
# Chapter 7

# Cell Structure and Function

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

# he 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

## oncept 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

# licroscopy

- 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 7.2a

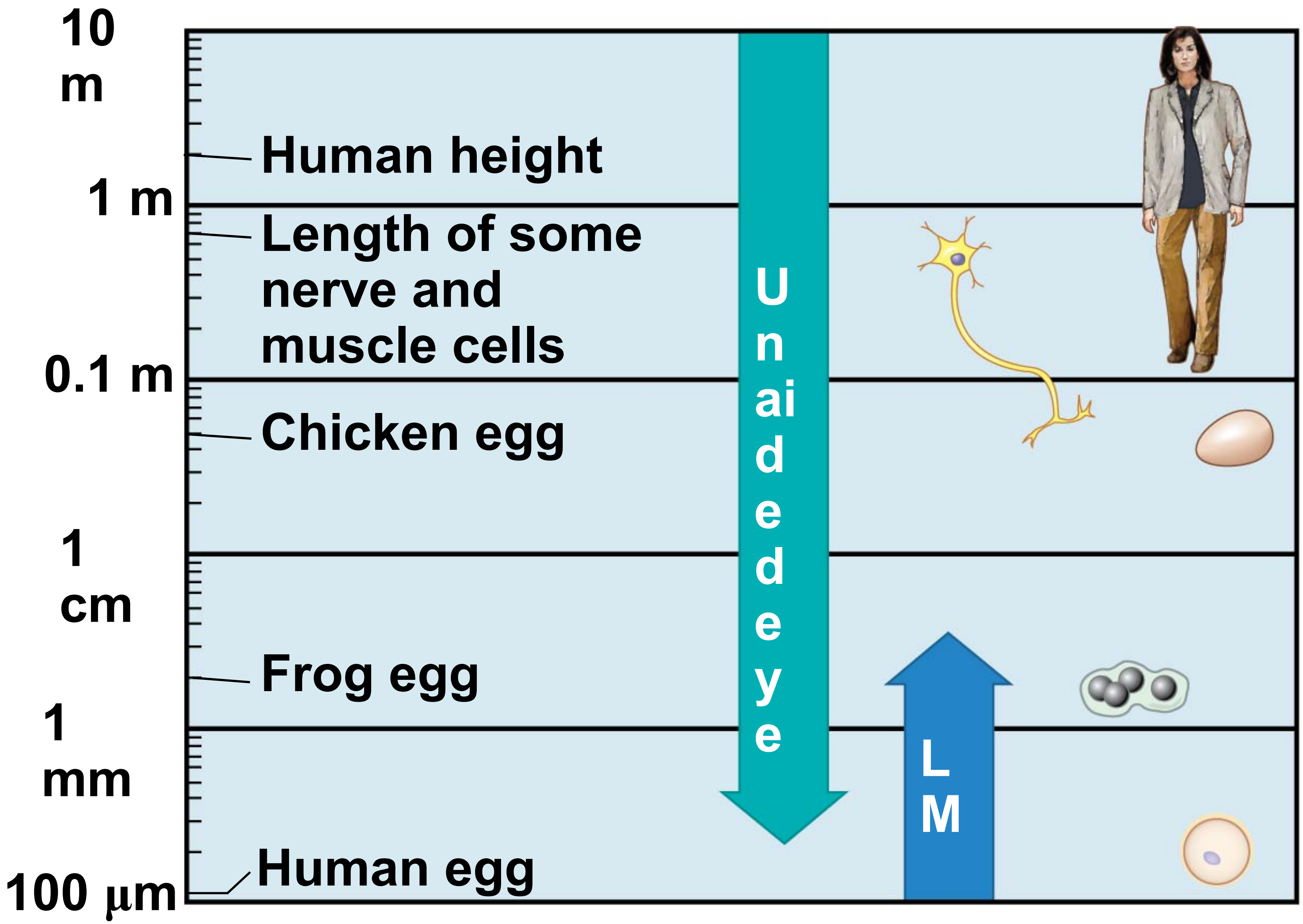

10 m
1 m
0.1 m
1 cm
1 mm
100 μm
Human height
Length of some nerve and muscle cells
Chicken egg
Frog egg
Human egg
Unaided eye
LM

Figure 7.2b

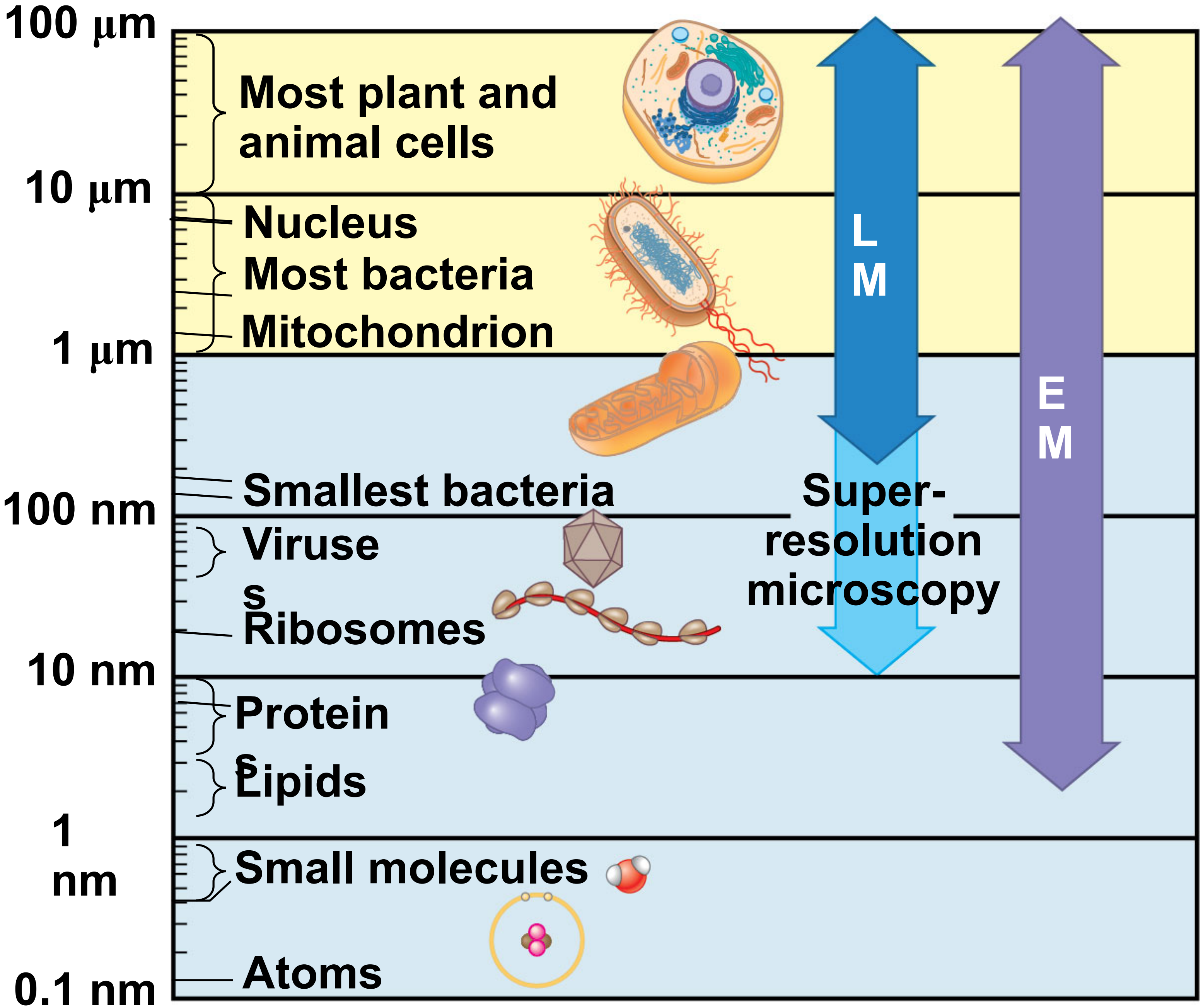
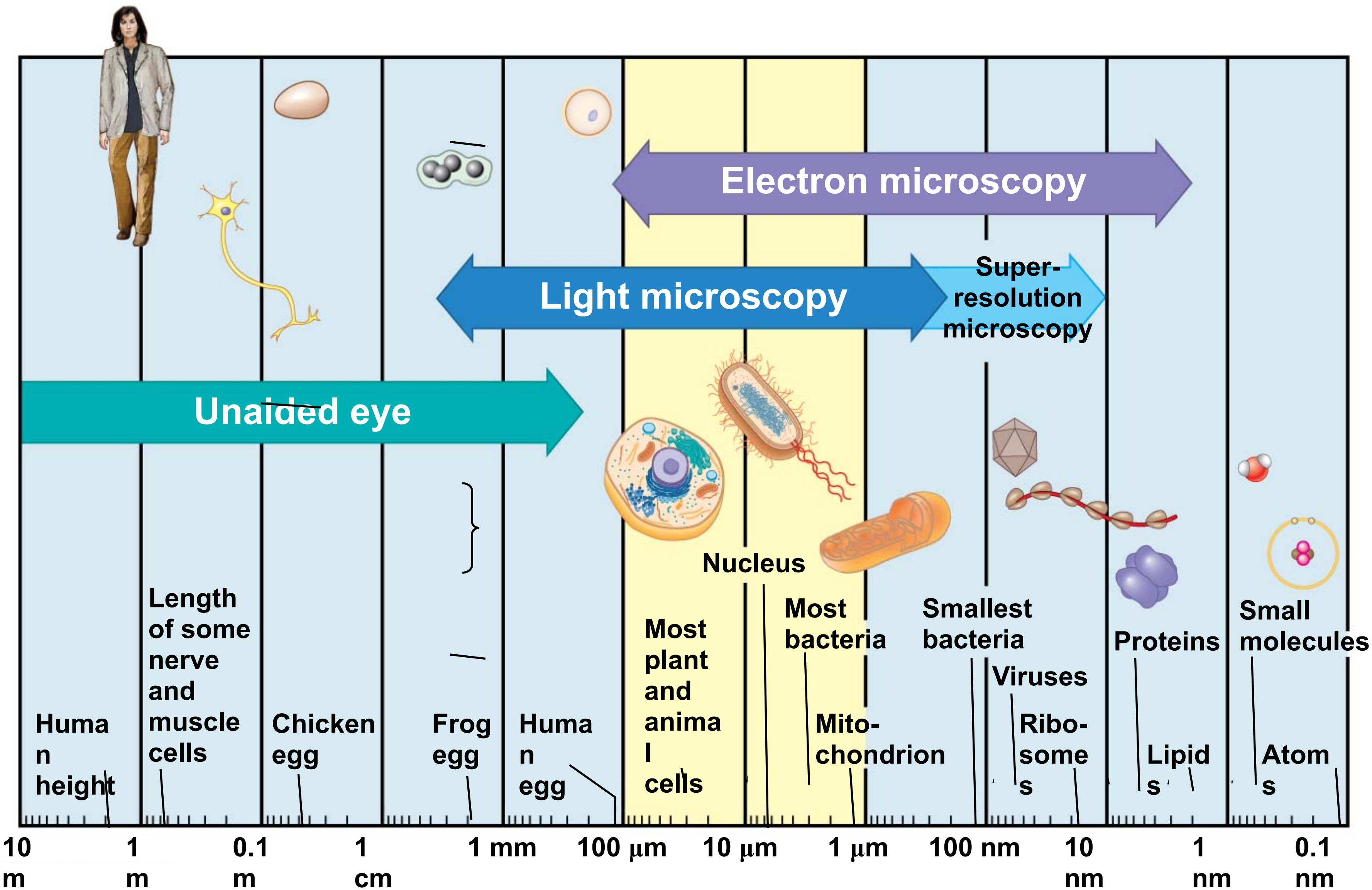
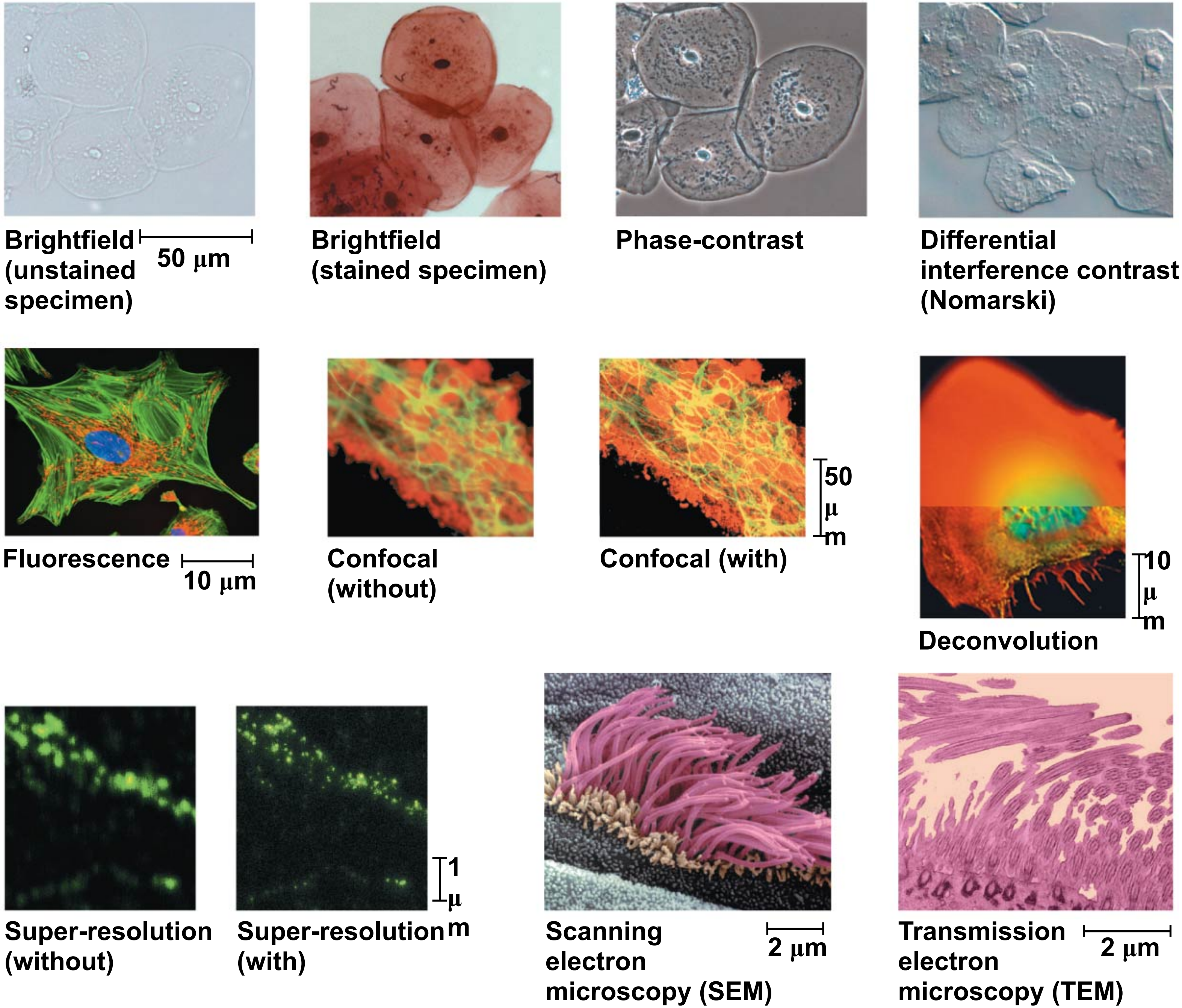

100 µm
Most plant and animal cells
10 µm
Nucleus
Most bacteria
Mitochondrion
1 µm
Smallest bacteria
100 nm
Viruses
Ribosomes
10 nm
Proteins
Lipids
1 nm
Small molecules
Atoms
0.1 nm
LM
EM
Super-resolution microscopy

Figure 7.2c


Electron microscopy
Light microscopy
Super-
resolution
microscopy
Unaided eye
Nucleus
Length
of some
nerve
and
muscle
cells
Most
plant
and
anima
l
cells
Most
bacteria
Smallest
bacteria
Viruses
Proteins
Small
molecules
Huma
n
height
Chicken
egg
Frog
egg
Huma
n
egg
Mito-
chondrion
Ribo-
some
s
Lipid
s
Atom
s
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

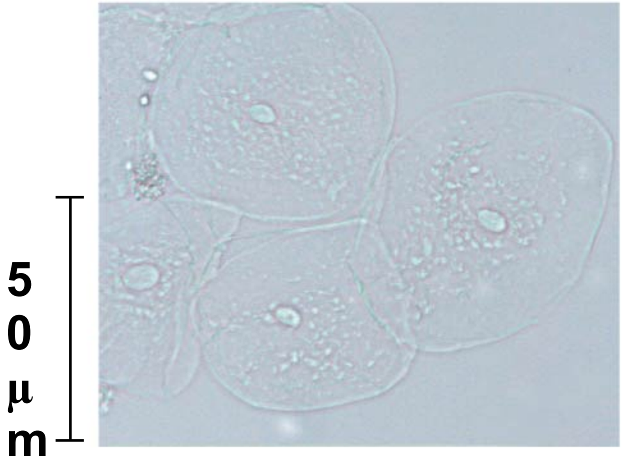
- Light microscopes can magnify effectively to about 1,000 times the size of the actual specimen
- Various techniques enhance contrast and enable cell components to be stained or labeled
- The resolution of standard light microscopy is too low to study **organelles**, the membrane-enclosed structures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

Figure 7.3

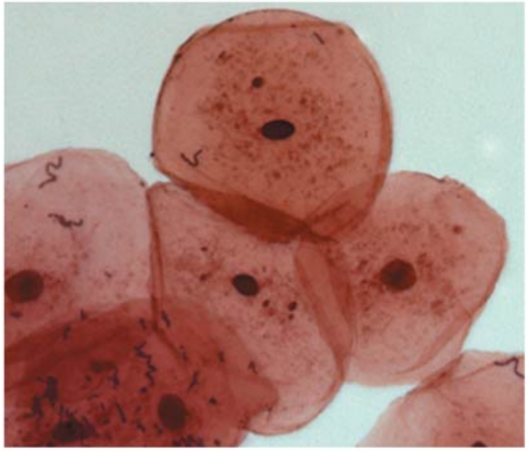


Brightfield (unstained specimen)
50 µm
Brightfield (stained specimen)
Phase-contrast
Differential interference contrast (Nomarski)
Fluorescence
10 µm
Confocal (without)
Confocal (with)
50 µm
Deconvolution
10 µm
Super-resolution (without)
Super-resolution (with)
1 µm
Scanning electron microscopy (SEM)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

# Light Microscopy (LM)

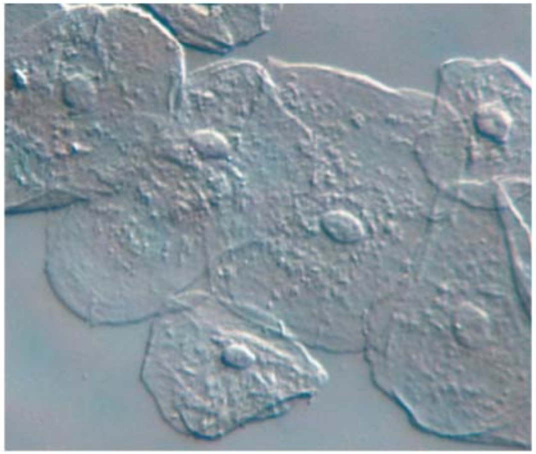



**Brightfield (unstained specimen)**



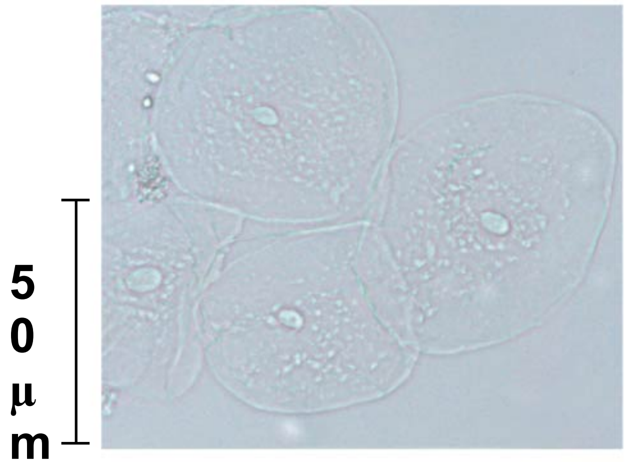
**Brightfield (stained specimen)**

**Phase-contrast**



**Differential interference contrast (Nomarski)**

Figure 7.3aa

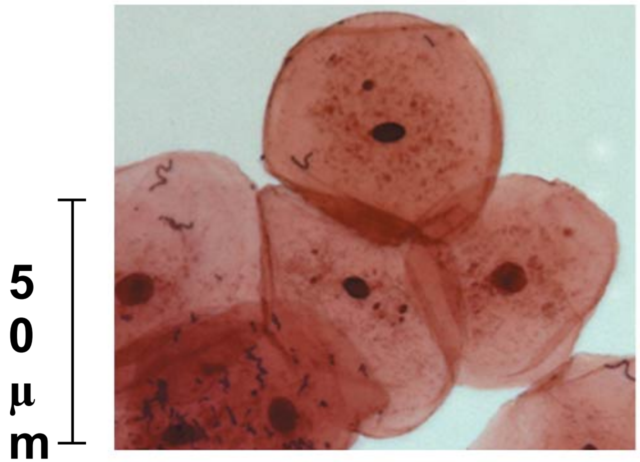



**Brightfield (unstained specimen)**

Light passes directly — unstained

⇒ low contrast.

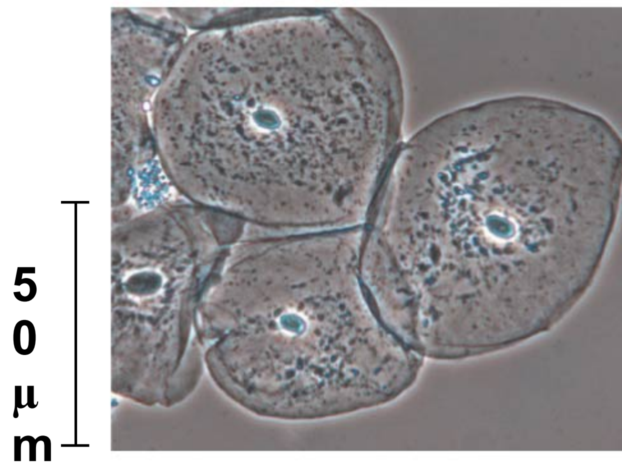
Figure 7.3ab




**Brightfield**
**(stained specimen)**

Light pass directly — stained

High contrast.




**Phase-contrast**

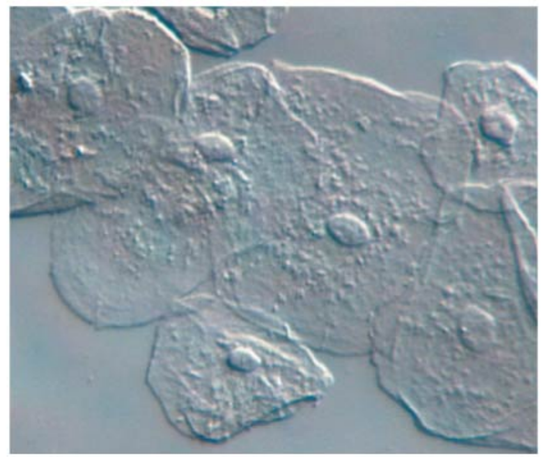
observing living cells.

Enhancing contrast without staining

— according to density variation.

Figure 7.3ad

50 µm

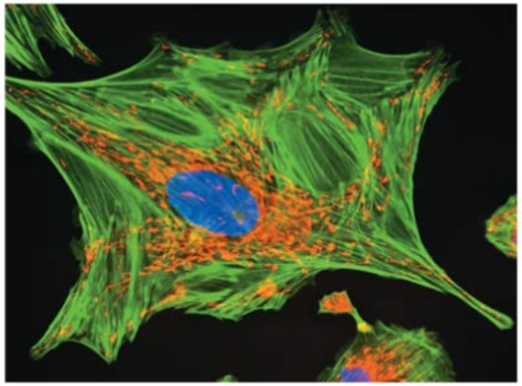


**Differential interference contrast (Nomarski)**

Optical modifications are used to exaggerate density difference — 3D image (almost appears so).

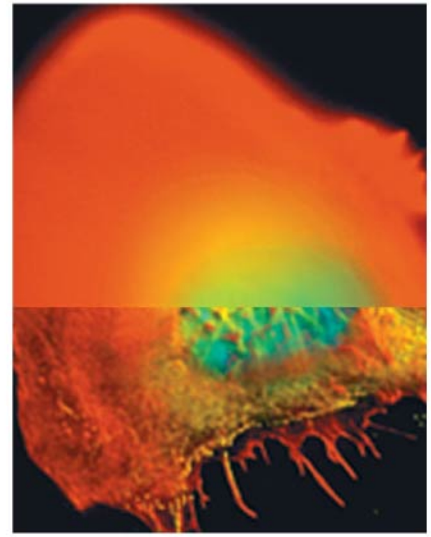
Figure 7.3b

# Light Microscopy (LM)



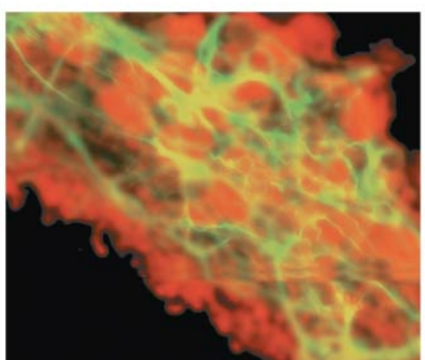
Fluorescence

10 μm

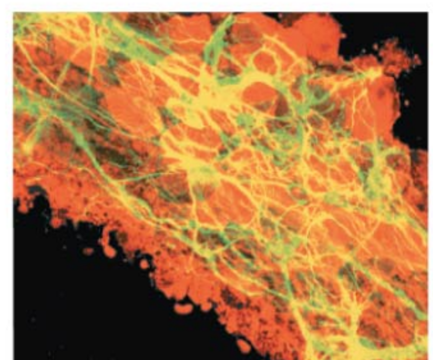


10 μm

Deconvolution



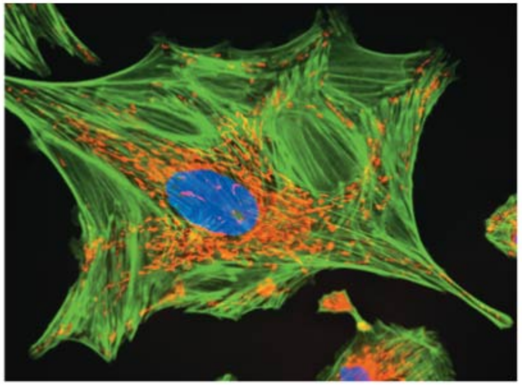
Confocal (without)



50 μm

Confocal (with)

Figure 7.3ba

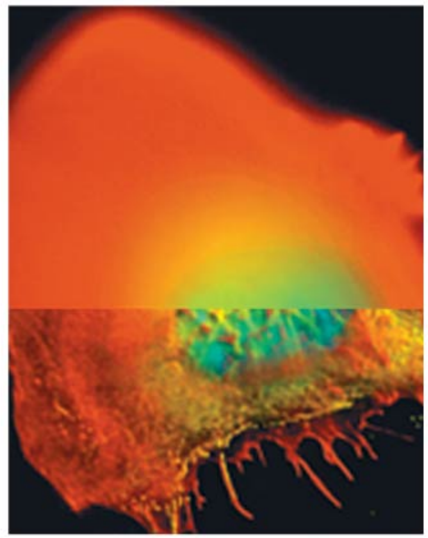


**Fluorescence** 10 µm

Labeling specific molecules with fluorescent dyes → absorb UV and emit visible light.

NO

Yes

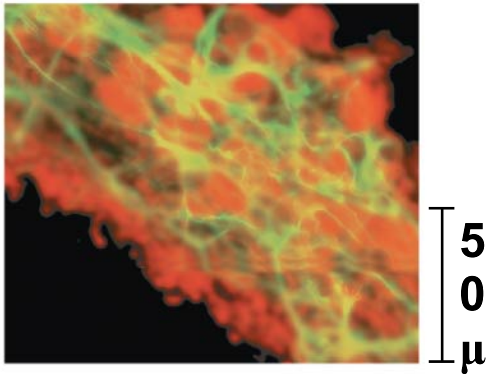


10 μm

Deconvolution

Digitally removes out-of-focus light and directs it to its source creating sharper an image — top is fluorescent micrographs of the same cell.

Figure 7.3bc

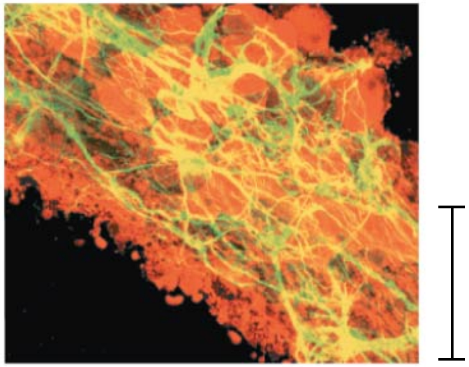



Confocal (without)

Standard fluorescence micrograph

→ out-of-focus light not excluded.

Figure 7.3bd

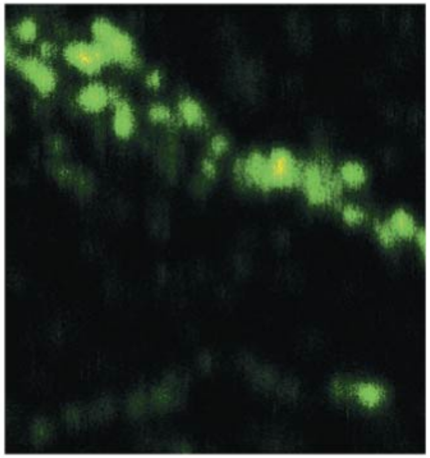



Confocal (with)

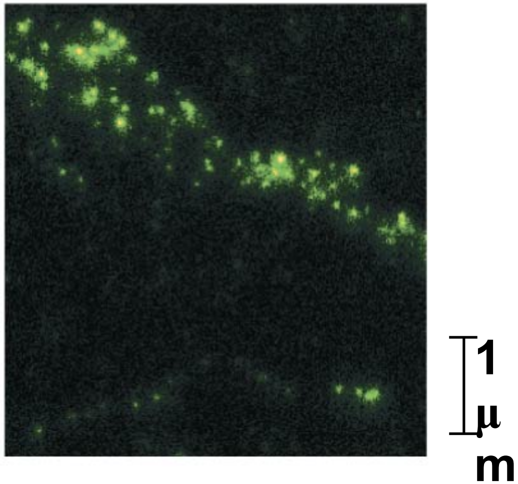
Fluorescence micrography where laser is used to create a single plane of fluorescence and out-of-focus light from other planes is emitted.

Figure 7.3c

## Light Microscopy (LM)

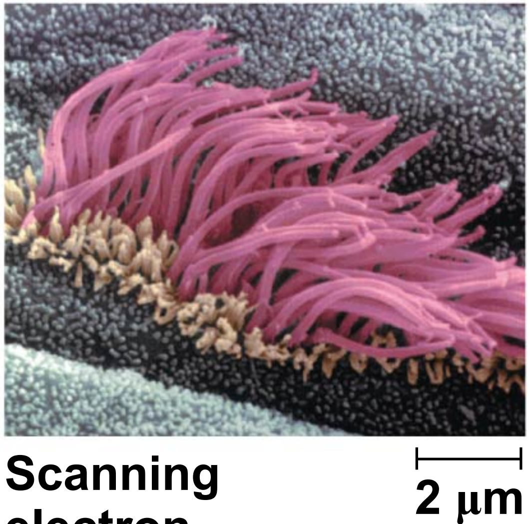


Super-resolution (without)

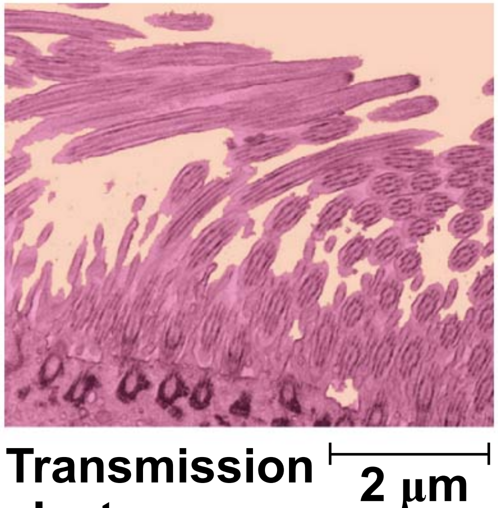



Super-resolution (with)

## Electron Microscopy (EM)

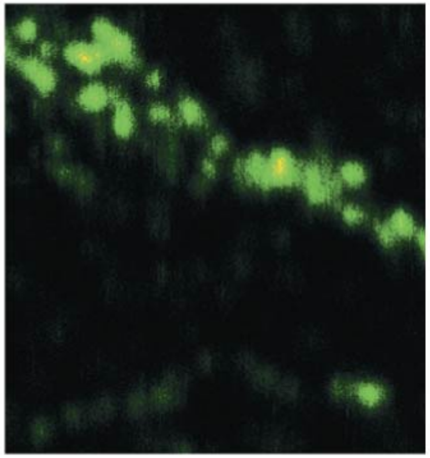



Scanning electron microscopy (SEM)




Transmission electron microscopy (TEM)

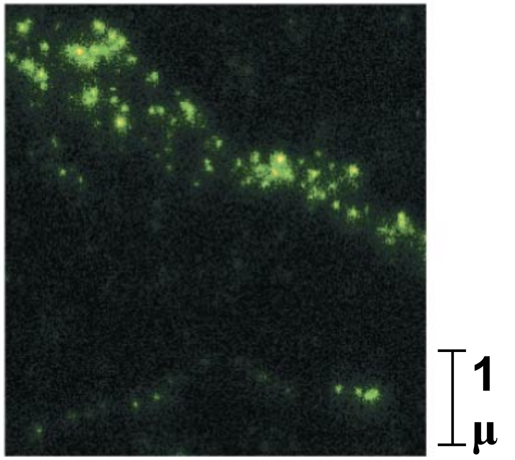
Figure 7.3ca




**Super-resolution (without)**

Standard LM — 200 nm limited.

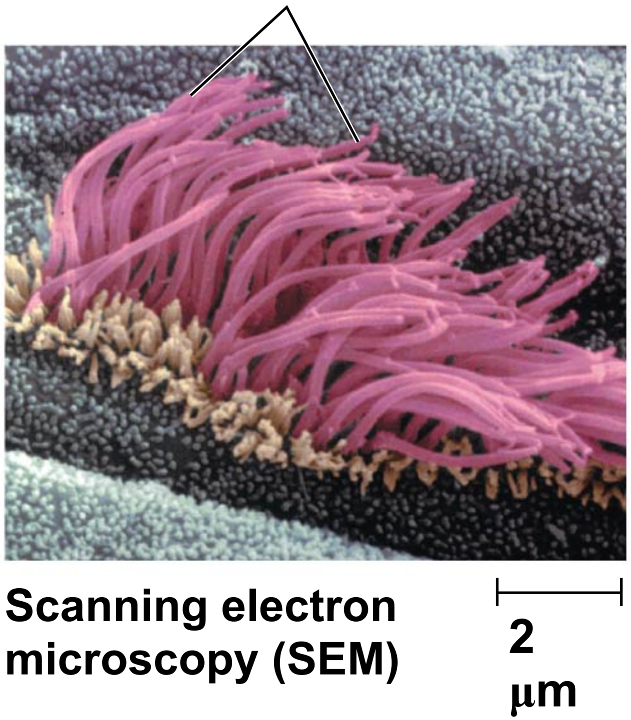
Figure 7.3cb




**Super-resolution (with)**

Individual fluorescent molecules excited and their positions recorded.
Combining info. from different molecules break the resolution barrier.

Figure 7.3cc




**Scanning electron microscopy (SEM)**

SEM's focus on the surfaces.

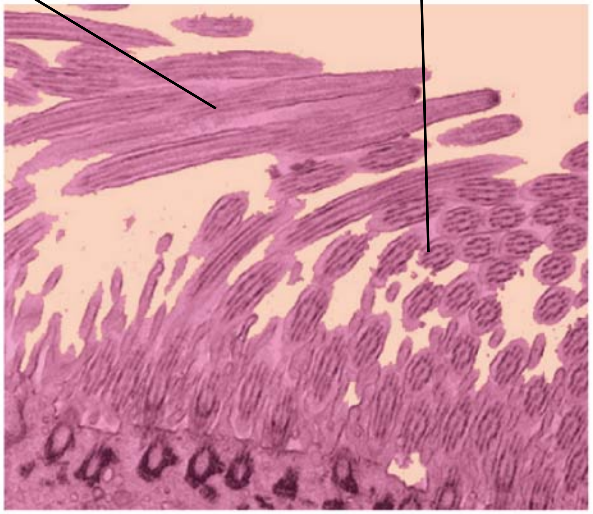
Both I & S Electron micrographs are usually B & W but artificially colored.

Figure 7.3cd

Cut in preparing the specimen.

Longitudinal section of cilium

Cross section of cilium



Transmission electron microscopy (TEM)

2 µm

(TEM)

Shows a section of the specimen, revealing its internal structure.

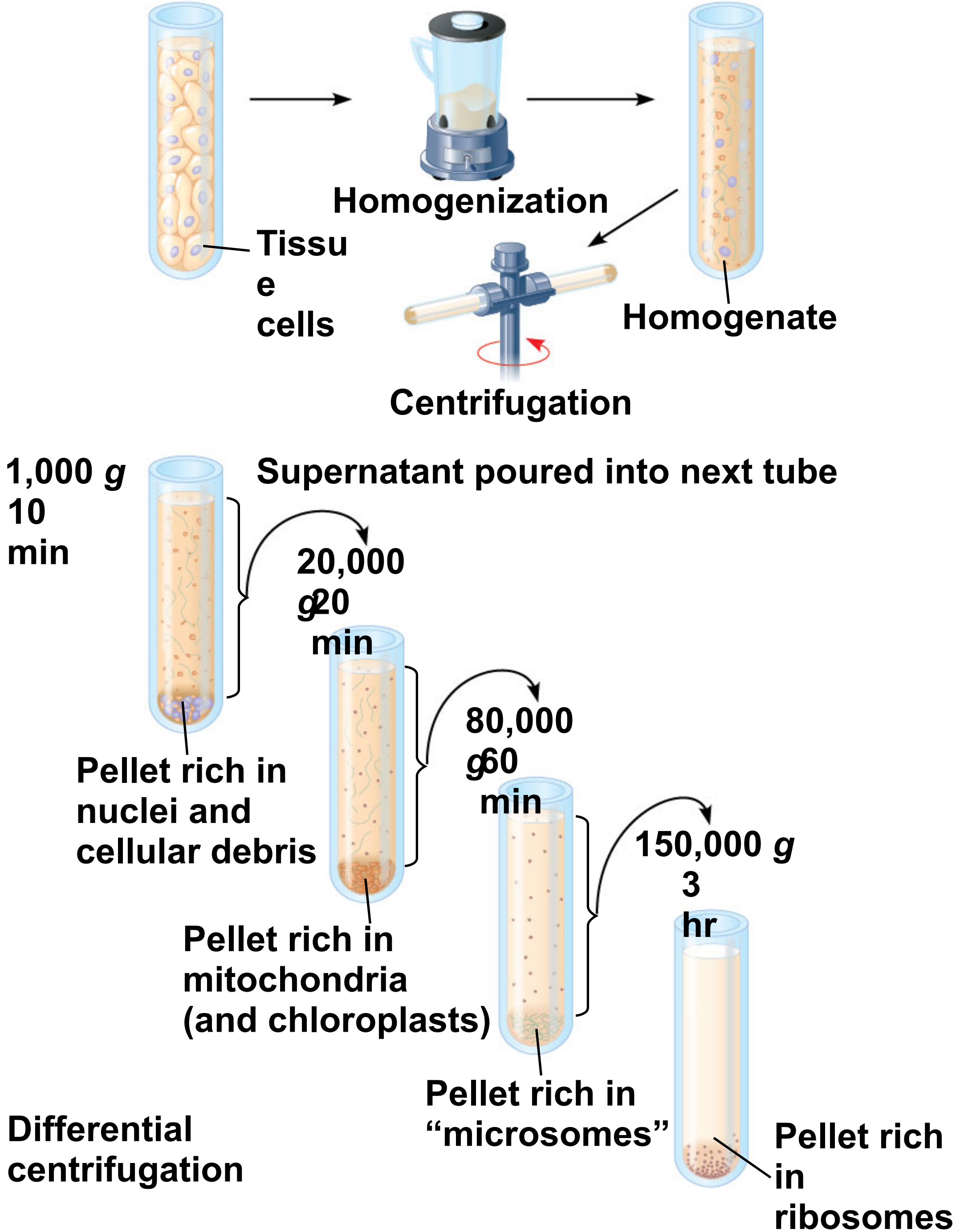
- Two basic types of **electron microscopes (EMs)** are used to study subcellular structures
- **Scanning electron microscopes (SEMs)** focus a beam of electrons onto the surface of a specimen, providing images that look 3-D
- **Transmission electron microscopes (TEMs)** focus a beam of electrons through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

# ell 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
Tissu
e
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

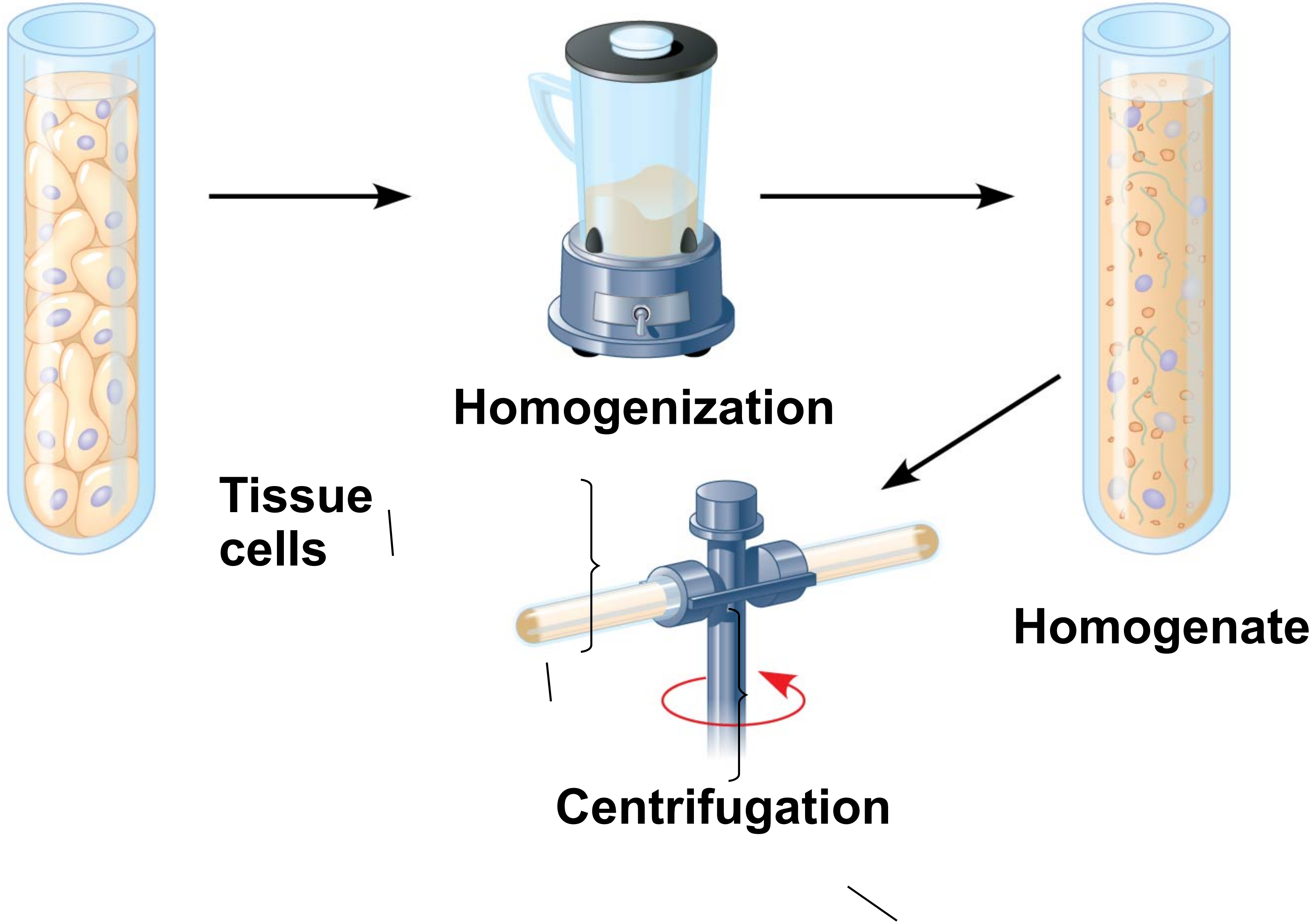
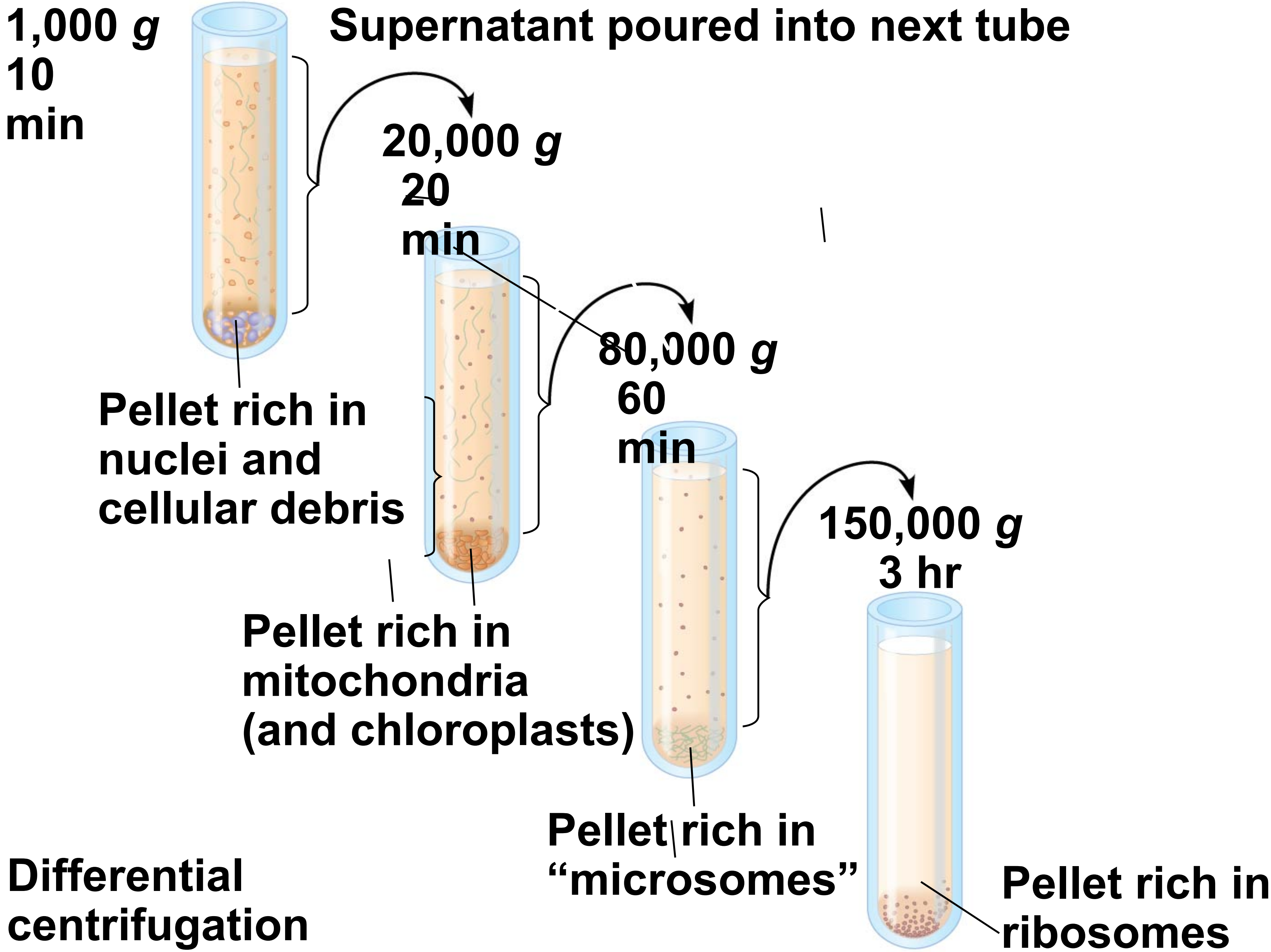


Figure 7.4b



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

Notes on 7.1 :

* standard LM's can't resolve detail finer than 0.2 μm or 200 nm

* In TEM's, specimen are stained with atoms of heavy metals to create density difference in some areas.

* Electromagnets replace lenses in the case of Electron microscopy (both SEM & TEM).

* A disadvantage of EM's is that electrons can kill specimen or introduce artifacts — small structures that do not exist in reality

* Super-resolution microscopy broke the resolution barrier — 200 nm — reaching 10 to 20 nm across.

* cryo-EM preserves specimen at extremely low temperatures avoiding the use of preservatives

* cryo-EM complement X-ray crystallography revealing objects as ribosomes.

* Microscopes are the most important tools of cytology — the study of cellular structure.

* Biochemistry is the study of chemical processes of cells (metabolism).

## oncept 7.2: Eukaryotic cells have internal membranes that compartmentalize their functions

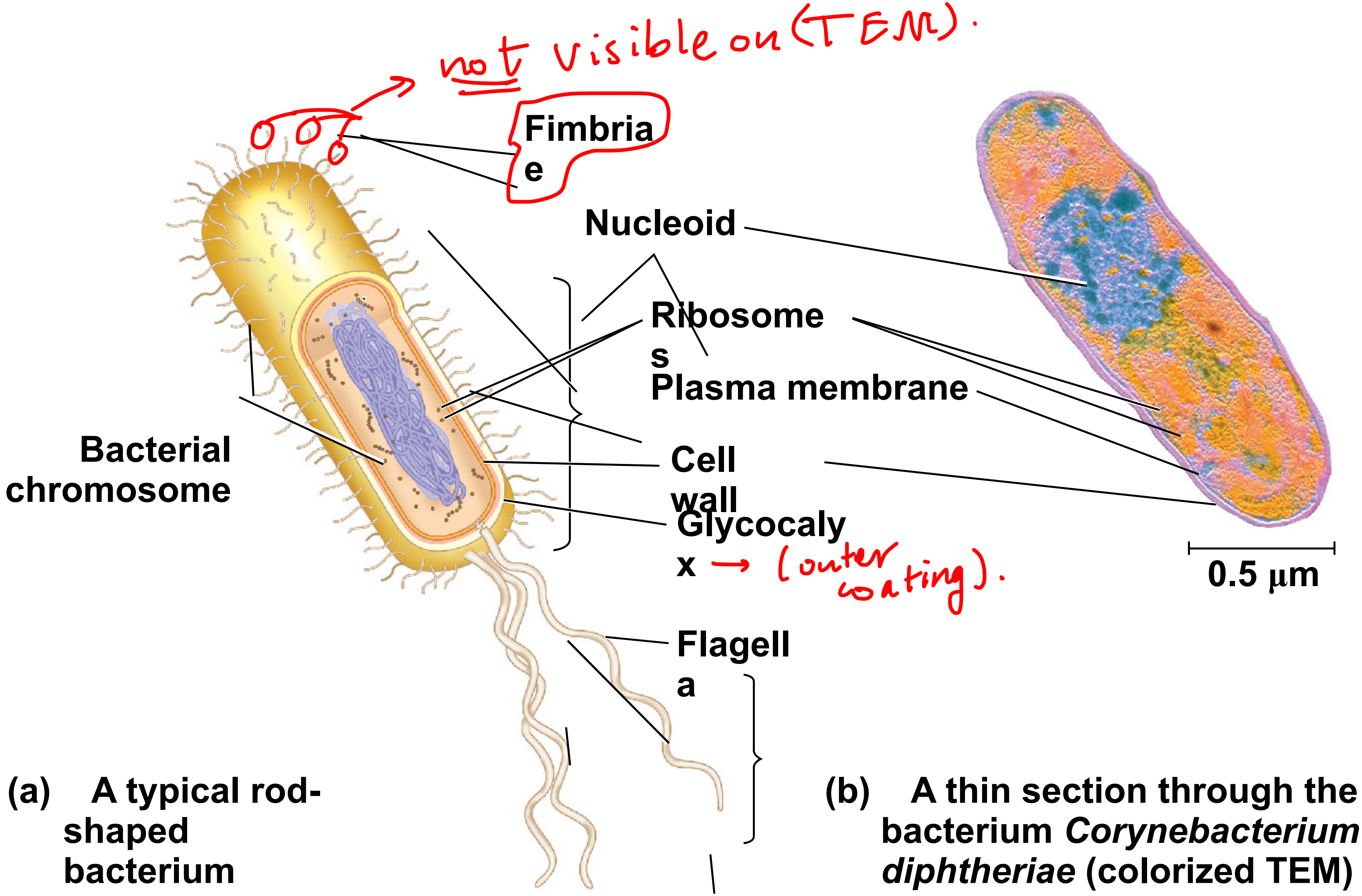
- The basic structural and functional unit of every organism is one of two types of cells: prokaryotic or eukaryotic
- Only organisms of the domains Bacteria and Archaea consist of prokaryotic cells
- Protists, fungi, animals, and plants all consist of eukaryotic cells

# omparing Prokaryotic and Eukaryotic Cells

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

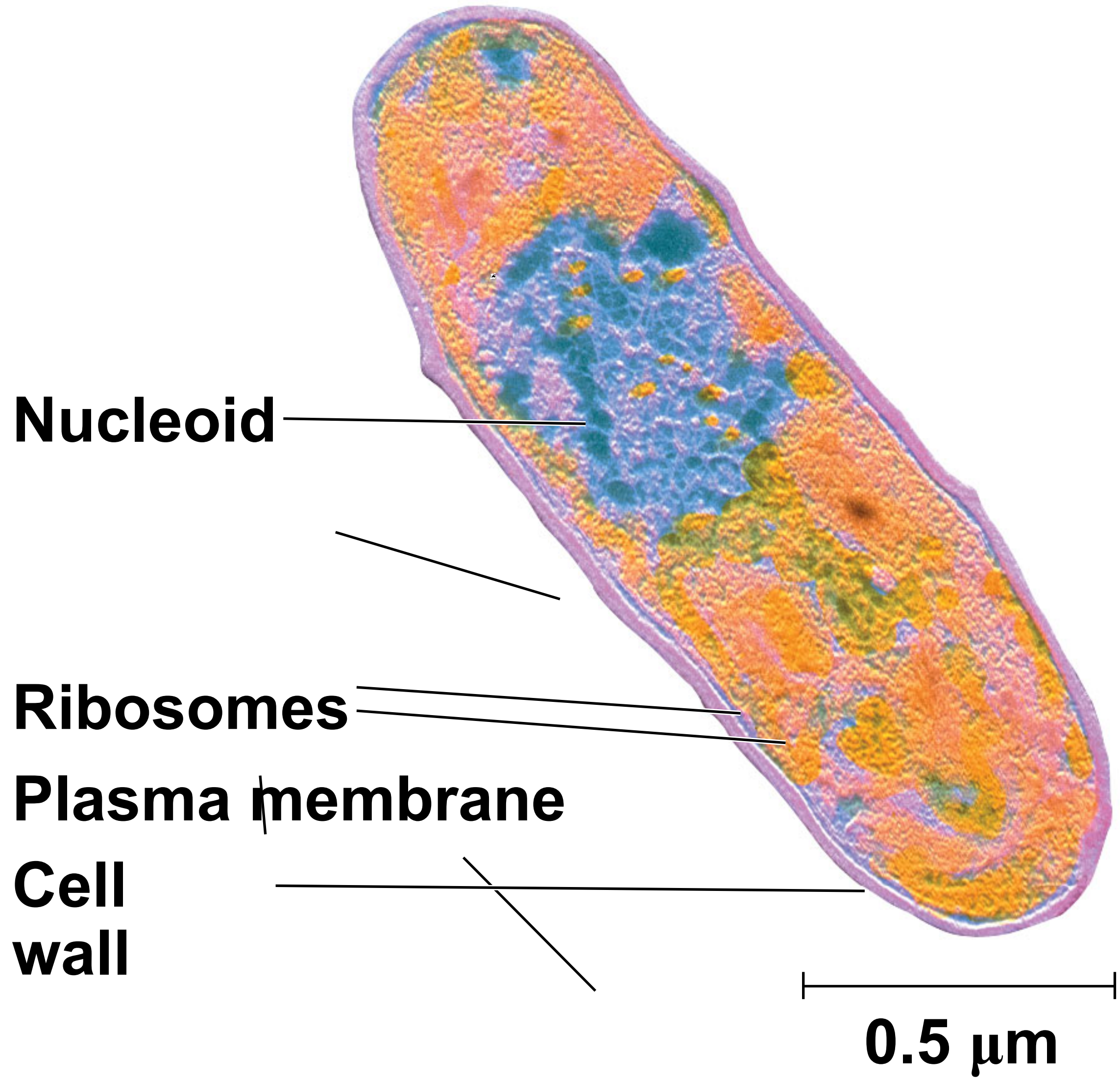
- **Prokaryotic cells** are characterized by having
  - No nucleus
  - DNA in an unbound region called the **nucleoid**
  - No membrane-bound organelles
  - **Cytoplasm** bound by the plasma membrane

Figure 7.5




(a) A typical rod-shaped bacterium

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

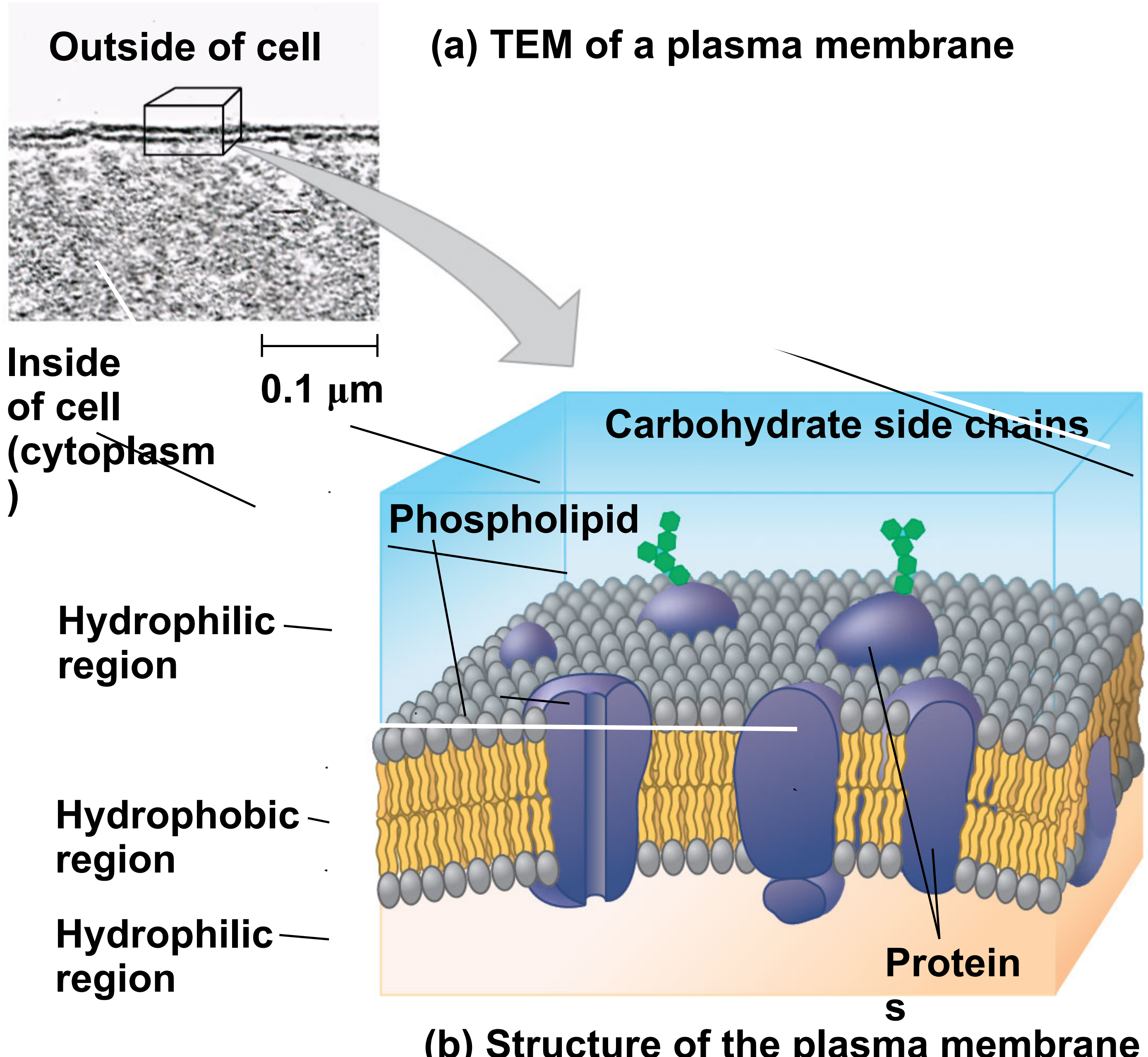



**(b) A thin section through the bacterium *Corynebacterium diphtheriae* (colorized TEM)**

- **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

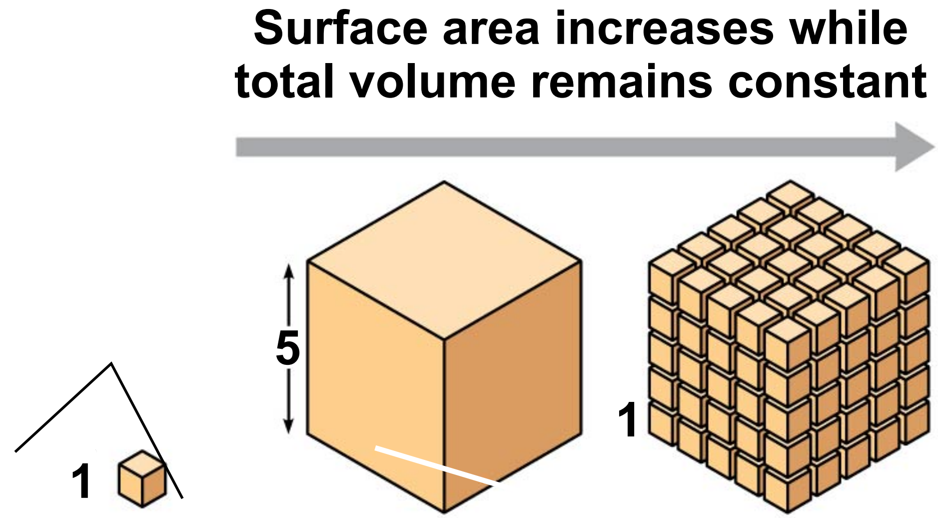
Figure 7.6



Outside of cell
Inside of cell (cytoplasm)
0.1 µm
(a) TEM of a plasma membrane
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

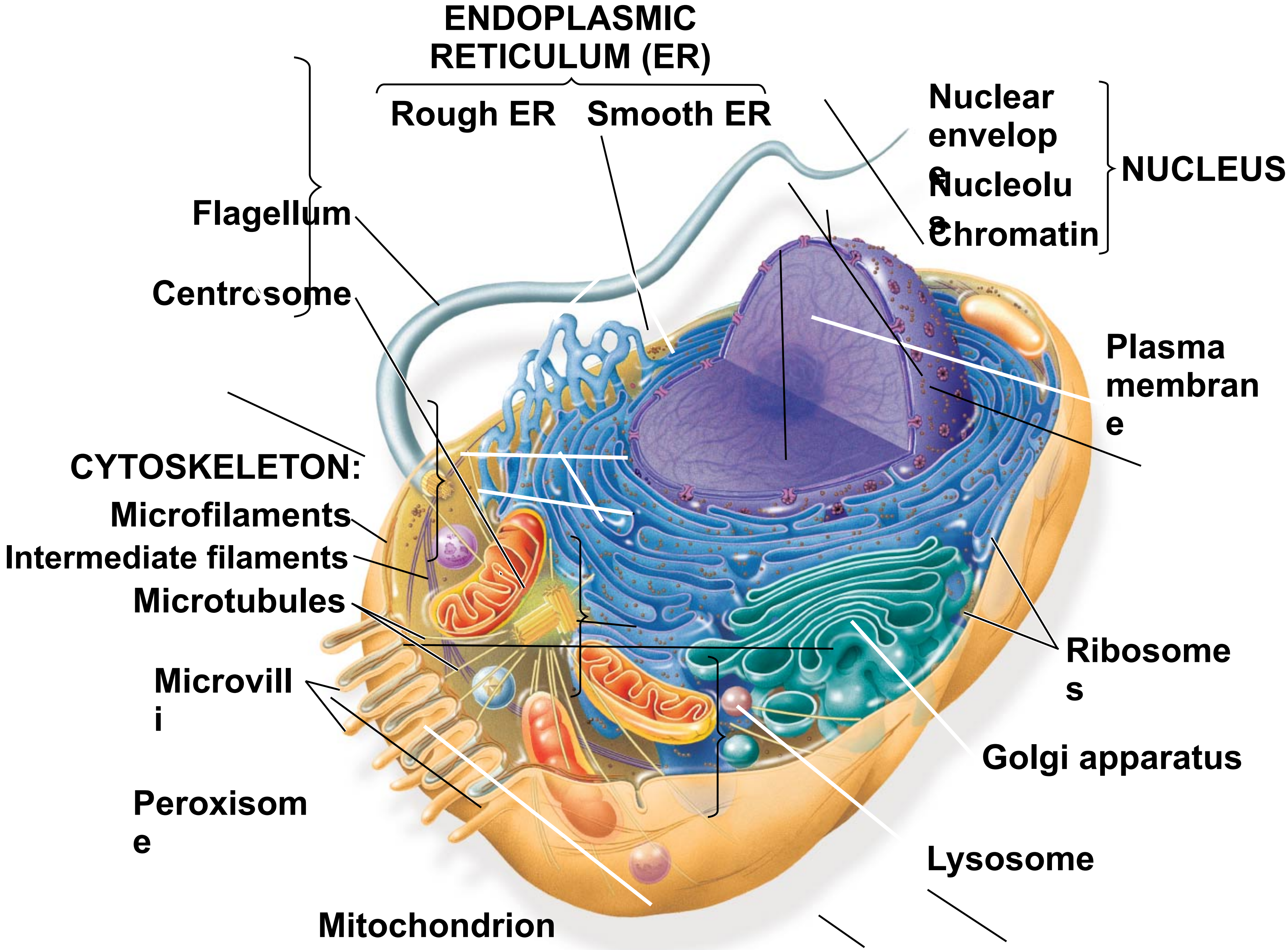



| | | | |
|---|---|---|---|
| **Total surface area [sum of the surface areas (height × width) of all box sides × number of boxes]** | **6** | **15<br>0** | **75<br>0** |
| **Total volume [height × width × length × number of boxes]** | **1** | **12<br>5** | **12<br>5** |
| **Surface-to-volume (S-to-V) ratio [surface area ÷ volume]** | **6** | **1.<br>2** | **6** |

# A Panoramic View of the Eukaryotic Cell

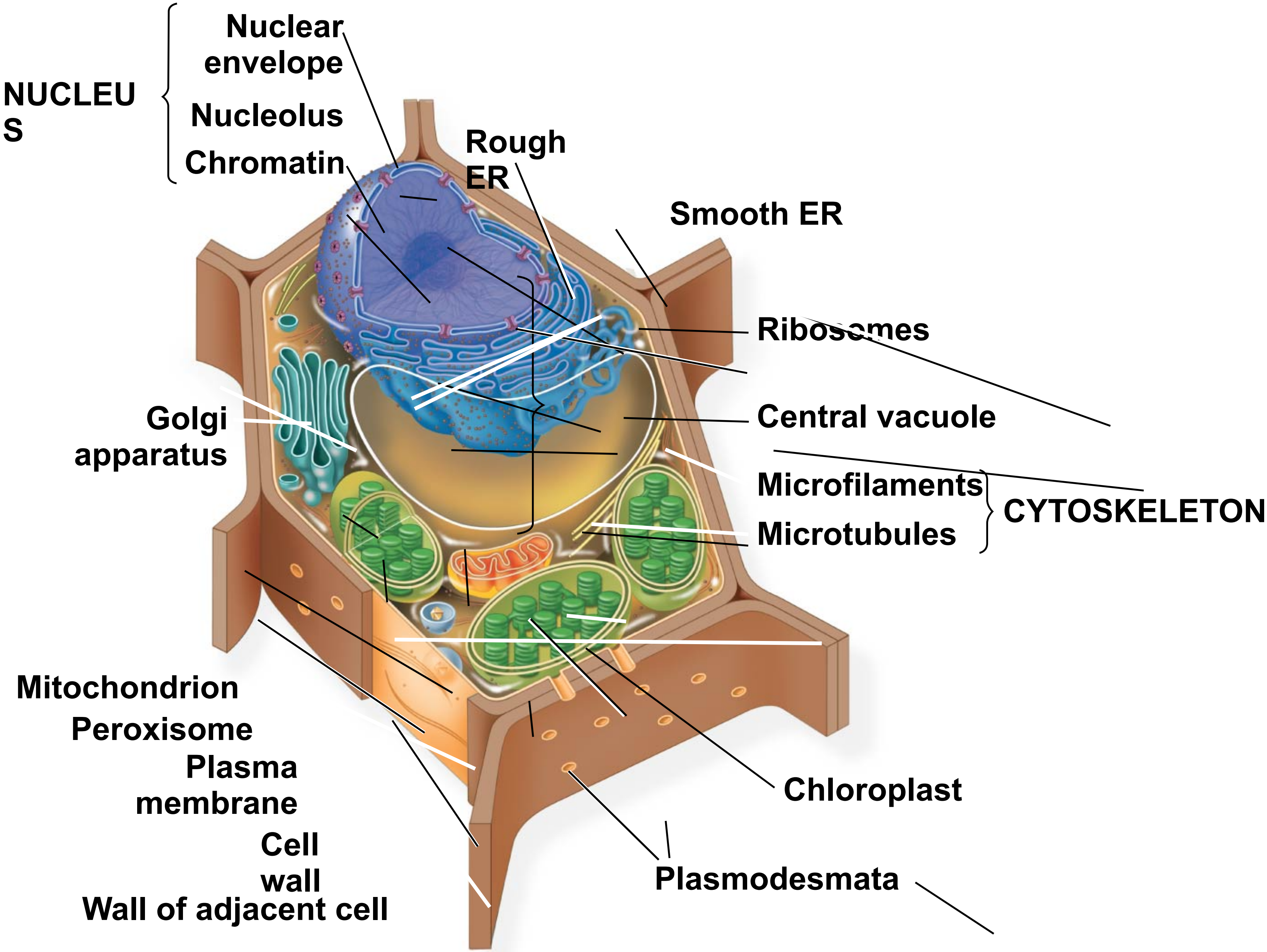
- A eukaryotic cell has internal membranes that divide the cell into compartments—the organelles
- The basic fabric of biological membranes is a double layer of phospholipids and other lipids
- Plant and animal cells have most of the same organelles

Figure 7.8a



ENDOPLASMIC
RETICULUM (ER)
Rough ER
Smooth ER
Nuclear
envelop
e
Nucleolu
s
Chromatin
NUCLEUS
Flagellum
Centrosome
Plasma
membran
e
CYTOSKELETON:
Microfilaments
Intermediate filaments
Microtubules
Microvill
i
Ribosome
s
Golgi apparatus
Peroxisom
e
Lysosome
Mitochondrion

Figure 7.8b



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

Notes on 7.2:

* Some prokaryotes contain regions surrounded by proteins where specific reactions take place

  ↳ not a phospholipid membrane

* Smallest cells known are a type of bacteria called mycoplasmas (0.1 → 1) μm Dia..

* Typical bacteria are (1 → 5) μm Dia..

* Typical eukaryotic cells are (10 → 100) μm Dia..

  common in "exchanging material" cells e.g: Intestines.

* Microvilli are cellular objections that increase surface area without an appreciable change in volume

# oncept 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

# he 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

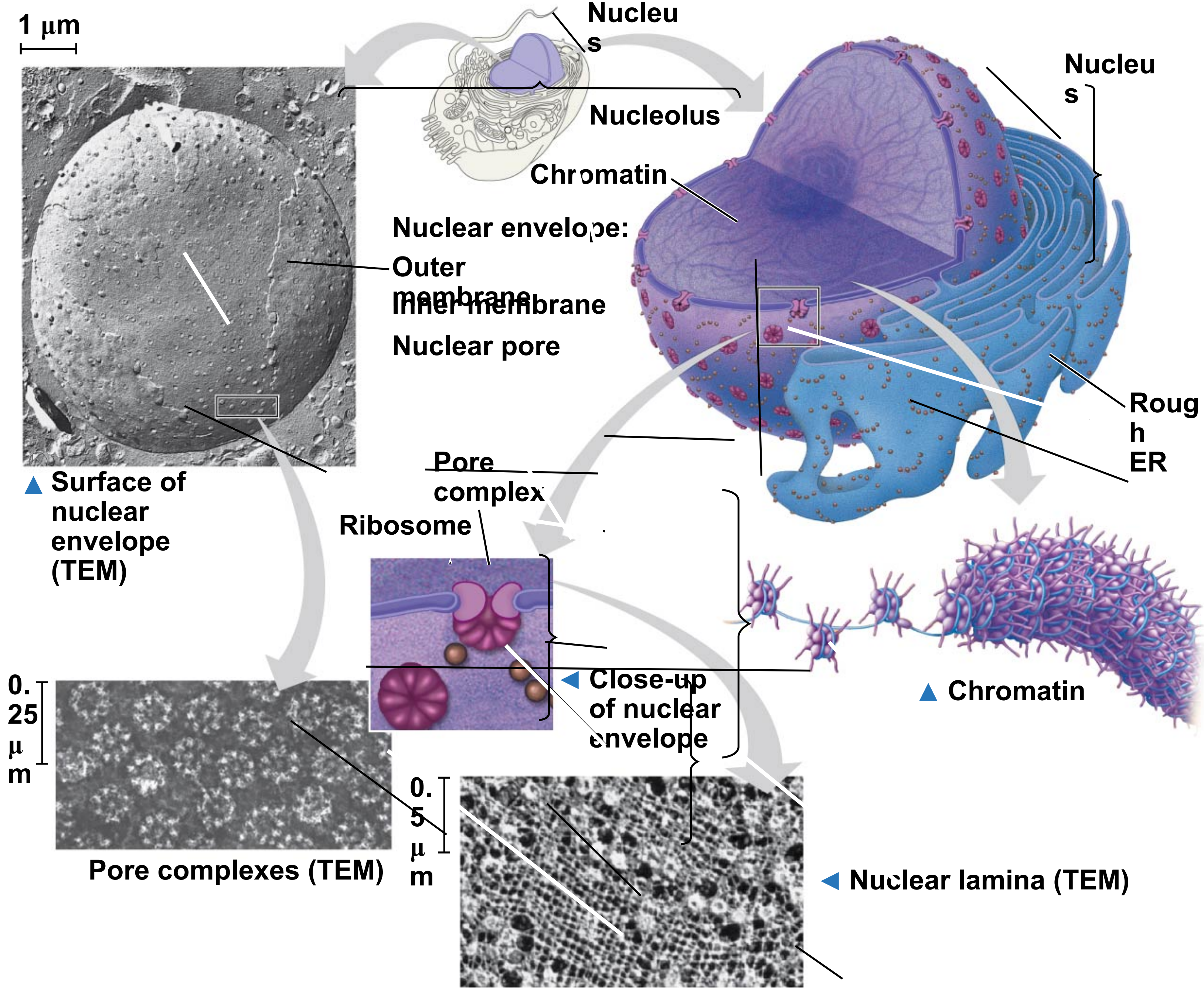

1 µm
Nucleu
s
Nucleolus
Chromatin
Nuclear envelope:
Outer
membrane
Inner membrane
Nuclear pore
Nucleu
s
Roug
h
ER
Surface of
nuclear
envelope
(TEM)
Pore
complex
Ribosome
Close-up
of nuclear
envelope
Chromatin
0.
25
µ
m
Pore complexes (TEM)
0.
5
µ
m
Nuclear lamina (TEM)

Figure 7.9a

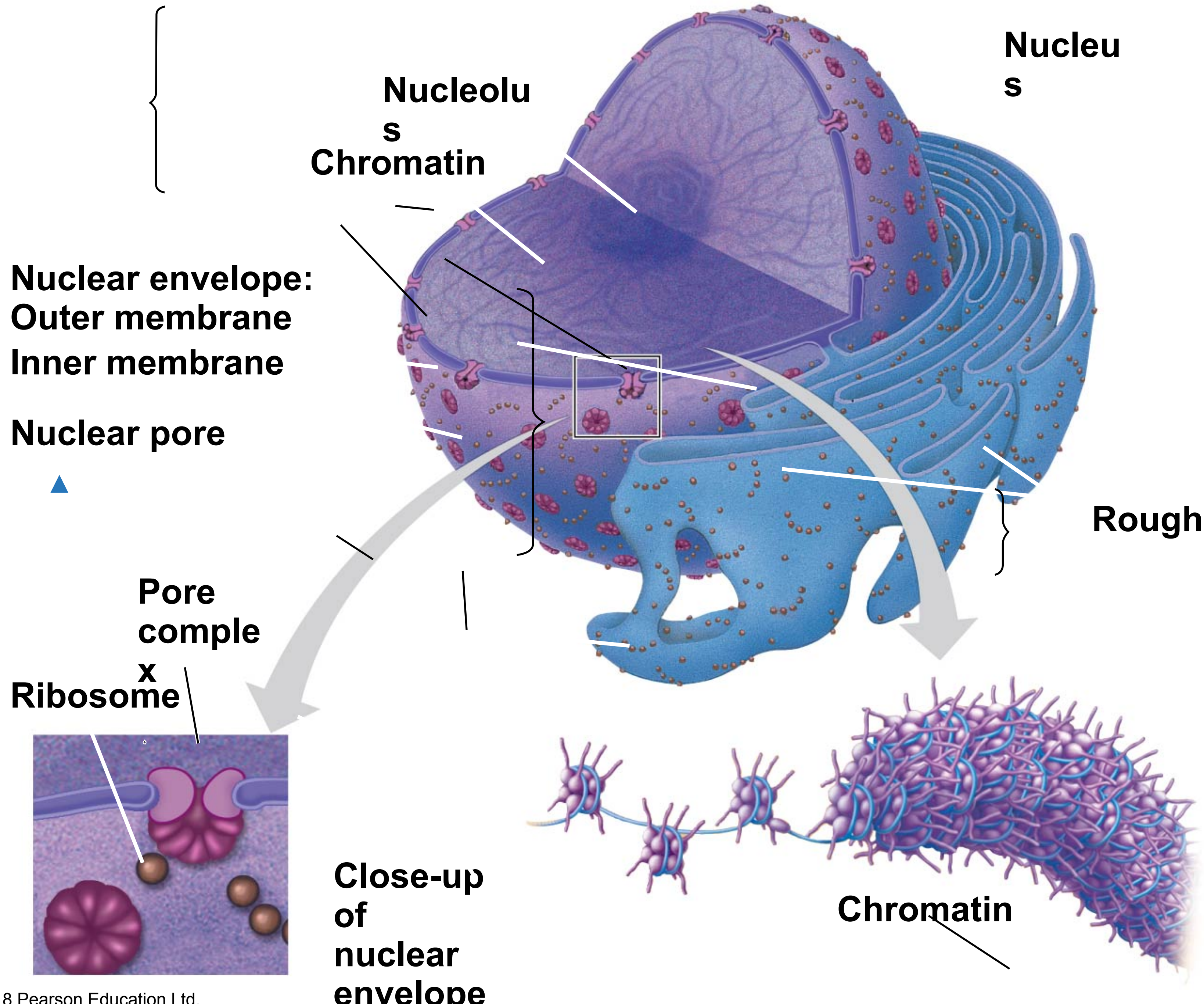
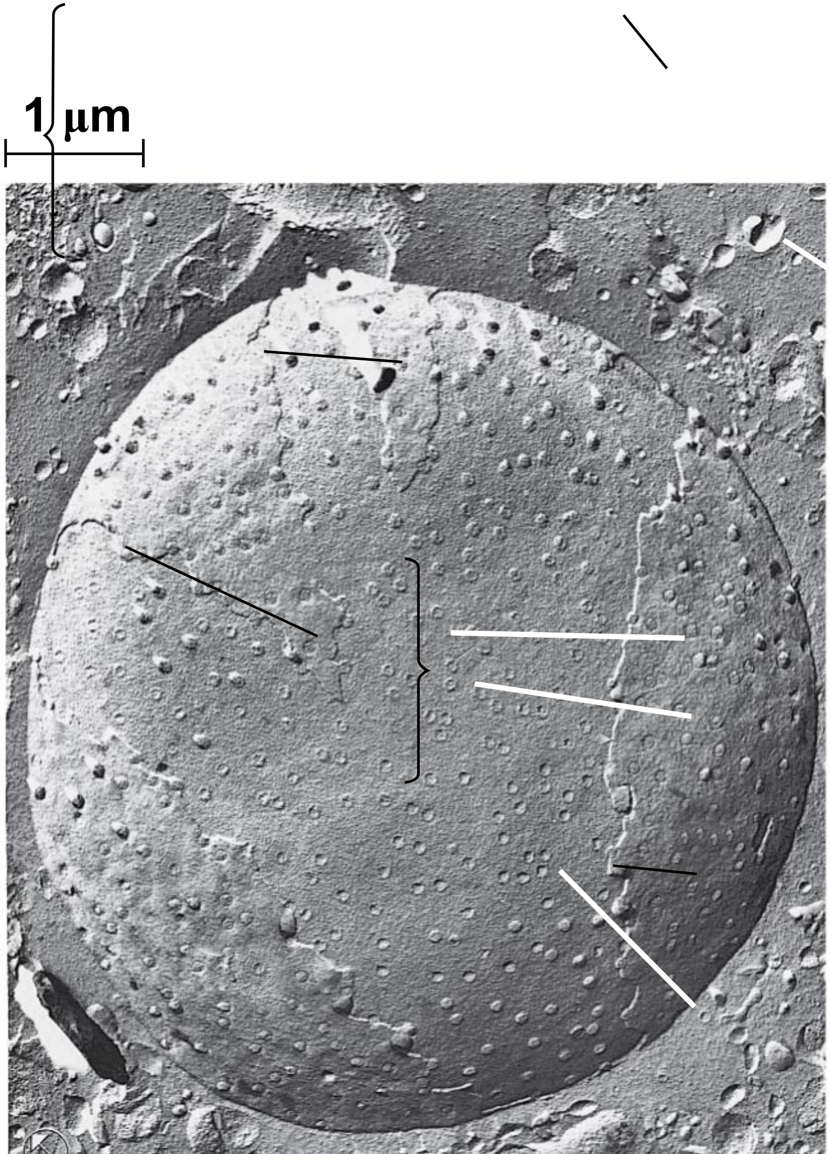
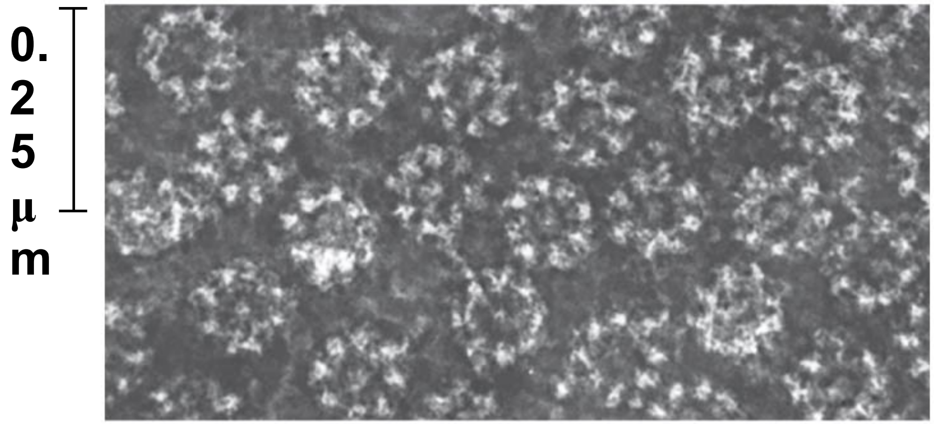

Nucleolus
Chromatin
Nucleus
Nuclear envelope:
Outer membrane
Inner membrane
Nuclear pore
Rough ER
Pore complex
Ribosome
Close-up of nuclear envelope
Chromatin

Figure 7.9b



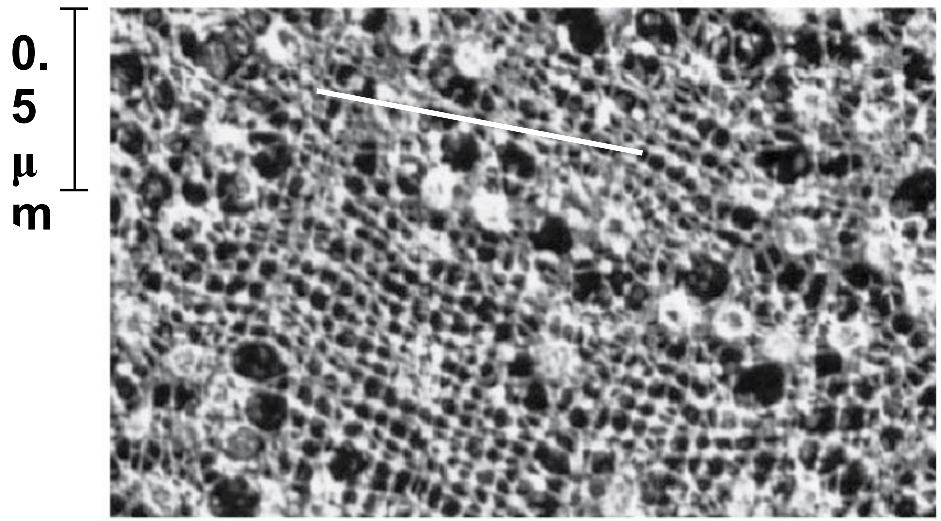

Surface of nuclear envelope (TEM)

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 side of the envelope is lined by the **nuclear lamina**, which is composed of proteins and maintains the shape of the nucleus

it helps organize the genetic material so it functions properly (with the help of a nuclear Matrix). [a framework of proteins].

- In the nucleus, DNA is organized into discrete units called **chromosomes**
- Each chromosome contains one DNA molecule associated with proteins, called (**chromatin**) → the complex raw material.
  → some are called histones.
- 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

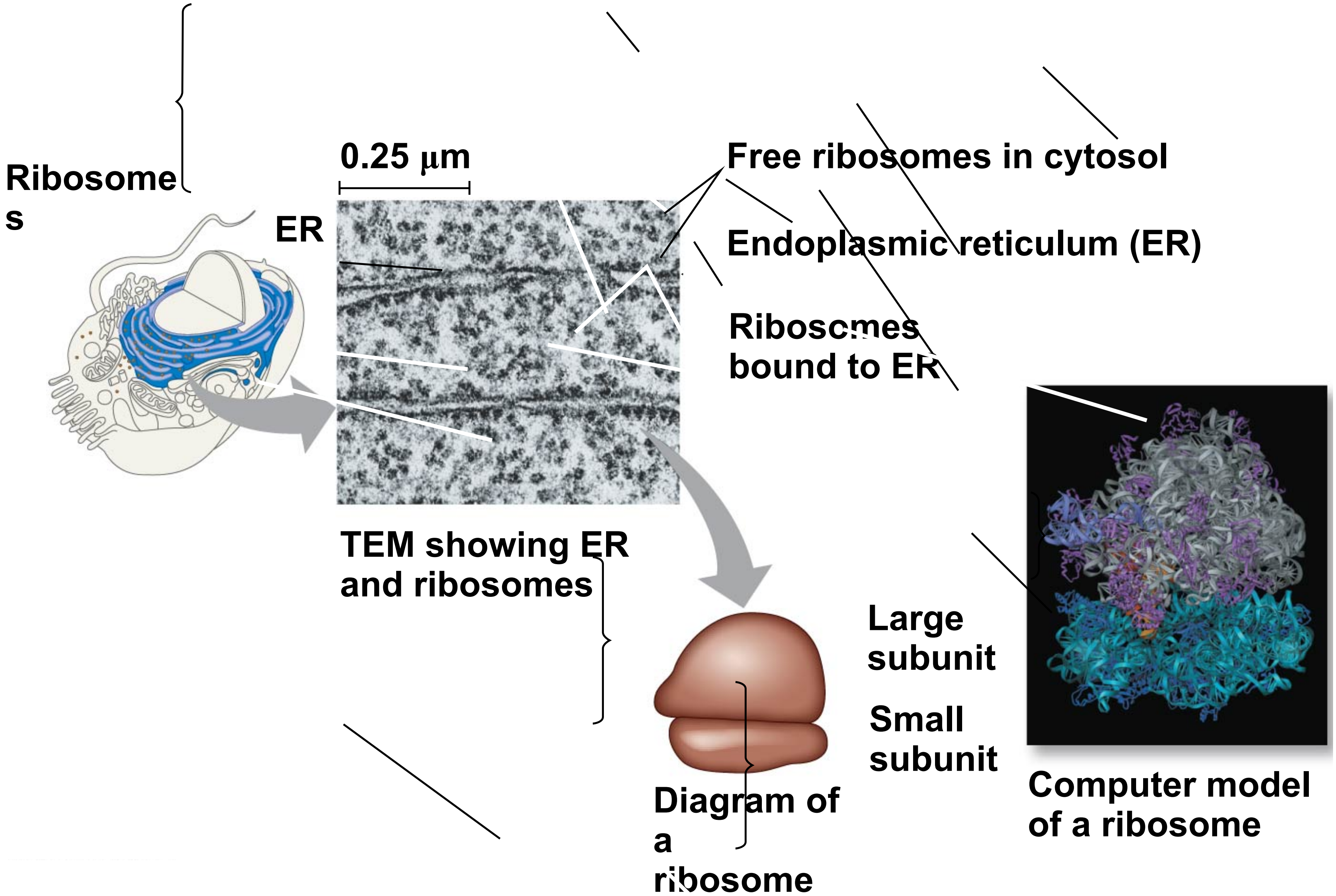
→ a mass of densely stained granules and fibers.

Sometimes, more than (1) nucleolus is in the nucleus.
depending on species, stage of cycle.

# ibosomes: Protein Factories

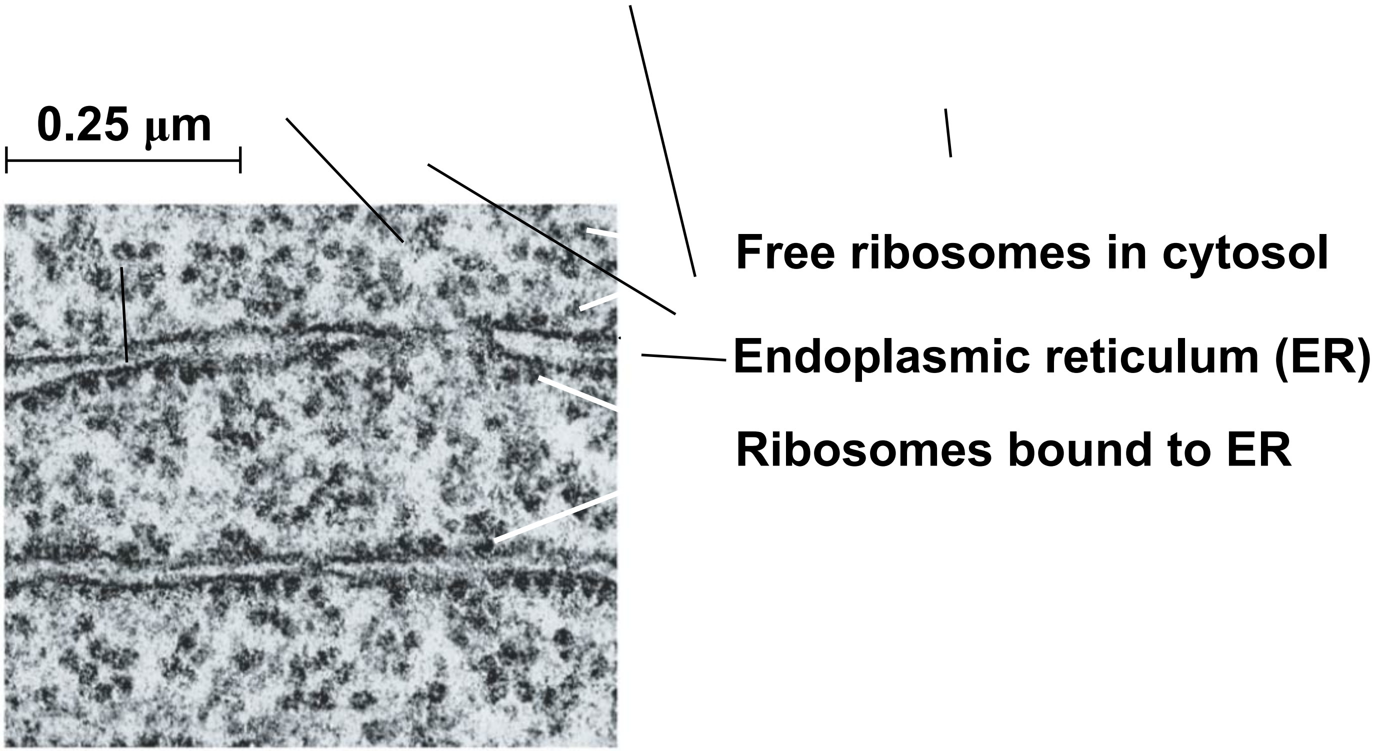
- **Ribosomes** are complexes made of ribosomal RNA and protein
- Ribosomes carry out protein synthesis in two locations:
  - In the cytosol (free ribosomes)
  - On the outside of the endoplasmic reticulum or the nuclear envelope (bound ribosomes)

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

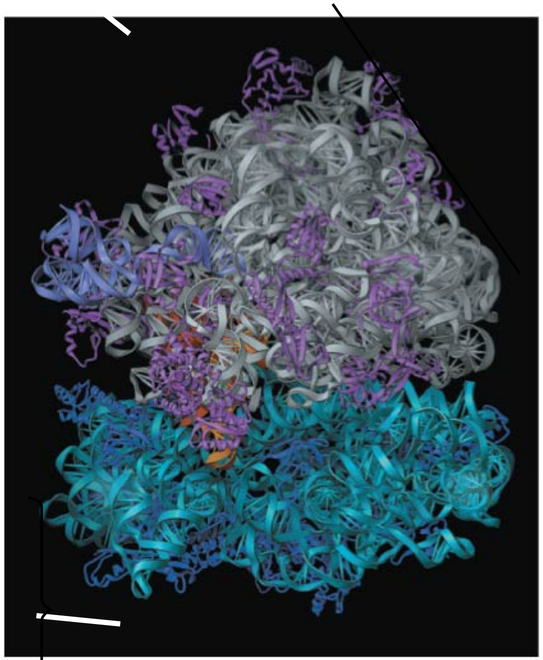
Figure 7.10a




TEM showing ER and ribosomes

Large subunit

Small subunit



Computer model of a ribosome

# Notes on 7.3:

* The nucleus, on average, is 5 μm Dia..
* The space between the 2 Bilayers (→ of the nucleus) ⇒ (20 → 40) nm.
* Nuclear pores are, on average, 100 nm Dia..
* Nuclear Lamina (which lines the inside of the inner membrane) is made of Intermediate Filaments.
  (inner membrane → except for pores (pore complex).) (Intermediate Filaments → (concept 7.6))
* Protein in chromatin helps it coil to fit.
* Chromatin (the web-form) is in-differentiable.
* For Fruit Flies ⇒ n = 4 chromosomes
  2n = 8 chromosomes

* Ribosomal Subunits are assembled in the nucleolus.

* they are (rRNA and proteins from the cytoplasm) and they exit through nuclear pores to the //.

* The translation of mRNA takes place in Ribosomes.
  translation = forming of polypeptide.

* cells with high Protein synthesis rates have many //.

* for e.g., a human pancreas cell has a few Million //.

2 types of ribosomes

1. free (in the cytosol)
   synthesizes protein usually functioning within cytosol.
   such as enzymes catalyzing first steps of Sugar breakdown.

2. bound (to R.ER or Nuclear envelope)
   synthesizes
   (a) proteins for insertion into membranes;
   (b) proteins for packaging in organelles e.g. in lysosomes
   (c) proteins for export (secretion). such as pancreas cells (high ratio of bound ribosomes).

# oncept 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

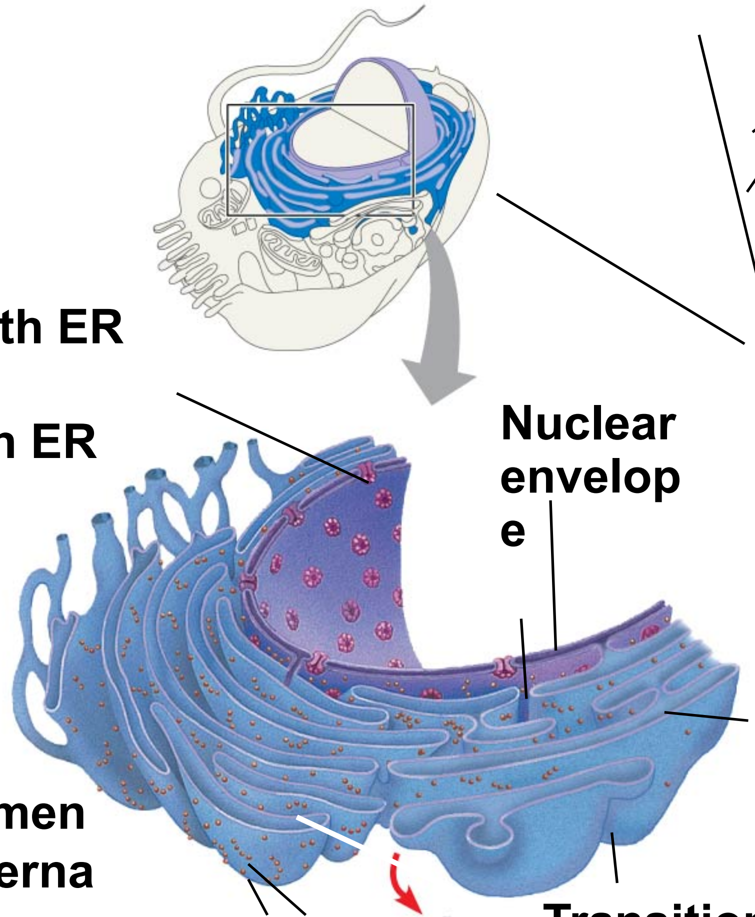
and vesicles (mainly).

- These components are either continuous or connected via transfer by **vesicles**

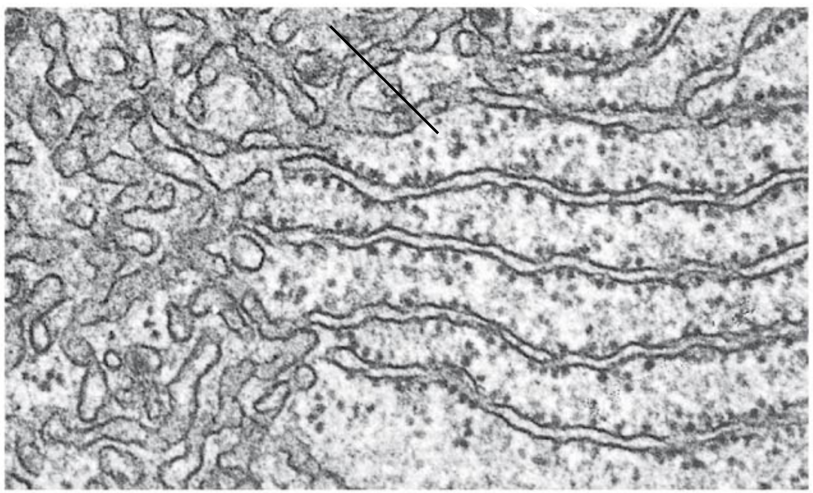
# he Endoplasmic Reticulum: Biosynthetic Factory

- 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
- they consist of a network of membranous tubules and sacs called cisternae.

Figure 7.11



Smooth ER
Rough ER
Nuclear envelop
e
ER lumen
Cisterna
e
Ribosome
s
Transport vesicle
Transitiona
l
ER

Smooth ER
Rough ER
0.2 µm

# unctions of Smooth ER

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

for new membrane

oils, steroids, phospholipids

sex hormones and other hormones of the adrenal gland.

cells in testes and ovaries are rich in Smooth ER.

involves adding (OH) groups to increase solubility to get rid of them.

with high consumption of alcohol and drugs, tolerance of S.ER can increase requiring higher doses to create a response.

In muscle cells, e.g., S.ER pumps $Ca^{2+}$ ions from cytosol → ER lumen

When Stimulated by a nerve impulse, $Ca^{2+}$ ions rush back to the cytosol to trigger contraction.

other cells may trigger different responses when $Ca^{2+}$ ions rush from ER lumen to cytosol.

# unctions 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 } → grows by adding membrane proteins and phospholipids to its own membrane

phospholipids are assembled from precursors raw mats. by membranous enzymes.

Steps of secreting proteins: [#'s are not precise].

Polypeptide chain (by bound ribosomes) —①→ ER lumen (via a pore in ER membrane)
pore formed by a protein complex

② the chain folds into its functional shape as it enters the ER lumen

③ Carbohydrates are attached to the protein by proteins built into ER membrane

④ Secretory protein depart ER "wrapped" in vesicles from the specialized ER region called transitional ER.

# he Golgi Apparatus: Shipping and Receiving Center

- The **Golgi apparatus** consists of flattened membranous sacs called cisternae → many (hundreds sts)
- The Golgi apparatus
  - Modifies products of the ER → different cisternae on the way include specialized enzymes.
  - Manufactures certain macromolecules → many polysaccarides (pectin and noncelluloses)
  - Sorts and packages materials into transport vesicles

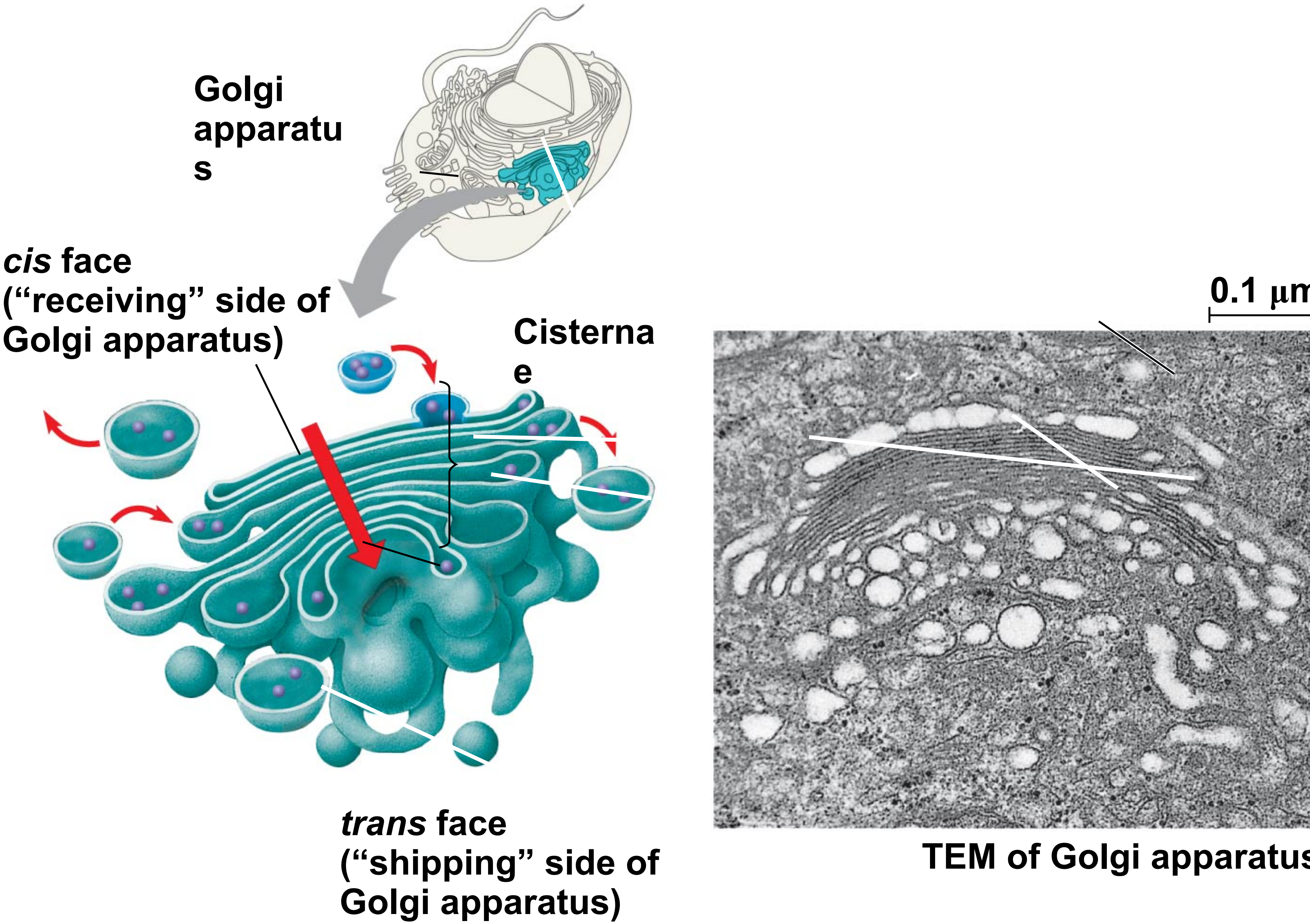
* Directionality:

cis-face recieves budding vesicles from ER

during the journey from cis → trans, products are modified e.g. glycoproteins have their carbohydrates modified changing sugar monomers; phospholipids can be altered as well.

trans-face transfers Pinching vesicles for shipping

Figure 7.12



Golgi
apparatu
s
*cis* face
(“receiving” side of
Golgi apparatus)
Cisterna
e
*trans* face
(“shipping” side of
Golgi apparatus)
0.1 µm
TEM of Golgi apparatus

# ysosomes: 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

if internals leak to cytosol, they aren't as efficient because pH ≈ 7.

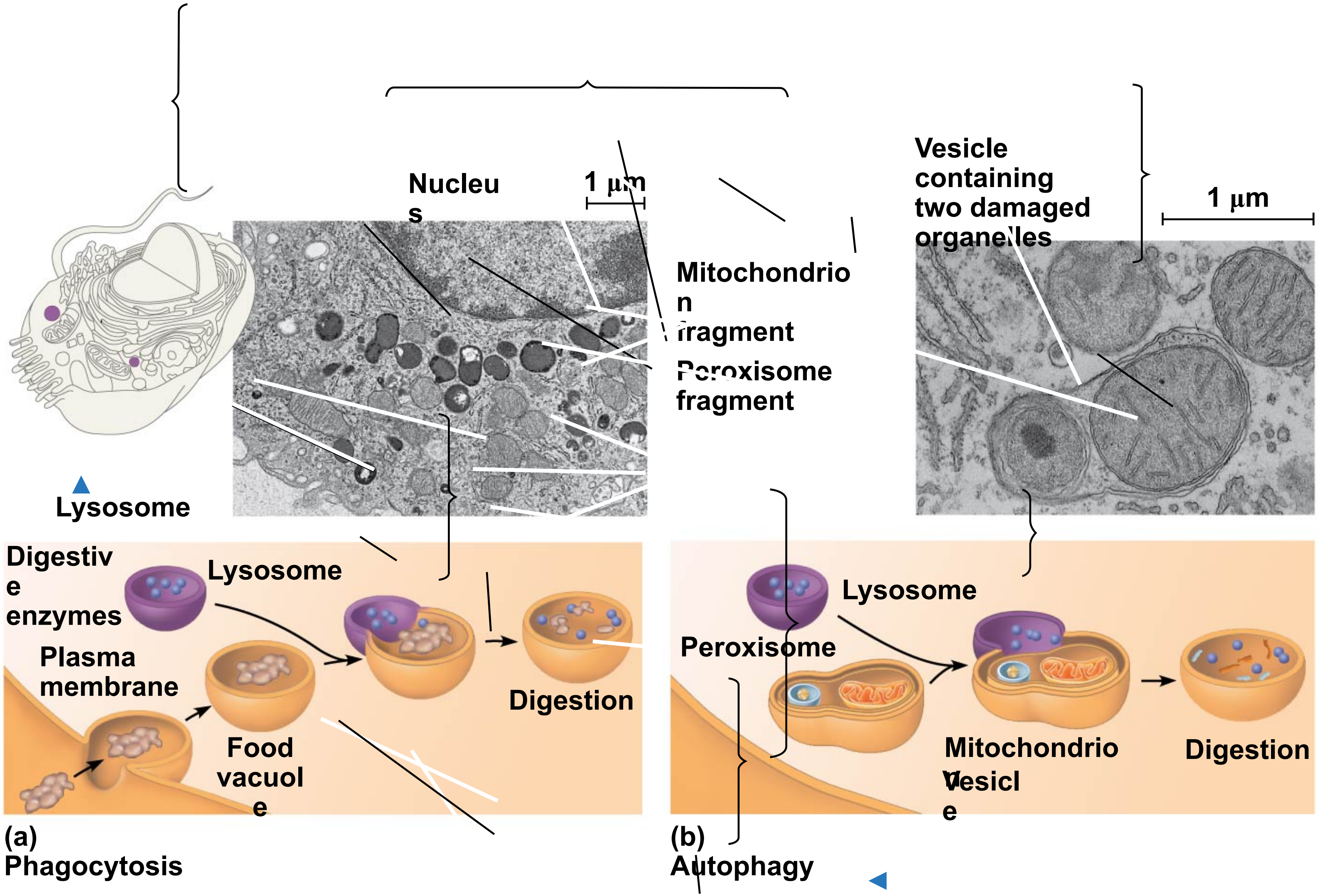
- [ ] Excessive leakage from lysosomal enzymes can destroy a cell by cell-destruction.
- [ ] The 3-D structures of proteins found on the inner side of lysosomes protect vulnerable bonds from enzymatic attacks.

- 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

Digestion products, including simply sugars, amino acids, and other monomers, pass into the cytosol and become nutrients for the cell.

Some human cells such as is macrophages, a type of white blood helps defend the body by engulfing and destroying bacteria and other invaders, carry out phagocytosis.

Figure 7.13


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

# acuoles: 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

  - colorful pigments → attract insects for pollination.
  - protection by storing poisonous compounds.

- **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

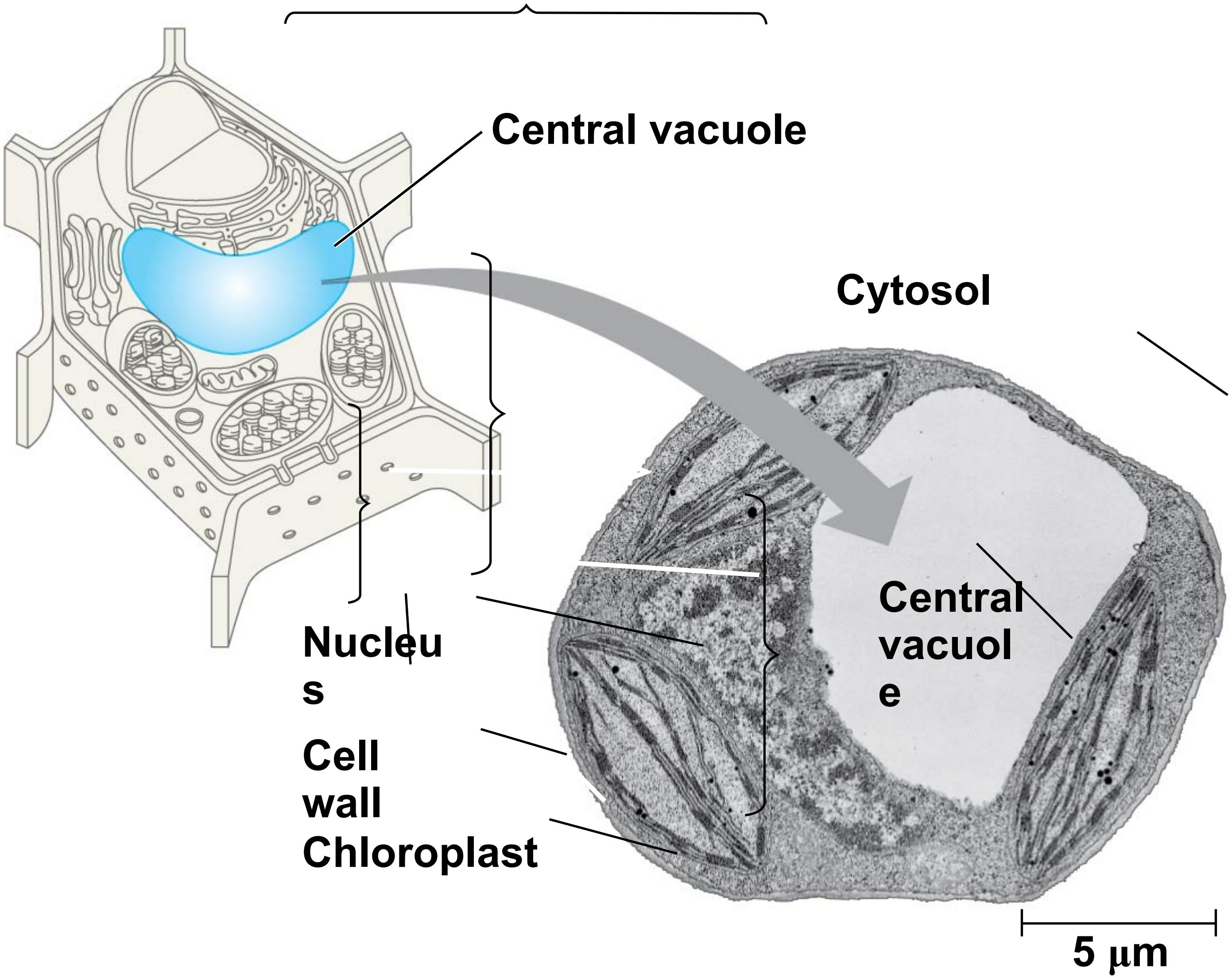
such as proteins stockpiled in seeds.

As the vacuole absorbs water enabling the cell to become larger with minimal investment in new cytoplasm, the central vacuole plays a major role in the growth of plant cells.

Solutions of which are called cell sap → main deposit of inorganic material.

The cytosol often occupies only a thin layer between the central vacuole and the plasma membrane, so the ratio of plasma membrane surface to cytosolic volume is sufficient even for a large plant cell.

Figure 7.14

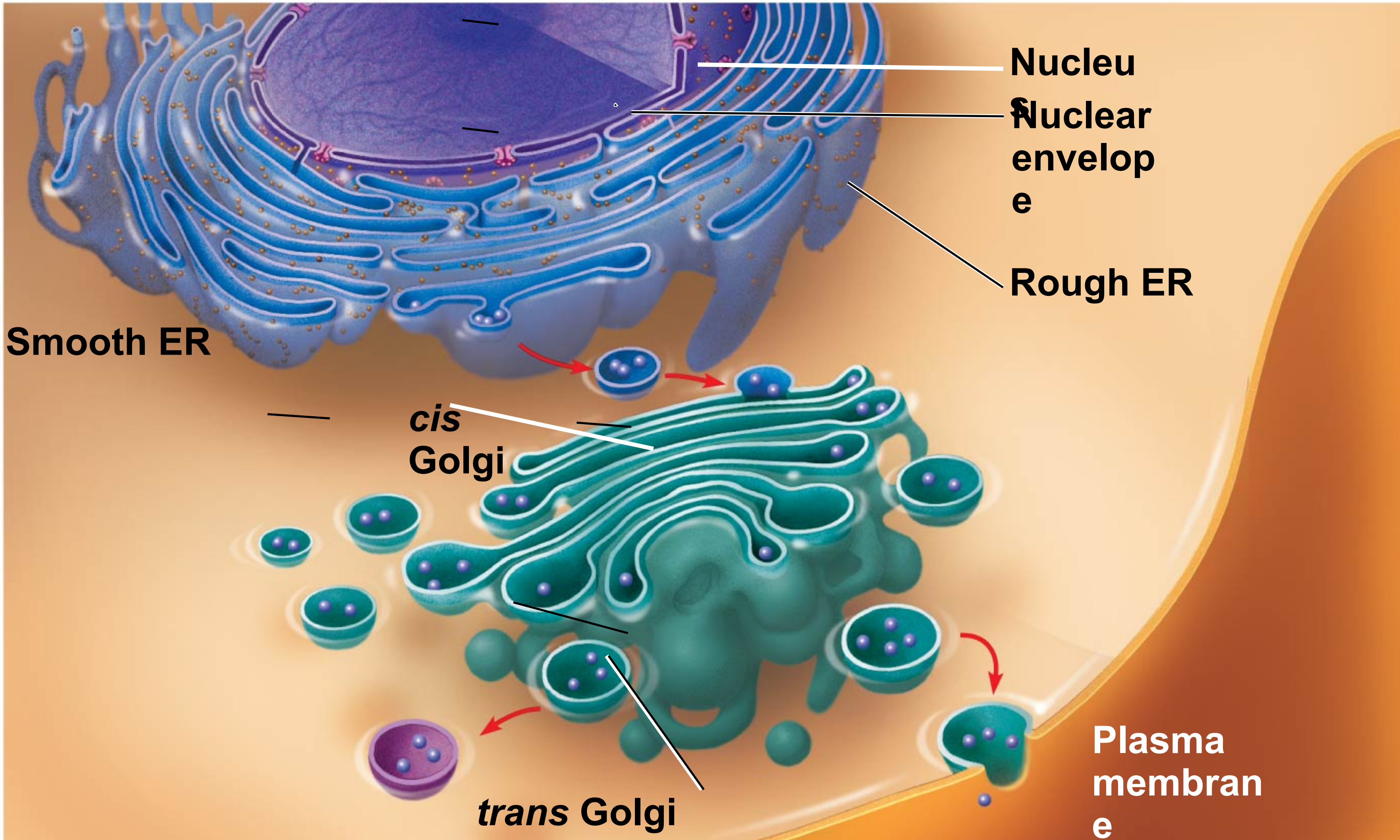


Central vacuole
Cytosol
Central
vacuol
e
Nucleu
s
Cell
wall
Chloroplast
5 μm

# he Endomembrane System: *A Review*

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

Figure 7.15


Nucleu
s
Nuclear
envelop
e
Rough ER
Smooth ER
cis
Golgi
trans Golgi
Plasma
membran
e

# Notes on 7.4.

* Various membranes are not identical in structure as they vary in thickness, molecular composition, and types of chemical reactions carried out.
They may be modified during the one membrane's life as well.

* ER lumen is the cavity also called cisternal space; which is separated from the cytoplasm by ER membrane.

* The space between nuclear membranes is continuous with the ER lumen because ER membranes and Nuclear envelope are continuous.

* The outer side of the nuclear envelope is in direct contact with ROUGH ER. [Both are studded with ribosomes].

* Responses to $Ca^{2+}$ ions can be, e.g., muscle contraction, secretion of vesicles carrying newly synthesized proteins [smooth ER related point].

* Protein insulin is secreted into the bloodstream after being synthesized by pancreatic cells.

* Secretory proteins are kept seperated from proteins formed by smooth ER which stay in the cytosol while secretory proteins stay in the cisternal space — ER lumen — before being packed into membrane-bound vesicles.

* Most secretory proteins are glycoproteins.
  → proteins with carbohydrates covalently bonded.

* Membrane proteins are anchored by Hydrophobic interactions (non-polar).

* Golgi Apparatus is extensive in Highly-secreting cells.

* plasma membrane's S.A. increase when secretory vesicles join coming from trans-face of the golgi.

* Phosphate groups are examples of tags which Golgi puts onto vesicles.

  tags → going to receptors in "goal" membrane.

* A human liver cell recycle half of its macromolecules every week.

* Tay-sachs disease causes lipids to accumulate in brain cells due to lack of lipid-digesting enzymes.

  [fortunately a disease of low prevalence]

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

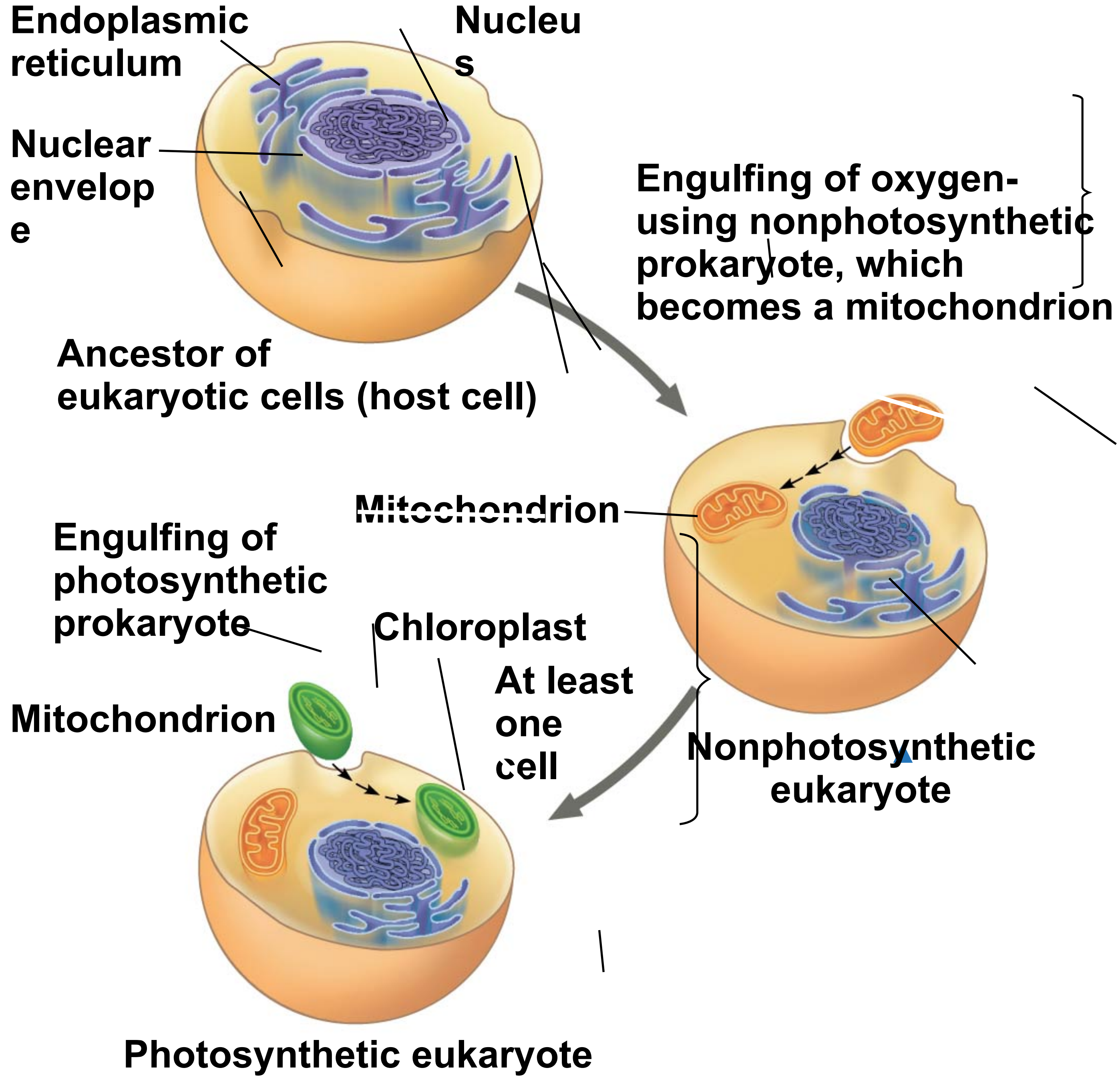
- **Mitochondria** are the sites of cellular respiration, a metabolic process that uses oxygen to generate ATP
- **Chloroplasts**, found in plants and algae, are the sites of photosynthesis
- Peroxisomes are oxidative organelles

# he 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

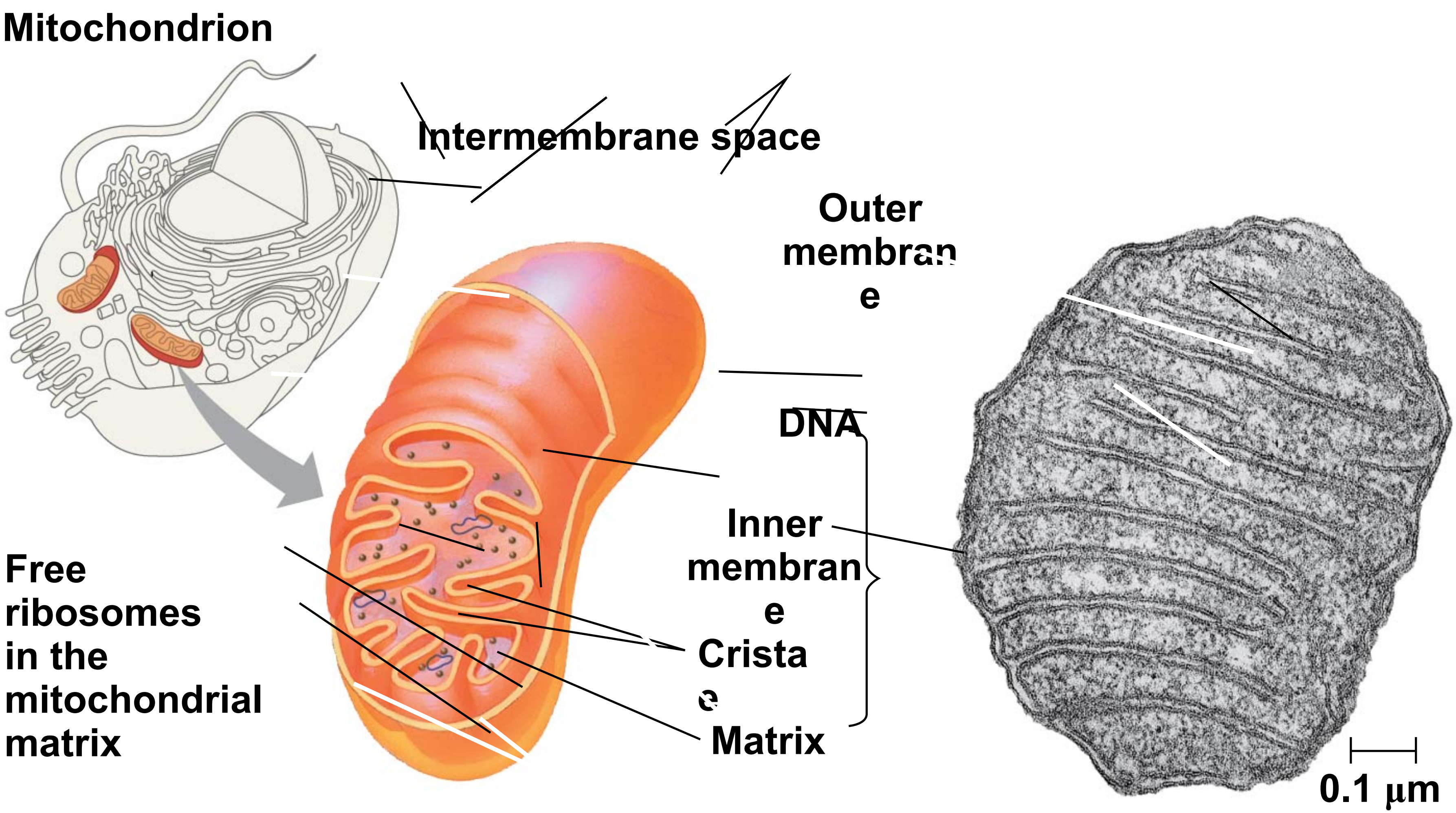
Figure 7.16


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

# litochondria: 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 7.17a

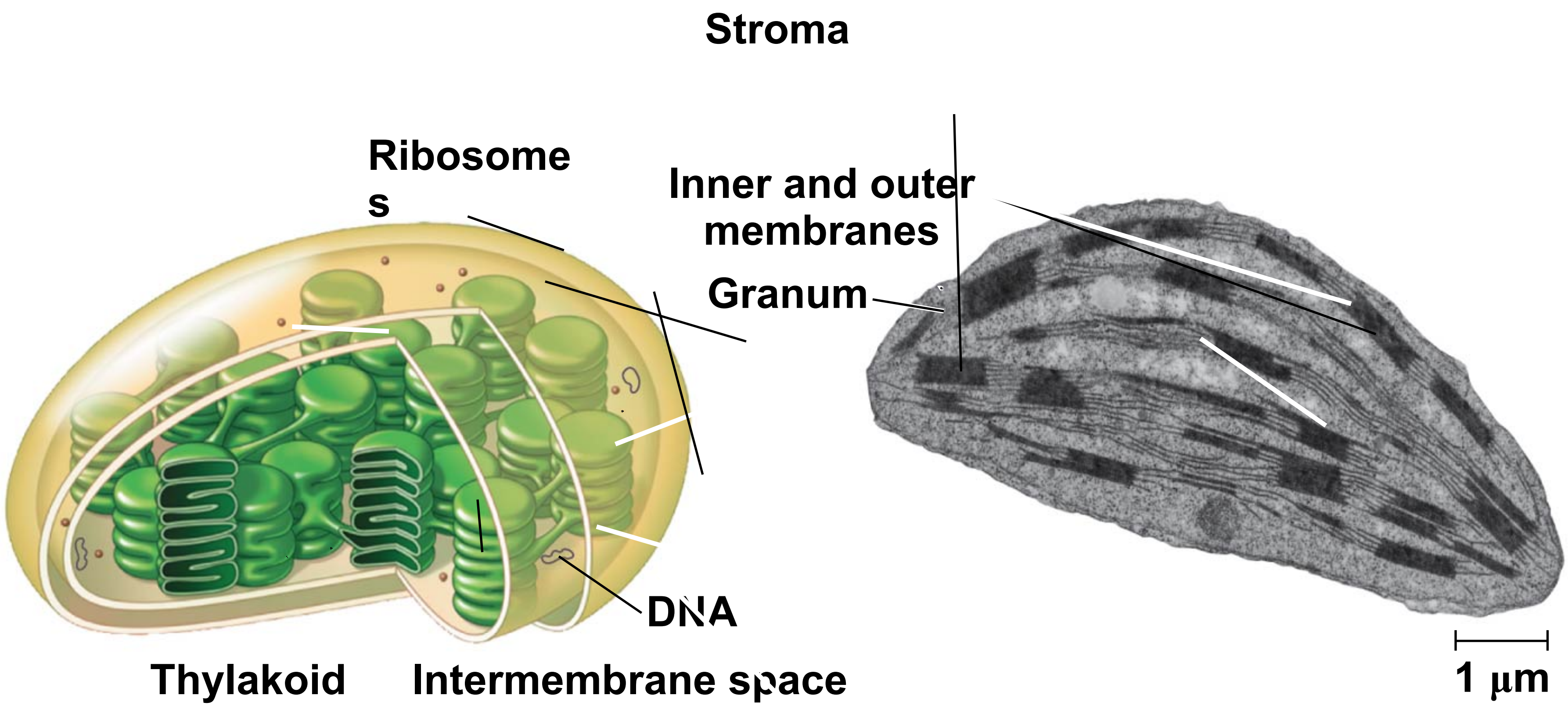



(a) Diagram and TEM of mitochondrion

# hloroplasts: 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 7.18a




(a) Diagram and TEM of chloroplast

- Chloroplast structure includes
  - **Thylakoids**, membranous sacs, stacked to form a **granum**
  - **Stroma**, the internal fluid
- The chloroplast is one of a group of plant organelles, called **plastids**

# eroxisomes: Oxidation

- **Peroxisomes** are specialized metabolic compartments bounded by a single membrane
- Peroxisomes produce hydrogen peroxide and convert it to water
- Peroxisomes perform reactions with many different functions
- How peroxisomes are related to other organelles is still unknown

# Notes on 7.5:

A cell might have a single large mitochondrion. but a typical cell has hundreds or thousands of mitochondria. The number is related with the cell's level of metabolic activity.

The inner membrane of the mitochondria is convoluted with infoldings called cristae while the outer membrane is smooth.

Mitochondria are generally in the range of 1–10 μm long

Mitochondria are dynamic structures which change their shapes and fuse, or divide into separate fragments unlike static structure scene in most diagrams. In skeletal muscles, this network has been referred to by researcher as a "power grid".

Enzymes that make ATP and other proteins are built in the inner membrane of the mitochondria.

Chloroplasts are lens shaped organelles about 3 to 6 µm in length.

Chloroplasts also do have two membranes. Both are smooth and separated by a very narrow intermembrane space.

The inner membrane and the thylakoid membrane separate the chloroplast into three compartments: intermembrane space, stroma, thylakoid space.

The chloroplast is a specialized member of a family of closely related plant organelles called plastids. One type of plastid, the amyloplast, is a colorless organelle that stores starch (amylose) particularly in roots and tubers. Another is the chromoplast which has pigments that give fruits and flowers their orange and yellow hues.

* Chloroplasts are dynamic as well, pinching in two, reproducing, and moving alongside mitochondria and other organelles along the cytoskeleton (concept 7.6).

Hydrogen peroxide is produced as a byproduct after removing hydrogen atoms from various substrates in different reactions. These reactions have many different function. Some peroxisomes use oxygen to break fatty acids down into smaller molecules that are transported to mitochondria, and used as fuel for cellular respiration.

Peroxisomes in the liver detoxify alcohol and other harmful compounds by transferring hydrogen from the poisonous compounds to oxygen forming hydrogen peroxide which is toxic but the organelle has a built-in enzyme that transforms it into water.

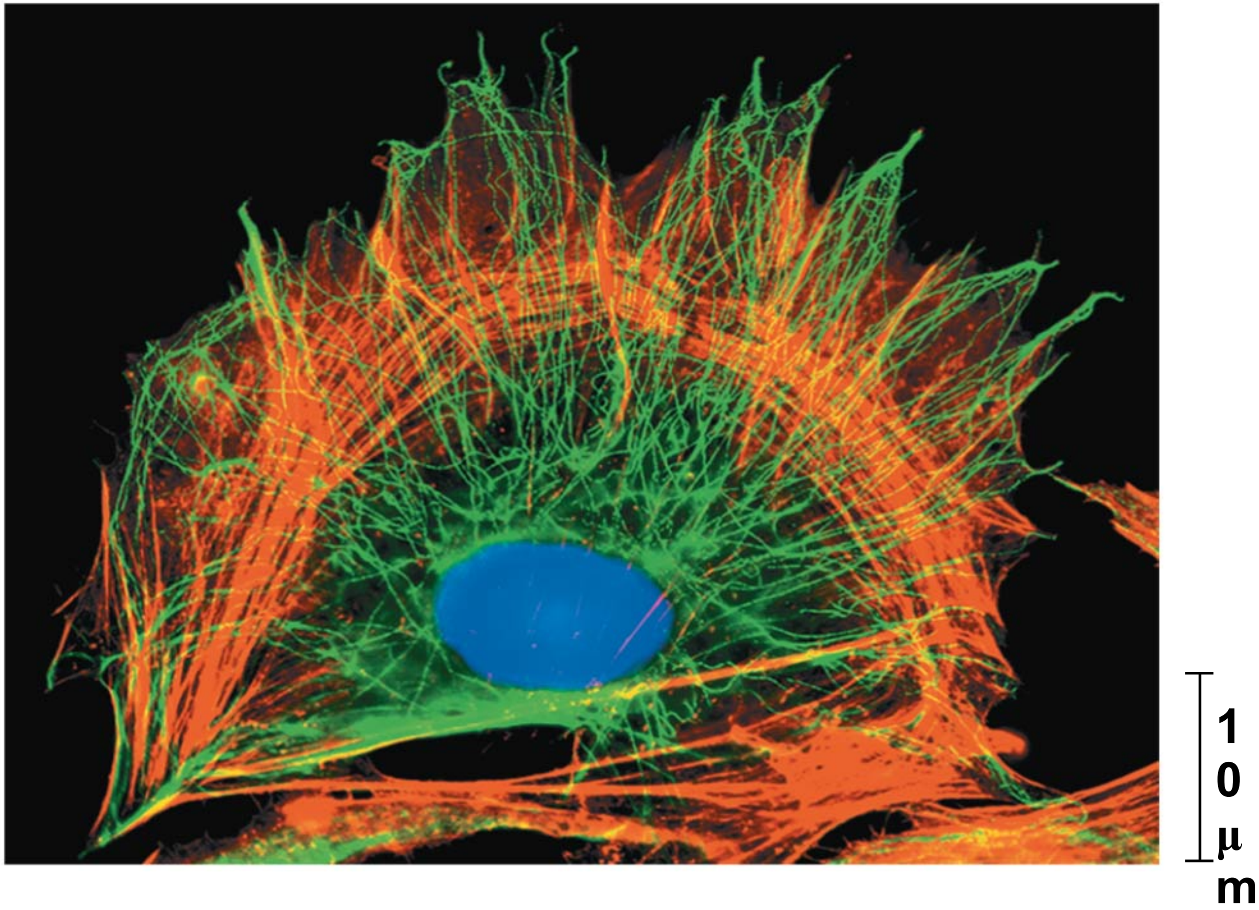
* Specialized peroxisomes called glyoxysomes, are found in plant seeds. They contain enzymes that initiate the conversion of fatty acids to sugars.

Peroxisomes grow larger by incorporating proteins made in the cytosol and ER, as well as lipids made in the ER, and within the peroxisome itself.

# oncept 7.6: The cytoskeleton is a network of fibers that organizes structures and activities in the cell

- The **cytoskeleton** is a network of fibers extending throughout the cytoplasm
- It organizes the cell's structures and activities, anchoring many organelles
- It is composed of three types of molecular structures
  - Microtubules
  - Microfilaments
  - Intermediate filaments

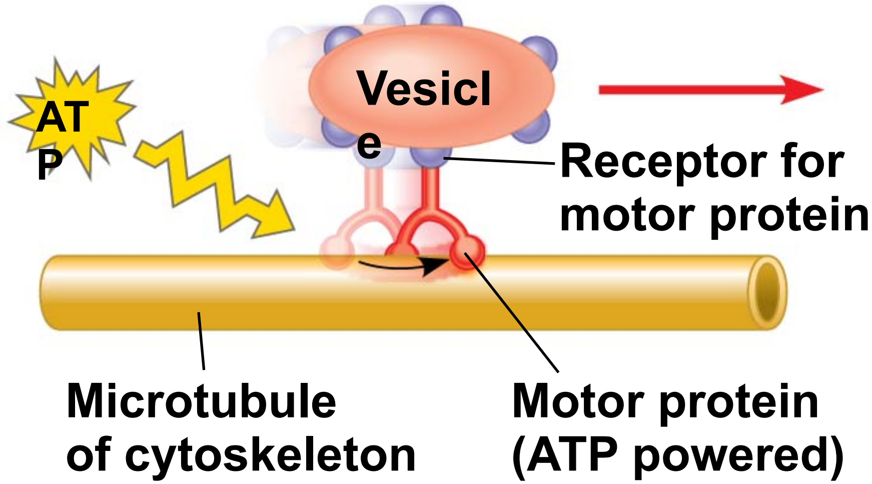
Figure 7.20



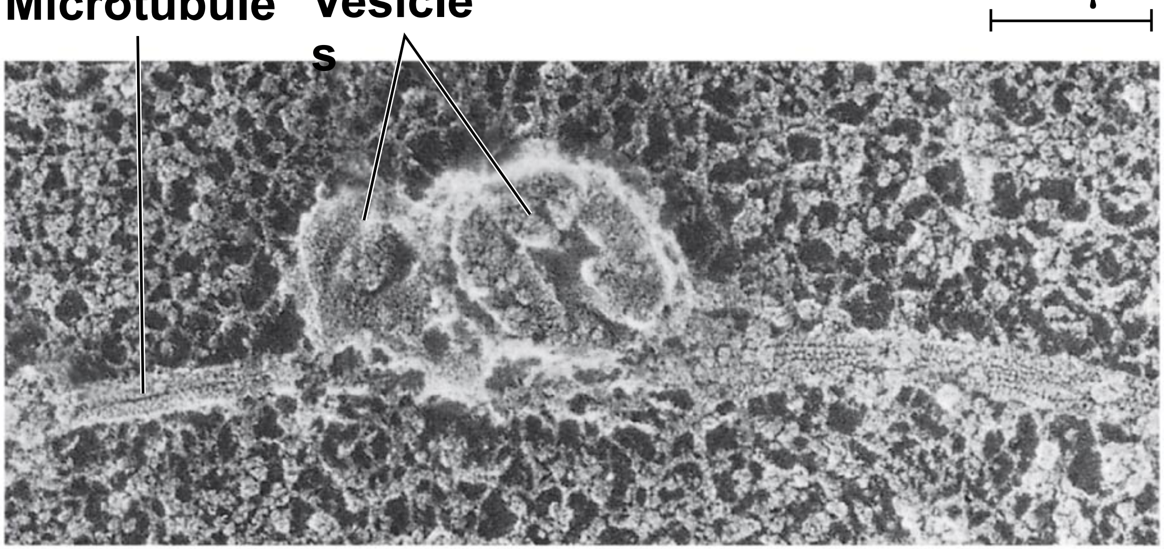
# Roles of the Cytoskeleton: Support and Motility

- The cytoskeleton helps to support the cell and maintain its shape
- It interacts with **motor proteins** to produce cell motility
- Inside the cell, vesicles can travel along tracks provided by the cytoskeleton

Figure 7.21




**(a) Motor proteins “walk” vesicles along
cytoskeletal fibers.**




**(b) Two vesicles move along a microtubule toward
the tip of an axon (SEM).**

# omponents of the Cytoskeleton

- Three main types of fibers make up the cytoskeleton
  - Microtubules are the thickest of the three components of the cytoskeleton
  - Microfilaments, also called actin filaments, are the thinnest components
  - Intermediate filaments are fibers with diameters in a middle range

Figure 7.T01

(SSS).

Table 7.1 **The Structure and Function of the Cytoskeleton**

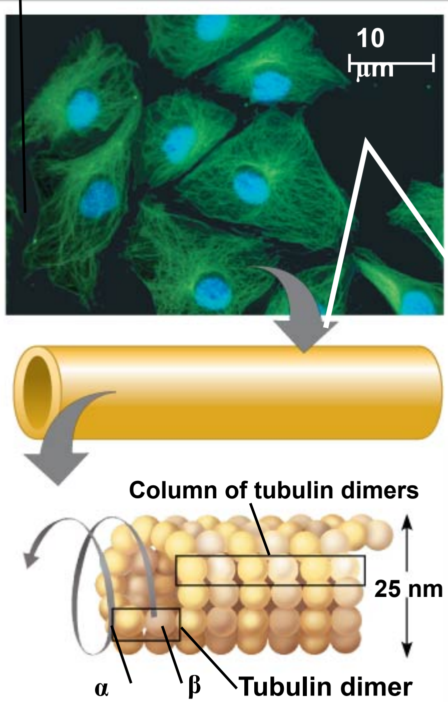
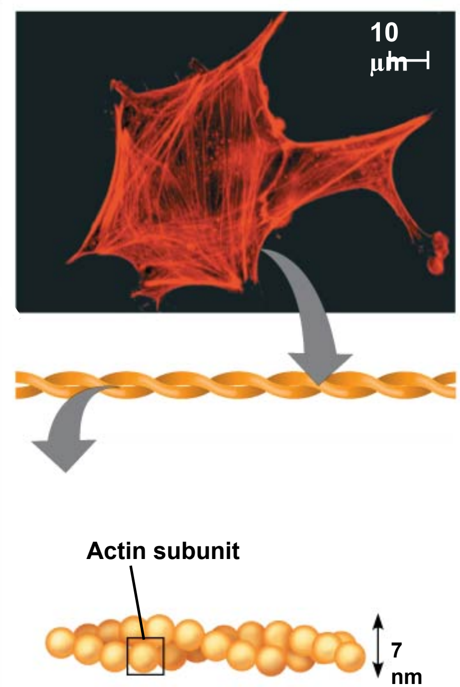
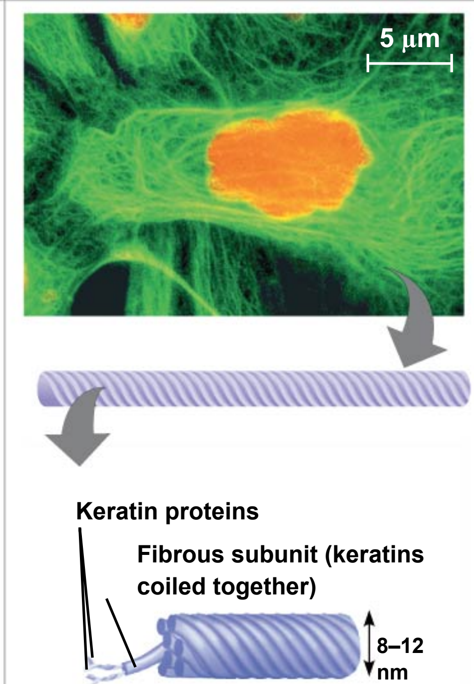
| Property | Microtubules (Tubulin Polymers) | Microfilaments (Actin Filaments) | Intermediate Filaments |
|---|---|---|---|
| Structure | Hollow tubes | Two intertwined strands of actin | Fibrous proteins coiled into cables |
| Diameter | 25 nm with 15-nm lumen | 7 nm | 8–12 nm |
| Protein subunits | Tubulin, a dimer consisting of α-tubulin and β-tubulin | Actin | One of several different proteins (such as keratins) |
| 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 in plant cells; cell motility (as in amoeboid movement); division of animal cells | Maintenance of cell shape (tension-bearing elements); anchorage of nucleus and certain other organelles; formation of nuclear lamina |
| Fluorescence micrographs of fibroblasts. Fibroblasts are a favorite cell type for cell biology studies because they spread out flat and their internal structures are easy to see. In each, the structure of interest has been tagged with fluorescent molecules. The DNA in the nucleus has also been tagged in the first micrograph (blue) and third micrograph (orange). |   |   |   |

Figure 7.T01a

**Table 7.1 The Structure and Function of the Cytoskeleton**

| Microtubules (Tubulin Polymers) | Microfilaments (Actin Filaments) | Intermediate Filaments |
|---|---|---|
| Hollow tubes | Two intertwined strands of actin | Fibrous proteins coiled into cables |
| 25 nm with 15-nm lumen | 7 nm | 8–12 nm |
| Tubulin, a dimer consisting of α-tubulin and β-tubulin | Actin | One of several different proteins (such as keratins) |
| 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 in plant cells; cell motility (as in amoeboid movement); division of animal cells | Maintenance of cell shape (tension-bearing elements); anchorage of nucleus and certain other organelles; formation of nuclear lamina |

| Microtubules (Tubulin Polymers) |
|---|
| Hollow tubes |
| 25 nm with 15-nm lumen |
| Tubulin, a dimer consisting of α-tubulin and β-tubulin |
| Maintenance of cell shape (compression-resisting "girder"); cell motility (as in cilia or flagella); chromosome movements in cell division; organelle movements |

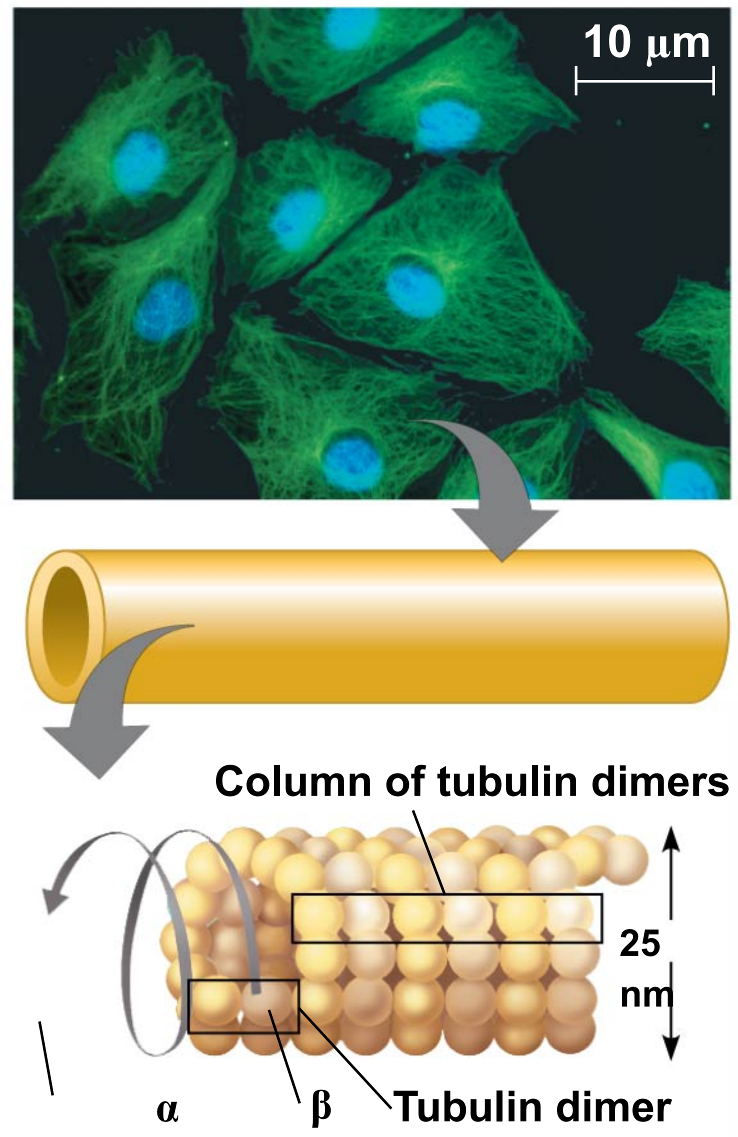


Figure 7.T01c

| Microfilaments (Actin Filaments) |
| --- |
| Two intertwined strands of actin |
| 7 nm |
| Actin |
| Maintenance of cell shape (tension-bearing elements); changes in cell shape; muscle contraction; cytoplasmic streaming in plant cells; cell motility (as in amoeboid movement); division of animal cells |

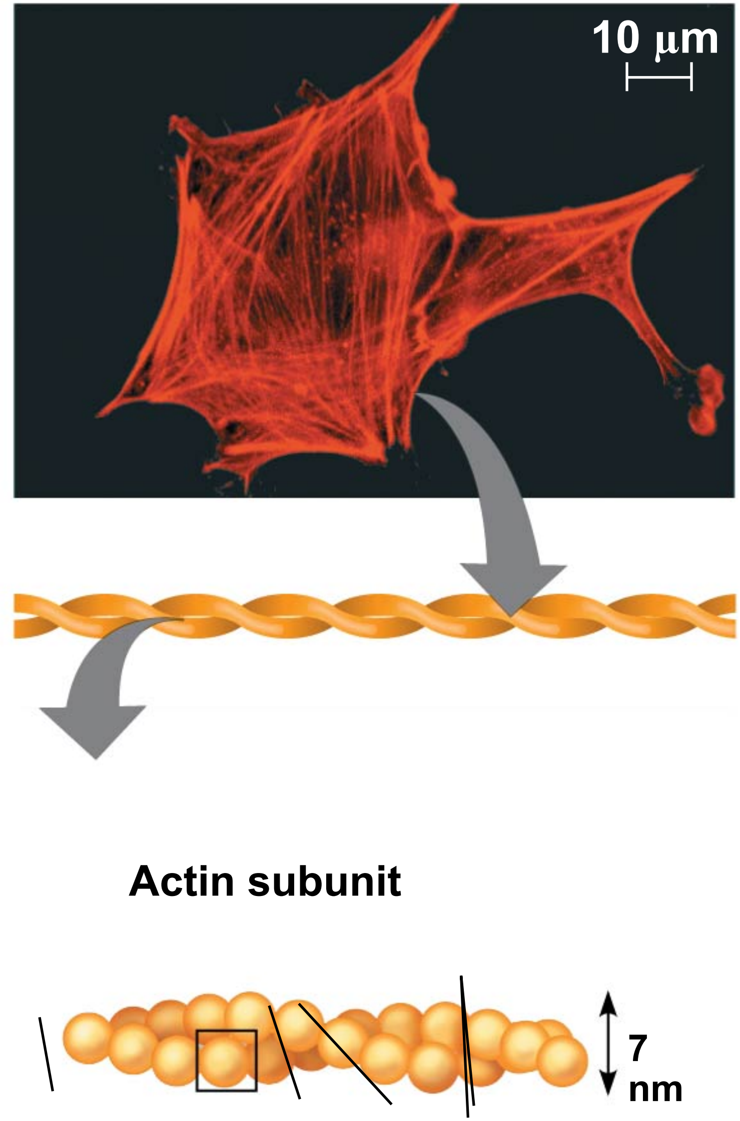
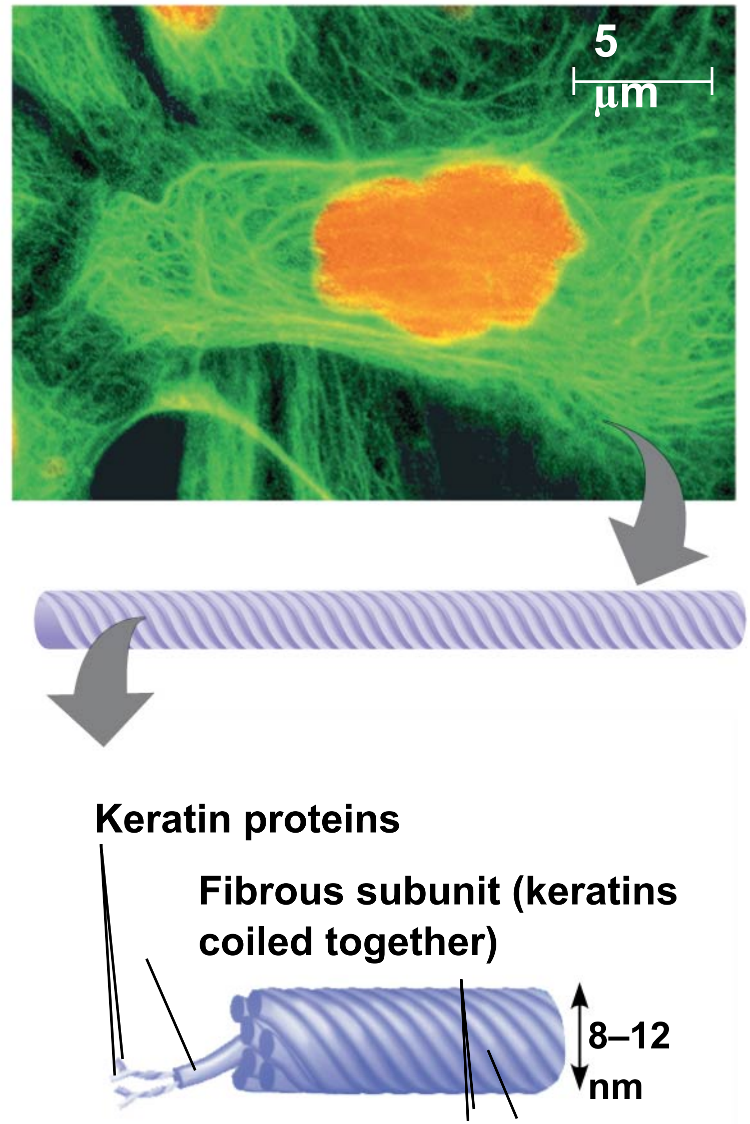


Figure 7.T01d

| Intermediate Filaments |
| --- |
| Fibrous proteins coiled into cables |
| 8–12 nm |
| One of several different proteins (such as keratins) |
| Maintenance of cell shape (tension-bearing elements); anchorage of nucleus and certain other organelles; formation of nuclear lamina |



# Microtubules

due to its dimer orientation, it has 2 distinct ends — the plus end is faster in adding or removing dimers.

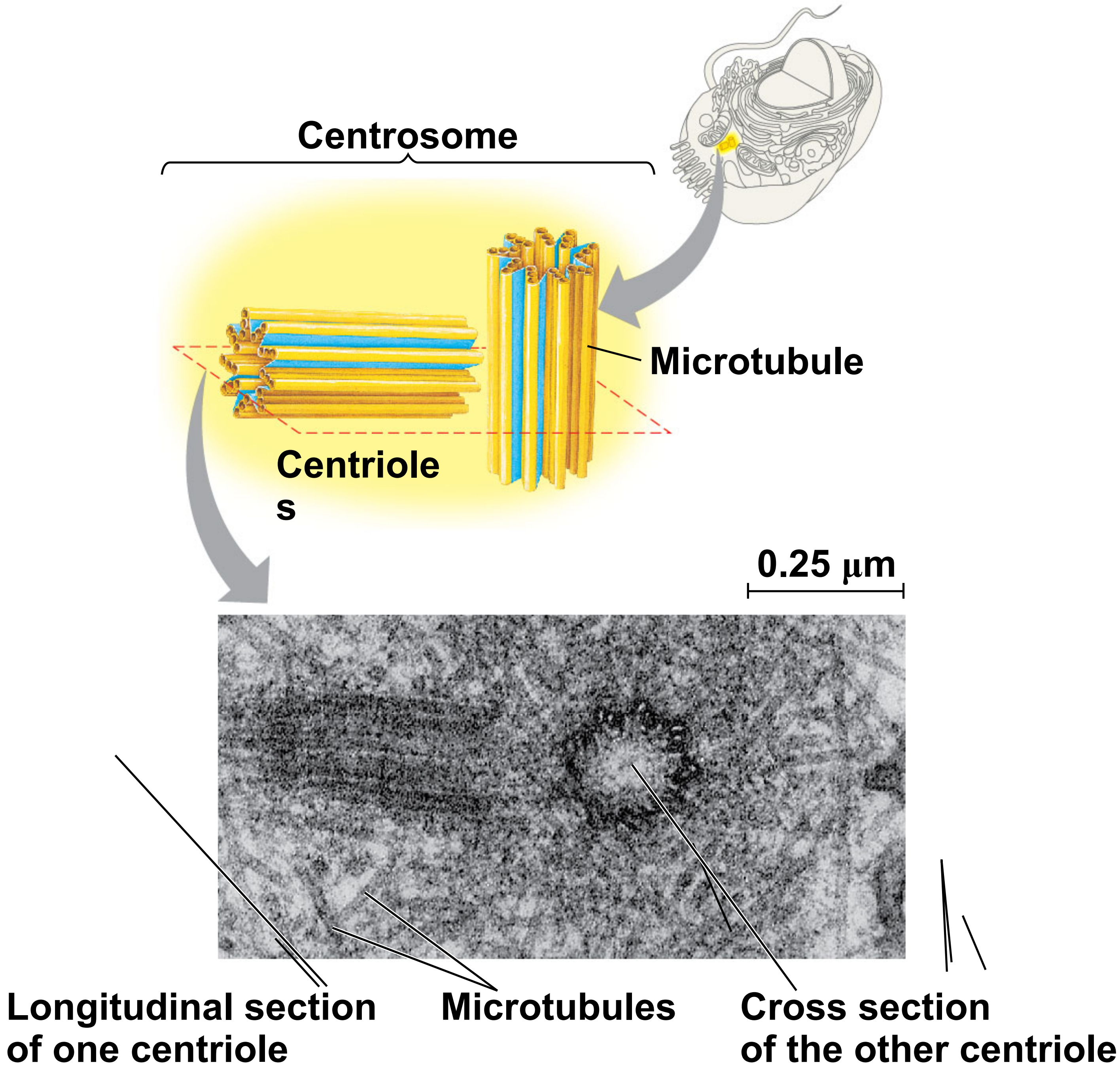
- **Microtubules** are hollow rods about 25 nm in diameter and about 200 nm to 25 microns long
- Microtubules are constructed of dimers of tubulin
- Functions of microtubules:
  - Shaping the cell
  - Guiding movement of organelles
  - Separating chromosomes during cell division

## Centrosomes and Centrioles

in some eukaryotes, centrosomes lack centrioles.

- In animal cells, microtubules grow out from a **centrosome** near the nucleus
- In animal cells, the centrosome has a pair of **centrioles**, each with nine triplets of microtubules arranged in a ring

Figure 7.22


Centrosome
Microtubule
Centriole
s
0.25 μm
Longitudinal section
of one centriole
Microtubules
Cross section
of the other centriole

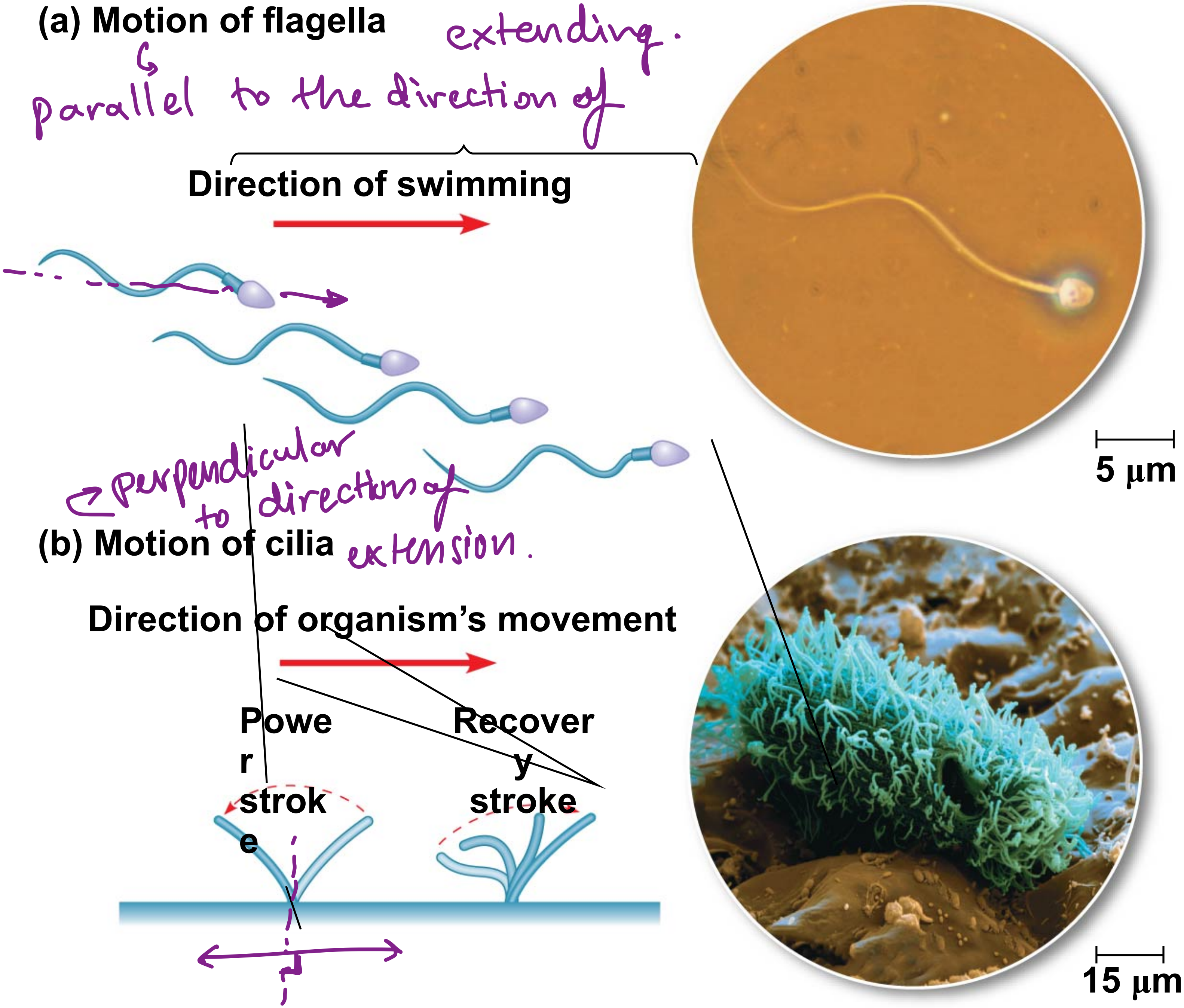
a flagellum is longer than a cilium and less abundant in a cell.

## Cilia and Flagella

- Microtubules control the beating of **flagella** and **cilia**, microtubule-containing extensions that project from some cells
- Many unicellular eukaryotes are propelled through water by cilia or flagella
- Cilia and flagella differ in their beating patterns

The ciliated lining of the trachea (windpipe) sweeps mucus containing debris out of the lungs.

Figure 7.23


(a) Motion of flagella
extending.
parallel to the direction of
Direction of swimming
5 µm
perpendicular to direction of extension.
(b) Motion of cilia
Direction of organism's movement
Power stroke
Recovery stroke
15 µm

"9 + 2" pattern.
(D)

Motile

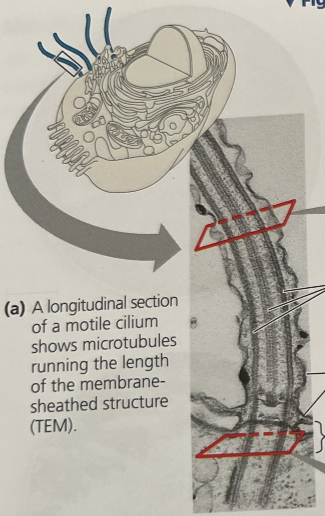
- Cilia and flagella share a common structure
  - A group of microtubules sheathed by an extension of the plasma membrane
  - A **basal body** that anchors the cilium or flagellum
  - A motor protein called **dynein**, which drives the bending movements of a cilium or flagellum

"9 + 0" → Triplets ≈ centrioles.

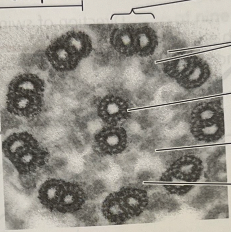
* Nonmotile primary cilia has "9 + 0".
(D)

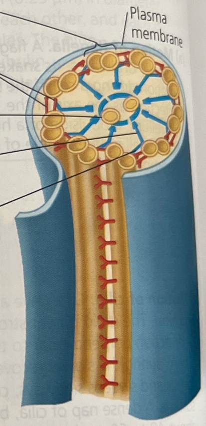
Important !!

**▼ Figure 7.24 Structure of a flagellum or motile cilium.**



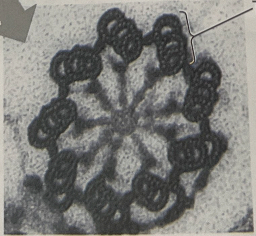

**(a)** A longitudinal section of a motile cilium shows microtubules running the length of the membrane-sheathed structure (TEM).



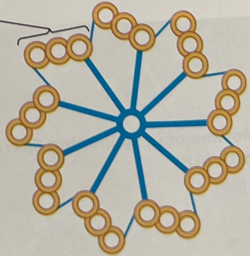




**(b)** A cross section through a motile cilium shows the "9 + 2" arrangement of microtubules (TEM). The outer microtubule doublets are held together with the two central microtubules by flexible cross-linking proteins (blue in art), including the radial spokes. The doublets also have attached motor proteins called dyneins (red in art).

**(c)** Basal body: The nine outer doublets of a cilium or flagellum extend into the basal body, where each doublet joins another microtubule to form a ring of nine triplets. Each triplet is connected to the next by nontubulin proteins (thinner blue lines in diagram). This is a "9 + 0" arrangement: The two central microtubules are not present because they terminate above the basal body (TEM).




Cross section of basal body

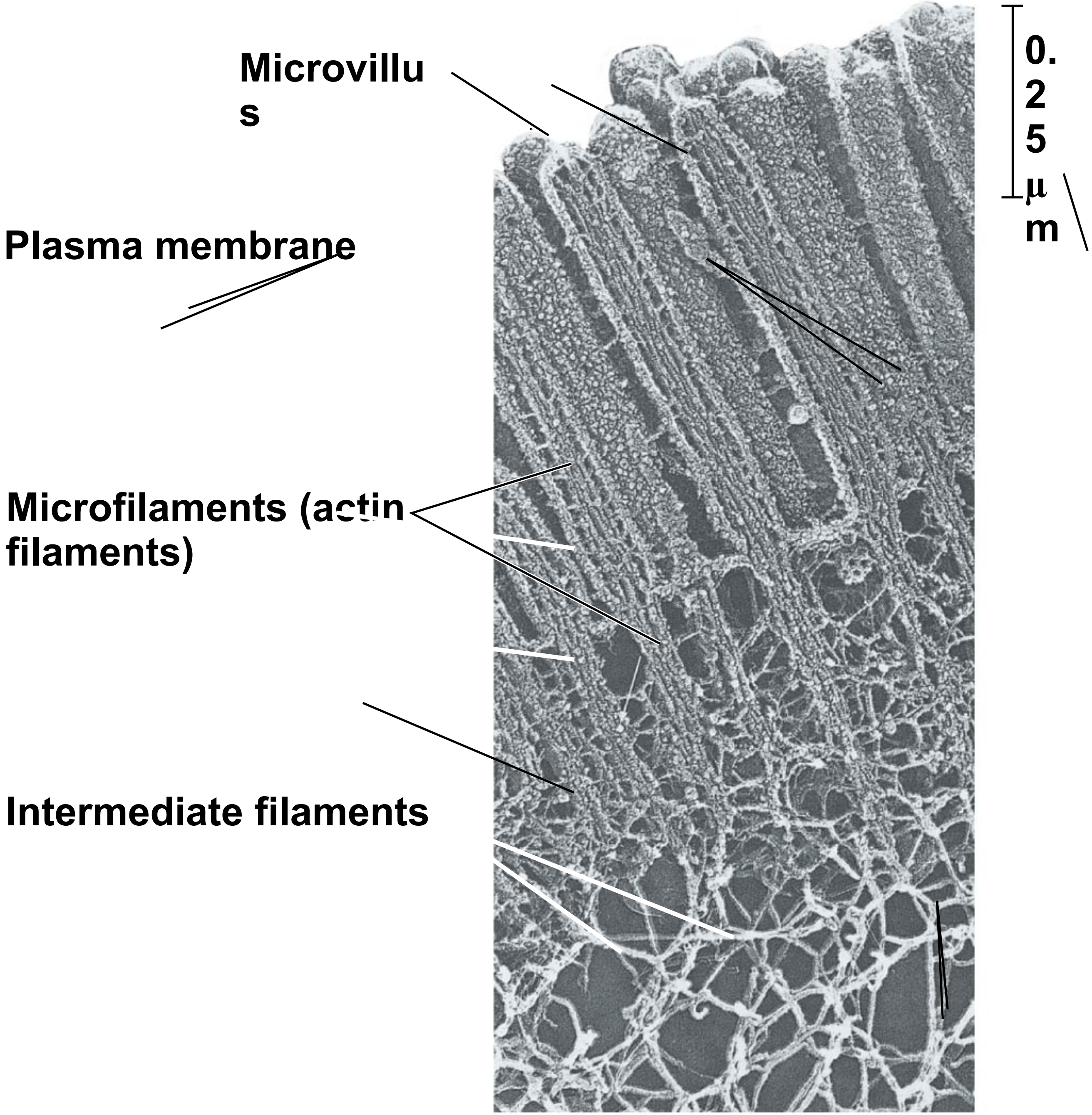


- Dynein has two “feet” that “walk” along microtubules
- One foot maintains contact, while the other releases and reattaches one step farther along
- Movements of the feet cause the microtubules to bend, rather than slide, because the microtubules are held in place

# Microfilaments (Actin Filaments)

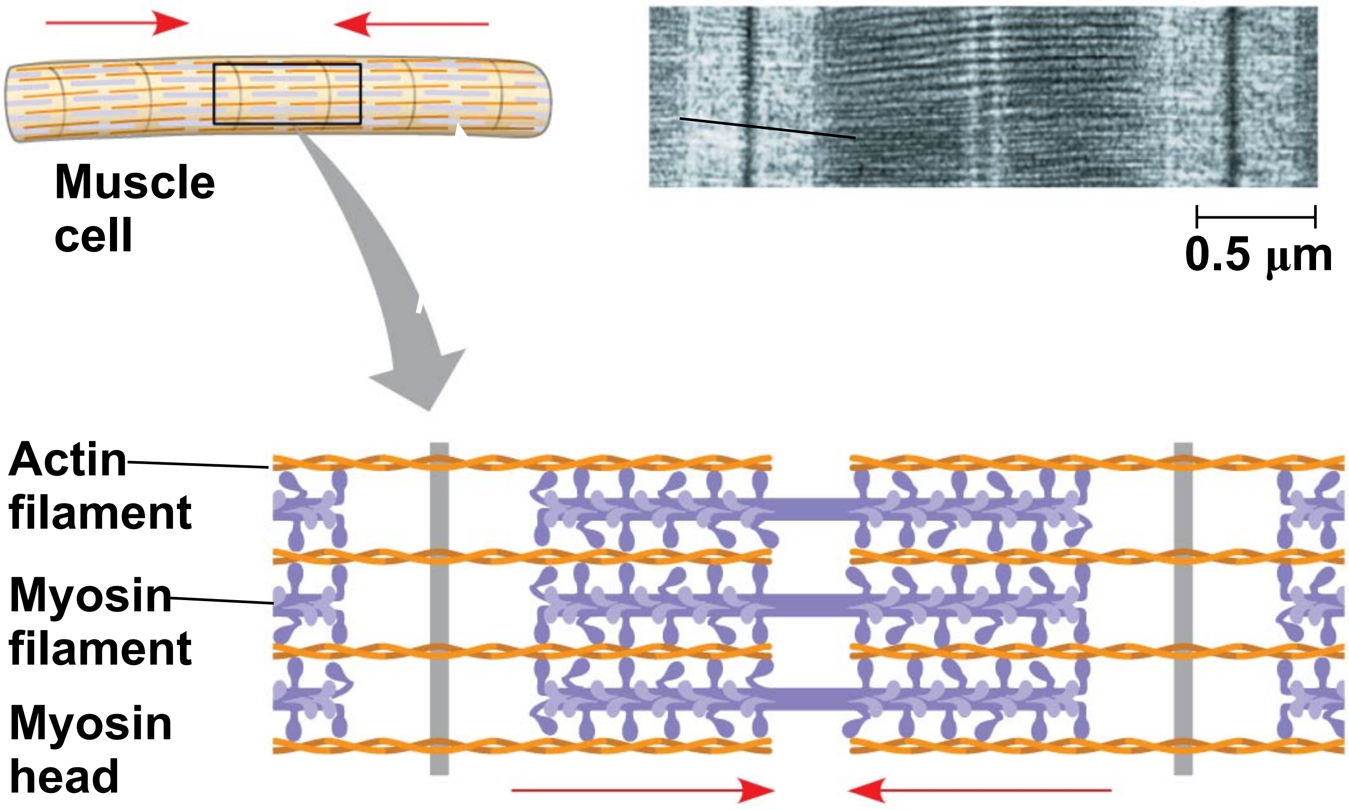
- **Microfilaments** are solid rods about 7 nm in diameter, built as a twisted double chain of **actin** subunits → a globular protein.
- A network of microfilaments helps support the cell's shape
- They form a **cortex** just inside the plasma membrane to help support the cell's shape
- Bundles of microfilaments make up the core of microvilli of intestinal cells

Figure 7.25


Microvillus
Plasma membrane
Microfilaments (actin filaments)
Intermediate filaments
0.25 µm

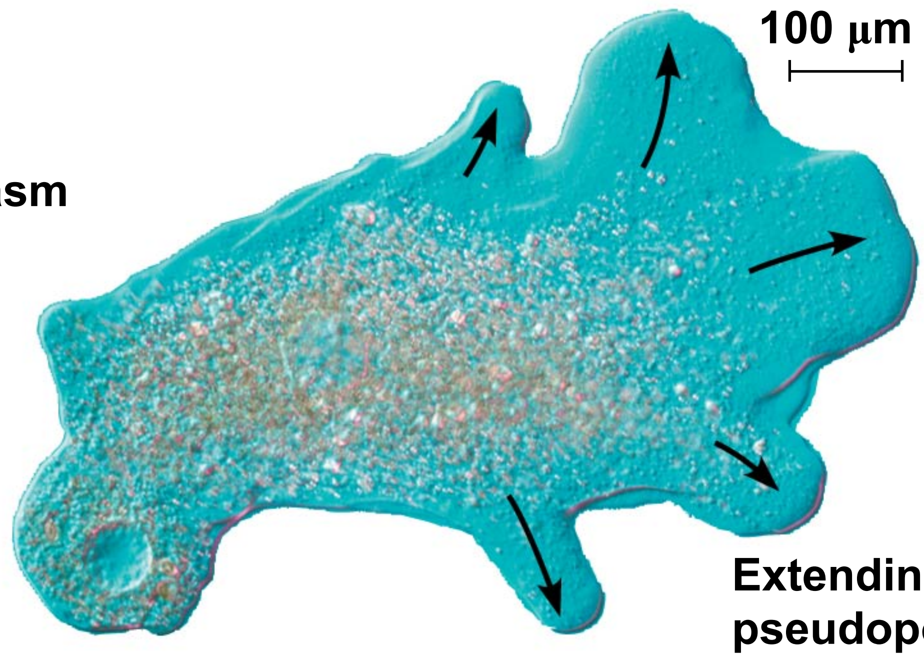
- Microfilaments that function in cellular motility contain the protein **myosin** in addition to actin
- Cells crawl along a surface by extending **pseudopodia** (cellular extensions) and moving toward them → amoebas and some white blood cells.
  "examples"
- **Cytoplasmic streaming** is a circular flow of cytoplasm within cells, driven by actin-myosin interactions

Figure 7.26a

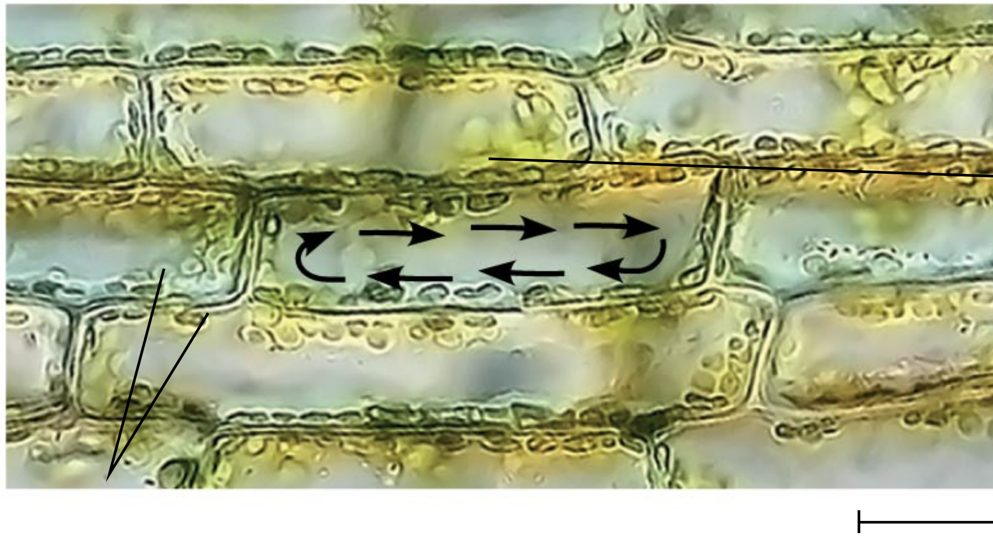



(a) Myosin motors in muscle cell contraction

Figure 7.26b




(b) Amoeboid movement




(c) Cytoplasmic streaming in plant cells

# ntermediate Filaments

multiple types of different protein subunits.

- **Intermediate filaments** range in diameter from 8 to 12 nanometers, larger than microfilaments but smaller than microtubules

  ① they make the nuclear lamina.

- Intermediate filaments are more permanent cytoskeleton fixtures than the other two classes
- They support cell shape and fix organelles in place

  Dead skin cells are mainly inter-- filaments.

  nuclei for example are caged.

While Microtubules and Microfilaments are found in all eukaryotic cells, intermediate filaments are in some animals, including vertebrates.

# Notes on 7.6:

* Cytoskeletons are more evident in animal cells as they lack cell walls.
* Motility = change in cell location and movement of internal structures.
* Fibroblasts are connective tissue cells favored for studies because of their flattened structure.

* Tubulins are globular proteins.
* "Primary cilium" is a signal-recieving "antenna" present in many cells, e.g., animals (vertebrates especially). → crucial to Brain function & embryonic development.

# oncept 7.7: Extracellular components and connections between cells help coordinate cellular activities

- Most cells synthesize and secrete materials that are external to the plasma membrane
- These extracellular materials and structures are involved in a great many cellular functions

# ell Walls of Plants

in plants, ranges from (0.1 → several) μm thickness.

- The **cell wall** is an extracellular structure that distinguishes plant cells from animal cells
- Prokaryotes, fungi, and some unicellular eukaryotes also have cell walls
- The cell wall protects the plant cell, maintains its shape, and prevents excessive uptake of water
- Plant cell walls are made of cellulose fibers embedded in other polysaccharides and protein

Cell walls are made of cellulose microfibrils embedded in extracellular space with proteins and other materials.

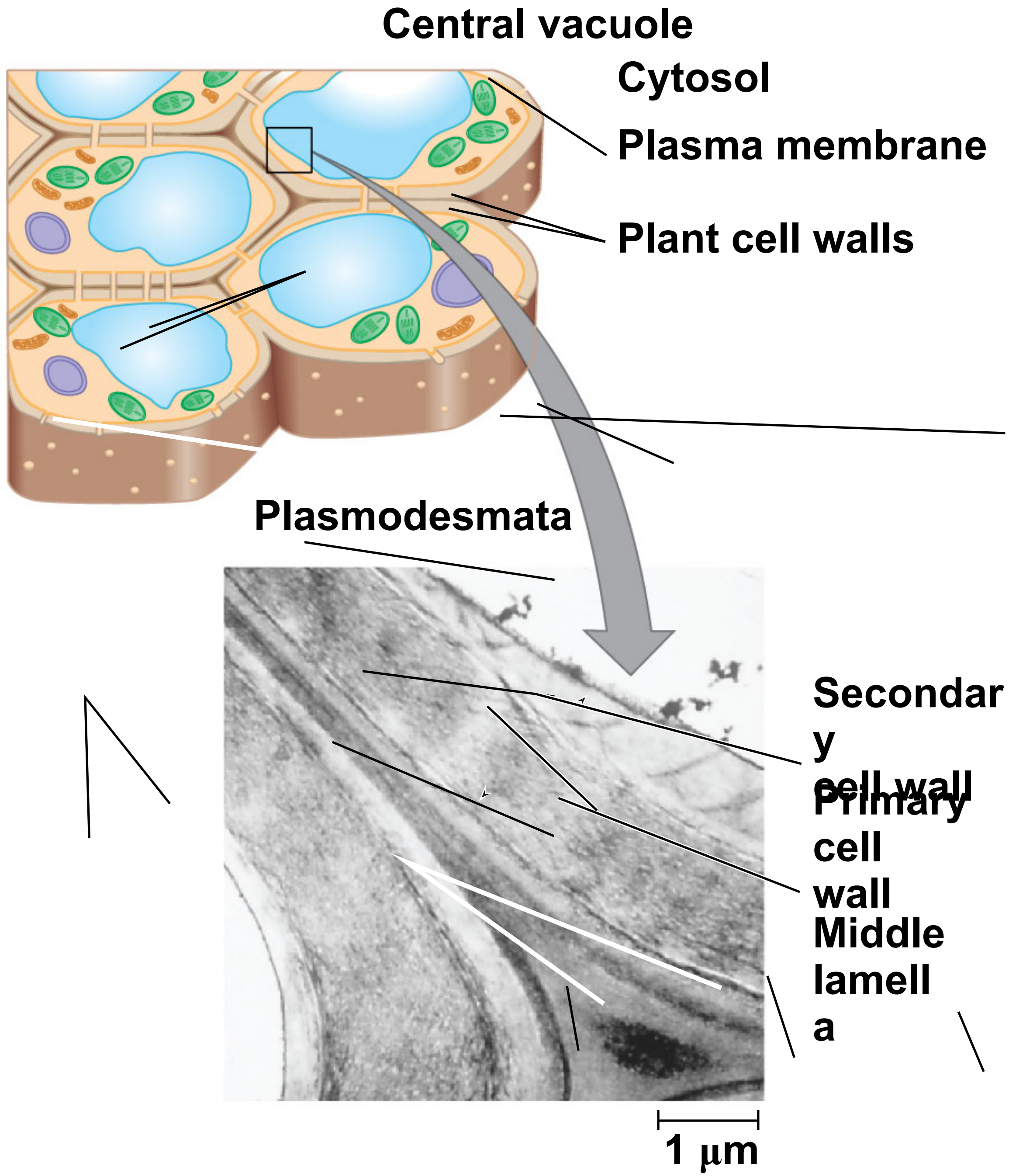
⊗ Some mature plants strengthen their walls by adding to its primary wall, others also adds a secondary wall.

- Plant cell walls may have multiple layers:
  - **Primary cell wall**: Relatively thin and flexible
  - **Middle lamella**: Thin layer between primary walls of adjacent cells
  - **Secondary cell wall** (in some cells): Added between the plasma membrane and the primary cell wall

⊗ Rich in Pectin (a sticky polysaccaride).

⊗ wood consists mainly of secondary walls.

Figure 7.27


Central vacuole
Cytosol
Plasma membrane
Plant cell walls
Plasmodesmata
Secondary cell wall
Primary cell wall
Middle lamella
1 μm

# he Extracellular Matrix (ECM) of Animal Cells

- Animal cells lack cell walls but are covered by an elaborate **extracellular matrix (ECM)**
- The ECM is made up of glycoproteins such as **collagen**, **proteoglycans**, and **fibronectin**
- ECM proteins bind to receptor proteins in the plasma membrane called **integrins**

→ 40% of protein in human body.

Figure 7.28

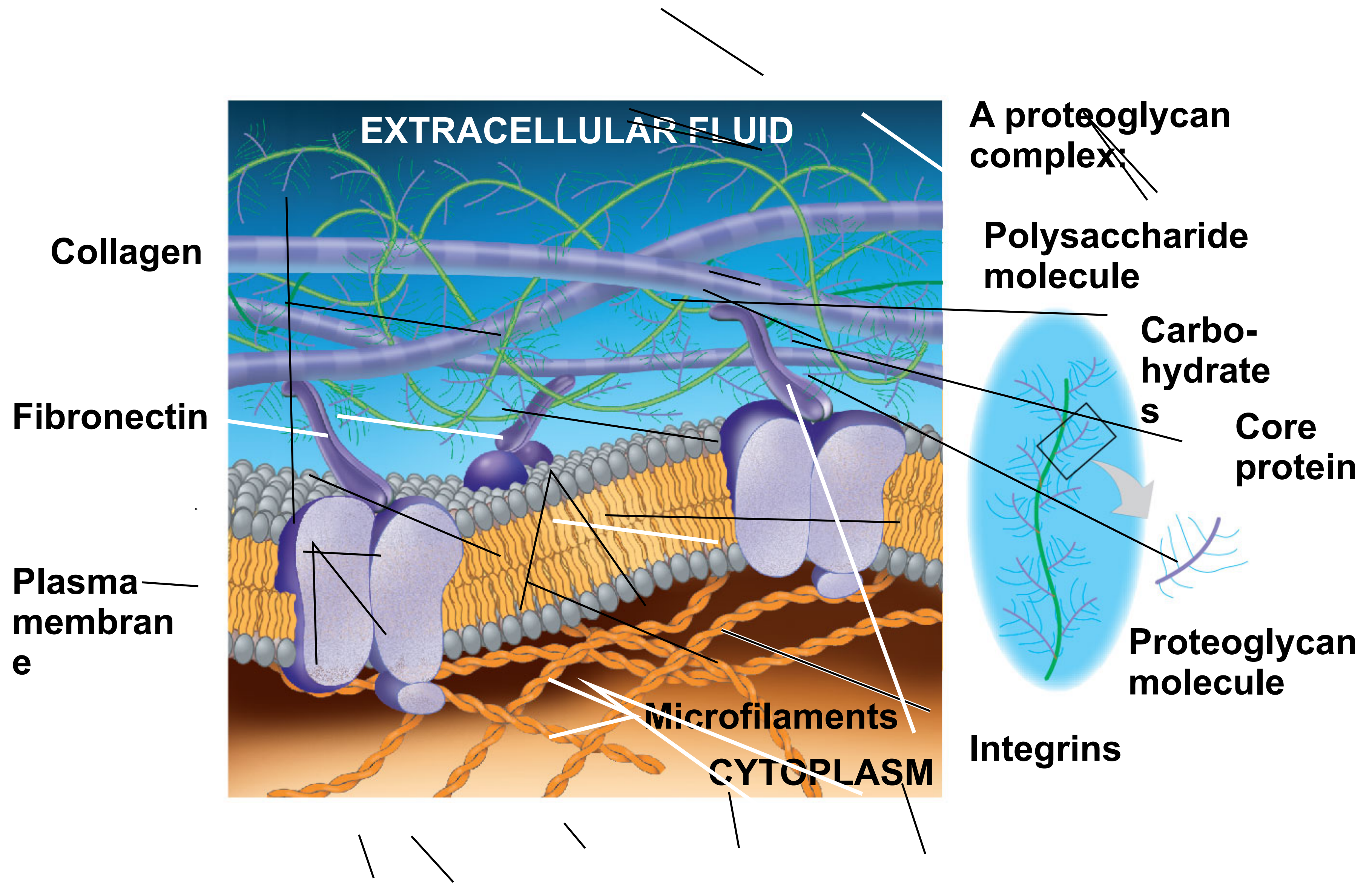
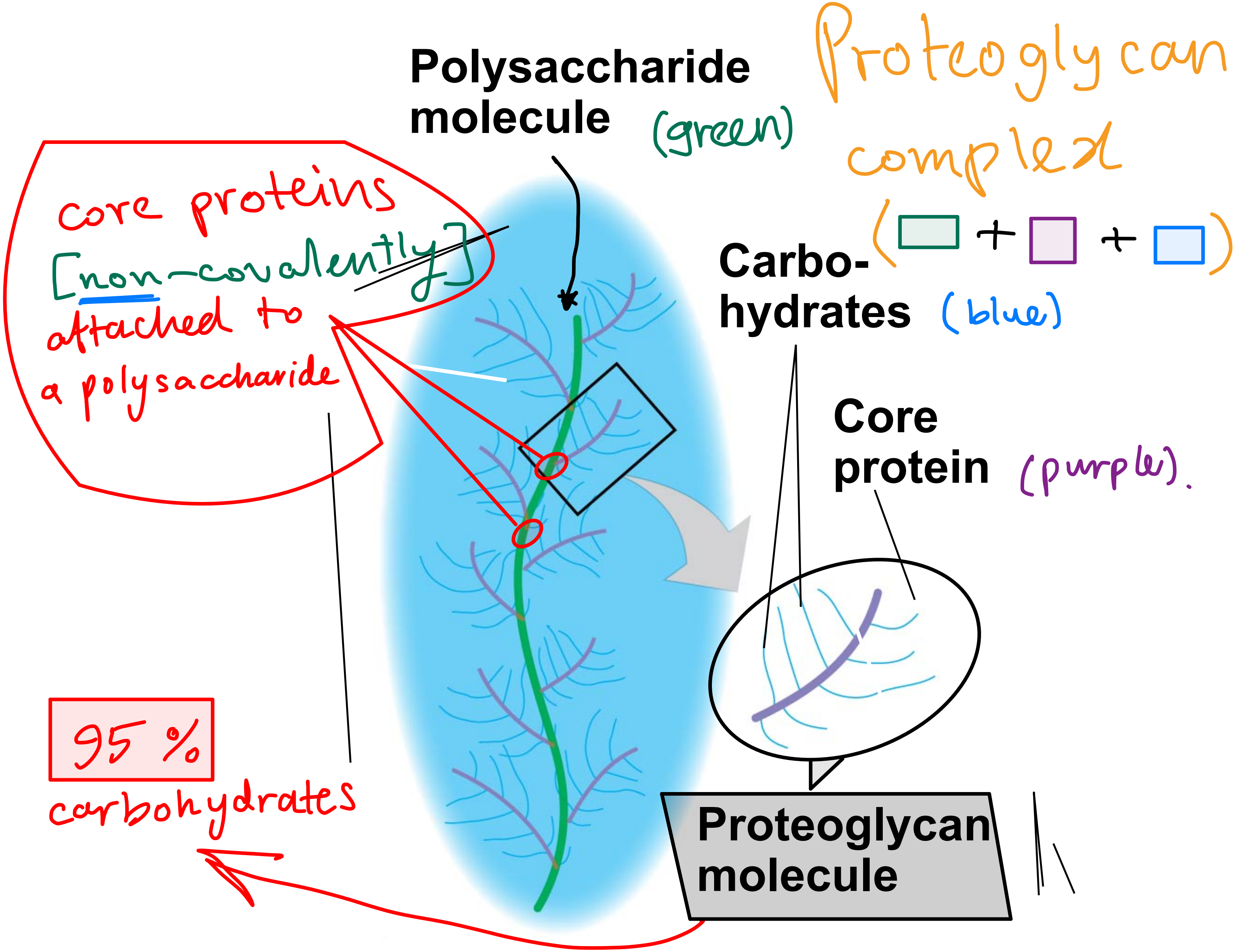

EXTRACELLULAR FLUID
A proteoglycan complex:
Polysaccharide molecule
Carbo-hydrates
Core protein
Proteoglycan molecule
Collagen
Fibronectin
Plasma membrane
Microfilaments
CYTOPLASM
Integrins

Figure 7.28a



Polysaccharide molecule
(green)
Proteoglycan complex
( + + ).
core proteins [non-covalently] attached to a polysaccharide
Carbo-hydrates
(blue)
Core protein
(purple).
95 %
carbohydrates
Proteoglycan molecule

- The ECM has an influential role in the lives of cells
- ECM can regulate a cell's behavior by communicating with a cell through integrins
- The ECM around a cell can influence the activity of gene in the nucleus
- Mechanical signaling may occur through cytoskeletal changes that trigger chemical signals in the cell

Integrins bind to : [connect the cell with the outside]

① fibronectins in the ECM.

② Microfilaments in the cytoplasmic side.

# ell Junctions

- Neighboring cells in tissues, organs, or organ systems often adhere, interact, and communicate through direct physical contact

# lasmodesmata in Plant Cells

singular : plasmodesma.

- **Plasmodesmata** are channels that perforate plant cell walls
- Through plasmodesmata, water and small solutes (and sometimes proteins and RNA) can pass from cell to cell

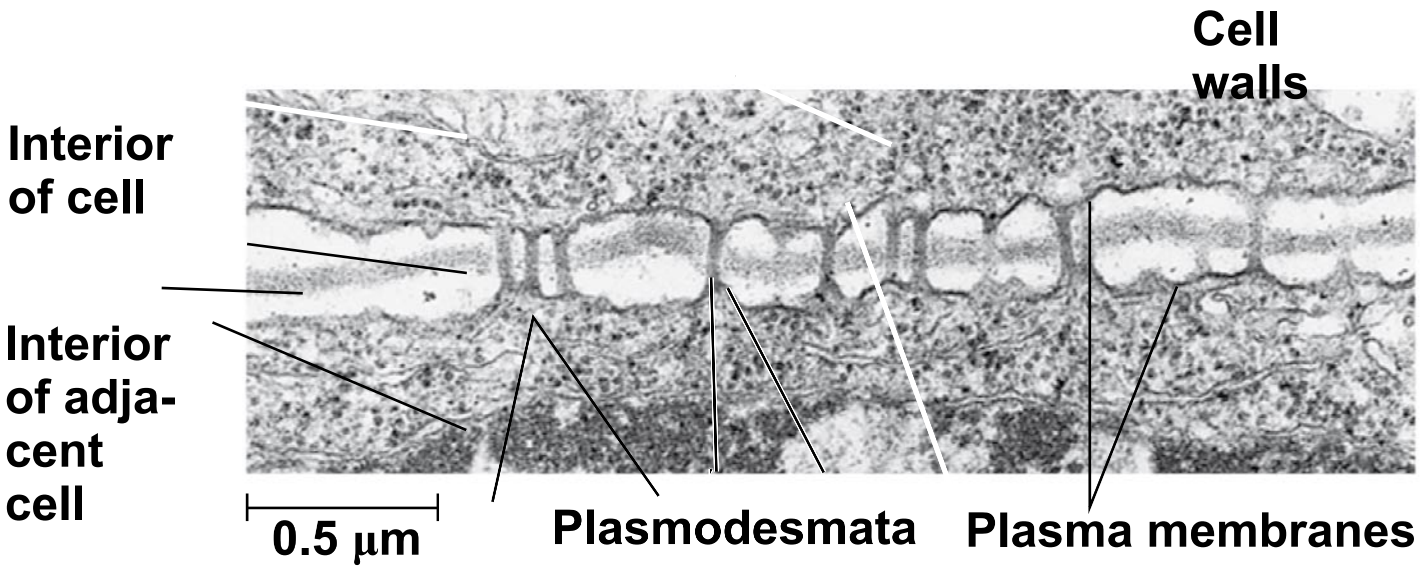
they are lined with plasmamembrane.

continuous cells

share the same chemical environment.

Macromolecules reach the plasmodesmata by fibers of cytoskeleton.

Figure 7.29



Cell walls
Interior of cell
Interior of adja-cent cell
0.5 µm
Plasmodesmata
Plasma membranes

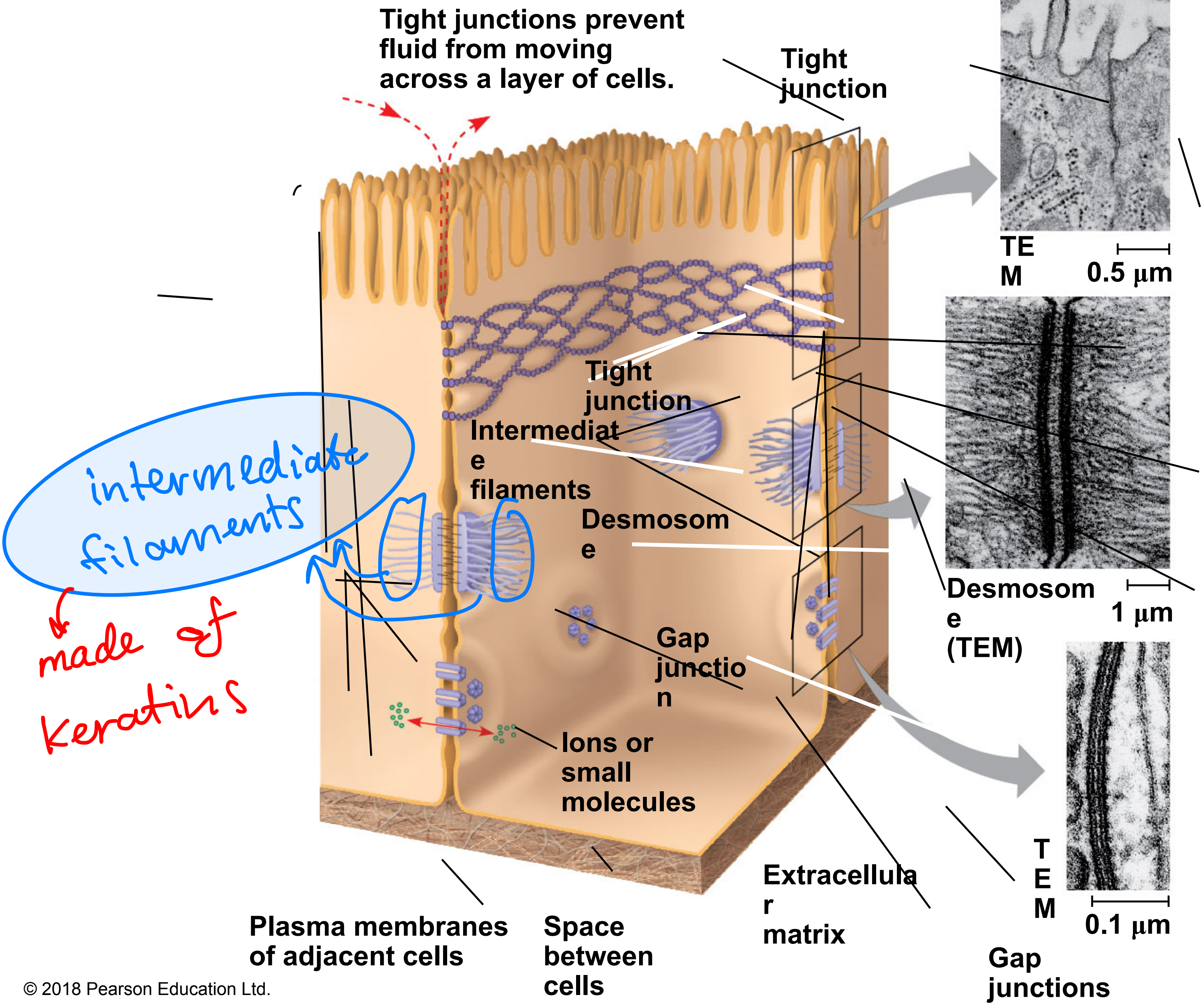
# ight Junctions, Desmosomes, and Gap Junctions in Animal Cells

- Three types of cell junctions are common in epithelial tissues
  skin cells e.g. makes us watertight.
  - At tight junctions, membranes of neighboring cells are pressed together, preventing leakage of extracellular fluid
    by specific proteins
  - Desmosomes (anchoring junctions) fasten cells together into strong sheets
    are anchored (themselves) by intermediate filaments
  - Gap junctions (communicating junctions) provide cytoplasmic channels between adjacent cells
    necessary for some tissues; such as heart & in embryos.

desmosomes connect muscle cells together.

"muscle tear" involves desmosome rupture.

Figure 7.30



Tight junctions prevent fluid from moving across a layer of cells.
Tight junction
TEM
0.5 µm
Tight junction
Intermediate filaments
Desmosome
Desmosome (TEM)
1 µm
Gap junction
Ions or small molecules
Extracellular matrix
TEM
0.1 µm
Gap junctions
Plasma membranes of adjacent cells
Space between cells
intermediate filaments
made of keratins

# oncept 7.8: A cell is greater than the sum of its parts

- Cells rely on the integration of structures and organelles in order to function
- For example, a macrophage’s ability to destroy bacteria involves the whole cell, coordinating components such as the cytoskeleton, lysosomes, and plasma membrane

Figure 7.31

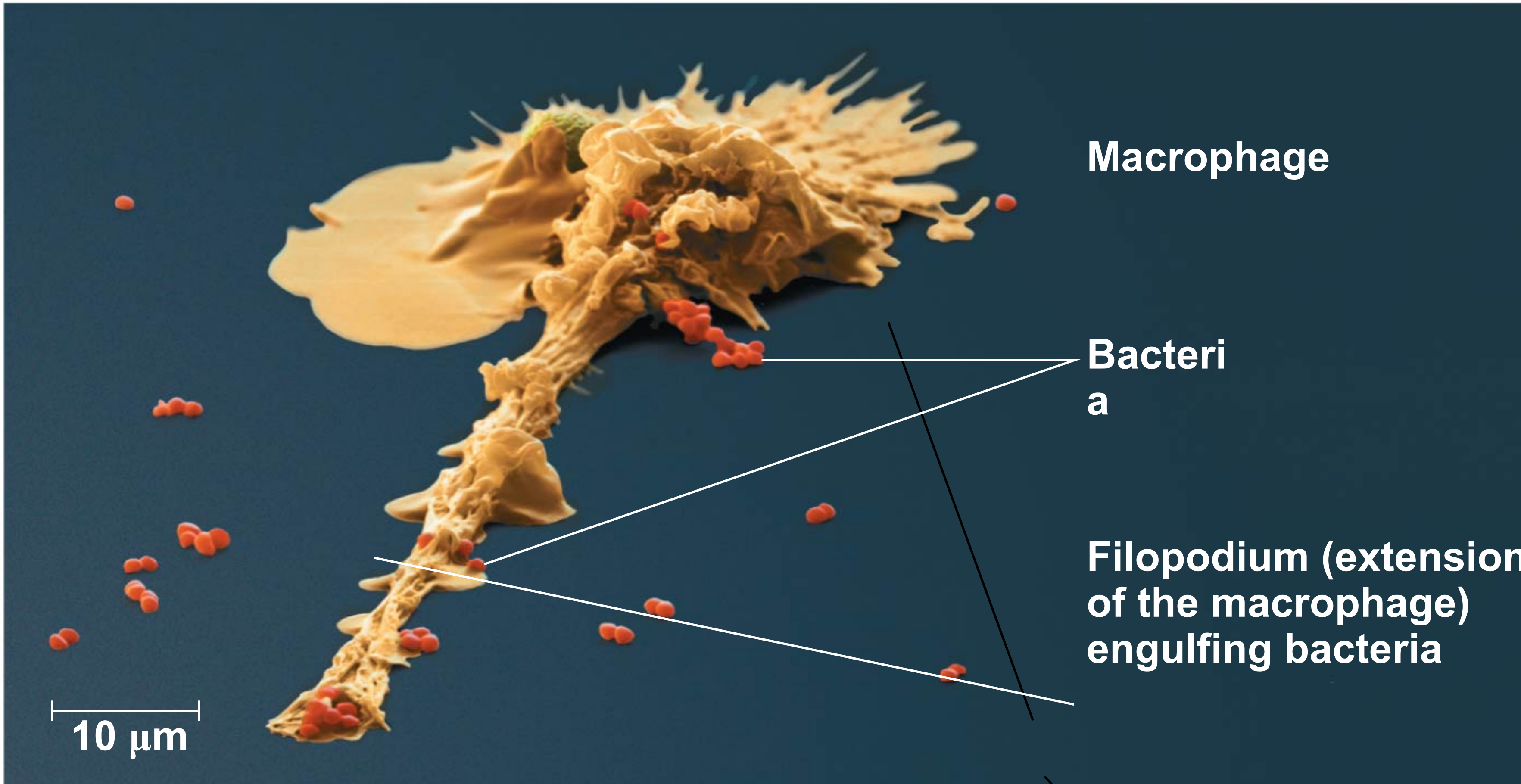
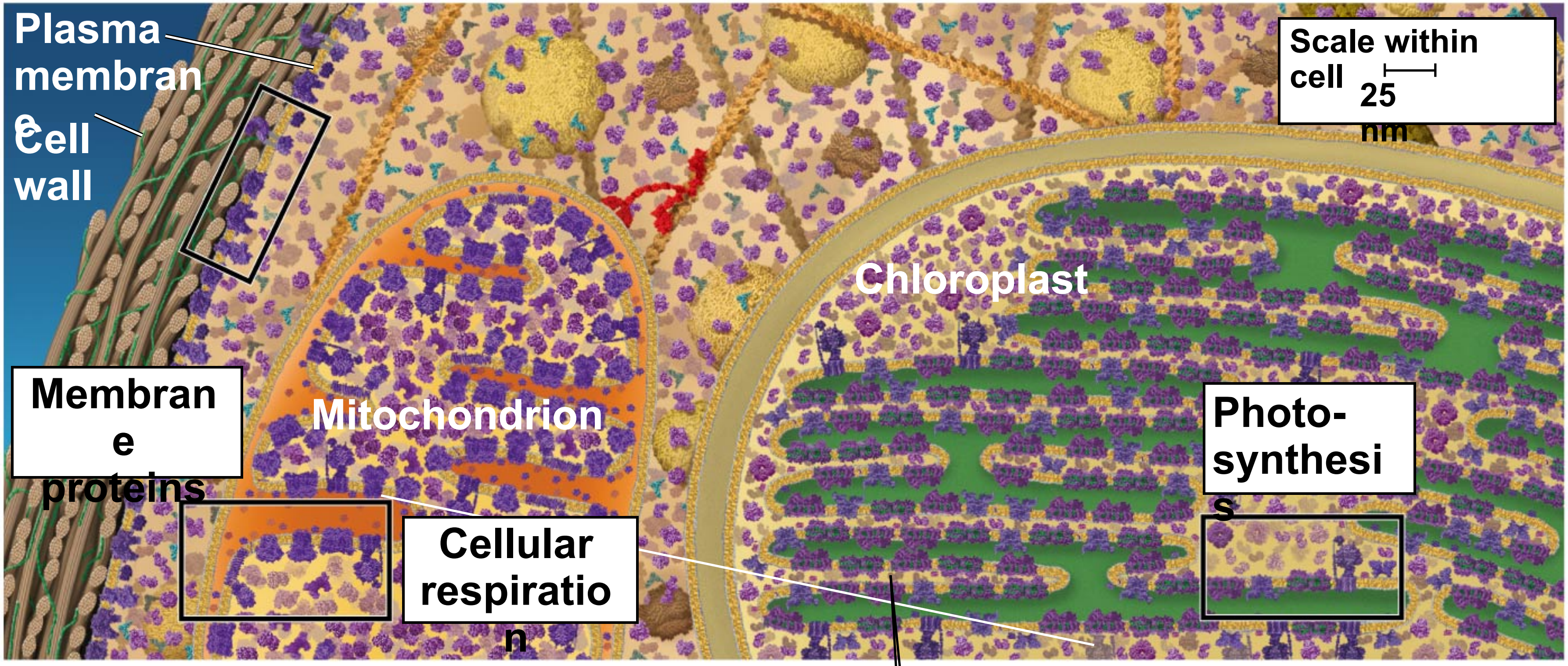
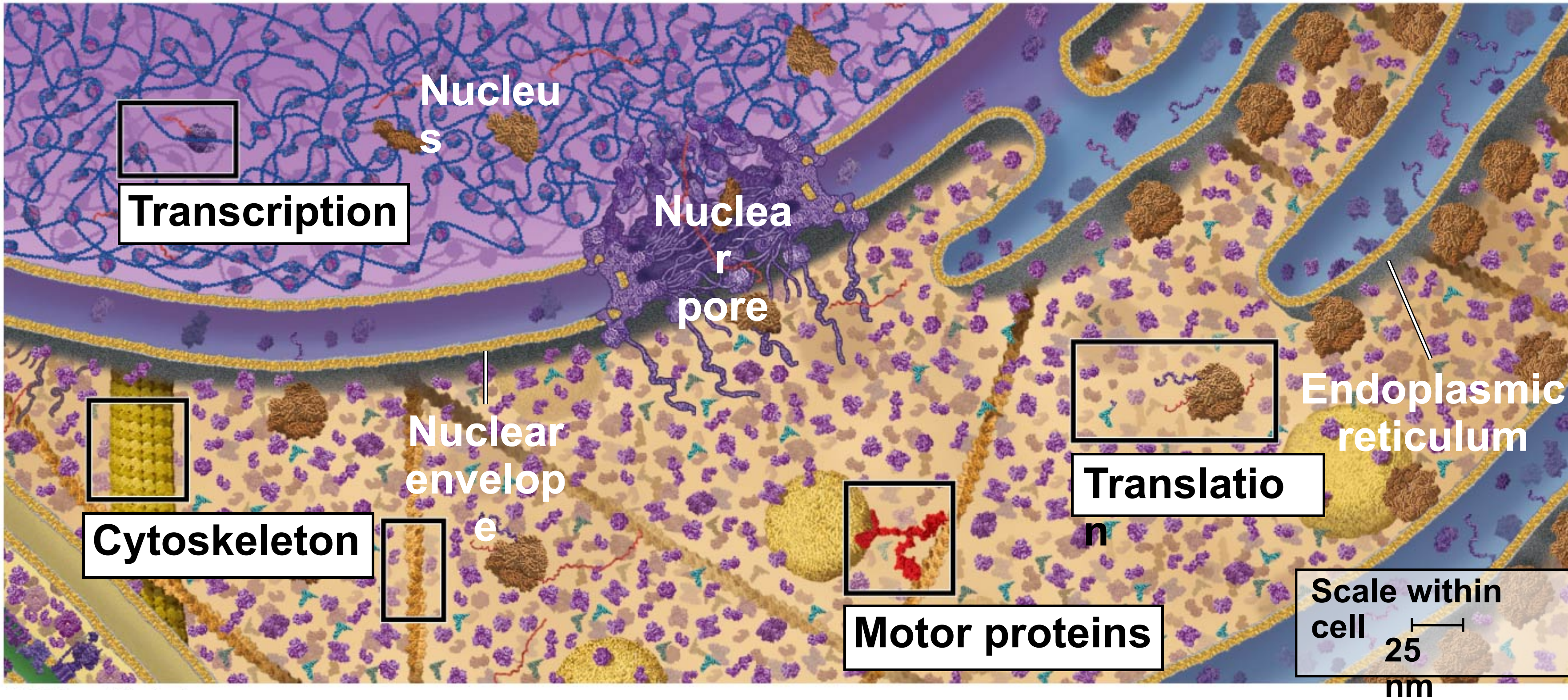

Macrophage
Bacteri
a
Filopodium (extension
of the macrophage)
engulfing bacteria
10 µm

Figure 7.32a



Plasma membrane
Cell wall
Scale within cell
25 nm
Chloroplast
Mitochondrion
Membrane proteins
Cellular respiration
Photo-synthesis

Figure 7.32b



Nucleu
s
Transcription
Nuclea
r
pore
Nuclear
envelop
e
Cytoskeleton
Endoplasmic
reticulum
Translatio
n
Motor proteins
Scale within
cell
25
nm

Figure 7.32c

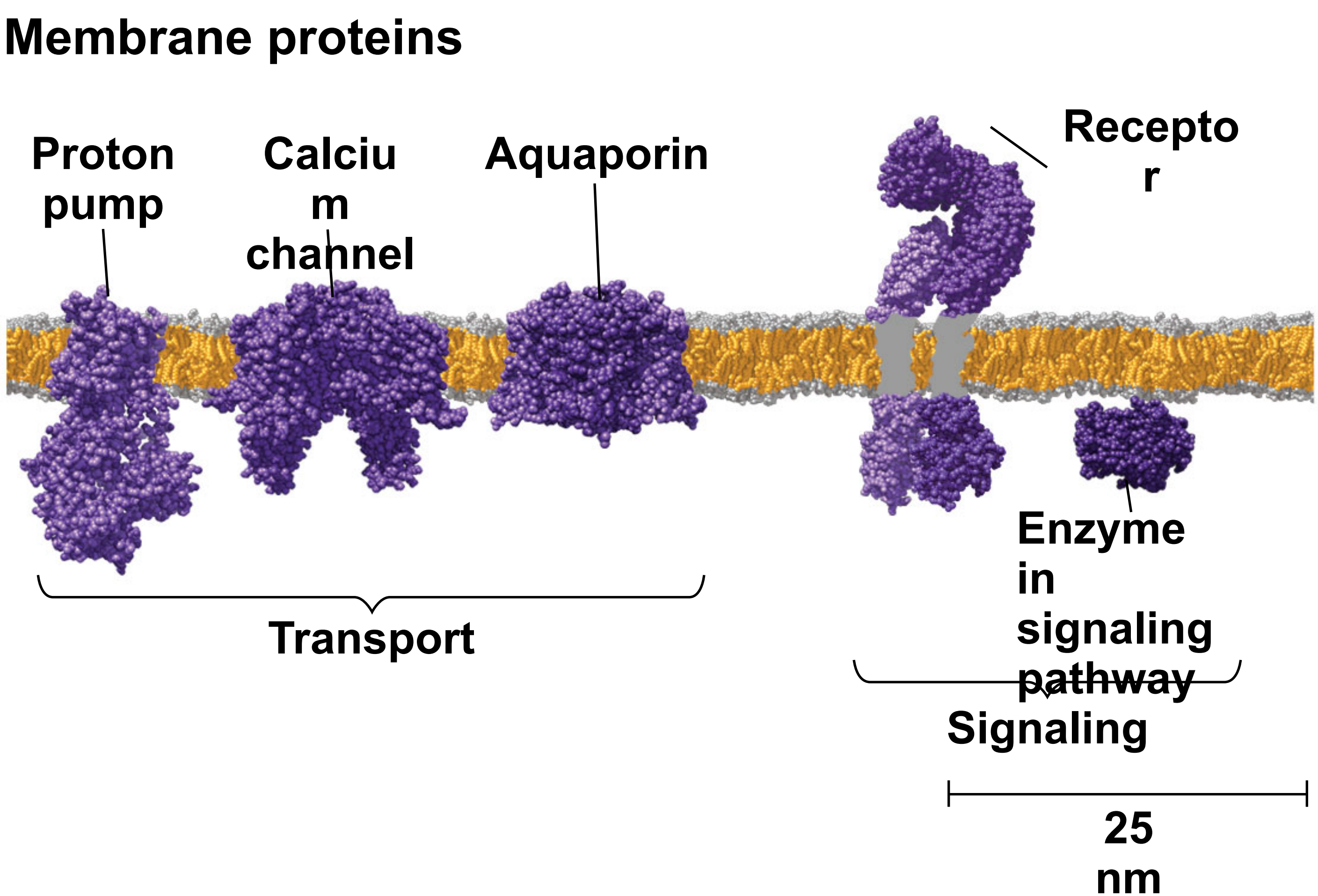

Membrane proteins
Proton pump
Calcium channel
Aquaporin
Receptor
Enzyme in signaling pathway
Transport
Signaling
25 nm

Figure 7.32d

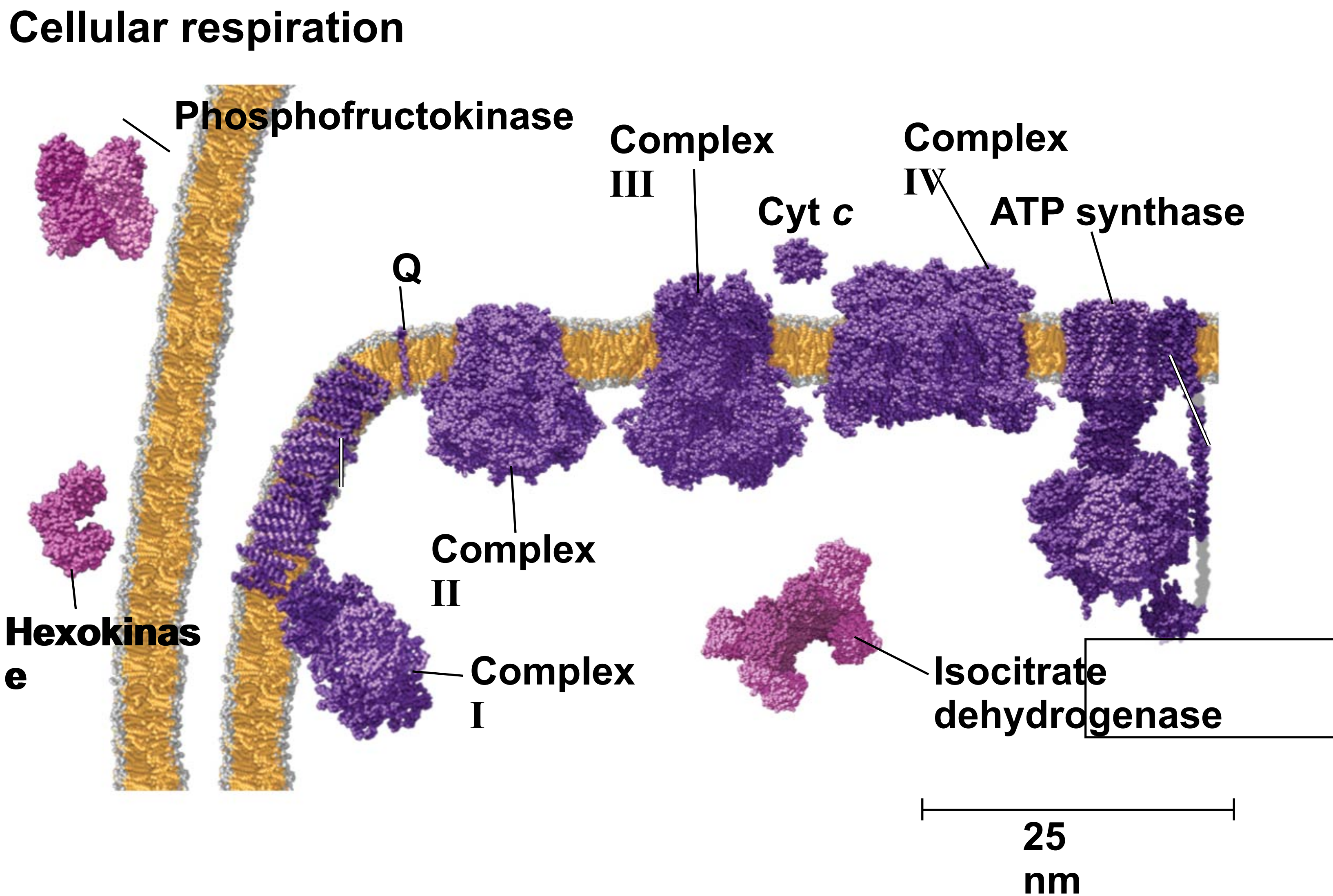
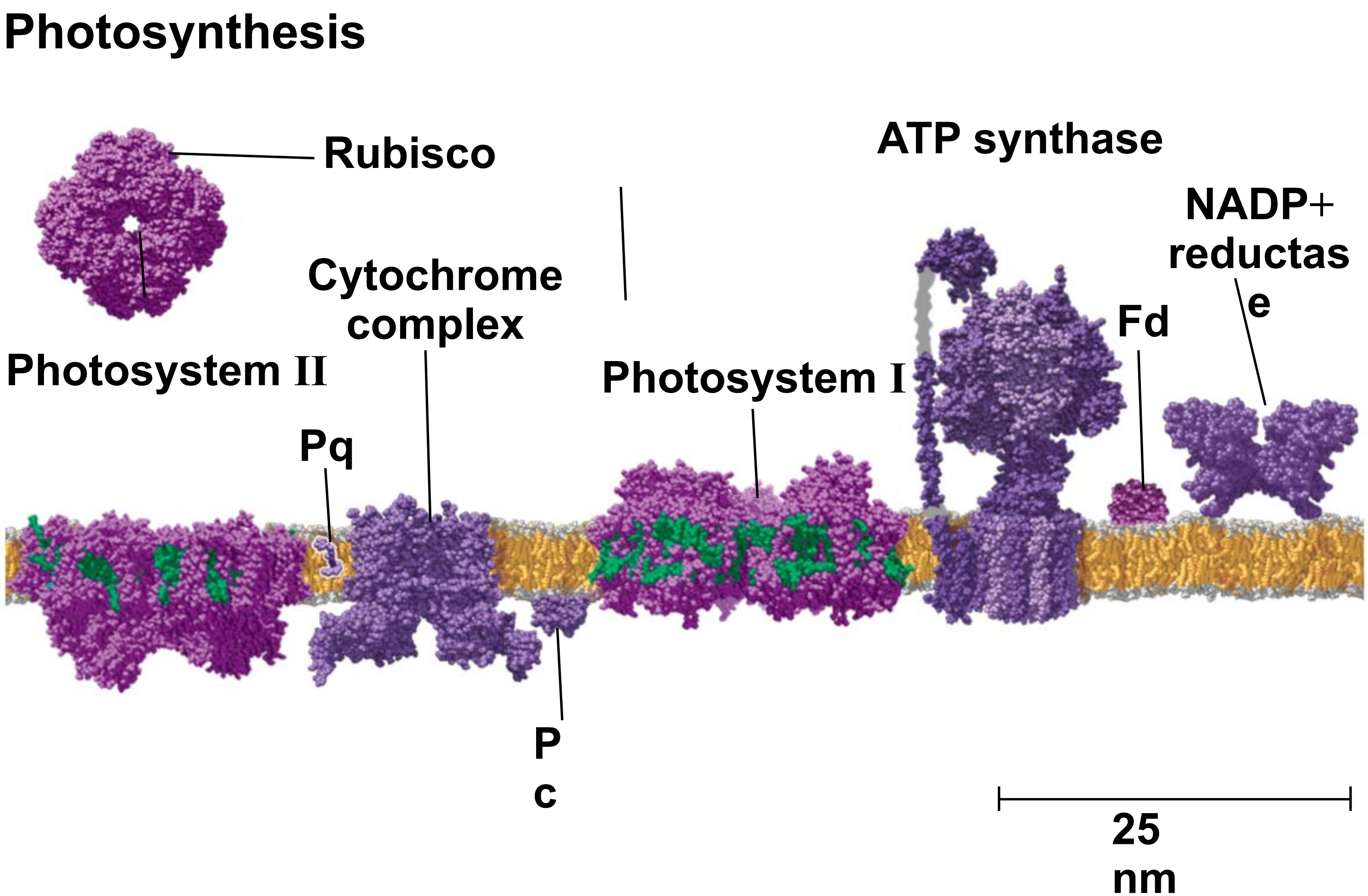
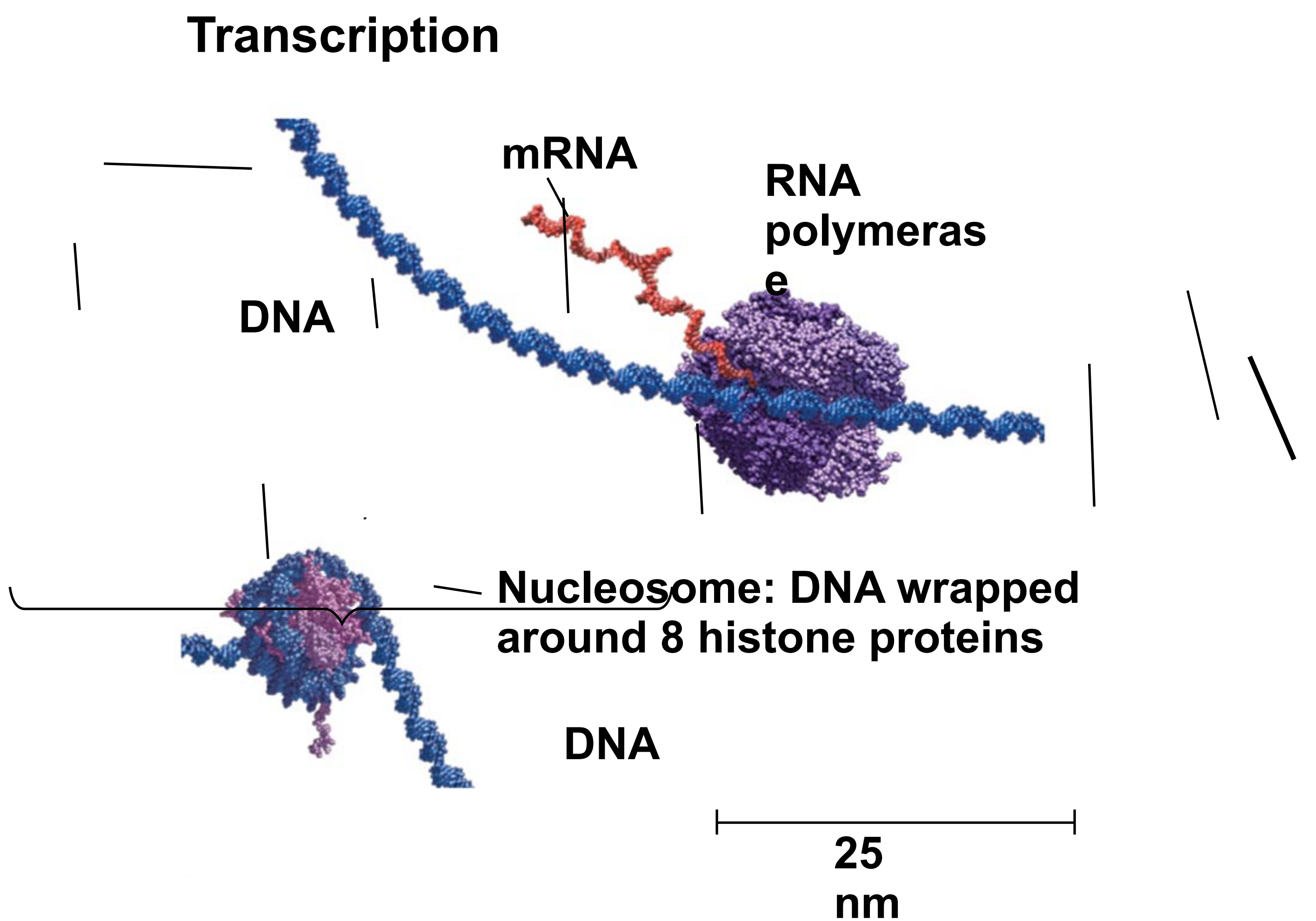

Cellular respiration
Phosphofructokinase
Complex III
Cyt c
Complex IV
ATP synthase
Q
Complex II
Hexokinase
Complex I
Isocitrate dehydrogenase
25 nm

Figure 7.32e


Photosynthesis
Rubisco
ATP synthase
NADP+
reductas
e
Cytochrome
complex
Fd
Photosystem II
Photosystem I
Pq
P
c
25
nm


Transcription
mRNA
RNA
polymeras
e
DNA
Nucleosome: DNA wrapped
around 8 histone proteins
DNA
25
nm

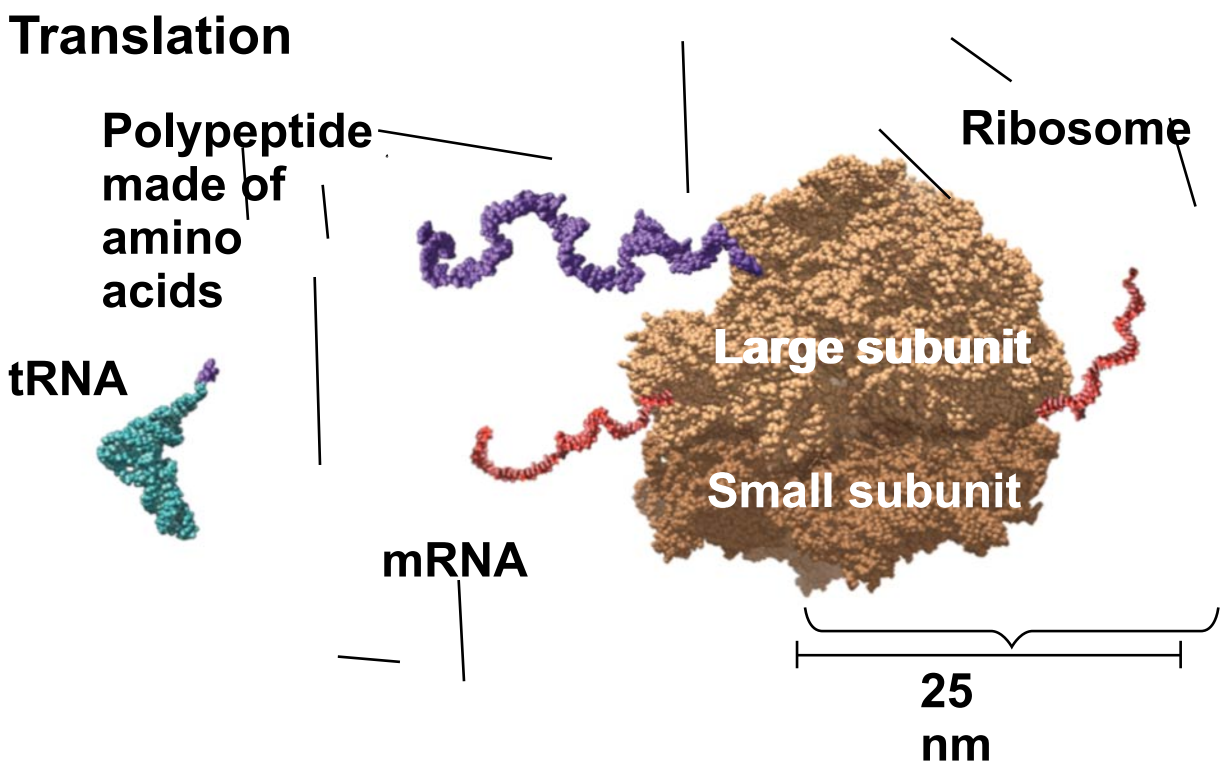

Translation
Polypeptide made of amino acids
Ribosome
tRNA
Large subunit
Small subunit
mRNA
25 nm

Figure 7.32h

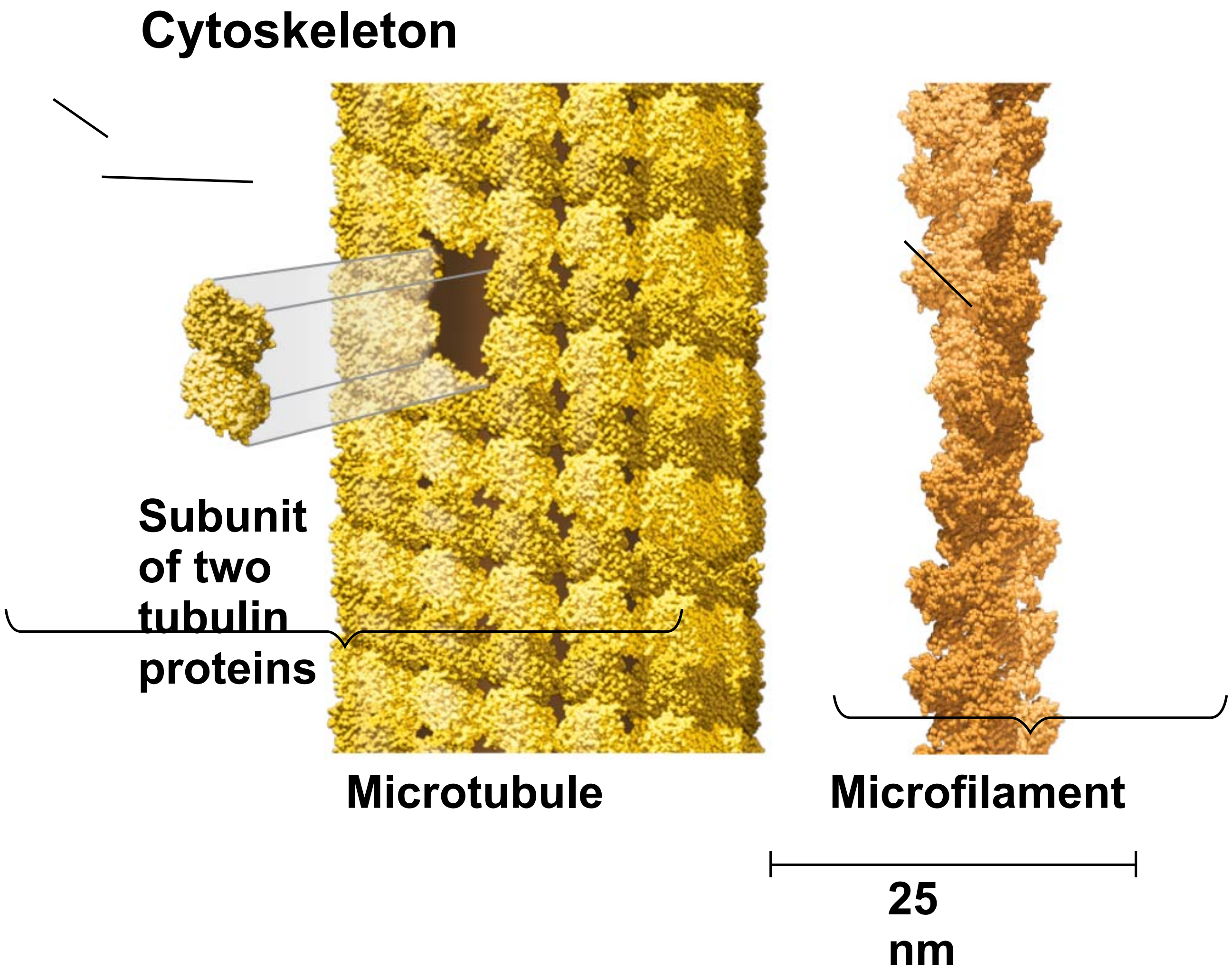

Cytoskeleton
Subunit of two tubulin proteins
Microtubule
Microfilament
25 nm

Figure 7.32i

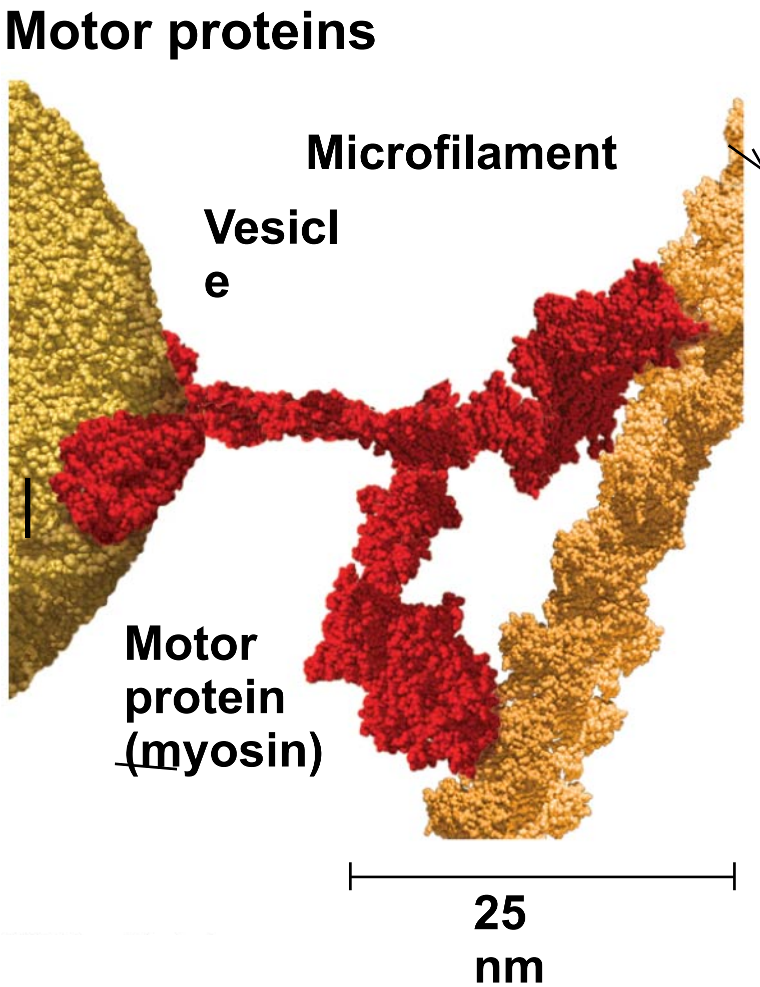

Motor proteins
Microfilament
Vesicl
e
Motor
protein
(myosin)
25
nm

Figure 7.UN03

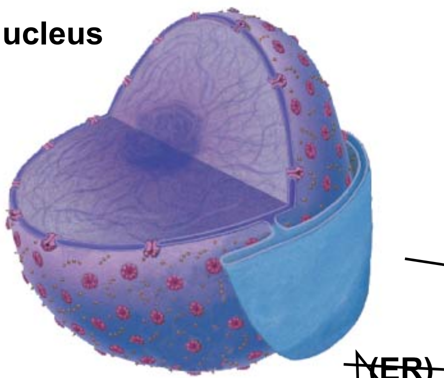
| Cell Component | Structure | Function |
|---|---|---|
| Nucleus   | Surrounded by nuclear envelope (double membrane) perforated by nuclear pores; nuclear envelope continuous with endoplasmic reticulum (ER) | Houses chromosomes, which are made of chromatin (DNA and proteins); contains nucleoli, where ribosomal subunits are made; pores regulate entry and exit of materials |
| Ribosome  | Two subunits made of ribosomal RNAs and proteins; can be free in cytosol or bound to ER | Protein synthesis |

Figure 7.UN04

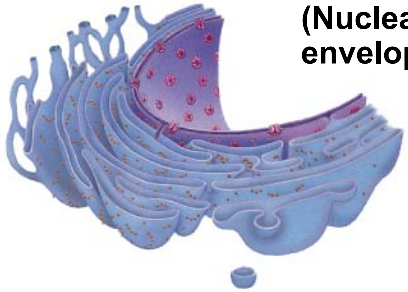
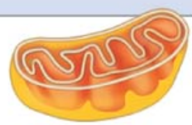
| Cell Component | Structure | Function |
|---|---|---|
| Endoplasmic reticulum (ER)   | Extensive network of membrane-bounded tubules and sacs; membrane separates lumen from cytosol; continuous with nuclear envelope | Smooth ER: synthesis of lipids, metabolism of carbohydrates, Ca2+ storage, detoxification of drugs and poisons<br>Rough ER: aids in synthesis of secretory and other proteins on bound ribosomes; adds carbohydrates to proteins to make glycoproteins; produces new membrane |
| Golgi apparatus  | Stacks of flattened membranous sacs; has polarity (*cis* and *trans* faces) | Modification of proteins, carbohydrates on proteins, and phospholipids; synthesis of many polysaccharides; sorting of Golgi products, which are then released In vesicles |
| Lysosome  | Membranous sac of hydrolytic enzymes (in animal cells) | Breakdown of ingested substances, cell macromolecules, and damaged organelles for recycling |
| Vacuole  | Large membrane-bounded vesicle | Digestion, storage, waste disposal, water balance, cell growth, and protection |

Figure 7.UN05

| Cell Component | Structure | Function |
|---|---|---|
| Mitochondrion  | Bounded by double membrane; inner membrane has infoldings | Cellular respiration |
| Chloroplast  | Typically two membranes around fluid stroma, which contains thylakoids stacked into grana | Photosynthesis (chloroplasts are in cells of photosynthetic eukaryotes, Including plants) |
| Peroxisome  | Specialized metabolic compartment bounded by a single membrane | Contains enzymes that transfer H atoms from substrates to oxygen, producing H2O2 (hydrogen peroxide), which is converted to H2O. |