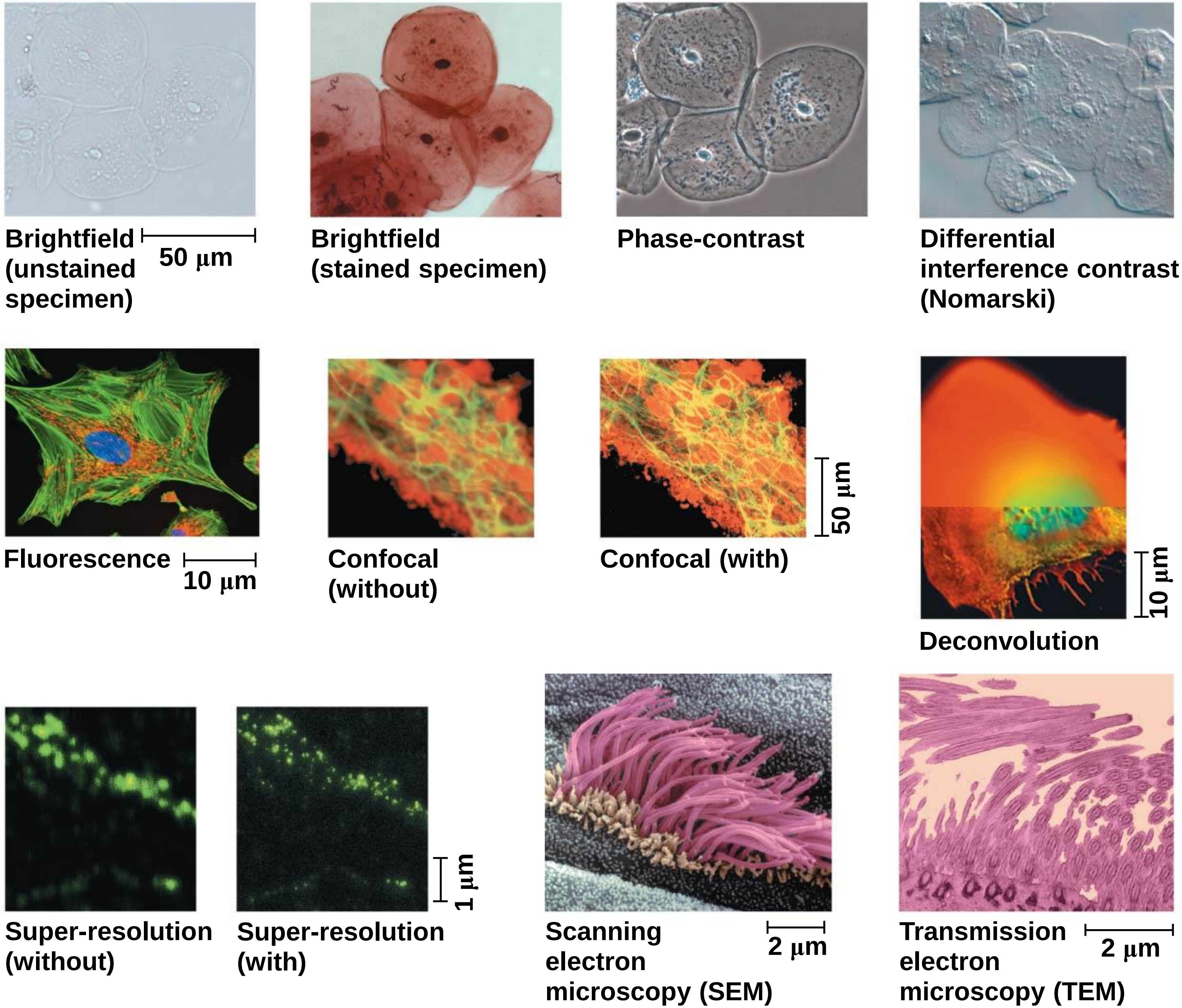

100 µm
10 µm
1 µm
100 nm
10 nm
1 nm
0.1 nm
Most plant and animal cells
Nucleus
Most bacteria
Mitochondrion
Smallest bacteria
Viruses
Ribosomes
Proteins
Lipids
Small molecules
Atoms
LM
EM
Super-resolution microscopy

Figure 7.2c


Electron microscopy
Super-resolution microscopy
Light microscopy
Unaided eye
Nucleus
Human height
Length of some nerve and muscle cells
Chicken egg
Frog egg
Human egg
Most plant and animal cells
Most bacteria
Mito-chondrion
Smallest bacteria
Viruses
Ribo-somes
Proteins
Lipids
Small molecules
Atoms
10 m
1 m
0.1 m
1 cm
1 mm
100 µm
10 µm
1 µm
100 nm
10 nm
1 nm
0.1 nm

- Light microscopes can magnify effectively to about 1,000 times the size of the actual specimen
- Various techniques enhance contrast and enable cell components to be stained or labeled
- The resolution of standard light microscopy is too low to study **organelles**, the membrane-enclosed structures in eukaryotic cells

Figure 7.3


Brightfield (unstained specimen)
50 µm
Brightfield (stained specimen)
Phase-contrast
Differential interference contrast (Nomarski)
Fluorescence
10 µm
Confocal (without)
Confocal (with)
50 µm
Deconvolution
10 µm
Super-resolution (without)
Super-resolution (with)
1 µm
Scanning electron microscopy (SEM)
2 µm
Transmission electron microscopy (TEM)
2 µm

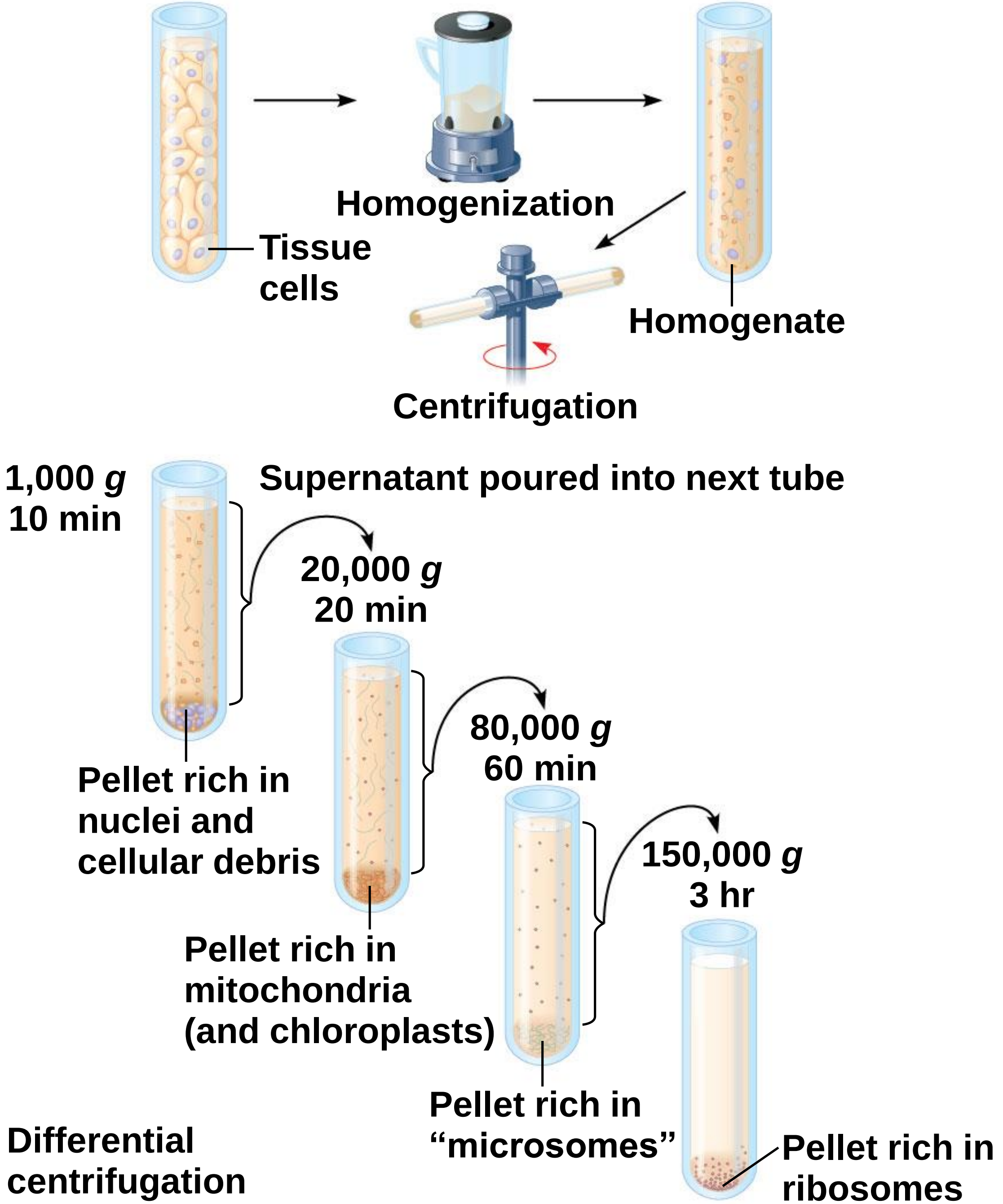
- Two basic types of **electron microscopes (EMs)** are used to study subcellular structures
- **Scanning electron microscopes (SEMs)** focus a beam of electrons onto the surface of a specimen, providing images that look 3-D
- **Transmission electron microscopes (TEMs)** focus a beam of electrons through a specimen
- TEMs are used mainly to study the internal structure of cells

- Recent advances in light microscopy:
  - Labeling individual cells with fluorescent markers improve the level of detail that can be seen
  - Confocal microscopy and deconvolution microscopy provide sharper images of three-dimensional tissues and cells
  - New techniques for labeling cells improve resolution
  - Super-resolution microscopy allows one to distinguish structures as small as 10–20 nm across

Cell Fractionation

- **Cell fractionation** takes cells apart and separates the major organelles from one another
- Centrifuges fractionate cells into their component parts
- Cell fractionation enables scientists to determine the functions of organelles
- Biochemistry and cytology help correlate cell function with structure

Figure 7.4



Homogenization
Tissue cells
Homogenate
Centrifugation
1,000 g
10 min
Supernatant poured into next tube
20,000 g
20 min
80,000 g
60 min
150,000 g
3 hr
Pellet rich in nuclei and cellular debris
Pellet rich in mitochondria (and chloroplasts)
Pellet rich in "microsomes"
Pellet rich in ribosomes
Differential centrifugation

Figure 7.4a

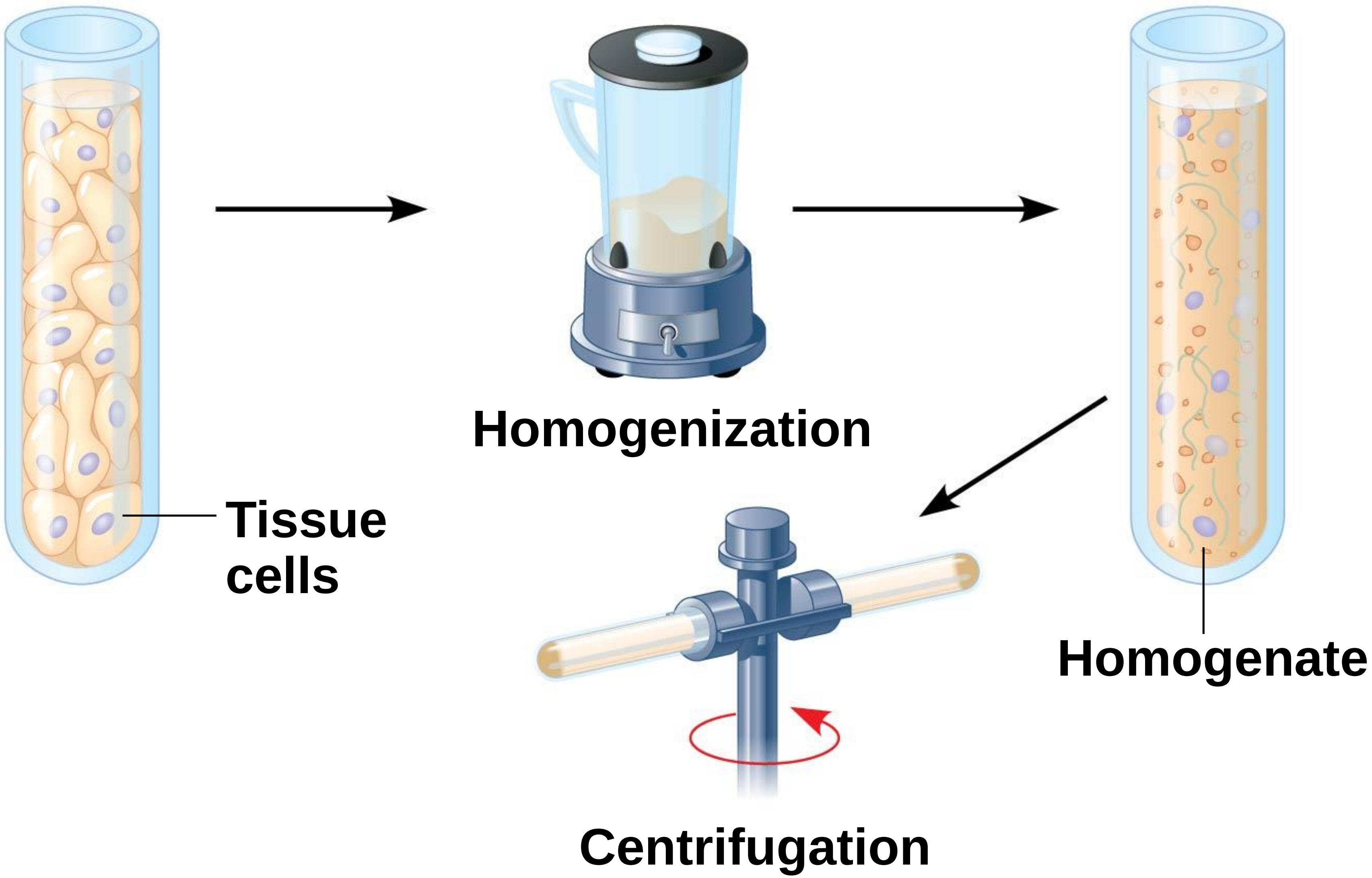
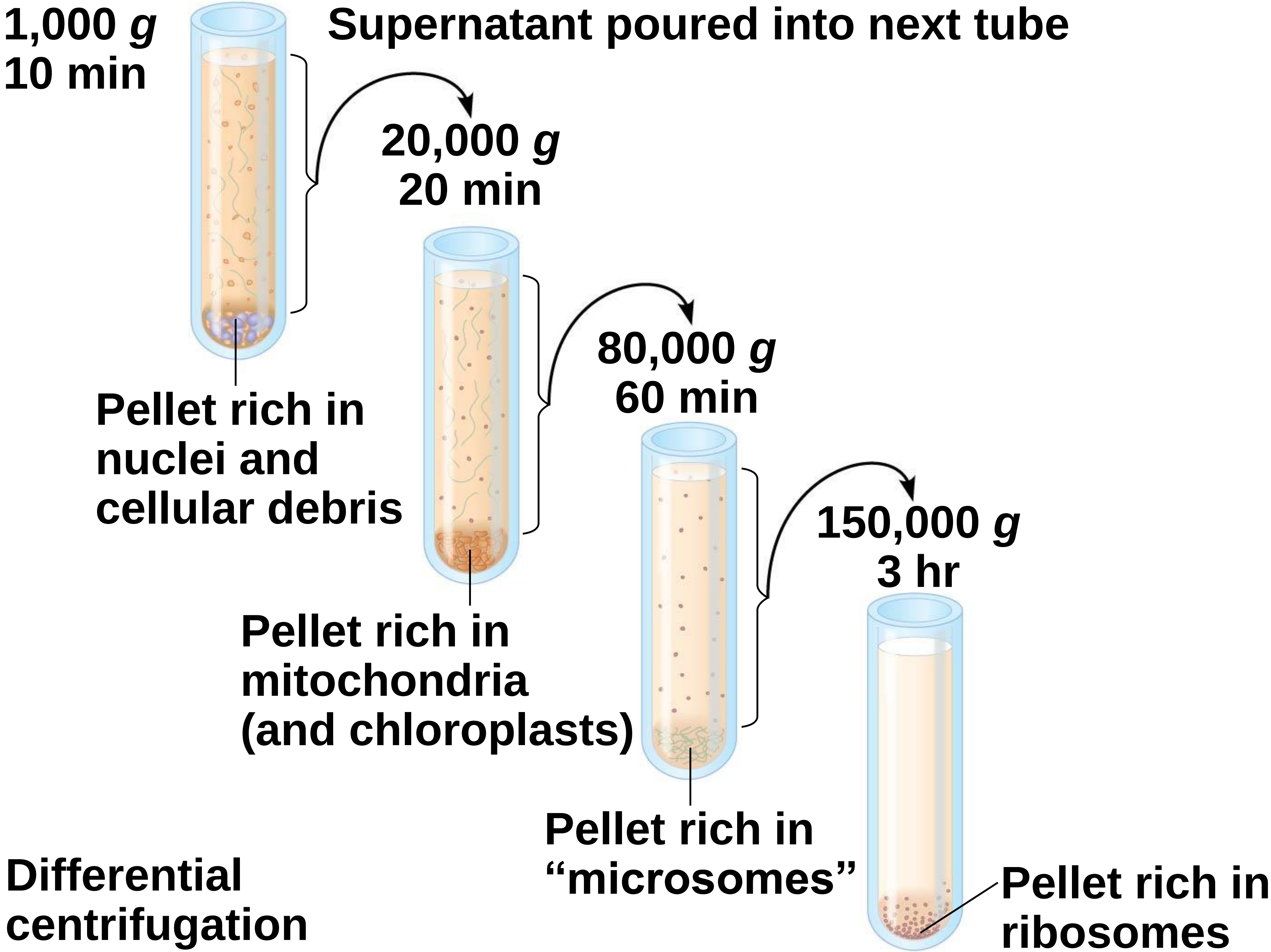


Figure 7.4b


1,000 g
10 min
Supernatant poured into next tube
20,000 g
20 min
80,000 g
60 min
150,000 g
3 hr
Pellet rich in nuclei and cellular debris
Pellet rich in mitochondria (and chloroplasts)
Pellet rich in "microsomes"
Pellet rich in ribosomes
Differential centrifugation

Concept 7.2: Eukaryotic cells have internal membranes that compartmentalize their functions

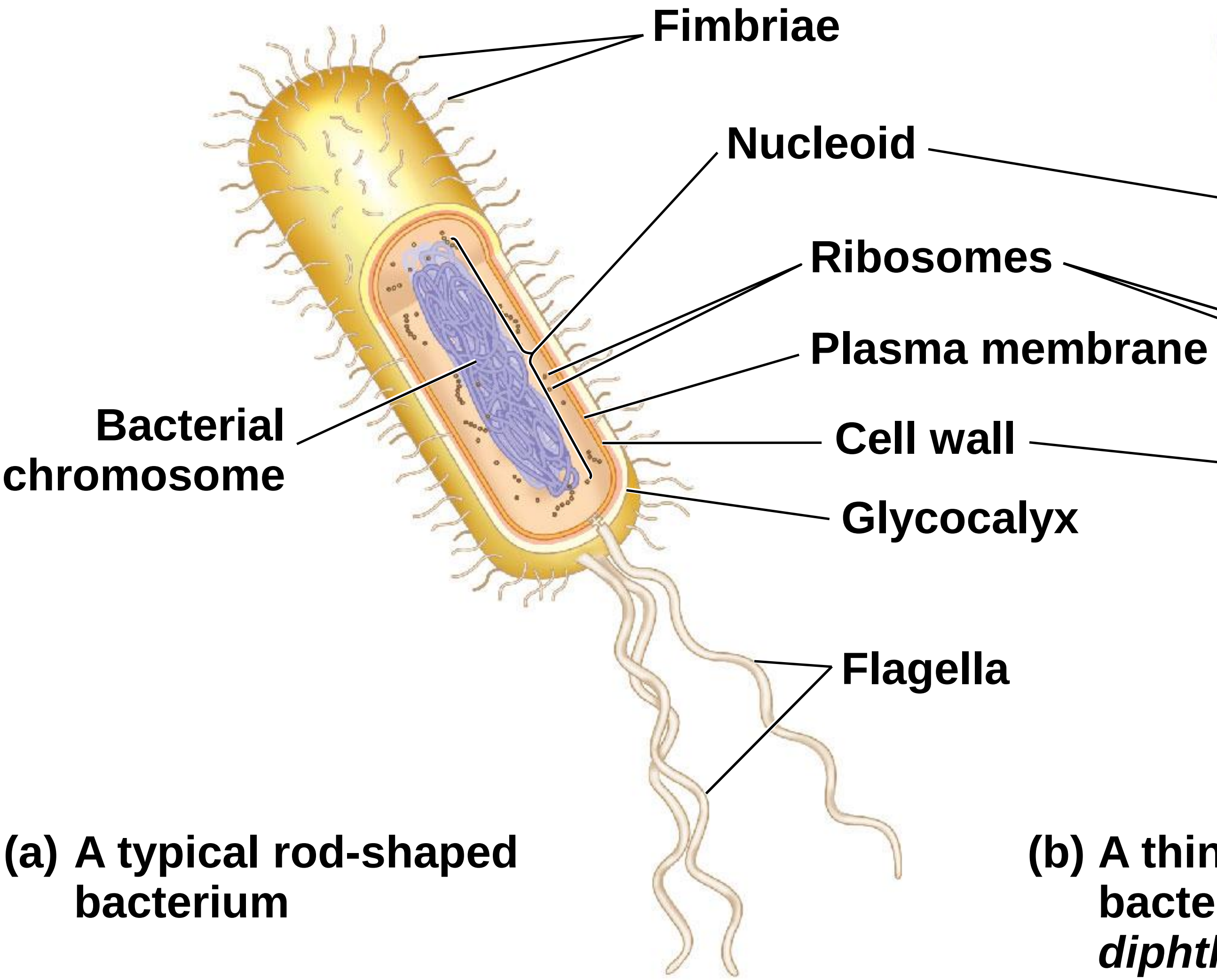
- The basic structural and functional unit of every organism is one of two types of cells: prokaryotic or eukaryotic
- Only organisms of the domains Bacteria and Archaea consist of prokaryotic cells
- Protists, fungi, animals, and plants all consist of eukaryotic cells

Comparing Prokaryotic and Eukaryotic Cells

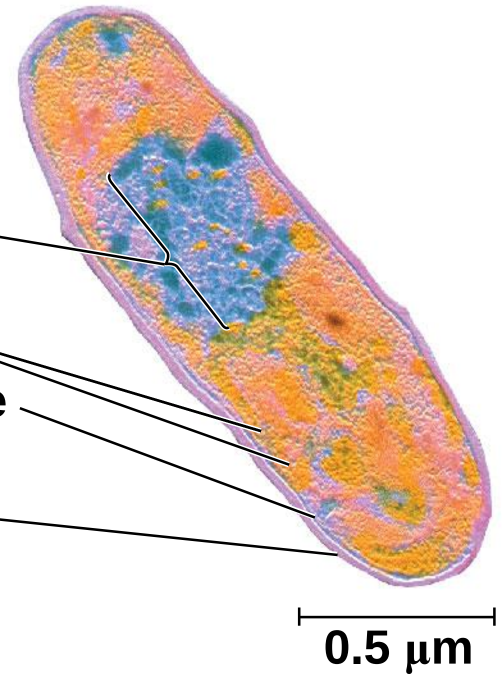
- Basic features of all cells:
  - Plasma membrane
  - Semifluid substance called **cytosol**
  - Chromosomes (carry genes)
  - Ribosomes (make proteins)

- **Prokaryotic cells** are characterized by having
  - No nucleus
  - DNA in an unbound region called the **nucleoid**
  - No membrane-bound organelles
  - **Cytoplasm** bound by the plasma membrane

Figure 7.5



(a) A typical rod-shaped bacterium

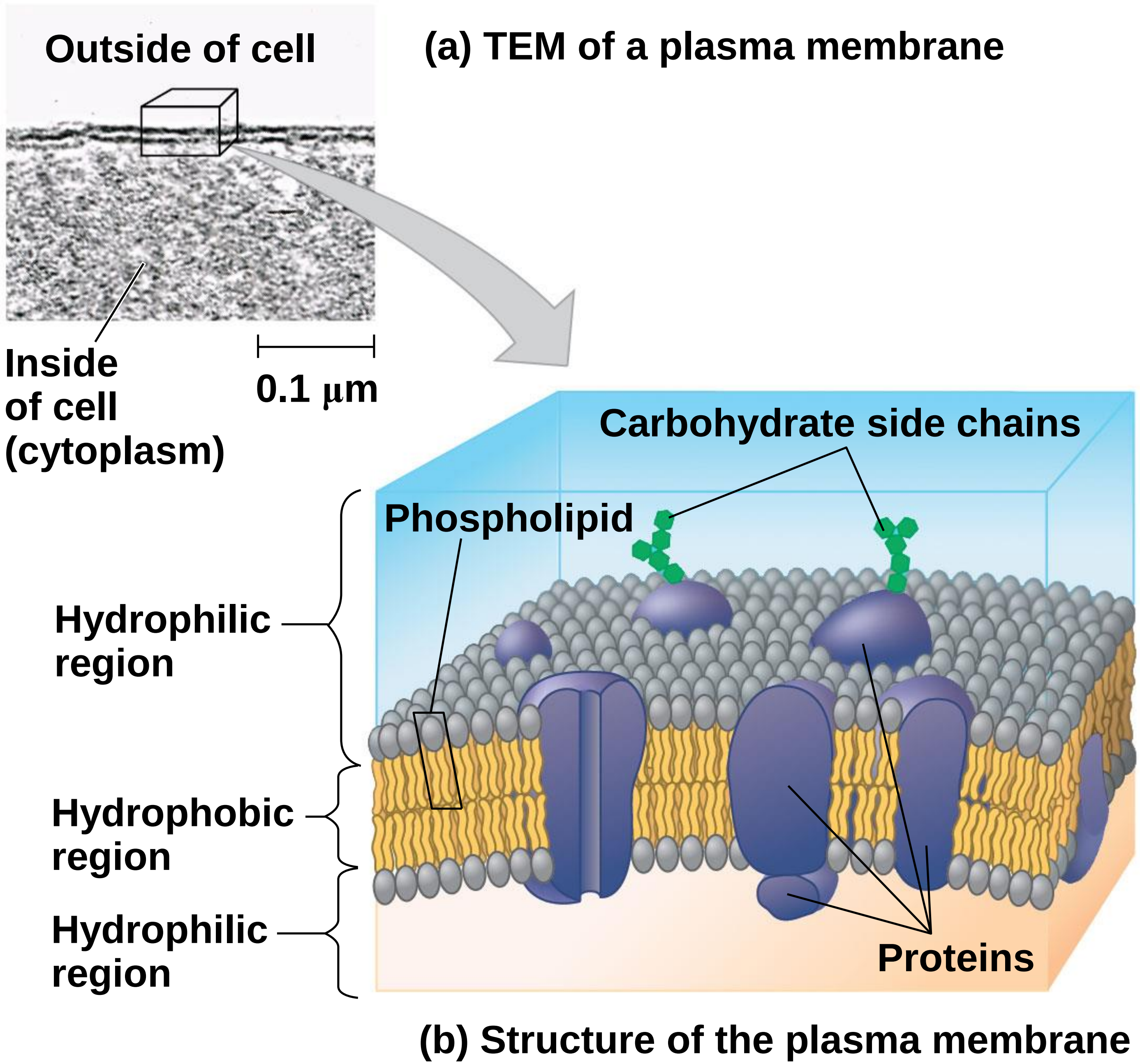


(b) A thin section through the bacterium *Corynebacterium diphtheriae* (colorized TEM)

- **Eukaryotic cells** are characterized by having
  - DNA in a nucleus that is bounded by a double membrane
  - Membrane-bound organelles
  - **Cytoplasm** in the region between the plasma membrane and nucleus
- Eukaryotic cells are generally much larger than prokaryotic cells

- The **plasma membrane** is a selective barrier that allows sufficient passage of oxygen, nutrients, and waste to service the volume of every cell

Figure 7.6

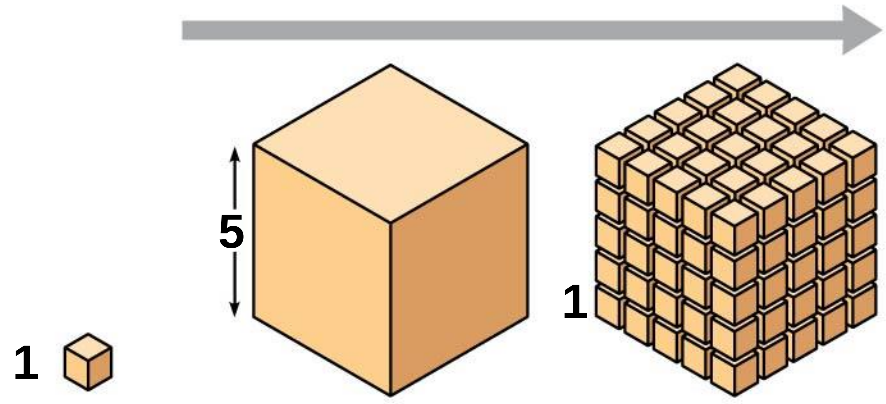


Outside of cell
(a) TEM of a plasma membrane
Inside of cell (cytoplasm)
0.1 µm
Carbohydrate side chains
Phospholipid
Hydrophilic region
Hydrophobic region
Hydrophilic region
Proteins
(b) Structure of the plasma membrane

- Metabolic requirements set upper limits on the size of cells
- The surface area to volume ratio of a cell is critical
- As a cell increases in size, its volume grows proportionately more than its surface area

Figure 7.7

Surface area increases while total volume remains constant

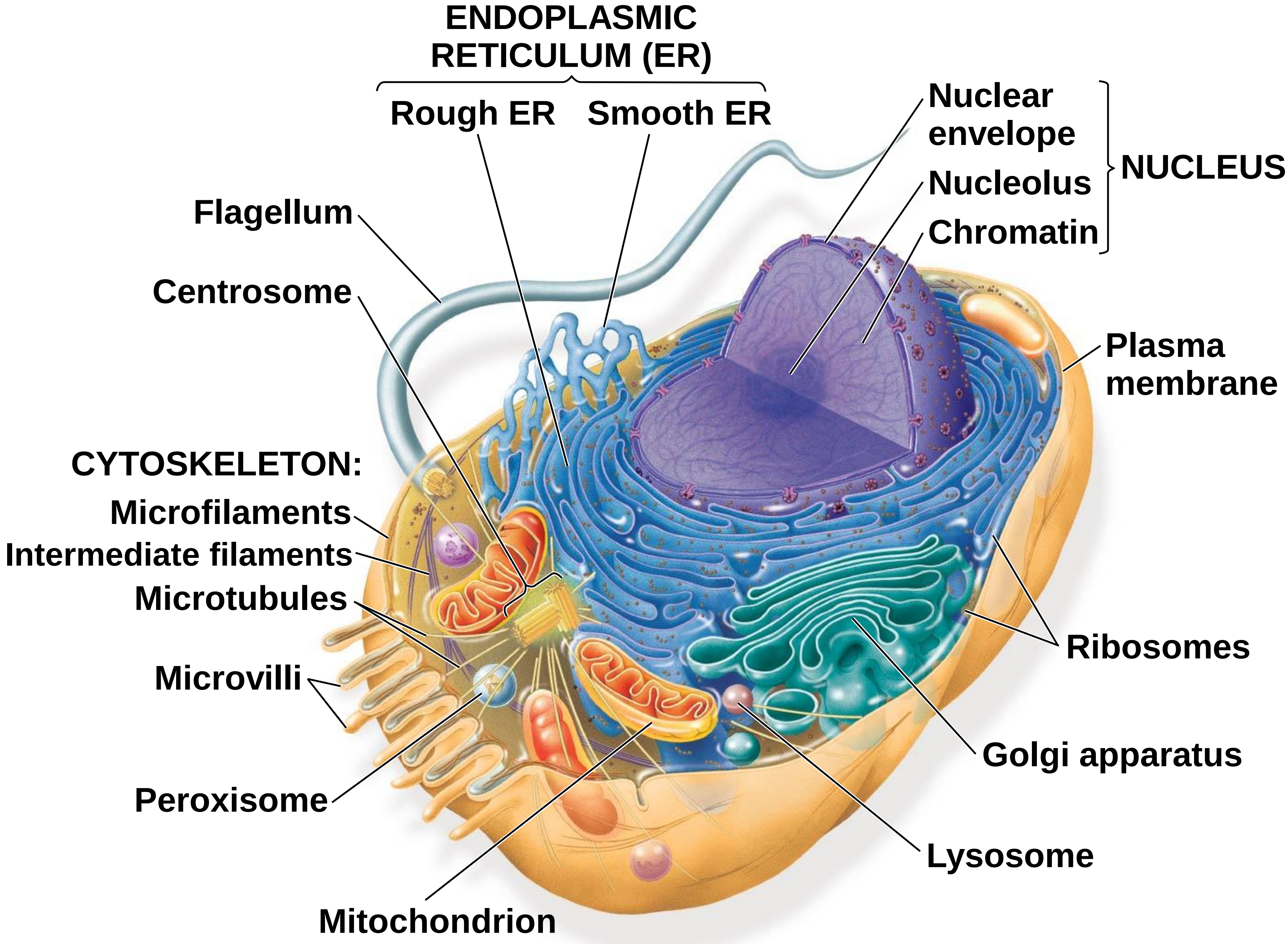


Total surface area [sum of the surface areas (height × width) of all box sides × number of boxes]	6	150	750
Total volume [height × width × length × number of boxes]	1	125	125
Surface-to-volume (S-to-V) ratio [surface area ÷ volume]	6	1.2	6

A Panoramic View of the Eukaryotic Cell

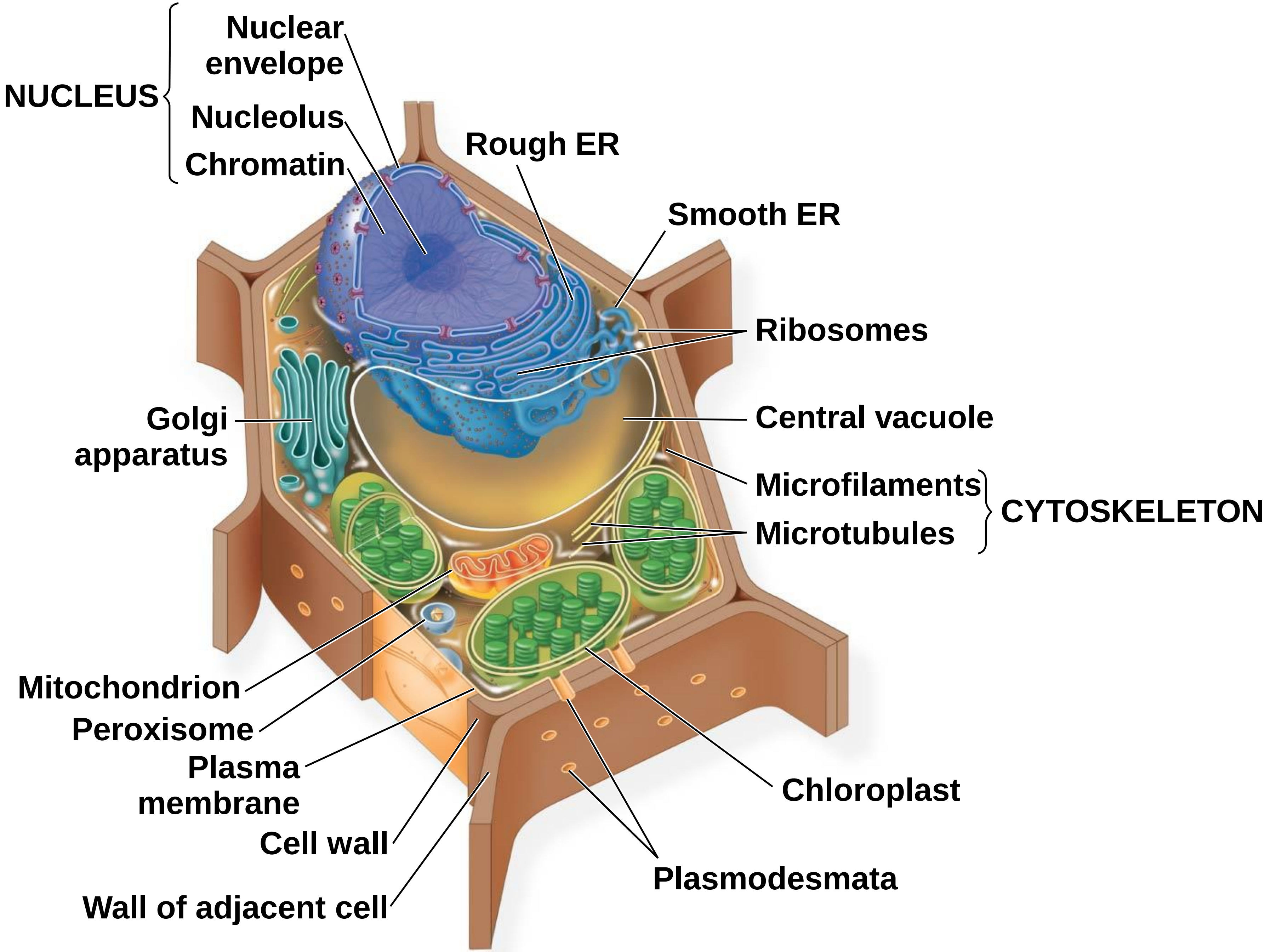
- A eukaryotic cell has internal membranes that divide the cell into compartments—the organelles
- The basic fabric of biological membranes is a double layer of phospholipids and other lipids
- Plant and animal cells have most of the same organelles

Figure 7.8a



ENDOPLASMIC RETICULUM (ER)
Rough ER
Smooth ER
Nuclear envelope
Nucleolus
Chromatin
NUCLEUS
Flagellum
Centrosome
Plasma membrane
CYTOSKELETON:
Microfilaments
Intermediate filaments
Microtubules
Ribosomes
Microvilli
Golgi apparatus
Peroxisome
Lysosome
Mitochondrion

Figure 7.8b


NUCLEUS
Nuclear envelope
Nucleolus
Chromatin
Rough ER
Smooth ER
Ribosomes
Central vacuole
Microfilaments
Microtubules
CYTOSKELETON
Golgi apparatus
Mitochondrion
Peroxisome
Plasma membrane
Cell wall
Wall of adjacent cell
Chloroplast
Plasmodesmata

Concept 7.3: The eukaryotic cell's genetic instructions are housed in the nucleus and carried out by the ribosomes

- The nucleus contains most of the DNA in a eukaryotic cell
- Ribosomes use the information from the DNA to make proteins

The Nucleus: Information Central

- The **nucleus** contains most of the cell's genes and is usually the most conspicuous organelle
- The **nuclear envelope** encloses the nucleus, separating it from the cytoplasm
- The nuclear envelope is a double membrane; each membrane consists of a lipid bilayer

Figure 7.9

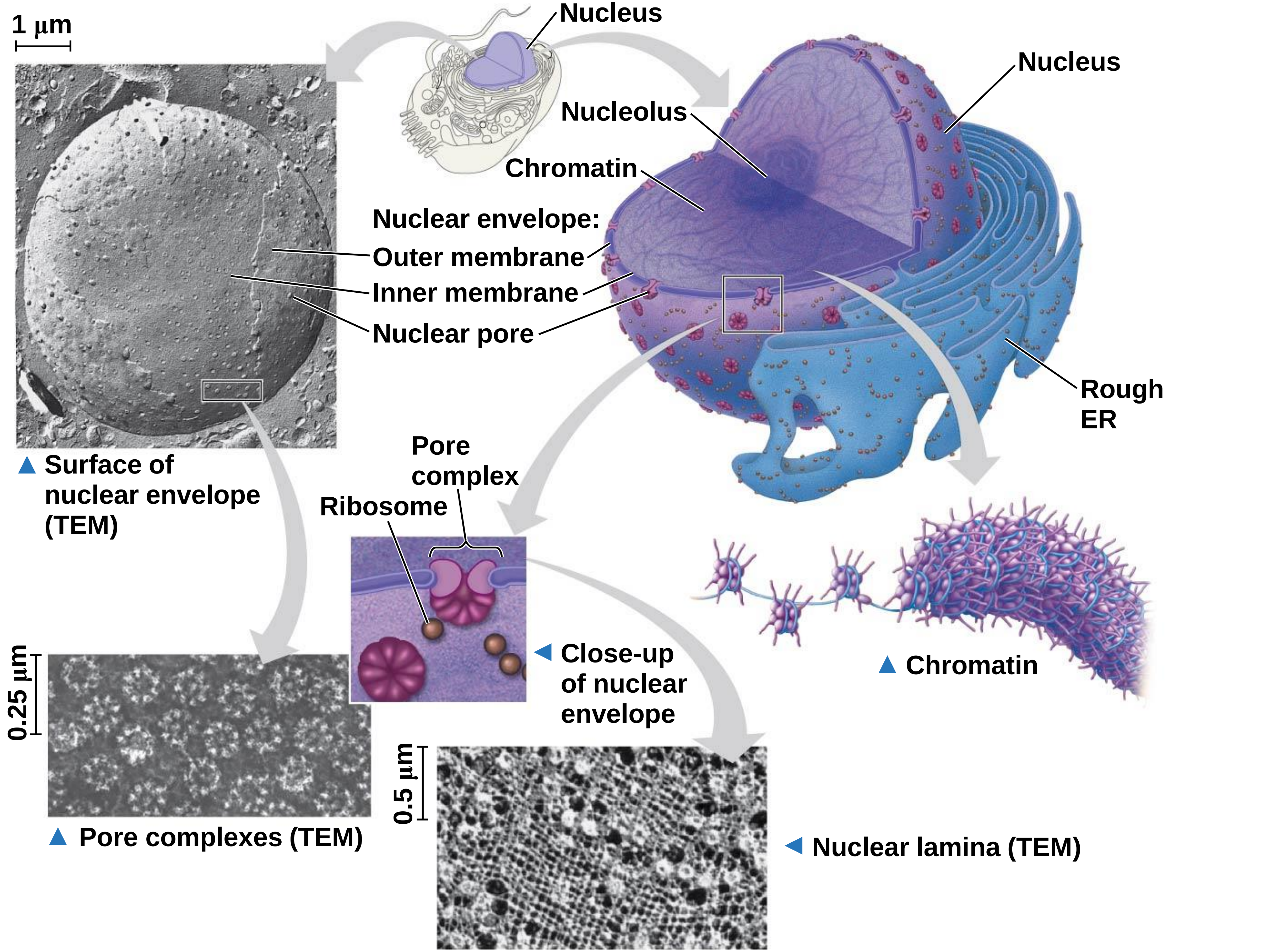
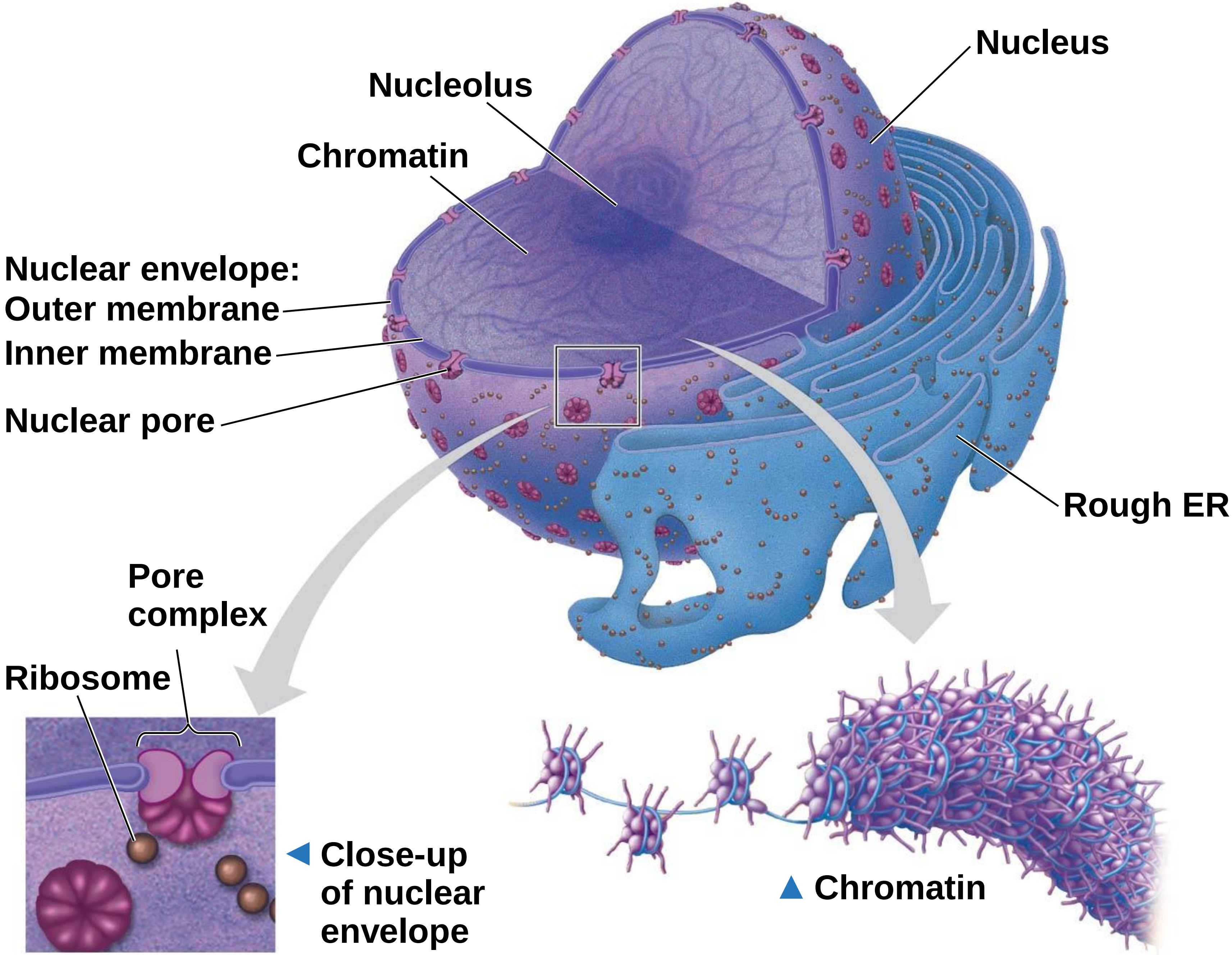

1 µm
Nucleus
Nucleus
Nucleolus
Chromatin
Nuclear envelope:
Outer membrane
Inner membrane
Nuclear pore
Rough ER
Surface of nuclear envelope (TEM)
Pore complex
Ribosome
Close-up of nuclear envelope
Chromatin
0.25 µm
Pore complexes (TEM)
0.5 µm
Nuclear lamina (TEM)

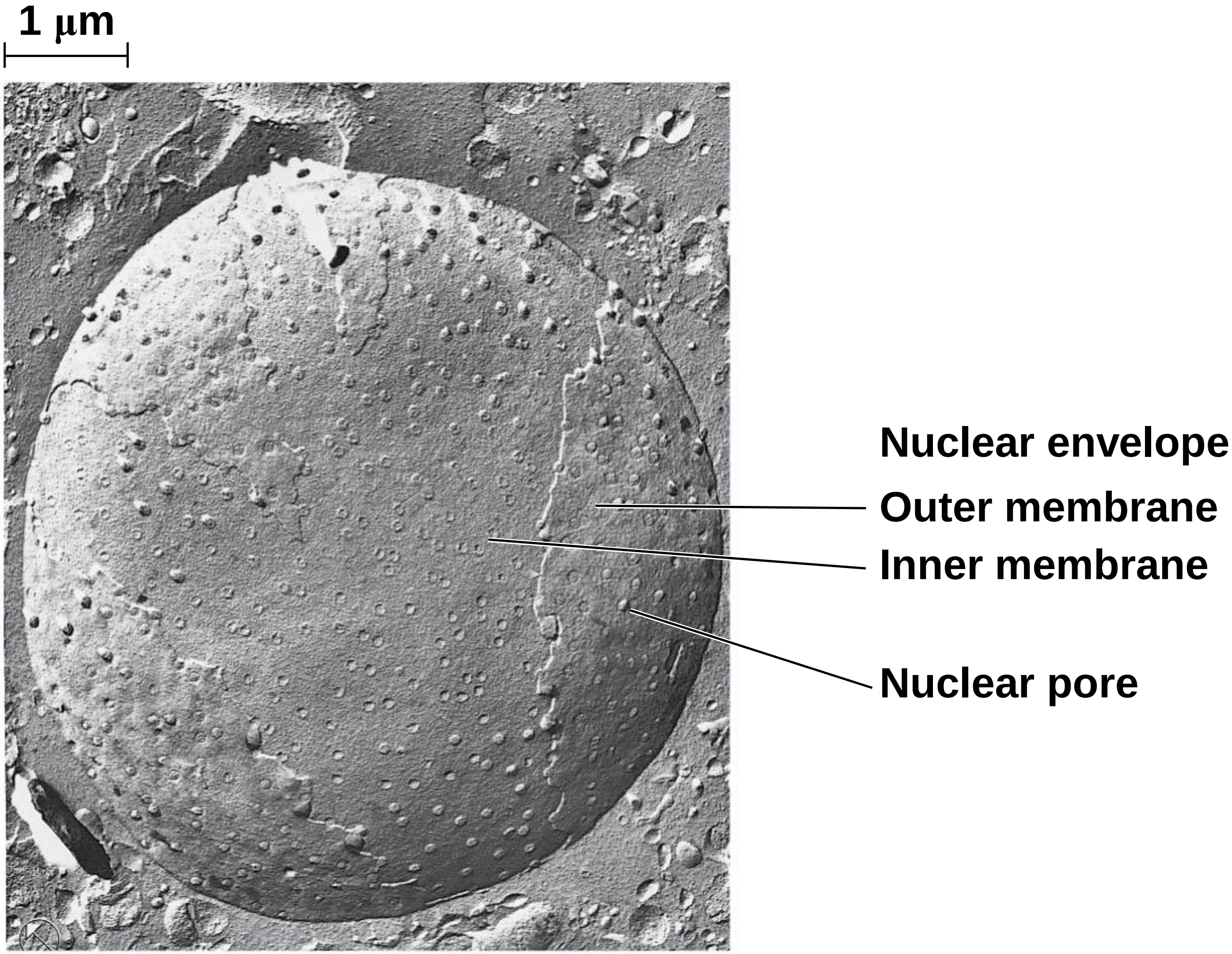
Figure 7.9a



◀ Close-up of nuclear envelope

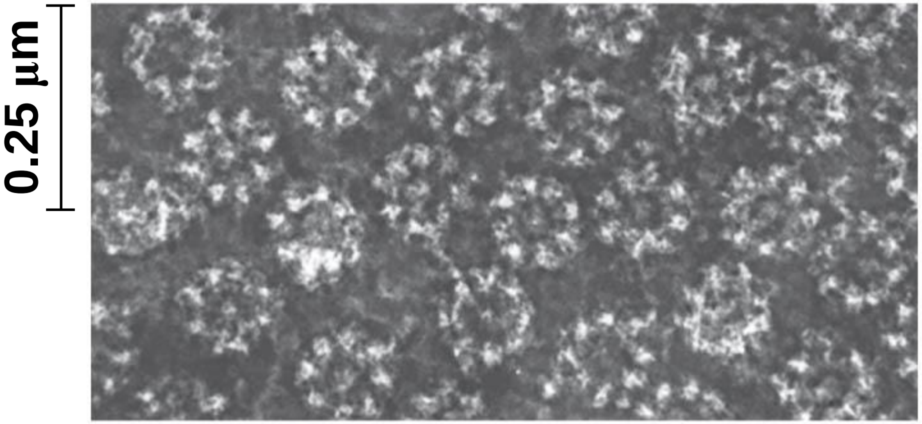
▲ Chromatin

Figure 7.9b



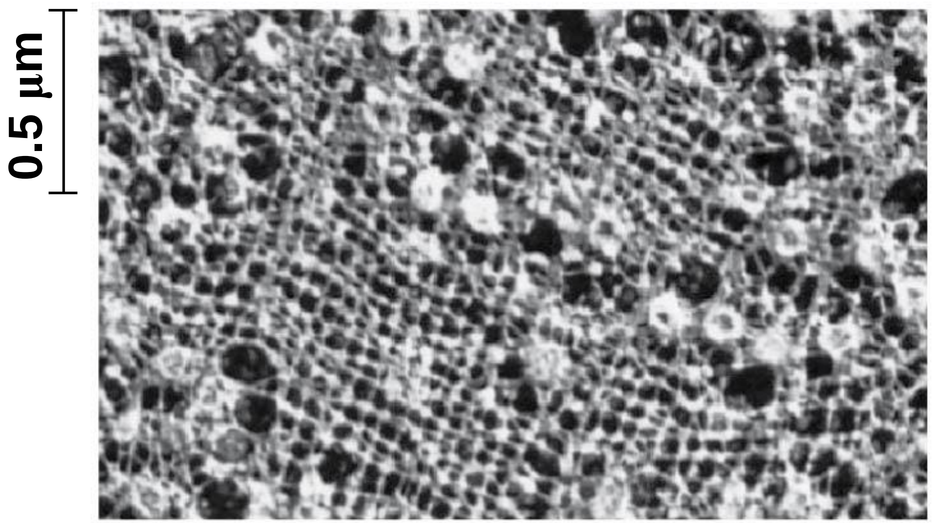
Surface of nuclear envelope (TEM)

Figure 7.9c



Pore complexes (TEM)

Figure 7.9d



Nuclear lamina (TEM)

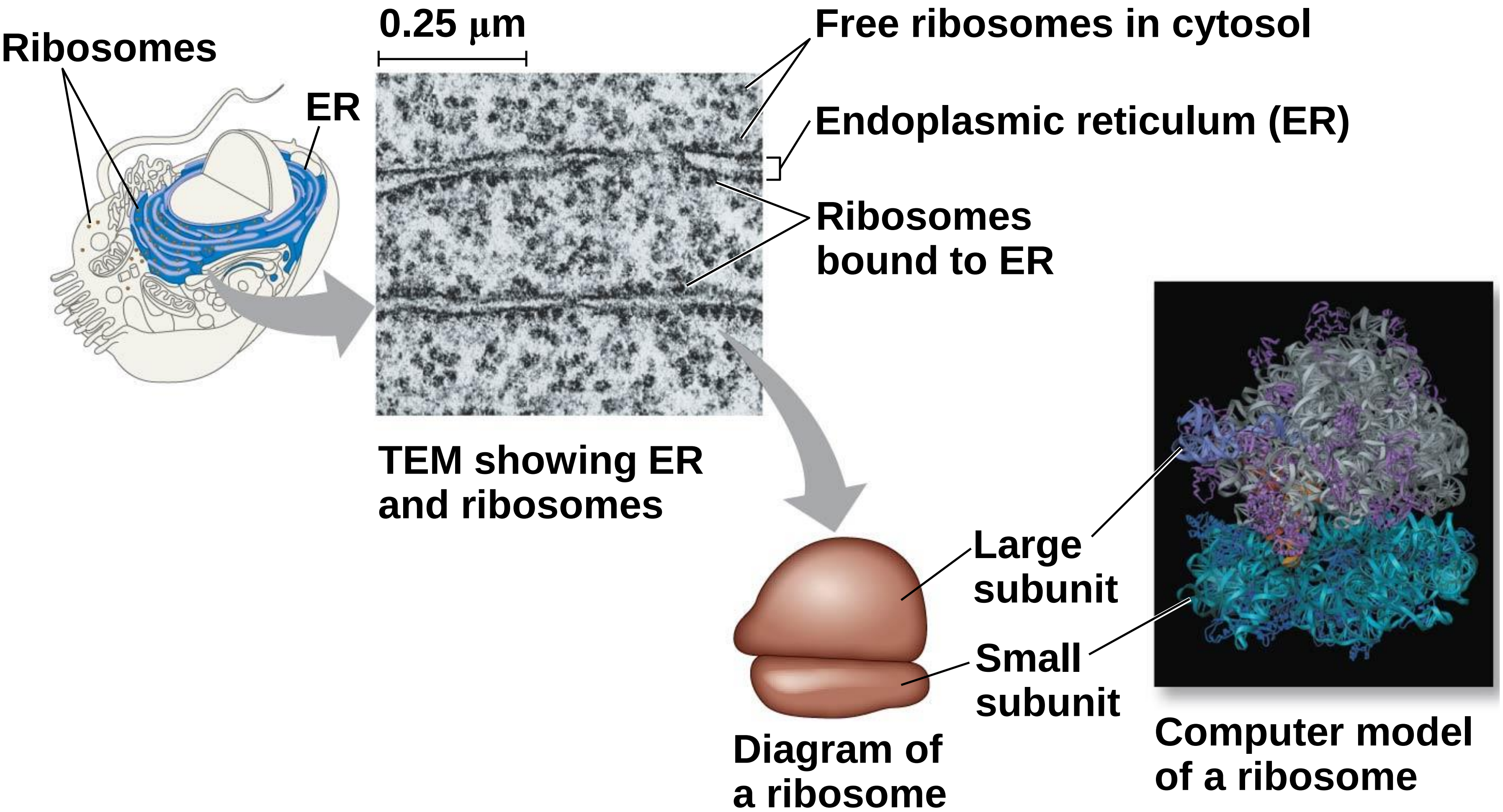
- Pores, lined with a structure called a pore complex, regulate the entry and exit of molecules from the nucleus
- The nuclear size of the envelope is lined by the **nuclear lamina**, which is composed of proteins and maintains the shape of the nucleus

- In the nucleus, DNA is organized into discrete units called **chromosomes**
- Each chromosome contains one DNA molecule associated with proteins, called **chromatin**
- Chromatin condenses to form discrete chromosomes as a cell prepares to divide
- The **nucleolus** is located within the nucleus and is the site of ribosomal RNA (rRNA) synthesis

Ribosomes: Protein Factories

- **Ribosomes** are complexes made of ribosomal RNA and protein
- Ribosomes carry out protein synthesis in two locations:
  - In the cytosol (free ribosomes)
  - On the outside of the endoplasmic reticulum or the nuclear envelope (bound ribosomes)

Figure 7.10



Ribosomes
ER
0.25 µm
Free ribosomes in cytosol
Endoplasmic reticulum (ER)
Ribosomes bound to ER
TEM showing ER and ribosomes
Large subunit
Small subunit
Diagram of a ribosome
Computer model of a ribosome

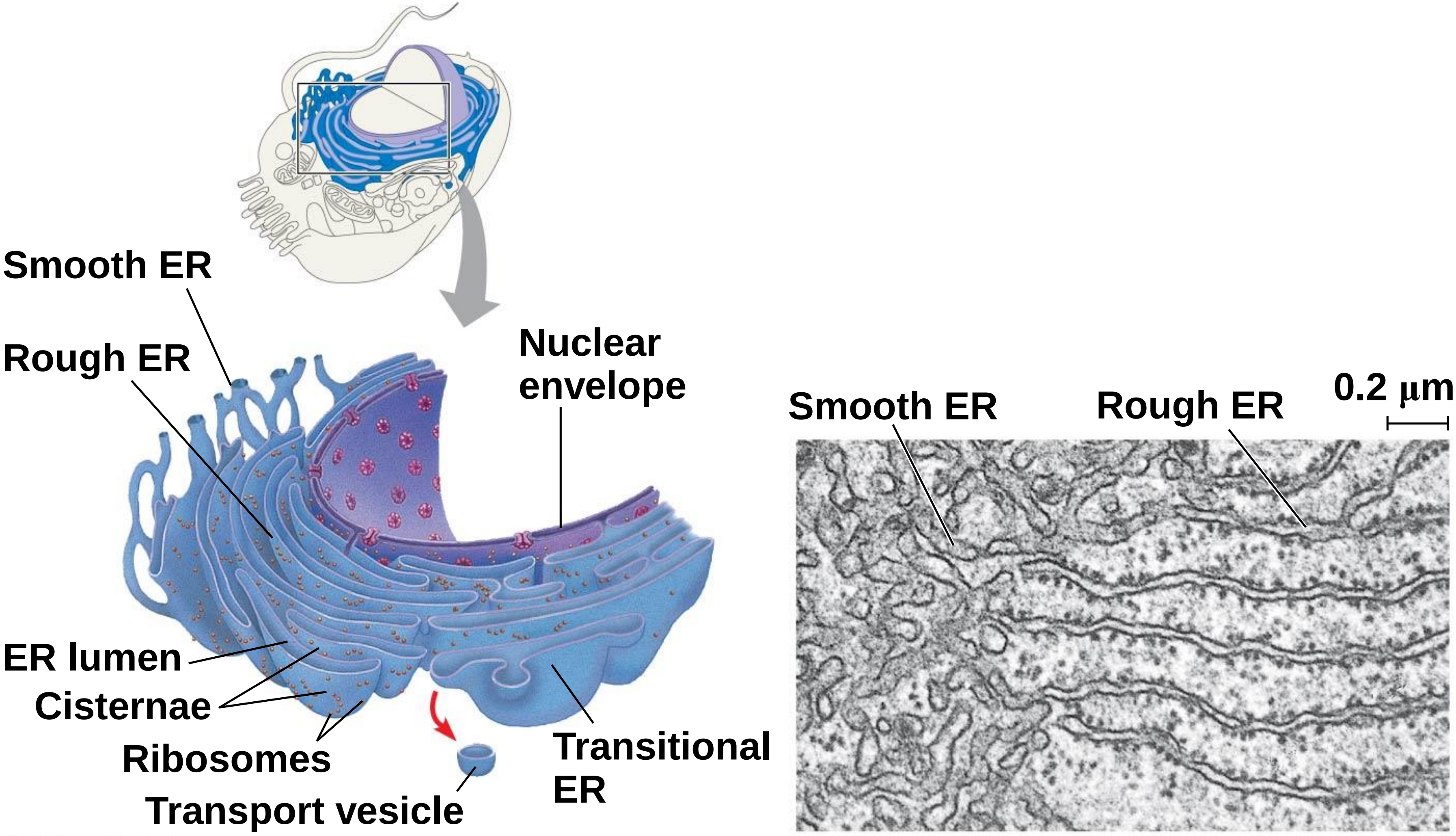
Concept 7.4: The endomembrane system regulates protein traffic and performs metabolic functions in the cell

- The **endomembrane system** consists of
  - Nuclear envelope
  - Endoplasmic reticulum
  - Golgi apparatus
  - Lysosomes
  - Vacuoles
  - Plasma membrane
- These components are either continuous or connected via transfer by **vesicles**

The Endoplasmic Reticulum: Biosynthetic Factory

- The **endoplasmic reticulum (ER)** accounts for more than half of the total membrane in many eukaryotic cells
- The ER membrane is continuous with the nuclear envelope
- There are two distinct regions of ER:
  - **Smooth ER**, which lacks ribosomes
  - **Rough ER**, whose surface is studded with ribosomes

Figure 7.11


Smooth ER
Rough ER
Nuclear envelope
ER lumen
Cisternae
Ribosomes
Transport vesicle
Transitional ER
Smooth ER
Rough ER
0.2 μm

Functions of Smooth ER

- The smooth ER
  - Synthesizes lipids
  - Metabolizes carbohydrates
  - Detoxifies drugs and poisons
  - Stores calcium ions

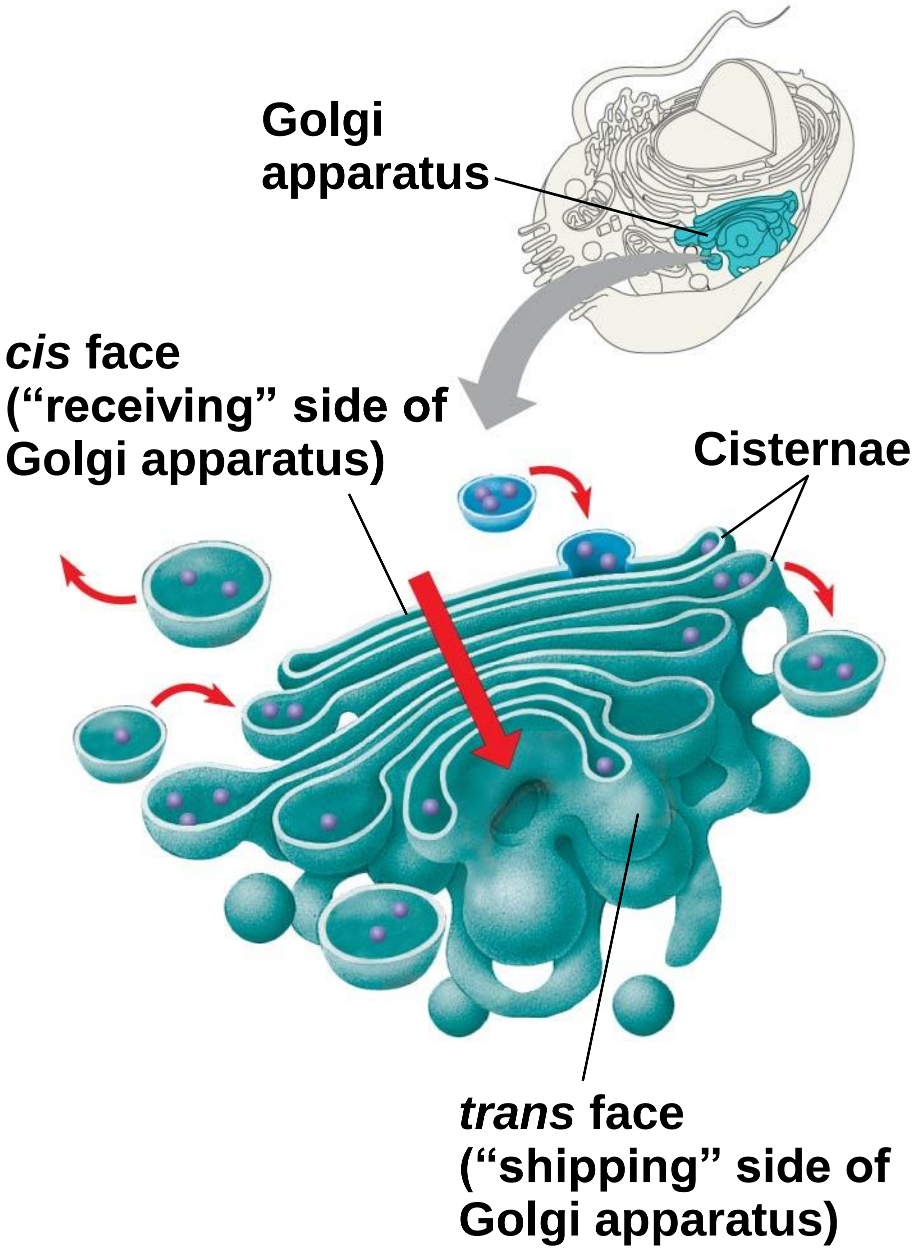
Functions of Rough ER

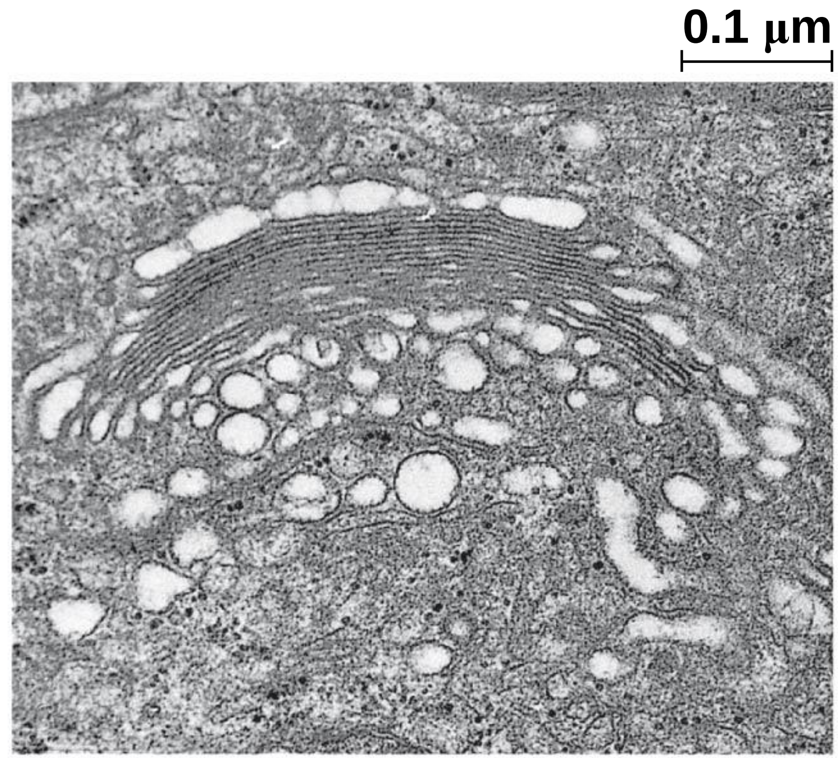
- The rough ER
  - Has bound ribosomes, which secrete **glycoproteins** (proteins covalently bonded to carbohydrates)
  - Distributes **transport vesicles**, secretory proteins surrounded by membranes
  - Is a membrane factory for the cell

The Golgi Apparatus: Shipping and Receiving Center

- The **Golgi apparatus** consists of flattened membranous sacs called cisternae
- The Golgi apparatus
  - Modifies products of the ER
  - Manufactures certain macromolecules
  - Sorts and packages materials into transport vesicles

Figure 7.12





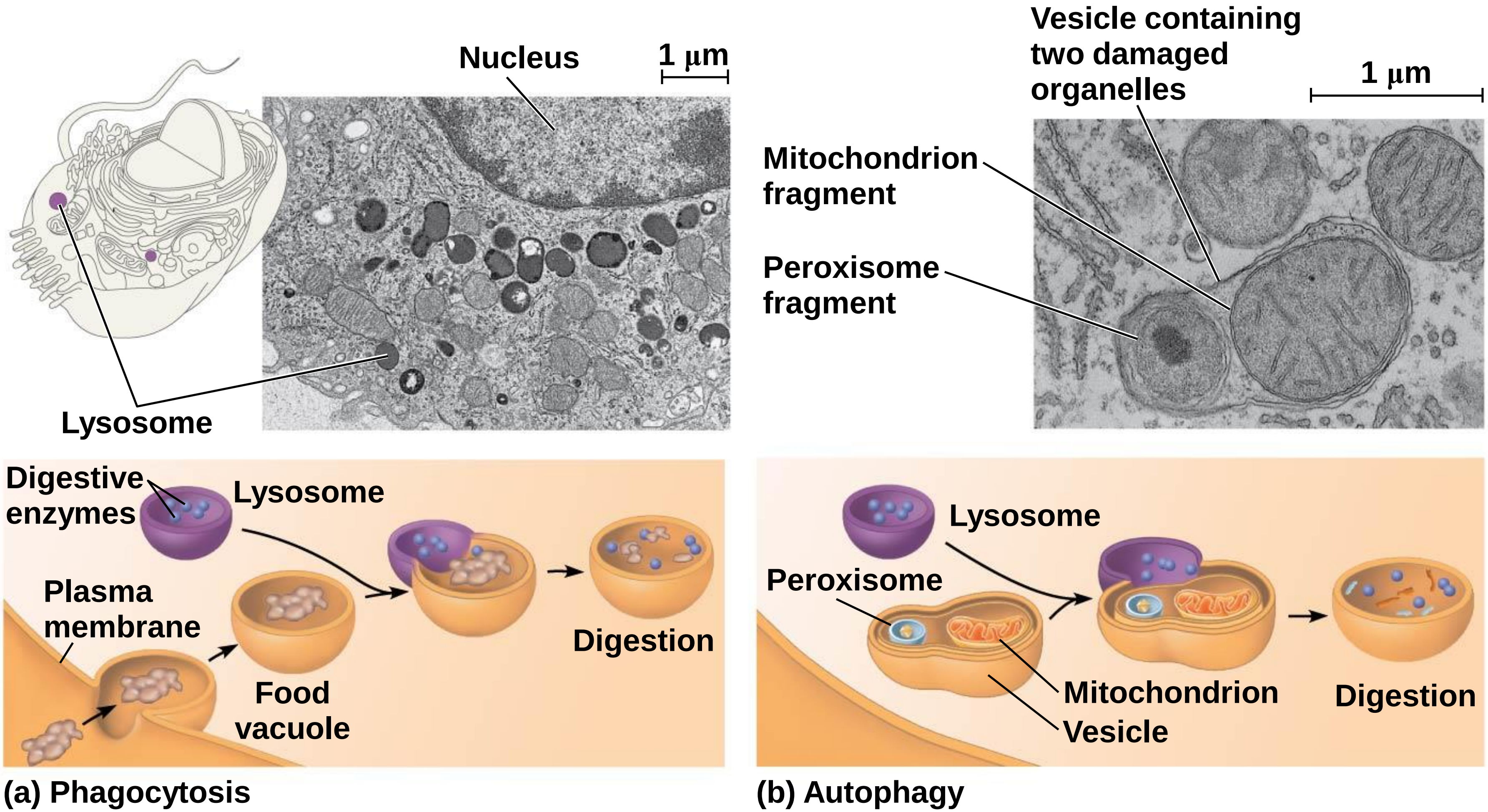
TEM of Golgi apparatus

Lysosomes: Digestive Compartments

- A **lysosome** is a membranous sac of hydrolytic enzymes that can digest macromolecules
- Lysosomal enzymes work best in the acidic environment inside the lysosome
- Hydrolytic enzymes and lysosomal membranes are made by rough ER and then transferred to the Golgi apparatus for further processing

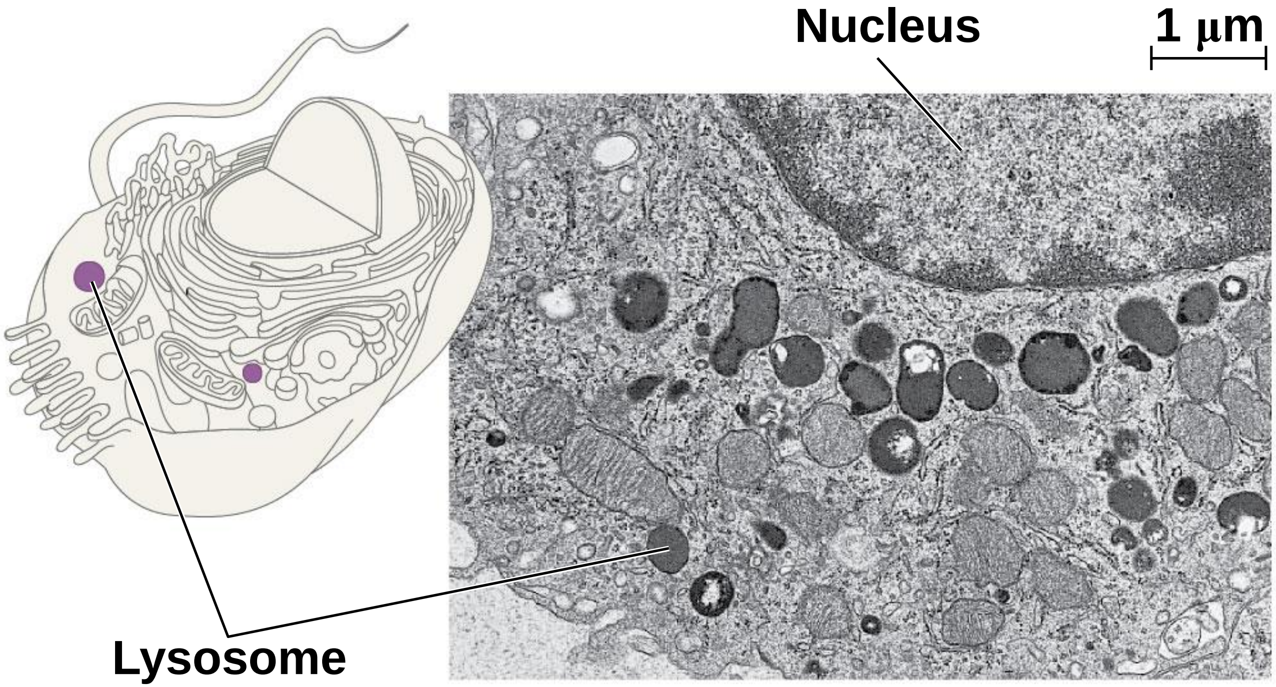
- Some types of cell can engulf another cell by **phagocytosis**; this forms a food vacuole
- A lysosome fuses with the food vacuole and digests the molecules
- Lysosomes also use enzymes to recycle the cell's own organelles and macromolecules, a process called autophagy

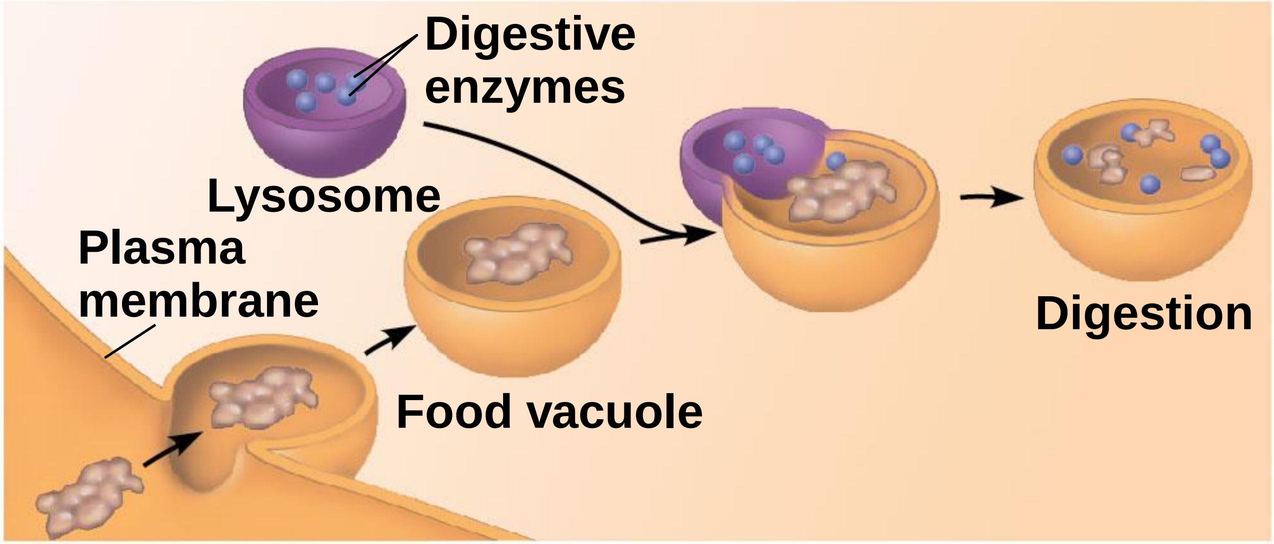
Figure 7.13



Nucleus
1 µm
Lysosome
Digestive enzymes
Lysosome
Plasma membrane
Food vacuole
Digestion
(a) Phagocytosis
Vesicle containing two damaged organelles
1 µm
Mitochondrion fragment
Peroxisome fragment
Lysosome
Peroxisome
Mitochondrion
Vesicle
Digestion
(b) Autophagy

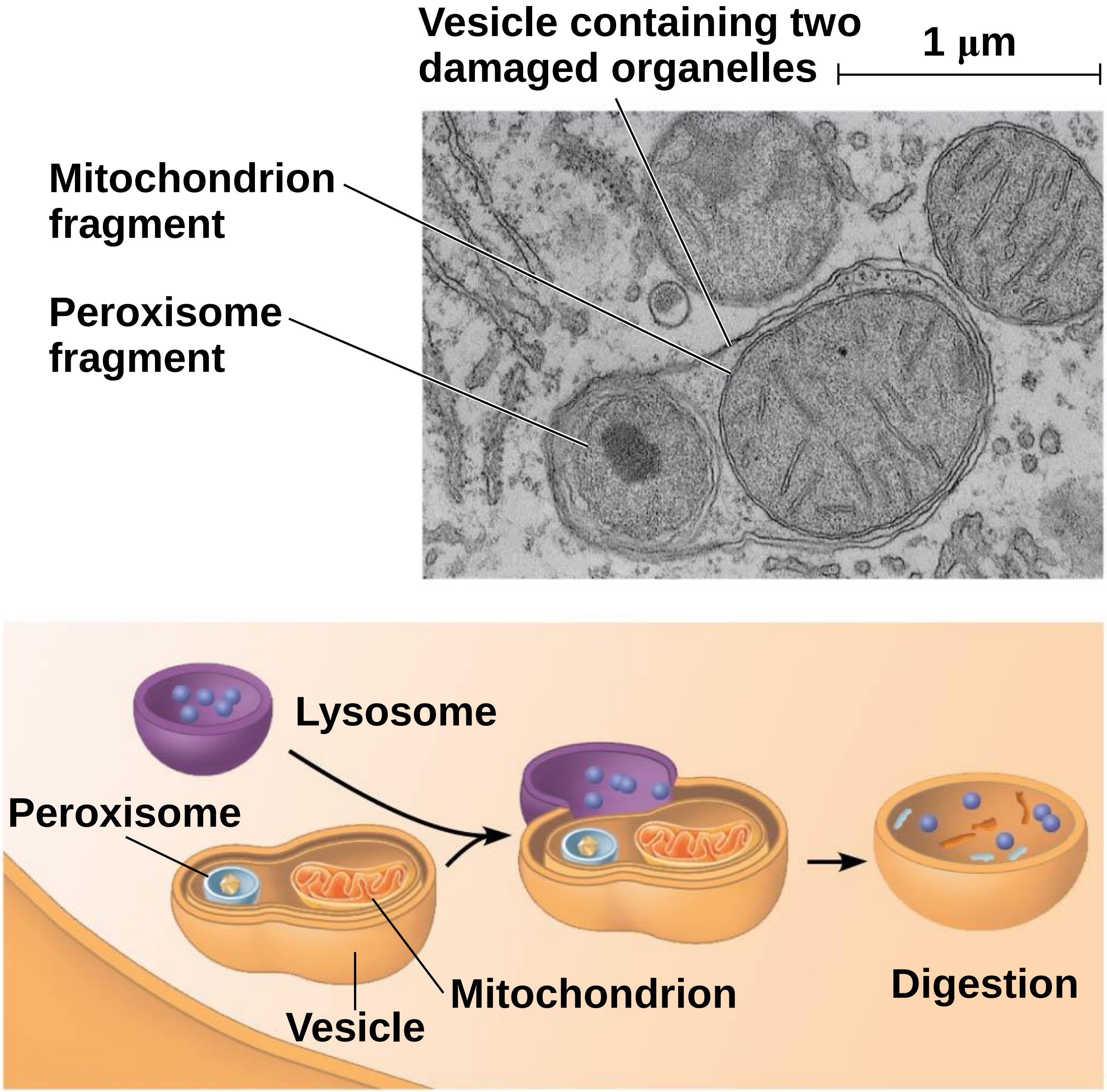
Figure 7.13a





(a) Phagocytosis

Figure 7.13b



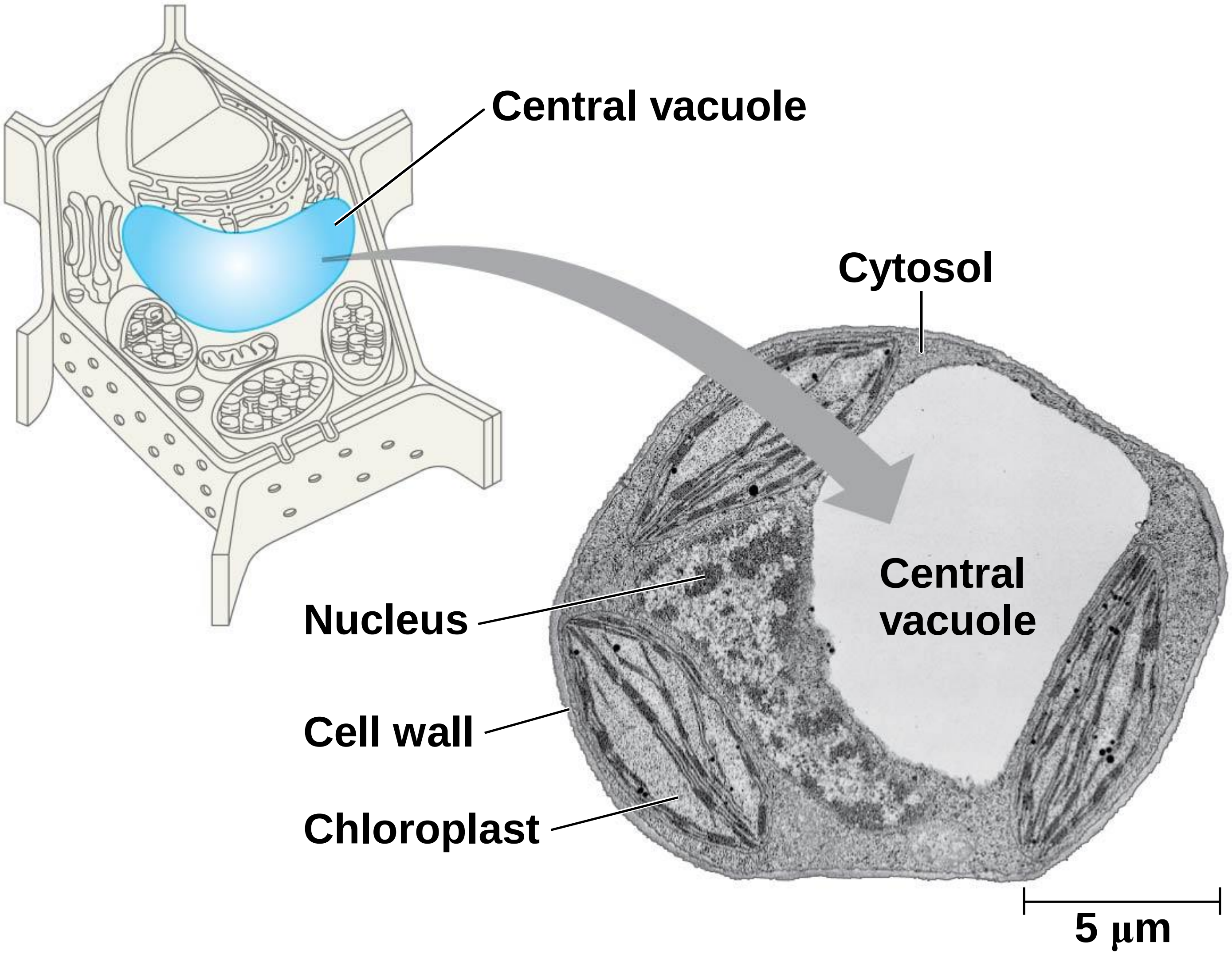
(b) Autophagy

Vacuoles: Diverse Maintenance Compartments

- **Vacuoles** are large vesicles derived from the ER and Golgi apparatus
- Vacuoles perform a variety of functions in different kinds of cells

- **Food vacuoles** are formed by phagocytosis
- **Contractile vacuoles**, found in many freshwater protists, pump excess water out of cells
- **Central vacuoles**, found in many mature plant cells, hold organic compounds and water

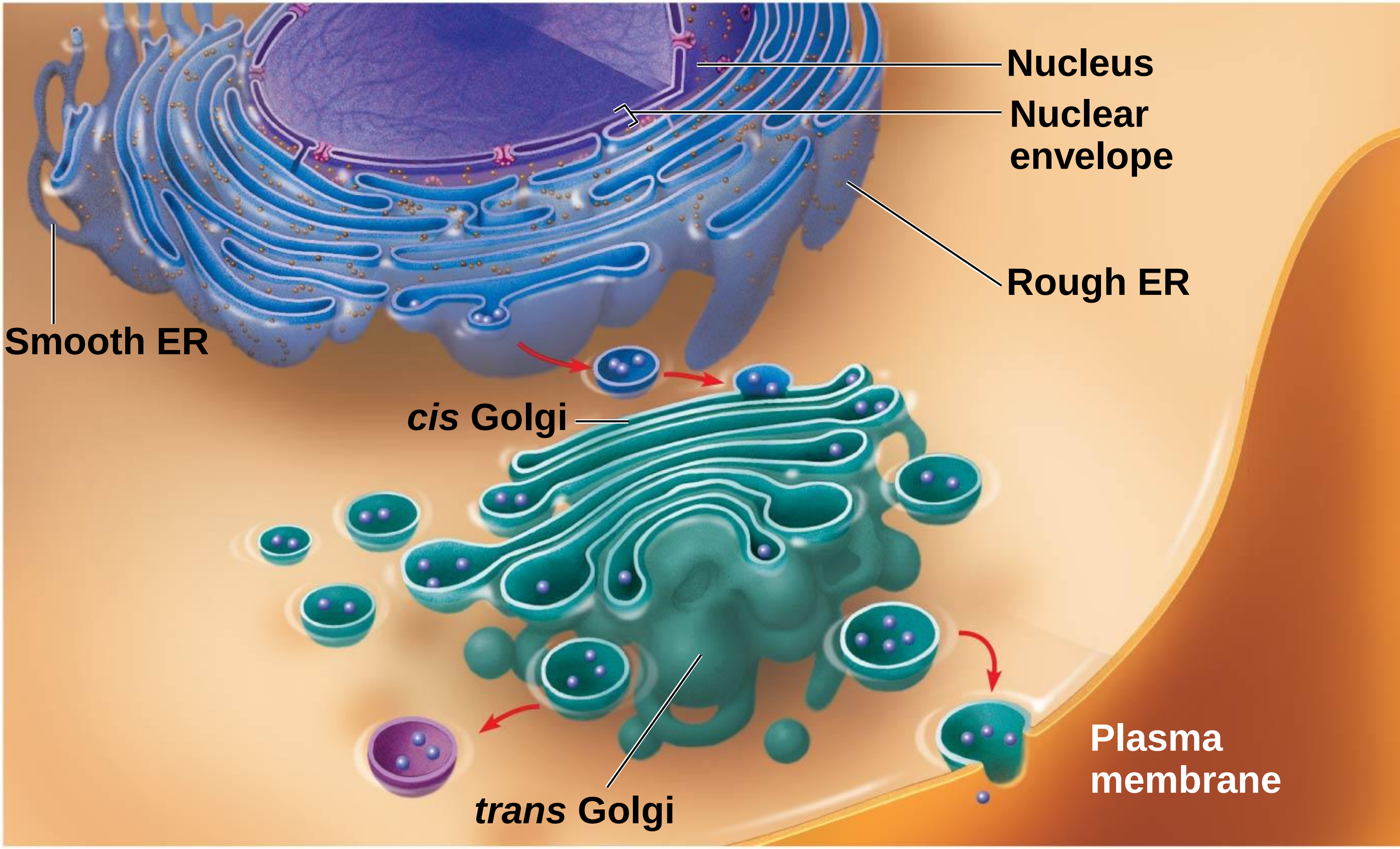
Figure 7.14


Central vacuole
Cytosol
Central
vacuole
Nucleus
Cell wall
Chloroplast
5 µm

The Endomembrane System: *A Review*

- The endomembrane system is a complex and dynamic player in the cell’s compartmental organization

Figure 7.15


Nucleus
Nuclear envelope
Rough ER
Smooth ER
cis Golgi
trans Golgi
Plasma membrane

Concept 7.5: Mitochondria and chloroplasts change energy from one form to another

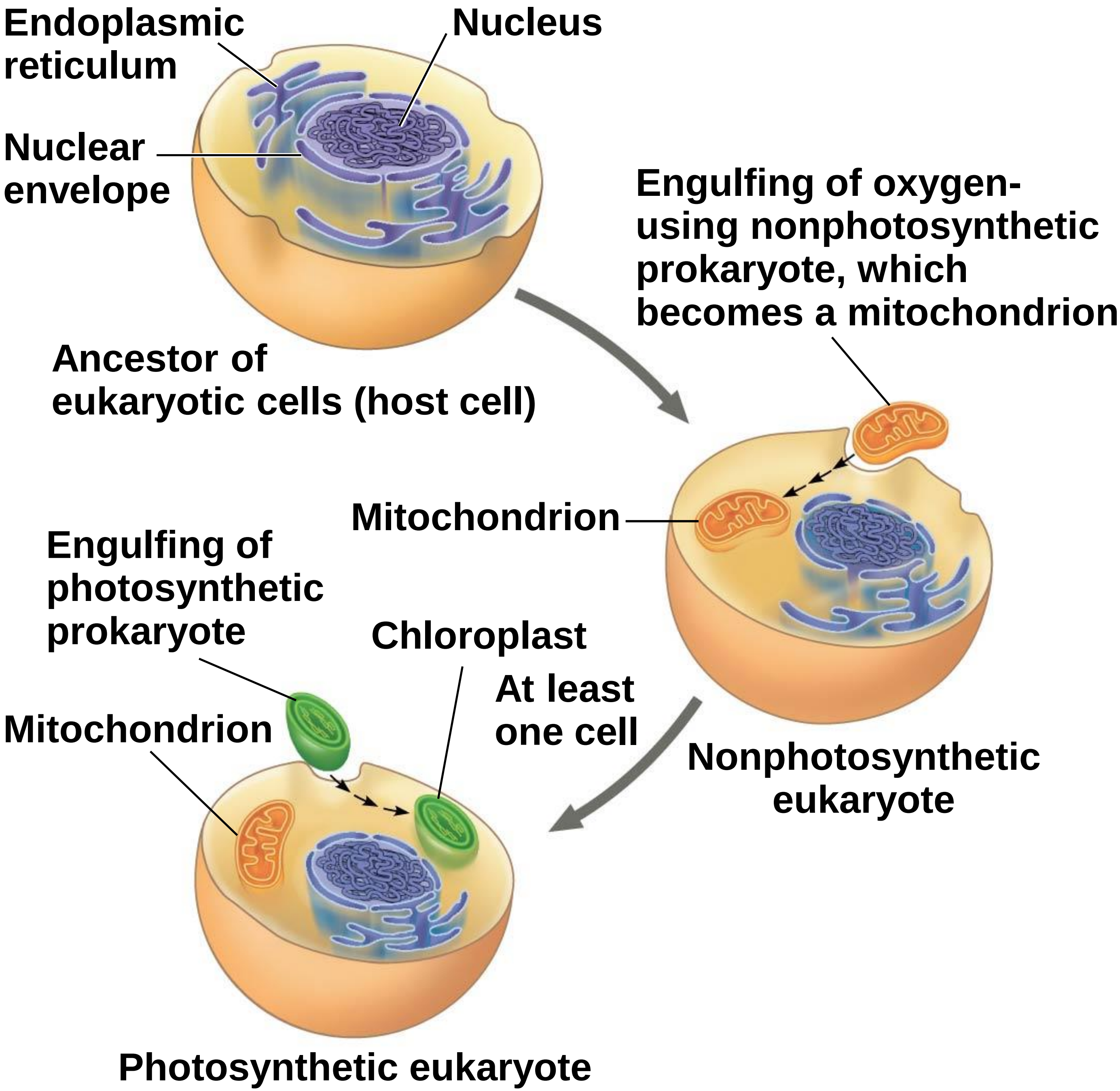
- **Mitochondria** are the sites of cellular respiration, a metabolic process that uses oxygen to generate ATP
- **Chloroplasts**, found in plants and algae, are the sites of photosynthesis
- Peroxisomes are oxidative organelles

The Evolutionary Origins of Mitochondria and Chloroplasts

- Mitochondria and chloroplasts have similarities with bacteria:
  - Enveloped by a double membrane
  - Contain free ribosomes and circular DNA molecules
  - Grow and reproduce somewhat independently in cells
- These similarities led to the **endosymbiont theory**

- The endosymbiont theory suggests that an early ancestor of eukaryotes engulfed an oxygen-using nonphotosynthetic prokaryotic cell
- The engulfed cell formed a relationship with the host cell, becoming an endosymbiont
- The endosymbionts evolved into mitochondria
- At least one of these cells may have then taken up a photosynthetic prokaryote, which evolved into a chloroplast

Figure 7.16

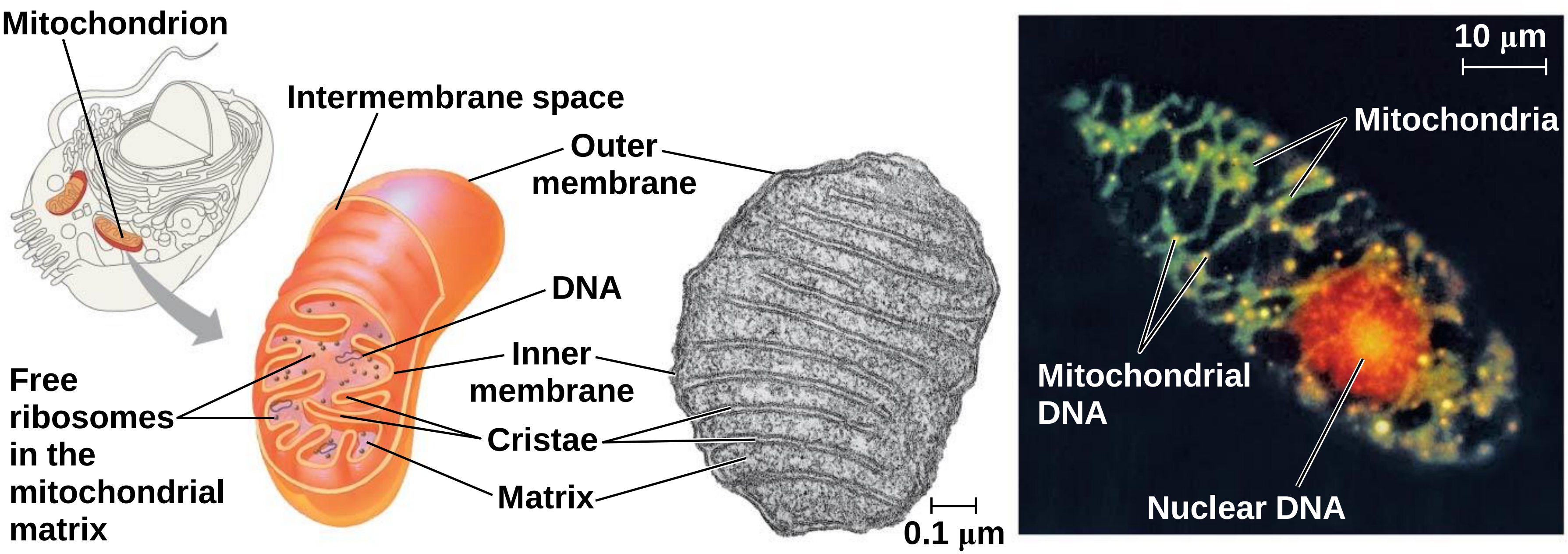


Endoplasmic reticulum
Nucleus
Nuclear envelope
Ancestor of eukaryotic cells (host cell)
Engulfing of oxygen-using nonphotosynthetic prokaryote, which becomes a mitochondrion
Mitochondrion
Nonphotosynthetic eukaryote
Engulfing of photosynthetic prokaryote
Chloroplast
At least one cell
Mitochondrion
Photosynthetic eukaryote

Mitochondria: Chemical Energy Conversion

- Mitochondria are found in nearly all eukaryotic cells
- They have a smooth outer membrane and an inner membrane folded into **cristae**
- The inner membrane creates two compartments: intermembrane space and **mitochondrial matrix**
- Some metabolic steps of cellular respiration are catalyzed in the mitochondrial matrix
- Cristae present a large surface area for enzymes that synthesize ATP

Figure 7.17



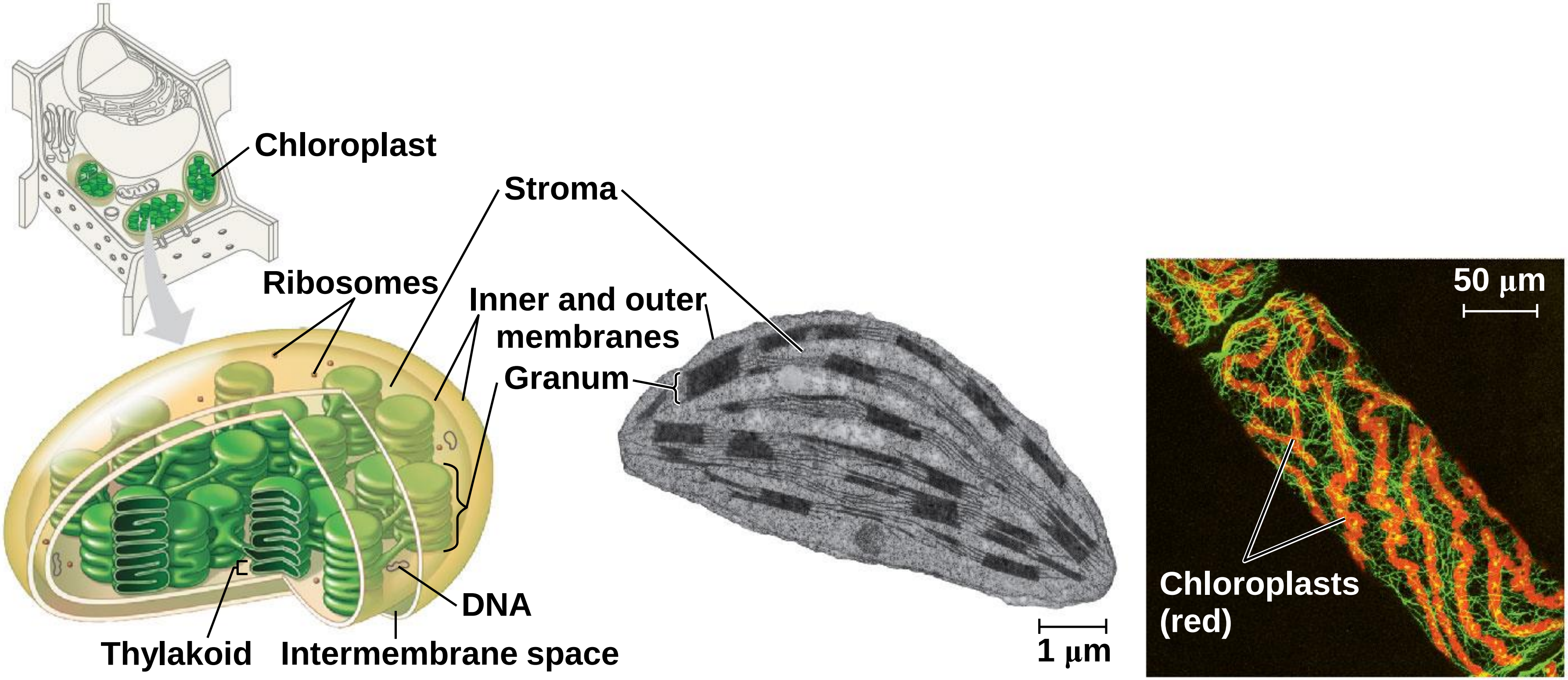
(a) Diagram and TEM of mitochondrion

(b) Network of mitochondria in *Euglena* (LM)

Chloroplasts: Capture of Light Energy

- Chloroplasts contain the green pigment chlorophyll, as well as enzymes and other molecules that function in photosynthesis
- Chloroplasts are found in leaves and other green organs of plants and in algae

Figure 7.18



(a) Diagram and TEM of chloroplast

(b) Chloroplasts in an algal cell