Modern Cell Theory

- All organisms composed of cells and cell products.
- Cell is the simplest structural and functional unit of life.
  - cells are alive
- An organism's structure and functions are due to the activities of its cells.
- Cells come only from preexisting cells, not from nonliving matter.
  - therefore, all life traces its ancestry to the same original cells
- Cells of all species have many fundamental similarities in their chemical composition and metabolic mechanisms.

Cell Shapes

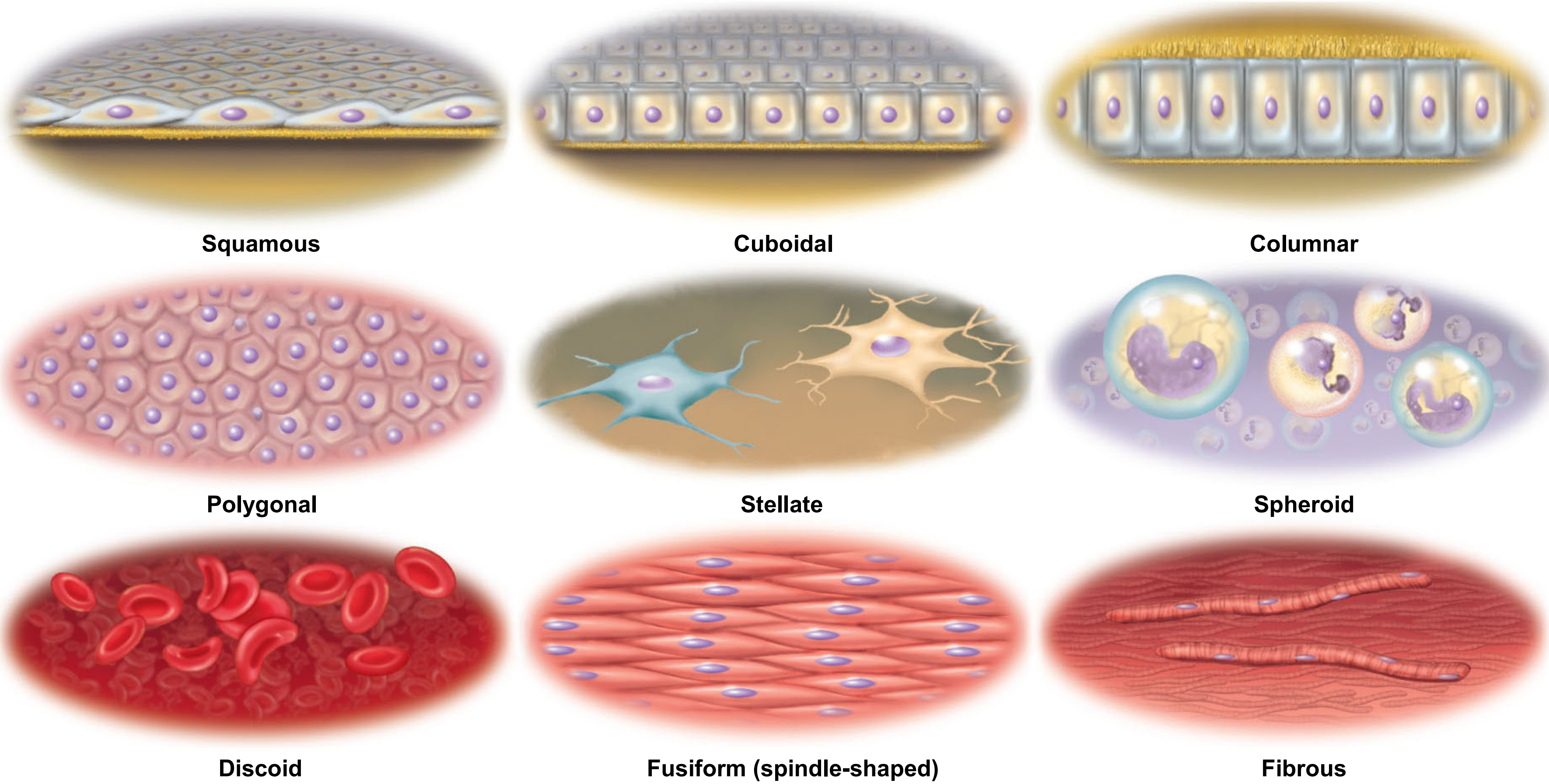


Figure 3.1

Cell Size

- Human cell size
  - 10 - 15 micrometers (μm) in diameter
    - egg cells (very large)100 μm diameter
      - barely visible to the naked eye
    - nerve cell at 1 meter long
- Limitations on cell size
  - cell growth increases volume more than surface area
    - nutrient absorption and waste removal utilize surface area

General Cell Structure

- Light microscope reveals plasma membrane, nucleus and cytoplasm
  - **cytoplasm** – fluid between the nucleus and surface membrane
- **Resolution** (ability to reveal detail) of electron microscopes reveals **ultrastructure**
  - **organelles, cytoskeleton and cytosol (ICF)**

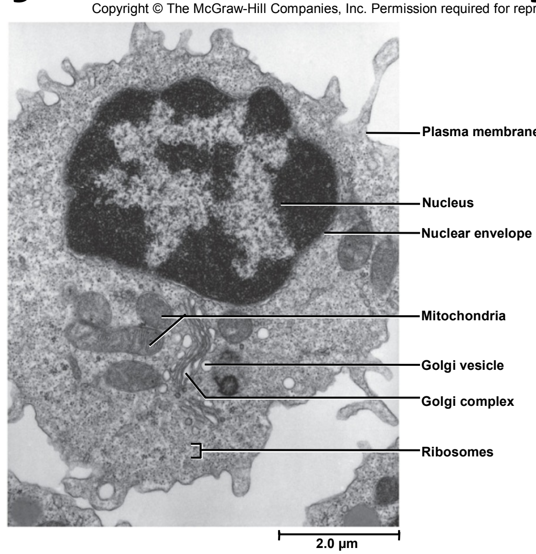
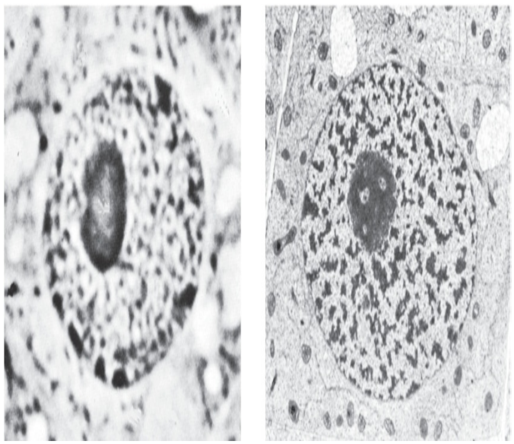


Figure 3.3

Magnification versus Resolution



(a) Light microscope (LM)

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Figure 3.4a

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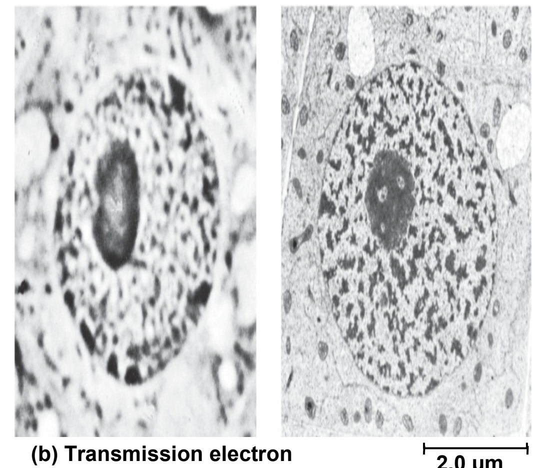

(b) Transmission electron microscope (TEM)

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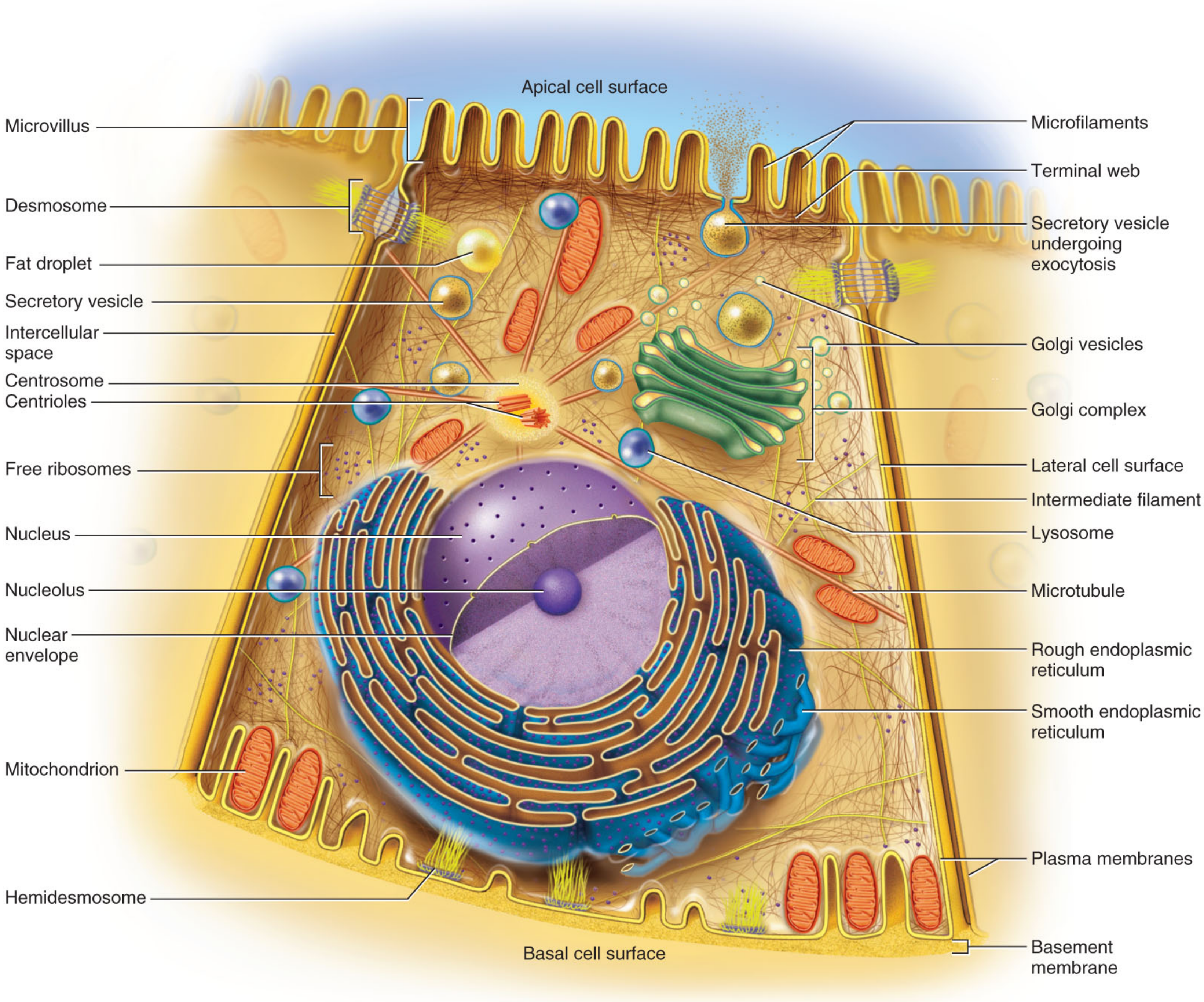
Figure 3.4b

- **Magnification** of 750x seen through both light and transmission electron microscope

- Increased **resolution** reveals the finer details

Major Constituents of Cell

- **plasma (cell) membrane**
  - surrounds cell
  - made of proteins and lipids
  - composition and function can vary from one region of the cell to another
- **cytoplasm**
  - organelles
  - cytoskeleton
  - cytosol (**intracellular fluid - ICF**)
- **extracellular fluid – ECF**
  - fluid outside of cell



Apical cell surface
Microvillus
Desmosome
Fat droplet
Secretory vesicle
Intercellular space
Centrosome
Centrioles
Free ribosomes
Nucleus
Nucleolus
Nuclear envelope
Mitochondrion
Hemidesmosome
Basal cell surface
Microfilaments
Terminal web
Secretory vesicle undergoing exocytosis
Golgi vesicles
Golgi complex
Lateral cell surface
Intermediate filament
Lysosome
Microtubule
Rough endoplasmic reticulum
Smooth endoplasmic reticulum
Plasma membranes
Basement membrane

Plasma Membrane

plasma membrane – membrane at cell surface

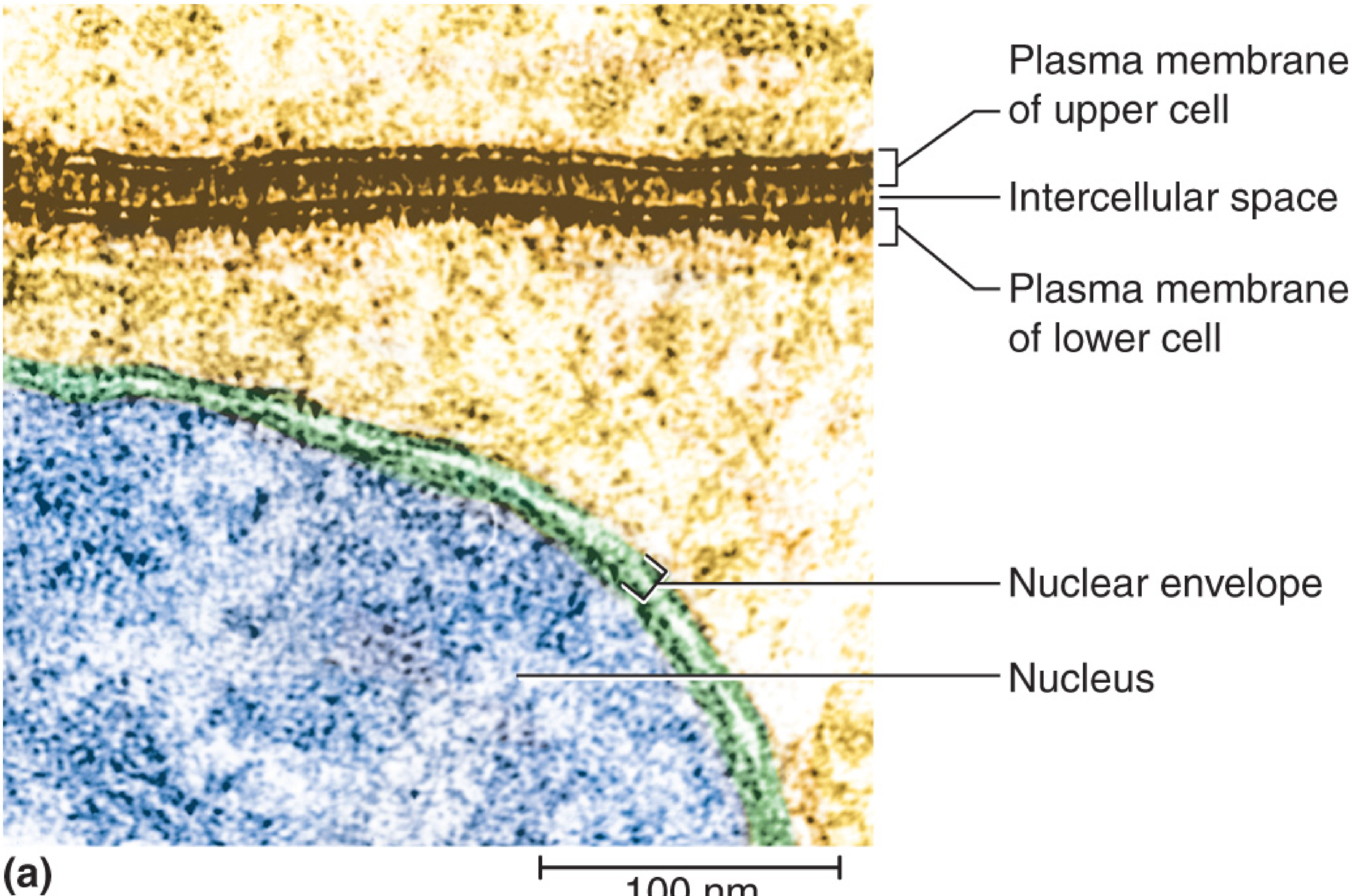
-defines cell boundaries

-governs interactions with other cells

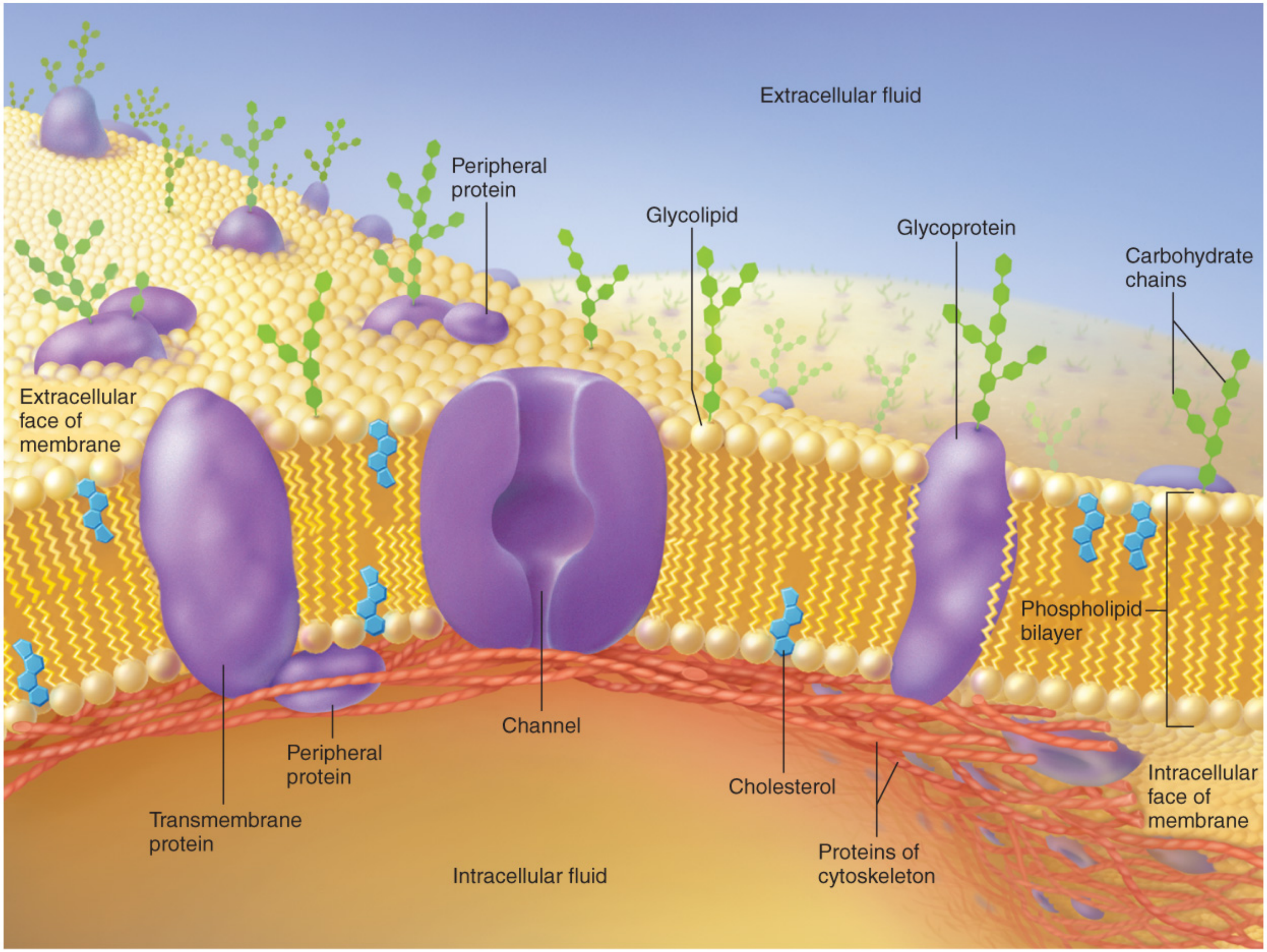
-controls passage of materials in and out of cell

-**intracellular face** – side that faces cytoplasm

-**extracellular face** – side that faces outward


Plasma membrane of upper cell
Intercellular space
Plasma membrane of lower cell
Nuclear envelope
Nucleus
(a)
100 nm

Plasma Membrane



(b)

- Oily film of lipids with diverse proteins embedded

Membrane Lipids

- **Phospholipids**
  - 75% of membrane lipids are phospholipids
  - **amphiphilic** molecules arranged in a bilayer
    - **hydrophilic** phosphate heads face water on each side of membrane
    - **hydrophobic** tails – directed toward the center, avoiding water
  - drift laterally from place to place
  - movement keeps membrane fluid
- **Cholesterol**
  - 20% of the membrane lipids
  - holds phospholipids still and can stiffen membrane
- **Glycolipids**
  - 5% of the membrane lipids
  - phospholipids with short carbohydrate chains on extracellular face
  - contributes to **glycocalyx** – carbohydrate coating on the cells surface

Membrane Proteins

- **Membrane proteins**
  - **2%** of the molecules in plasma membrane
  - **50%** of its weight
- **Transmembrane proteins**
  - pass through membrane
  - have hydrophilic regions in contact with cytoplasm and extracellular fluid
  - have hydrophobic regions that pass back and forth through the lipid of the membrane
  - most are glycoproteins
  - can drift about freely in phospholipid film
  - some anchored to cytoskeleton
- **Peripheral proteins**
  - adhere to one face of the membrane
  - usually tethered to the cytoskeleton

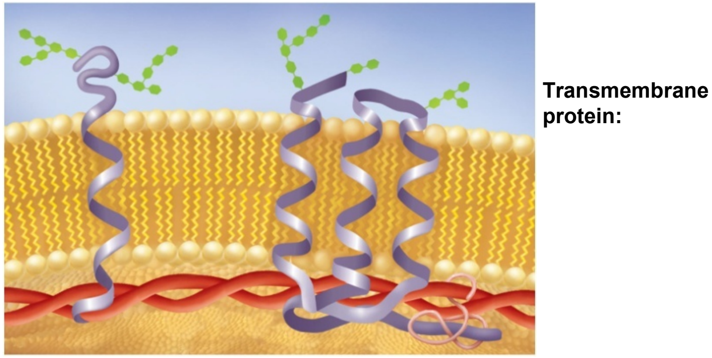
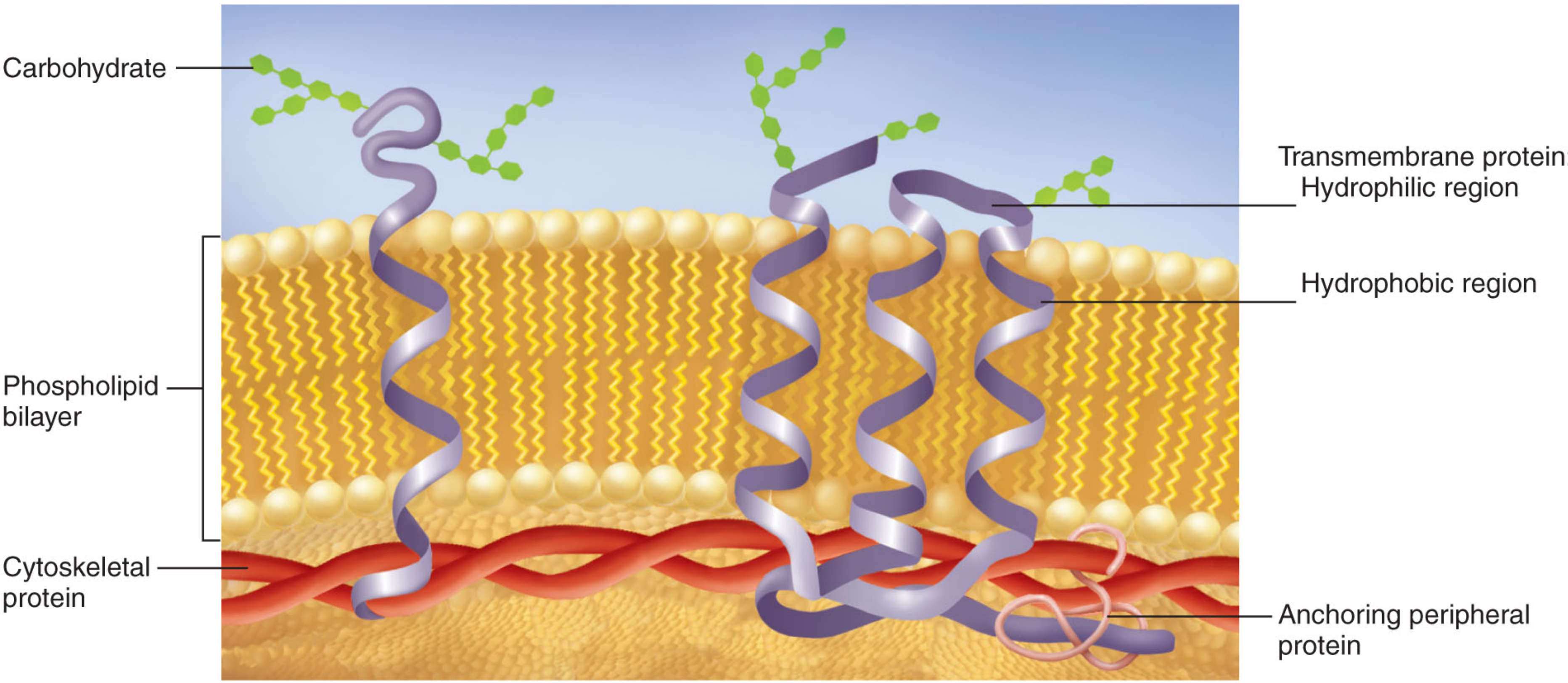


Figure 3.7


Carbohydrate
Phospholipid bilayer
Cytoskeletal protein
Transmembrane protein:
Hydrophilic region
Hydrophobic region
Anchoring peripheral protein

Membrane Protein Functions

- receptors, second-messenger systems, enzymes, ion channels, carriers, cell-identity markers, cell-adhesion molecules

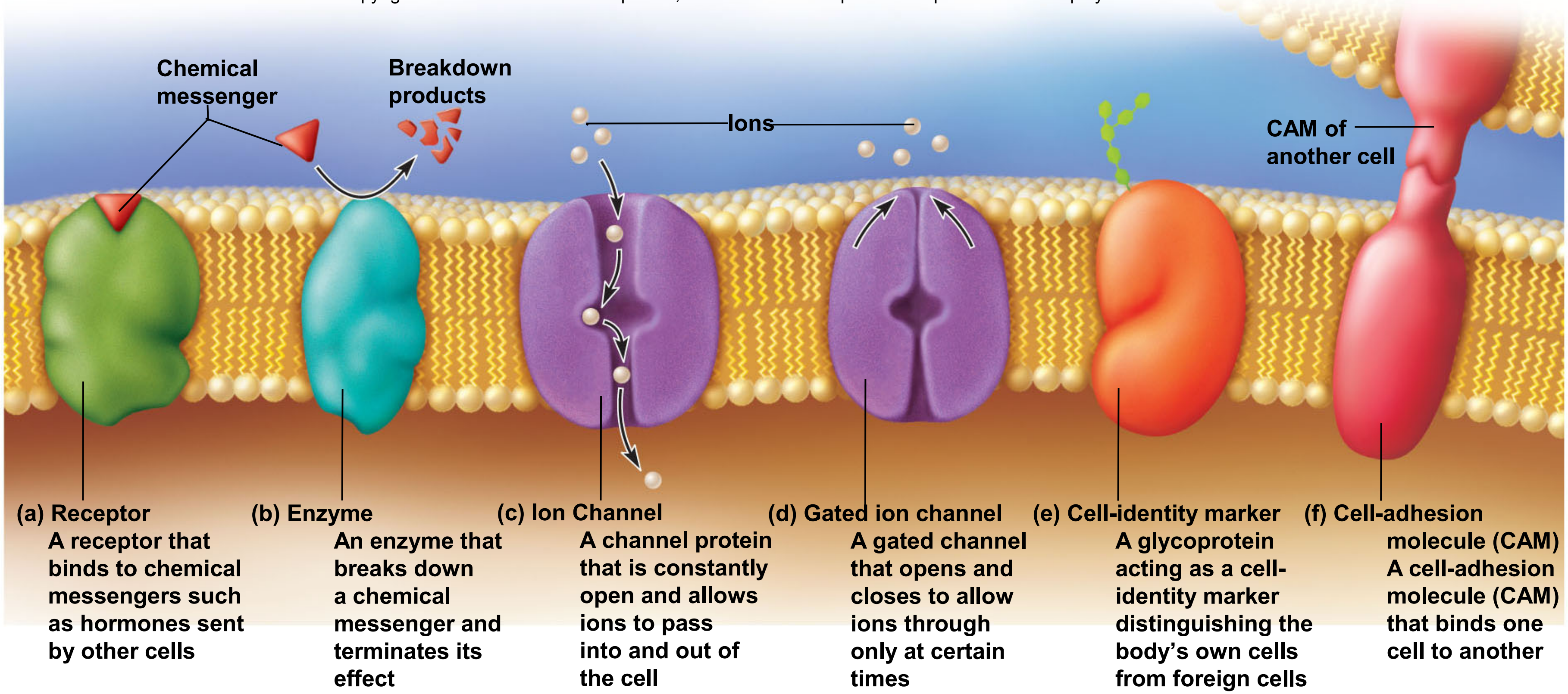


Figure 3.8

Membrane Receptors

- **Cell communication** via chemical signals
  - **receptors** – surface proteins on plasma membrane of target cell
  - bind these chemicals (hormones, neurotransmitters)
  - receptor usually specific for one substrate

Second Messenger System

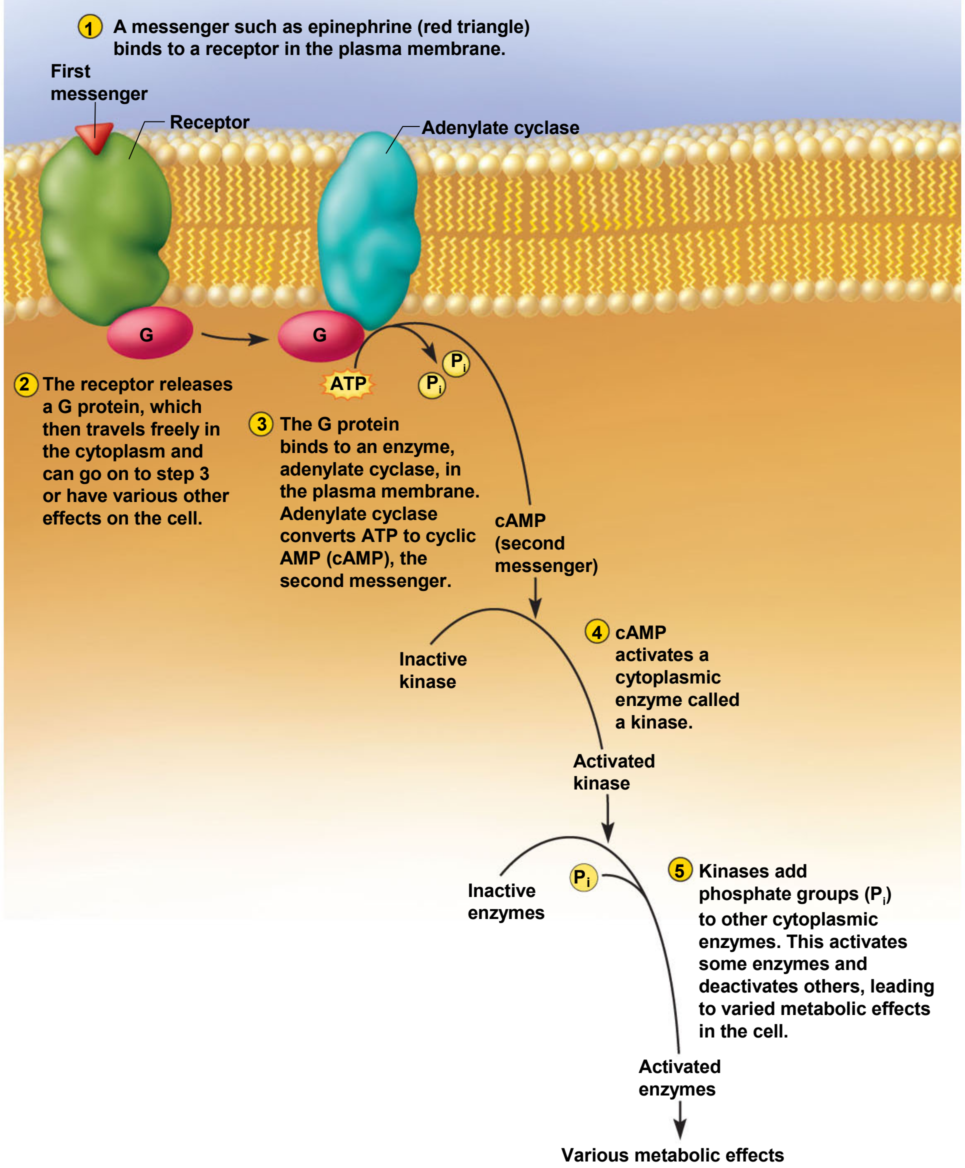


Figure 3.9

Second Messenger System

- Chemical **first messenger** (epinephrine) binds to a surface receptor
  - triggers changes within the cell that produces a second messenger in the cytoplasm
- **Receptor** activates **G protein**
  - an intracellular peripheral protein
  - **guanosine triphosphate** (GTP) an ATP like compound
- G protein relays signal to **adenylate cyclase** which converts ATP to **cAMP** (2nd messenger)
- cAMP activates a **kinase** in the cytosol
- Kinases **add phosphate groups** to other cellular enzymes
  - activates some enzymes, and inactivates others triggering a wide variety of physiological changes in cells
- Up to 60% of modern drugs work by altering activity of G proteins.

Membrane Enzymes

- enzymes in plasma membrane carry out final stages of starch and protein digestion in small intestine
- help produce second messengers (cAMP)
- break down chemical messengers and hormones whose job is done
  - stops excessive stimulation

Ion Channels

- **Transmembrane proteins with pores** that allow water and dissolved ions to pass through membrane
  - some **constantly open**
  - some are **gated-channels** that open and close in response to **stimuli**
    - **ligand** (chemically)-regulated gates
    - **voltage**-regulated gates
    - **mechanically** regulated gates (stretch and pressure)
- play an important role in the timing of nerve signals and muscle contraction

Membrane Carriers or Pumps

- Transmembrane proteins bind to glucose, electrolytes, and other solutes
  - transfer them across membrane
- Pumps consume ATP in the process

Cell-Identity Markers

- Glycoproteins contribute to the glycocalyx
  - carbohydrate surface coating
  - acts like a cell's 'identification tag'

- Enables our bodies to identify which cells belong to it and which are foreign invaders

Cell-Adhesion Molecules

- Adhere cells to each other and to extracellular material
- cells do not grow or survive normally unless they are mechanically linked to the extracellular material

Glycocalyx

- carbohydrate groups of membrane glycoproteins and glycolipids
  - unique in everyone, but identical twins

Microvilli

- Extensions of membrane (1-2 µm)
  - serves to increase cell’s surface area
  - best developed in cells specialized in **absorption**
  - gives 15 – 40 times more absorptive surface area

- on some cells they are very dense and appear as a fringe – **“brush border”**
  - milking action of actin
    - actin filaments shorten microvilli
      - pushing absorbed contents down into cell

Microvilli

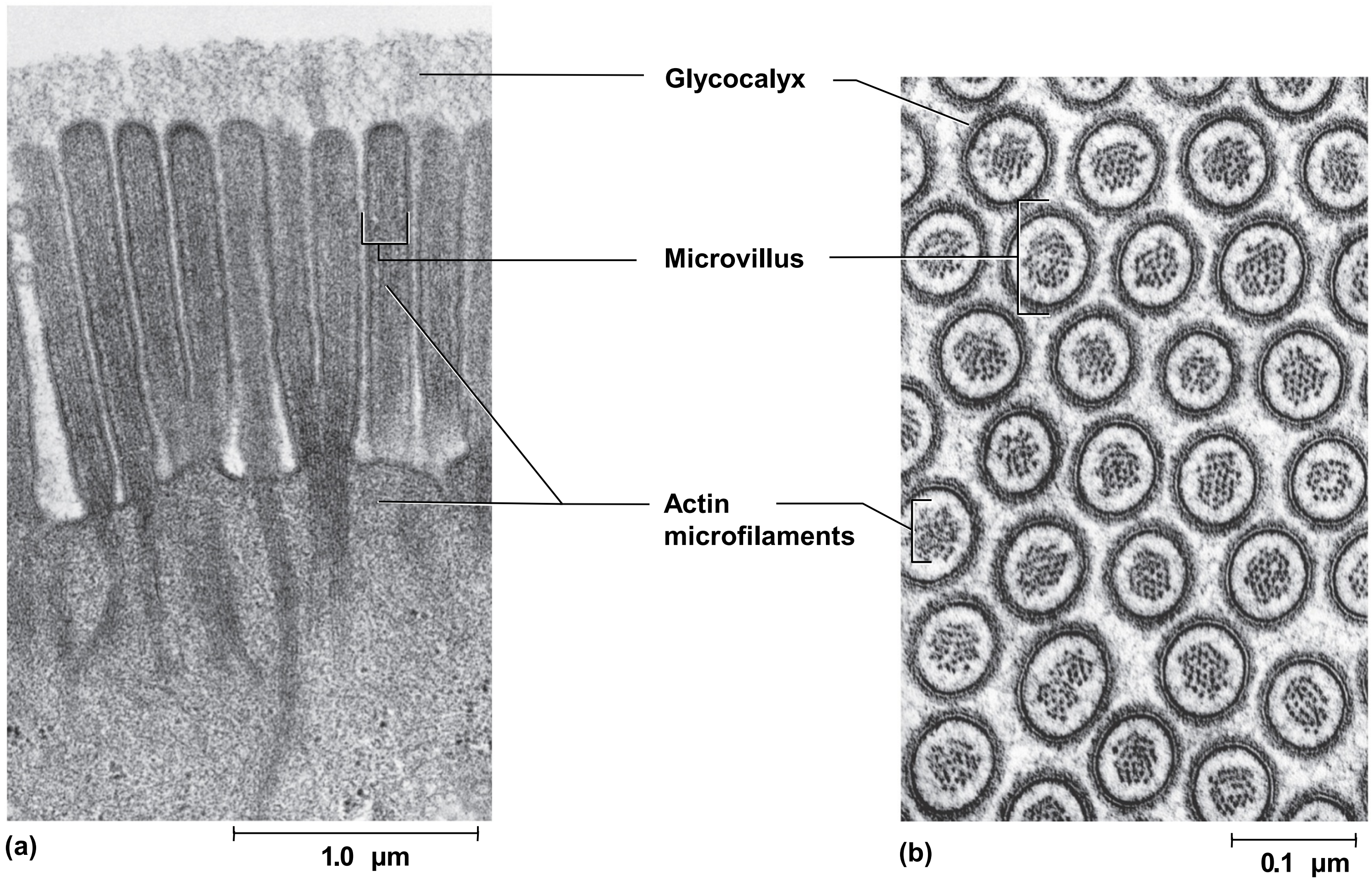


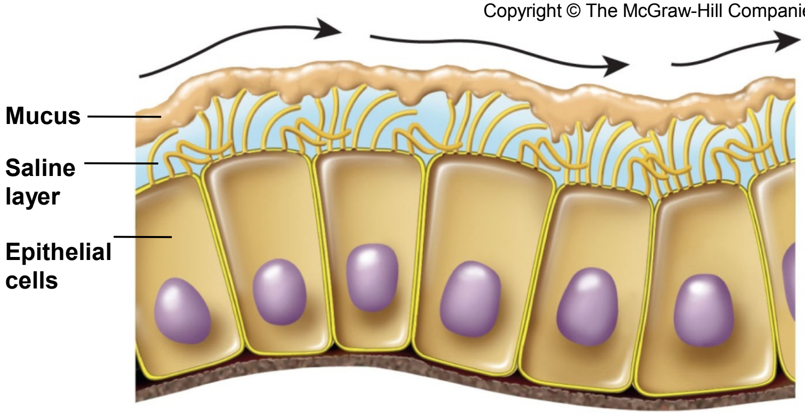
Figure 3.10a

Figure 3.10b

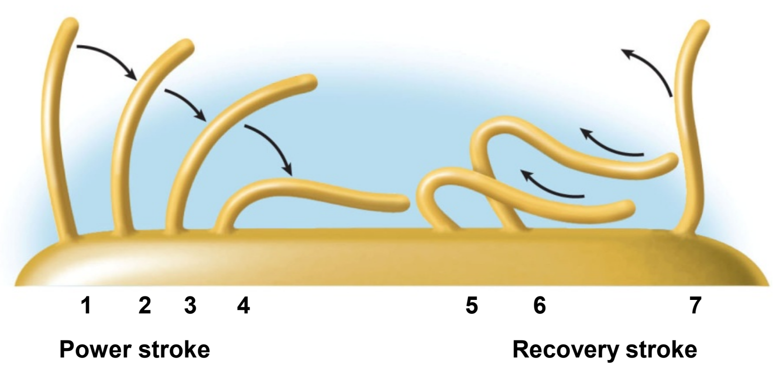
Actin microfilaments are found in center of each microvilli.

Cilia

- Hairlike processes 7-10 µm long
  - single, **nonmotile primary cilium** found on nearly every cell
  - "antenna' for monitoring nearby conditions
  - sensory in inner ear, retina, nasal cavity, and kidney
- **Motile cilia** – respiratory tract, uterine tubes, ventricles of the brain, efferent ductules of testes
  - beat in waves
  - sweep substances across surface in same direction
  - power strokes followed by recovery strokes



(a) Figure 3.12a



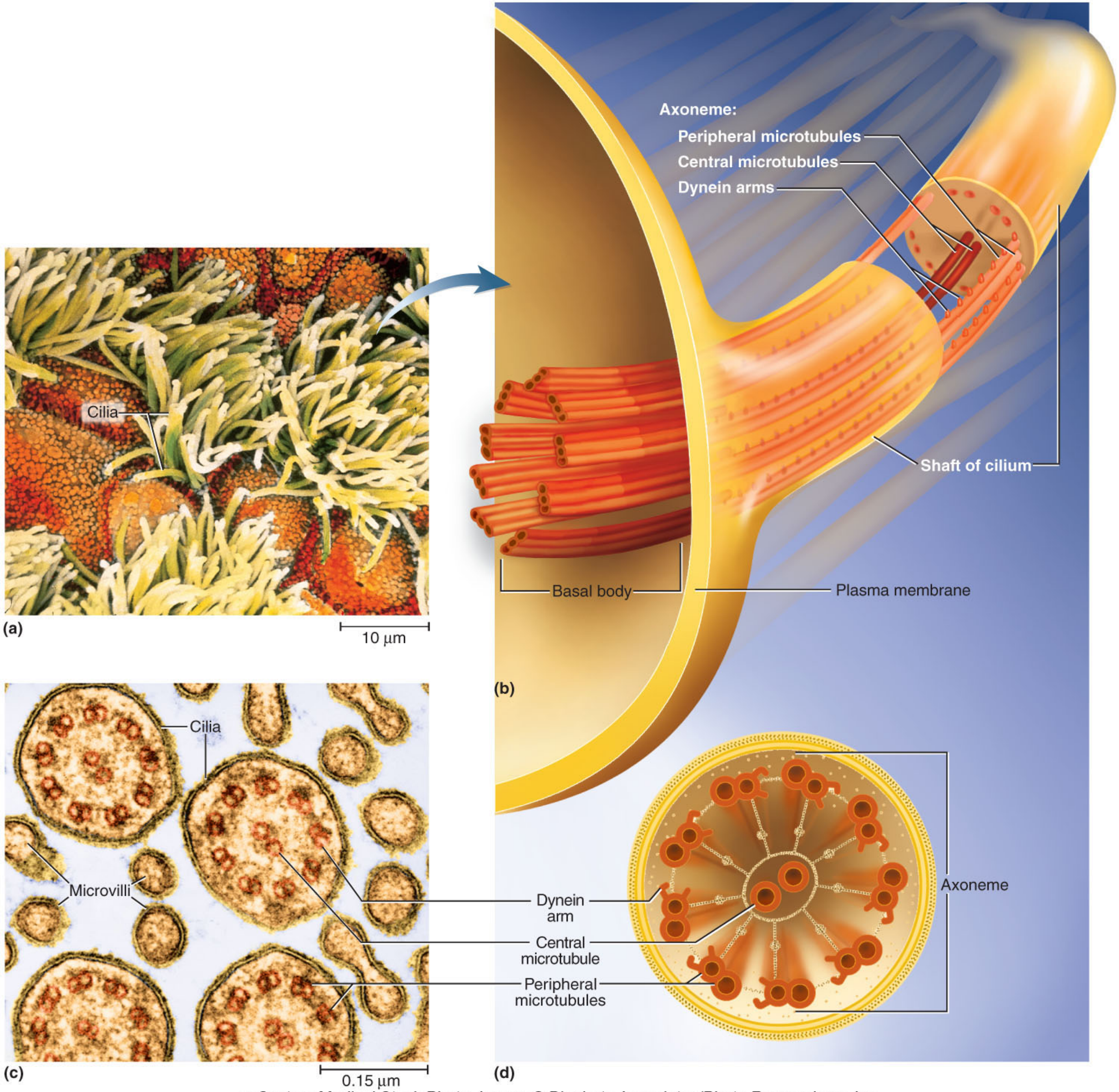
(b) Figure 3.12b

Cross Section of a Cilium

- **Axoneme** - core of cilia that is the structural basis for ciliary movement

- has **9 + 2 structure** of **microtubules**
  - 9 pairs form **basal body** inside the cell membrane
    - anchors cilium
  - **dynein arms** “crawls” up adjacent microtubule bending the cilia
    - uses energy from ATP

- **Saline Layer**
  - chloride pumps pump Cl- into ECF
  - Na+ and H_2O follows
  - cilia beat freely in saline layer


Cilia
(a)
10 µm
Axoneme:
Peripheral microtubules
Central microtubules
Dynein arms
Shaft of cilium
Basal body
Plasma membrane
(b)
Cilia
Microvilli
Dynein arm
Central microtubule
Peripheral microtubules
Axoneme
(c)
0.15 µm
(d)

Cilia & Cystic Fibrosis

- Saline layer at cell surface due to chloride pumps move Cl- out of cell. Na+ ions and H_2O follow

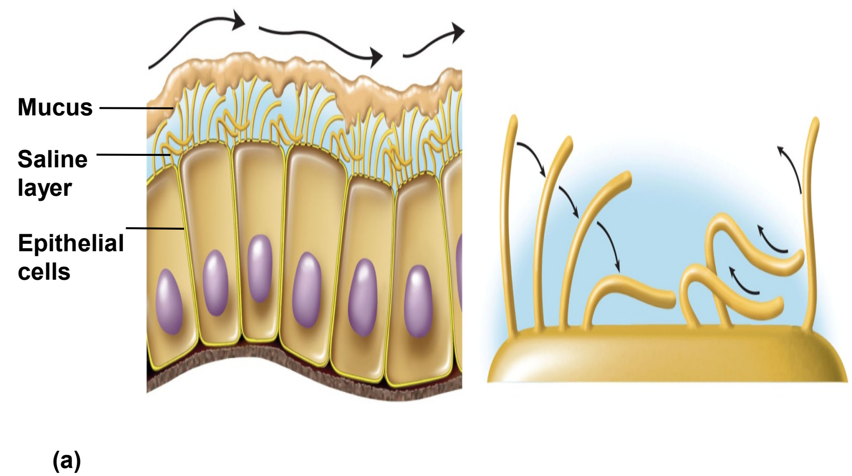


Figure 3.12a

- **Cystic fibrosis** – hereditary disease in which cells make chloride pumps, but fail to install them in the plasma membrane
  - chloride pumps fail to create adequate saline layer on cell surface
- thick mucus plugs pancreatic ducts and respiratory tract
  - inadequate digestion of nutrients and absorption of oxygen
  - chronic respiratory infections
  - life expectancy of 30

Flagella

- **tail of the sperm** - only functional flagellum
- whiplike structure with axoneme identical to cilium
  - much longer than cilium
  - stiffened by coarse fibers that supports the tail
- movement is more undulating, snakelike
  - no power stroke or recovery stroke as in cilia

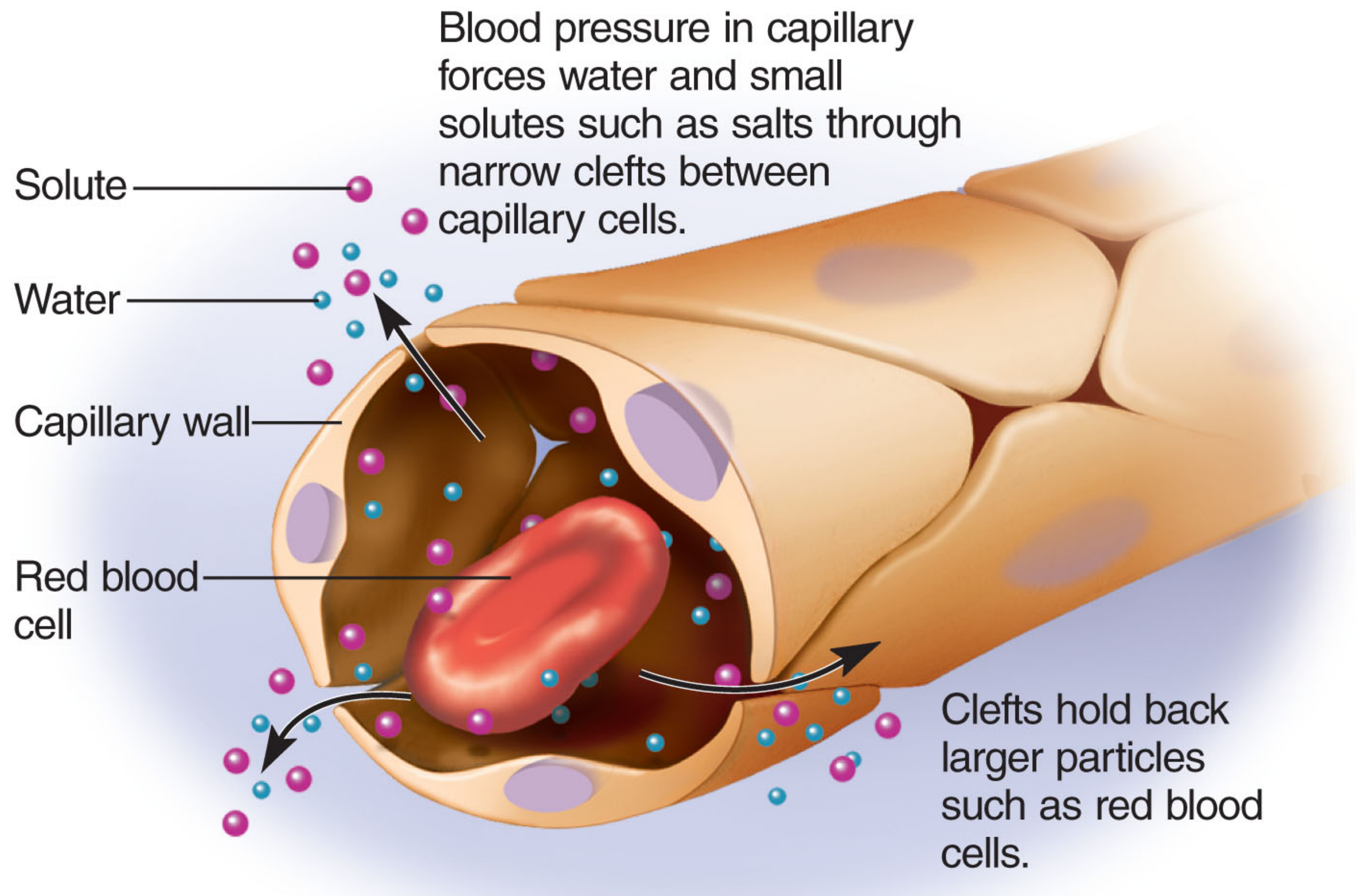
Membrane Transport

- **plasma membrane** – a barrier and a gateway between the cytoplasm and ECF
  - **selectively permeable** – allows some things through, and prevents other things from entering and leaving the cell
- **passive transport mechanisms** requires no ATP
  - random molecular motion of particles provides the necessary energy
  - filtration, diffusion, osmosis
- **active transport mechanisms** consumes ATP
  - active transport and vesicular transport
- **carrier-mediated mechanisms** use a membrane protein to transport substances from one side of the membrane to the other

Filtration

- **Filtration** - process in which particles are driven through a selectively permeable membrane by **hydrostatic pressure** (force exerted on a membrane by water)

- Examples
  - filtration of nutrients through gaps in blood capillary walls into tissue fluids
  - filtration of wastes from the blood in the kidneys while holding back blood cells and proteins


Blood pressure in capillary forces water and small solutes such as salts through narrow clefts between capillary cells.
Solute
Water
Capillary wall
Red blood cell
Clefts hold back larger particles such as red blood cells.

Simple Diffusion

- **Simple Diffusion** – the net movement of particles from area of high concentration to area of low concentration
  – due to their constant, spontaneous motion
- Also known as movement down the **concentration gradient –** concentration of a substance differs from one point to another

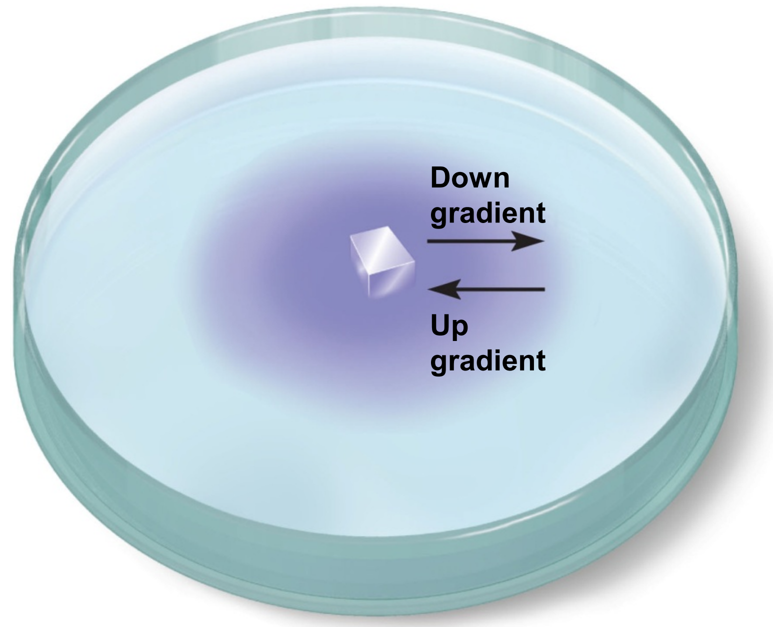


Figure 3.14

Diffusion Rates

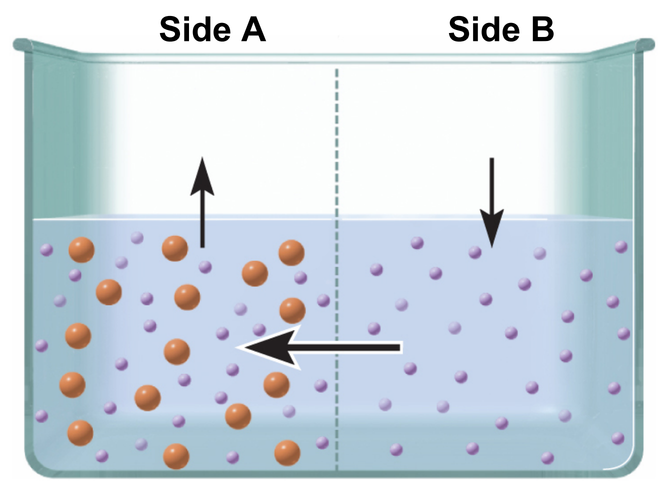
- **Factors affecting diffusion rate through a membrane**
  - **temperature -** ✸temp., ✸motion of particles
  - **molecular weight -** larger molecules move slower
  - **steepness of concentrated gradient -** ✸difference, ✸rate
  - **membrane surface area -** ✸area, ✸rate
  - **membrane permeability -** ✸permeability, ✸rate

Membrane Permeability

- **Diffusion through lipid bilayer**
  - Nonpolar, hydrophobic, lipid-soluble substances diffuse through lipid layer
- **Diffusion through channel proteins**
  - water and charged, hydrophilic solutes diffuse through channel proteins in membrane
- **Cells control permeability** by regulating number of channel proteins or by opening and closing gates

Osmosis

- **Osmosis** - flow of water from one side of a selectively permeable membrane to the other
  - from side with higher water concentration to the side with lower water concentration
  - reversible attraction of water to solute particles forms **hydration spheres**
  - makes those water molecules less available to diffuse back to the side from which they came
- **Aquaporins** - channel proteins specialized for passage of water

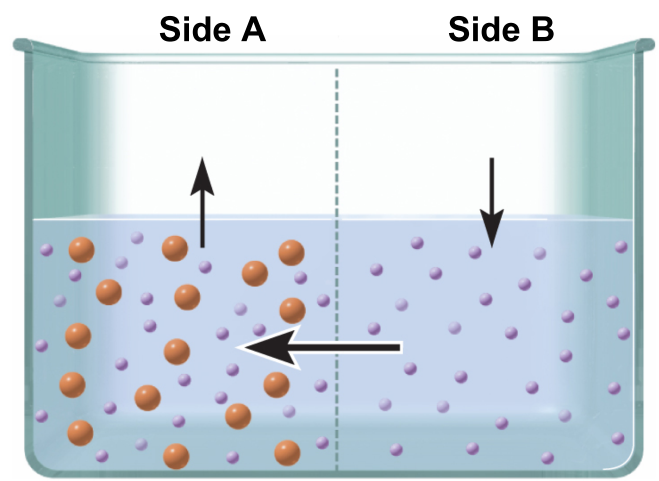


(a) Start

Figure 3.15a

Aquaporins

- **Aquaporins** - channel proteins in plasma membrane specialized for passage of water
  - – cells can increase the rate of osmosis by installing more aquaporins
  - – decrease rate by removing them
- Significant amounts of water diffuse even through the hydrophobic, phospholipid regions of the plasma membrane

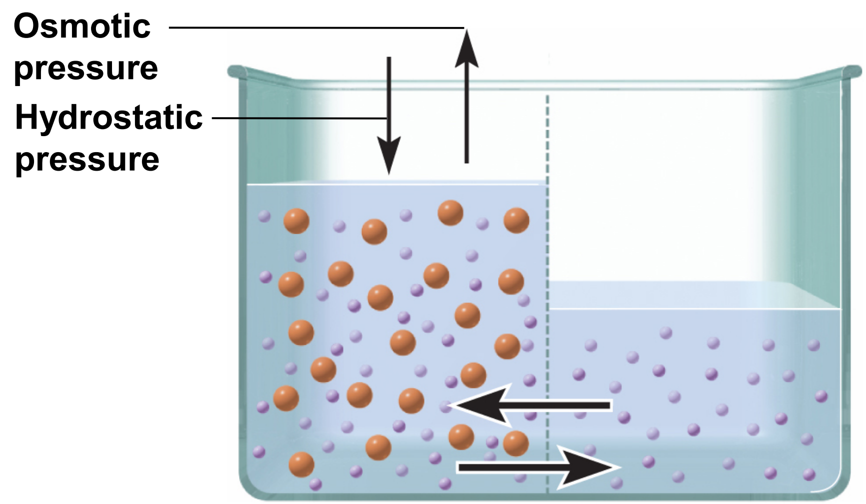


(a) Start

Figure 3.15a

Osmotic Pressure

- **Osmotic Pressure** - amount of hydrostatic pressure required to stop osmosis
- Osmosis slows due to hydrostatic pressure
- Heart drives water out of capillaries by reverse osmosis – **capillary filtration**
- **Osmolarity measure of osmotic potential**



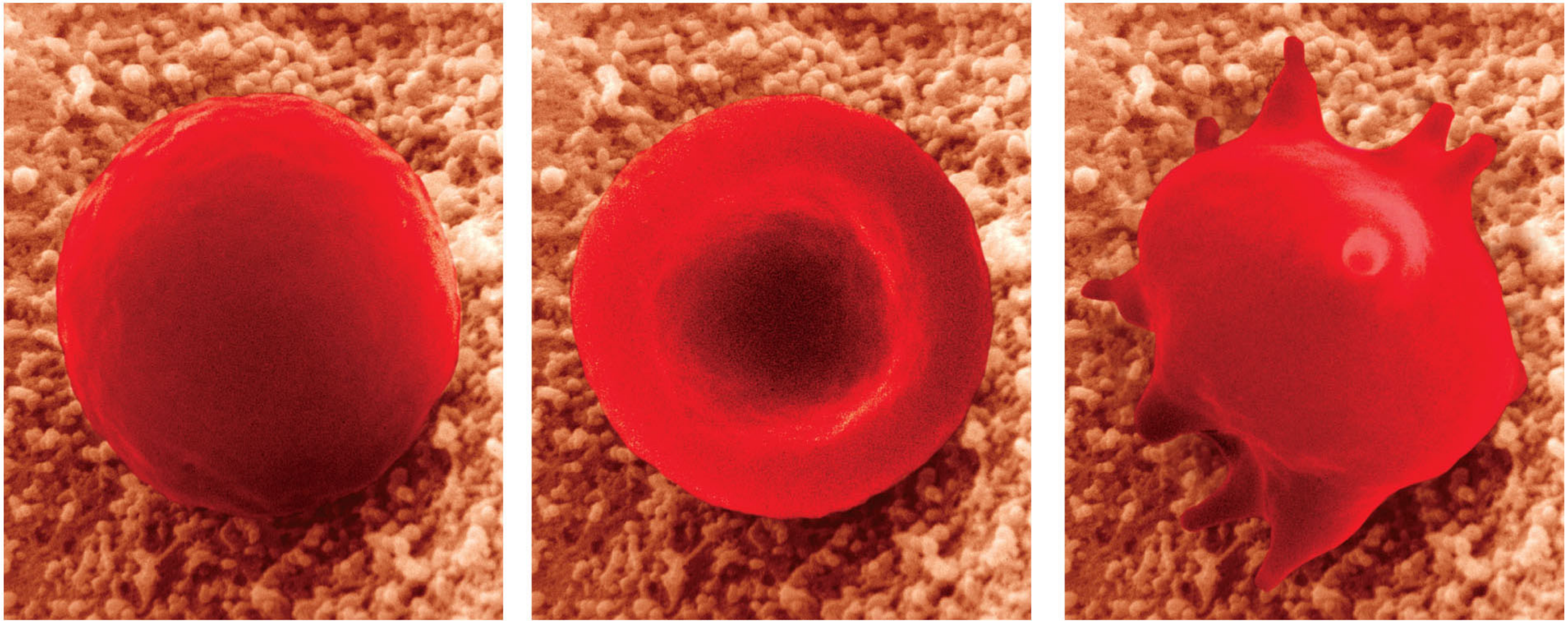
(b) 30 minutes later

Figure 3.15b

Tonicity

- **Tonicity** - ability of a solution to affect fluid volume and pressure in a cell
  - depends on concentration and permeability of solute
- **Hypotonic solution**
  - has a lower concentration of nonpermeating solutes than intracellular fluid (ICF)
    - high water concentration
  - cells absorb water, swell and may burst (lyse)
- **Hypertonic solution**
  - has a higher concentration of nonpermeating solutes
    - low water concentration
  - cells lose water + shrivel (crenate)
- **Isotonic solution**
  - concentrations in cell and ICF are the same
  - cause no changes in cell volume or cell shape
  - normal saline

Effects of Tonicity on RBCs



(a) Hypotonic (b) Isotonic (c) Hypertonic

Figure 3.16a Figure 3.16b Figure 3.16c

Hypotonic, isotonic and hypertonic solutions affect the fluid volume of a red blood cell. Notice the crenated and swollen cells.

Carrier-Mediated Transport

- **Transport proteins** in the plasma membrane that carry solutes from one side of the membrane to the other
- Specificity:
  - transport proteins specific for a certain **ligand**
  - solute binds to a specific receptor site on carrier protein
  - differs from membrane enzymes because carriers do not chemically change their ligand
    - simply picks them up on one side of the membrane, and release them, unchanged, on the other
- Saturation:
  - as the solute concentration rises, the rate of transport rises, but only to a point – **Transport Maximum (T_m)**
- 2 types of carrier mediated transport
  - **facilitated diffusion** and **active transport**

Membrane Carrier Saturation

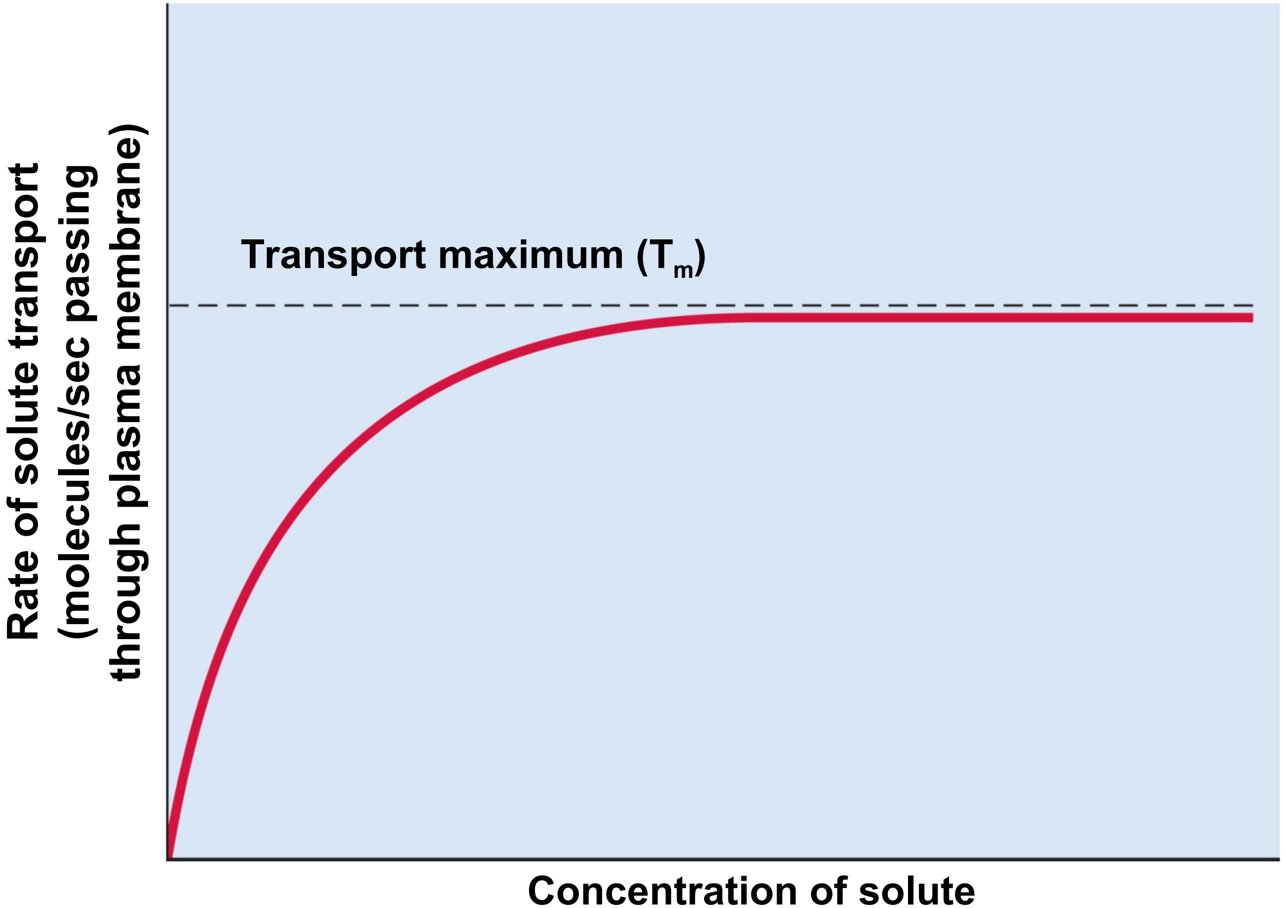


Figure 3.17

- **Transport maximum -** transport rate when all carriers are occupied

Membrane Carriers

- **Uniport**
  - carries only one solute at a time
- **Symport**
  - carries 2 or more solutes simultaneously in same direction **(cotransport)**
- **Antiport**
  - carries 2 or more solutes in opposite directions **(countertransport)**
  - sodium-potassium pump brings in K^+ and removes Na^+ from cell
- carriers employ two methods of transport
  - facilitated diffusion
  - active transport

Facilitated Diffusion

- **facilitated diffusion** - carrier-mediated transport of solute through a membrane down its concentration gradient
- does not consume ATP
- solute attaches to binding site on carrier, carrier changes confirmation, then releases solute on other side of membrane

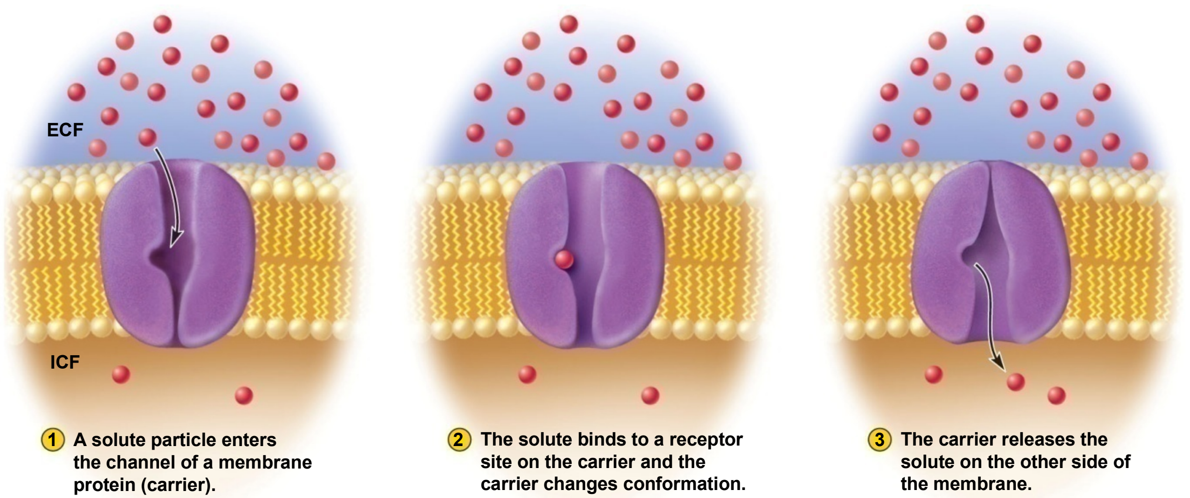


Figure 3.18

Active Transport

- **active transport** – carrier-mediated transport of solute through a membrane up (against) its concentration gradient
- ATP energy consumed to change carrier
- Examples of uses:
  - **sodium-potassium pump** keeps K+ concentration higher inside the cell
  - bring amino acids into cell
  - pump Ca^{2+} out of cell

Sodium-Potassium Pump

- each pump cycle consumes one ATP and exchanges three Na+ for two K+
- keeps the K+ concentration higher and the Na+ concentration lower with in the cell than in ECF
- necessary because Na^+ and K^+ constantly leak through membran
  - half of daily calories utilized for Na+ - K+ pump

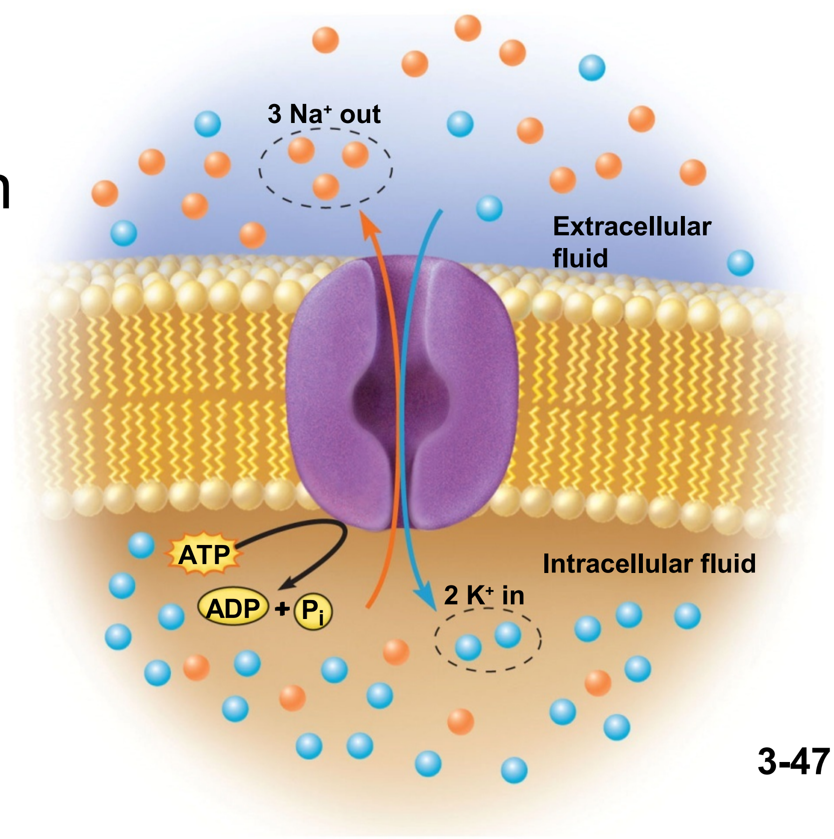


Figure 3.19

Functions of Na^+ -K^+ Pump

- **Regulation of cell volume**
  - “fixed anions” attract cations causing osmosis
  - cell swelling stimulates the Na^+- K^+ pump to ✵ion concentration, ✵osmolarity and cell swelling
- **Secondary active transport**
  - steep concentration gradient maintained between one side of the membrane and the other – (water behind a dam)
  - Sodium-glucose transport protein (SGLT) – simultaneously binds Na+ and glucose and carries both into the cell
  - does not consume ATP
- **Heat production**
  - thyroid hormone increase # of Na+ - K+ pumps
  - consume ATP and produce heat as a by-product
- **Maintenance of a membrane potential** in all cells
  - pump keeps inside more negative, outside more positive
  - necessary for nerve and muscle function

Vesicular Transport

- **Vesicular Transport** – processes that move large particles, fluid droplets, or numerous molecules at once through the membrane in **vesicles** – bubblelike enclosures of membrane
  - motor proteins consumes ATP
- **Endocytosis** –vesicular processes that bring material into the cell
  - **phagocytosis** – "cell eating" - engulfing large particles
    - pseudopods phagosomes macrophages
  - **pinocytosis** – "cell drinking" taking in droplets of ECF containing molecules useful in the cell
    - pinocytic vesicle
  - **receptor-mediated endocytosis** – particles bind to specific receptors on plasma membrane
    - clathrin-coated vesicle
- **Exocytosis** – discharging material from the cell
- Utilizes motor proteins energized by ATP

Phagocytosis or “Cell-Eating”

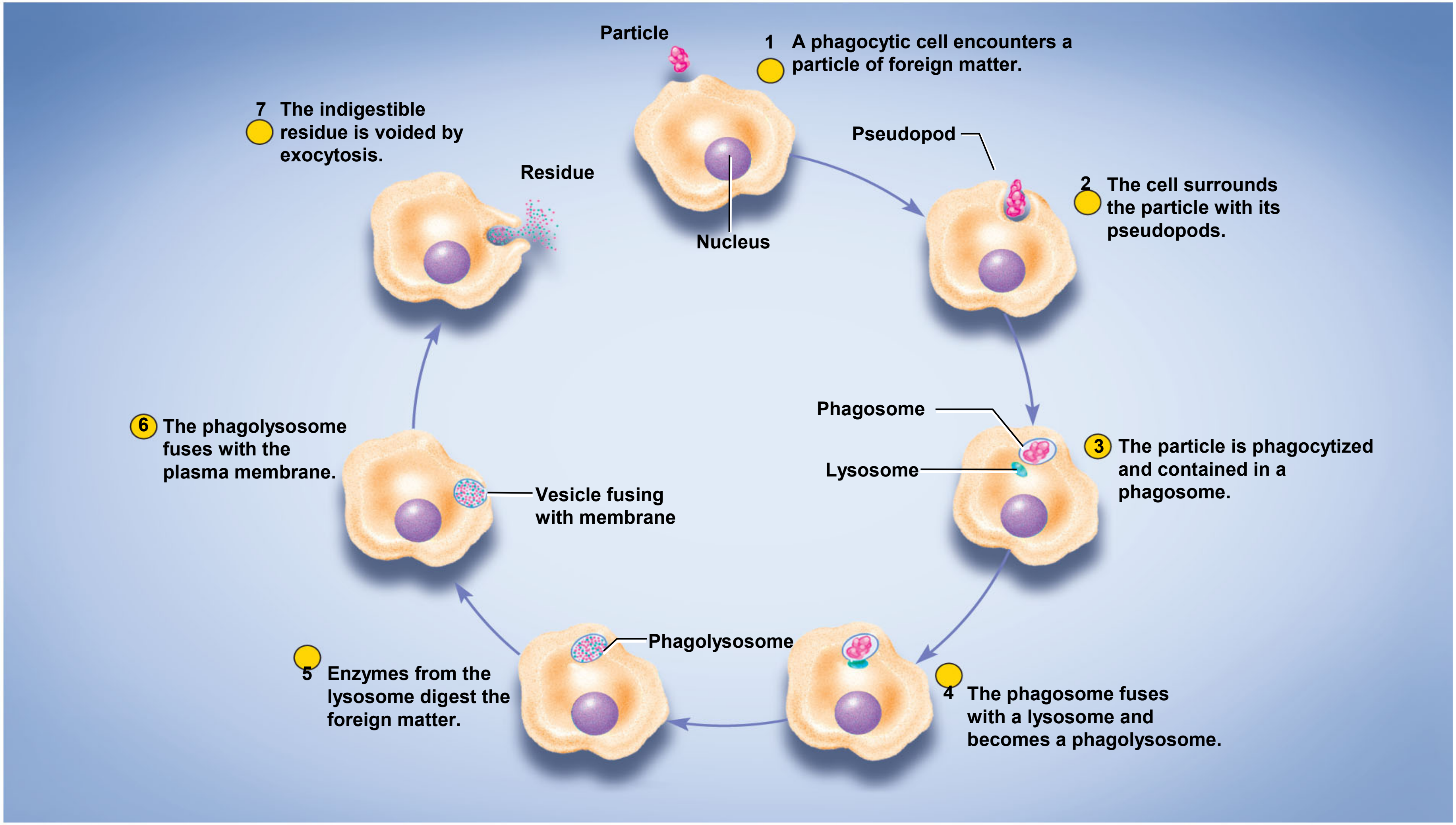


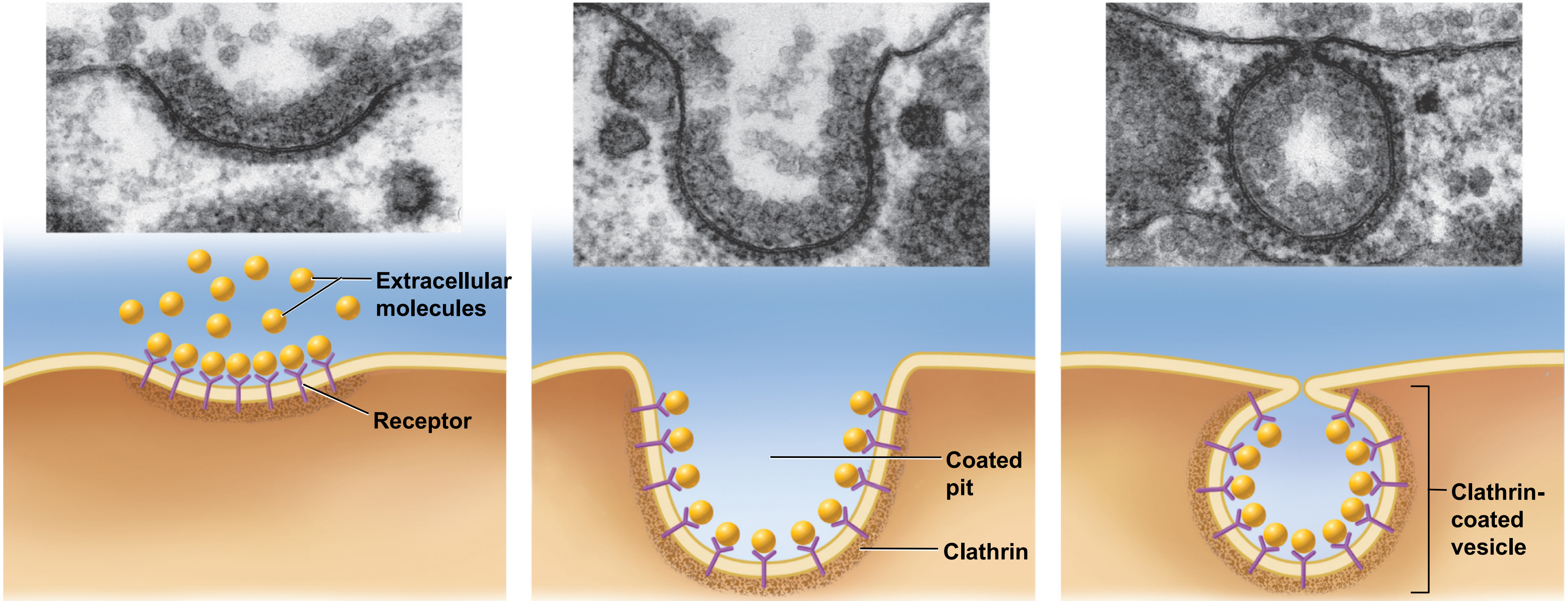
Figure 3.21

Keeps tissues free of debris and infectious microorganisms.

Pinocytosis or “Cell-Drinking”

- Taking in **droplets of ECF**
  - occurs in all human cells
- Membrane caves in, then pinches off into the cytoplasm as **pinocytotic vesicle**

Receptor Mediated Endocytosis



1 Extracellular molecules bind to receptors on plasma membrane; receptors cluster together.

2 Plasma membrane sinks inward, forms clathrin-coated pit.

3 Pit separates from plasma membrane, forms clathrin-coated vesicle containing concentrated molecules from ECF.

(all): Company of Biologists, Ltd.

Figure 3.22 (1,2 and 3)

Receptor Mediated Endocytosis

- more selective endocytosis
- enables cells to take in specific molecules that bind to extracellular receptors
- Clathrin-coated vesicle in cytoplasm
  - uptake of LDL from bloodstream

Transcytosis

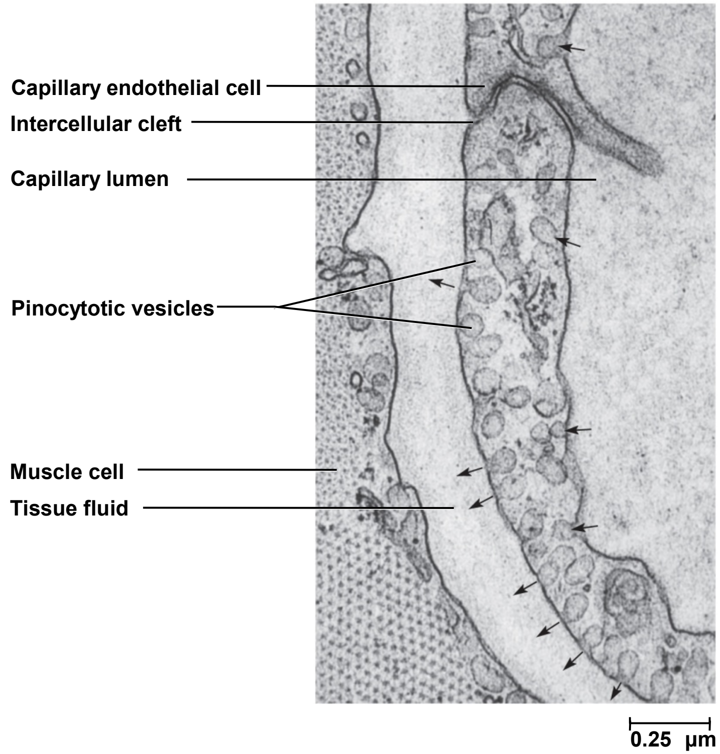
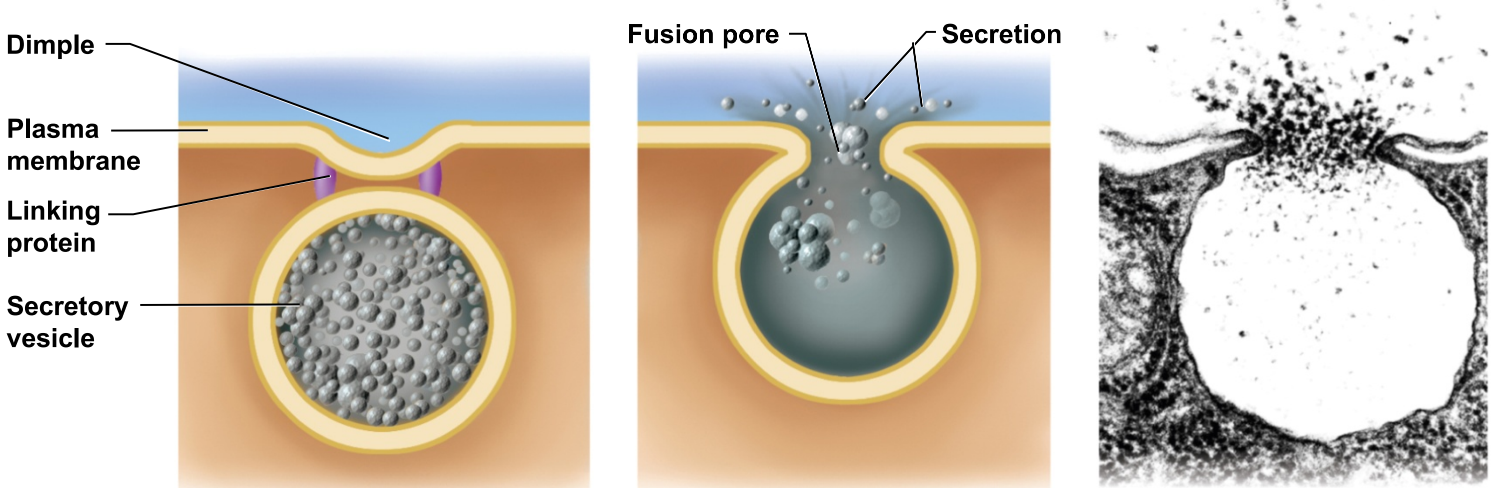


Figure 3.23

- Transport of material across the cell by capturing it on one side and releasing it on the other
- **Receptor-mediated endocytosis** moves it into cell and **exocytosis** moves it out the other side
  - insulin

Exocytosis

- Secreting material
- replacement of plasma membrane removed by endocytosis



(a) 1 A secretory vesicle approaches the plasma membrane and docks on it by means of linking proteins. The plasma membrane caves in at that point to meet the vesicle.

2 The plasma membrane and vesicle unite to form a fusion pore through which the vesicle contents are released.

(b)

Courtesy of Dr. Birgit Satir, Albert Einstein College of Medicine

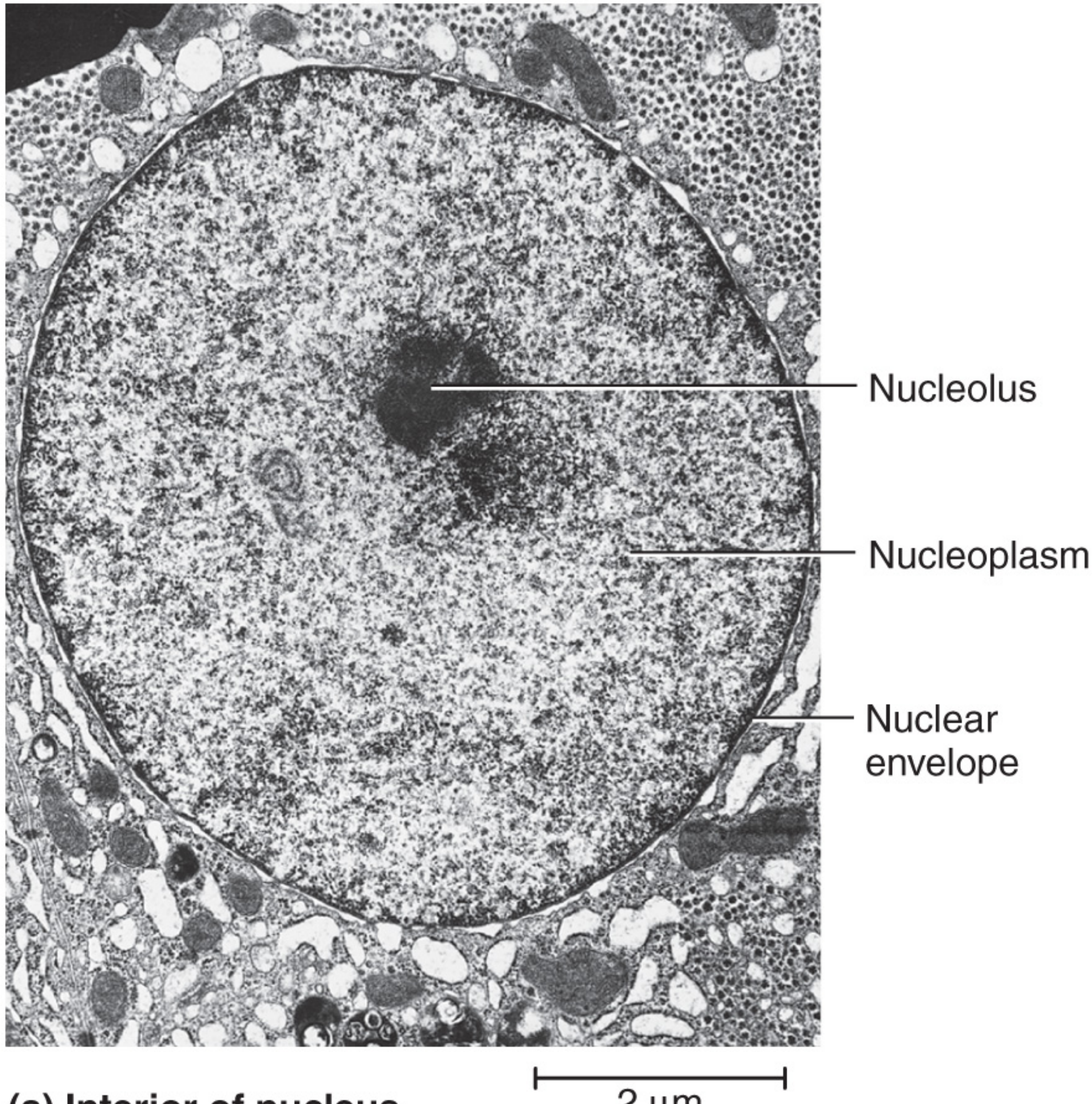
Figure 3.24a,b

The Cell Interior

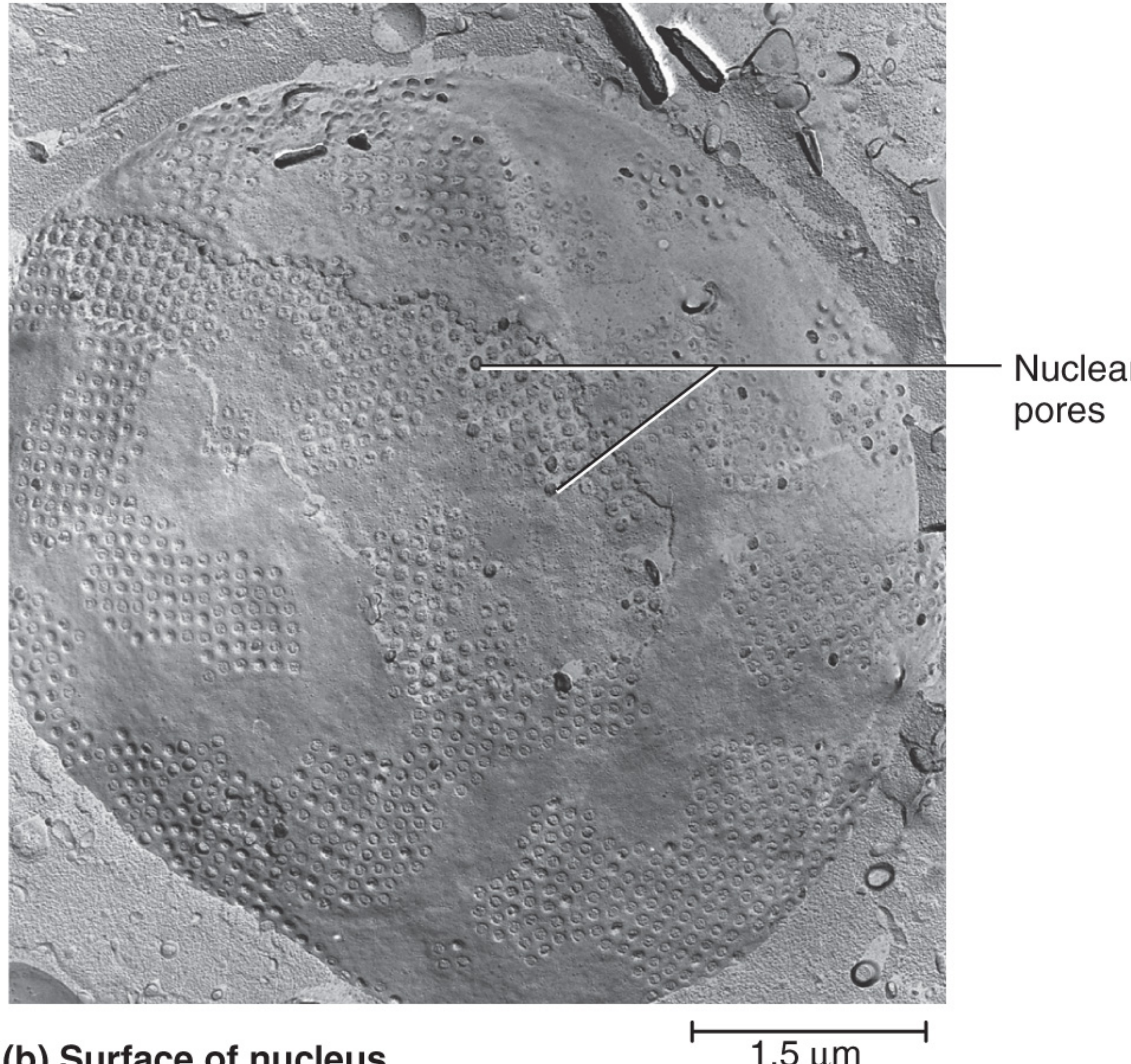
- structures in the **cytoplasm**
  - **organelles, cytoskeleton, and inclusions**
  - all embedded in a clear gelatinous **cytosol**
- **Organelles –** internal structures of a cell that carry out specialized metabolic tasks
  - **membranous organelles** – those surrounded by one or two layers of unit membrane
    - nucleus, mitochondria, lysosome, peroxisome, endoplasmic reticulum, and Golgi complex
  - organelles not surrounded by membranes
    - ribosome, centrosome, centriole, basal bodies
- **Cytoskeleton**
  - collection of protein filaments
  - microfilaments, intermediate filaments, and microtubules
- **Inclusions**
  - stored cellular components and fat droplets

Nucleus

- Largest organelle (5 μm in diameter)
  - most cells have one nucleus
  - a few cells are **anuclear** or **multinucleate**
- **nuclear envelope -** two unit membranes surround nucleus
  - perforated by **nuclear pores** formed by rings of protein
    - regulate molecular traffic through envelope
    - hold two unit membranes together
  - supported by nuclear lamina
    - web of protein filaments
    - supports nuclear envelope and pores
    - provides points of attachment and organization for chromatin
    - plays role in regulation of the cell life cycle
- **nucleoplasm** – material in nucleus
  - **chromatin** (thread-like matter) composed of DNA and protein
  - **nucleoli** – one or more dark masses where **ribosomes** are produced



(a) Interior of nucleus



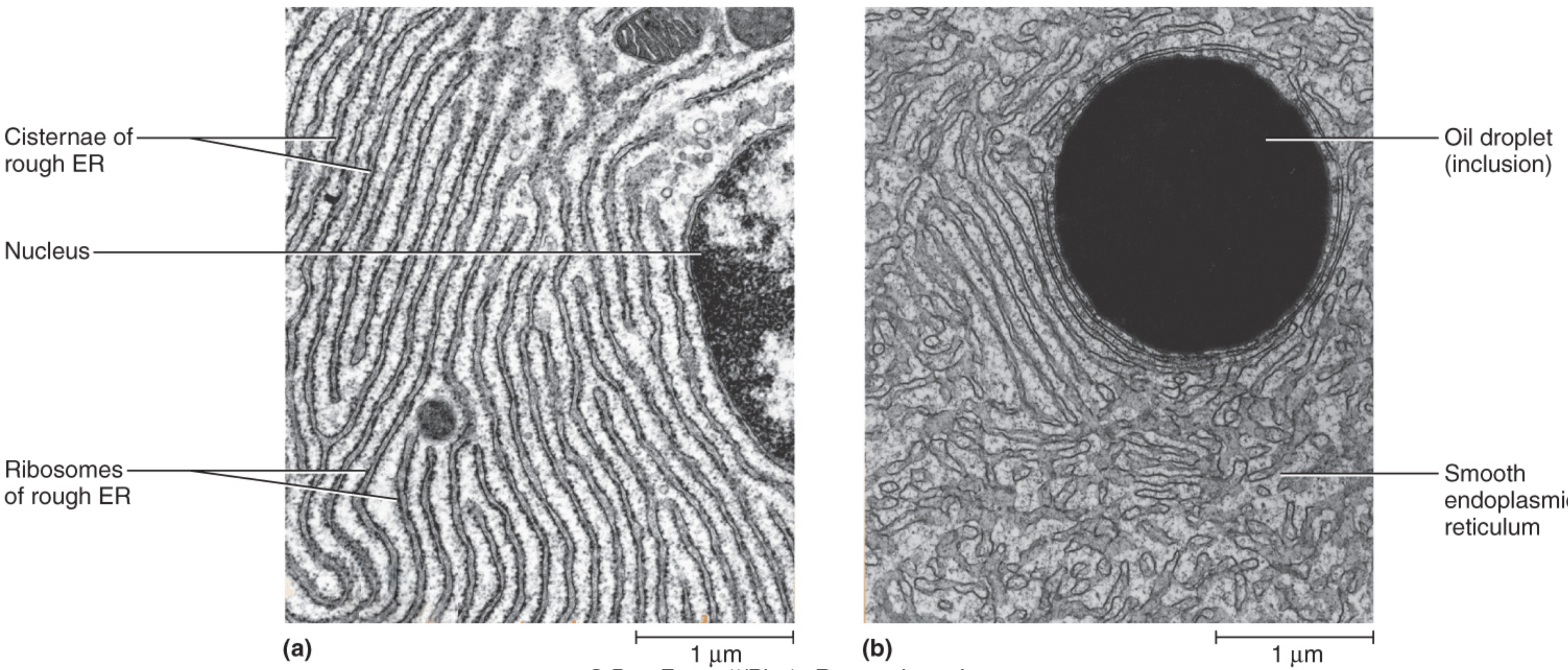
(b) Surface of nucleus

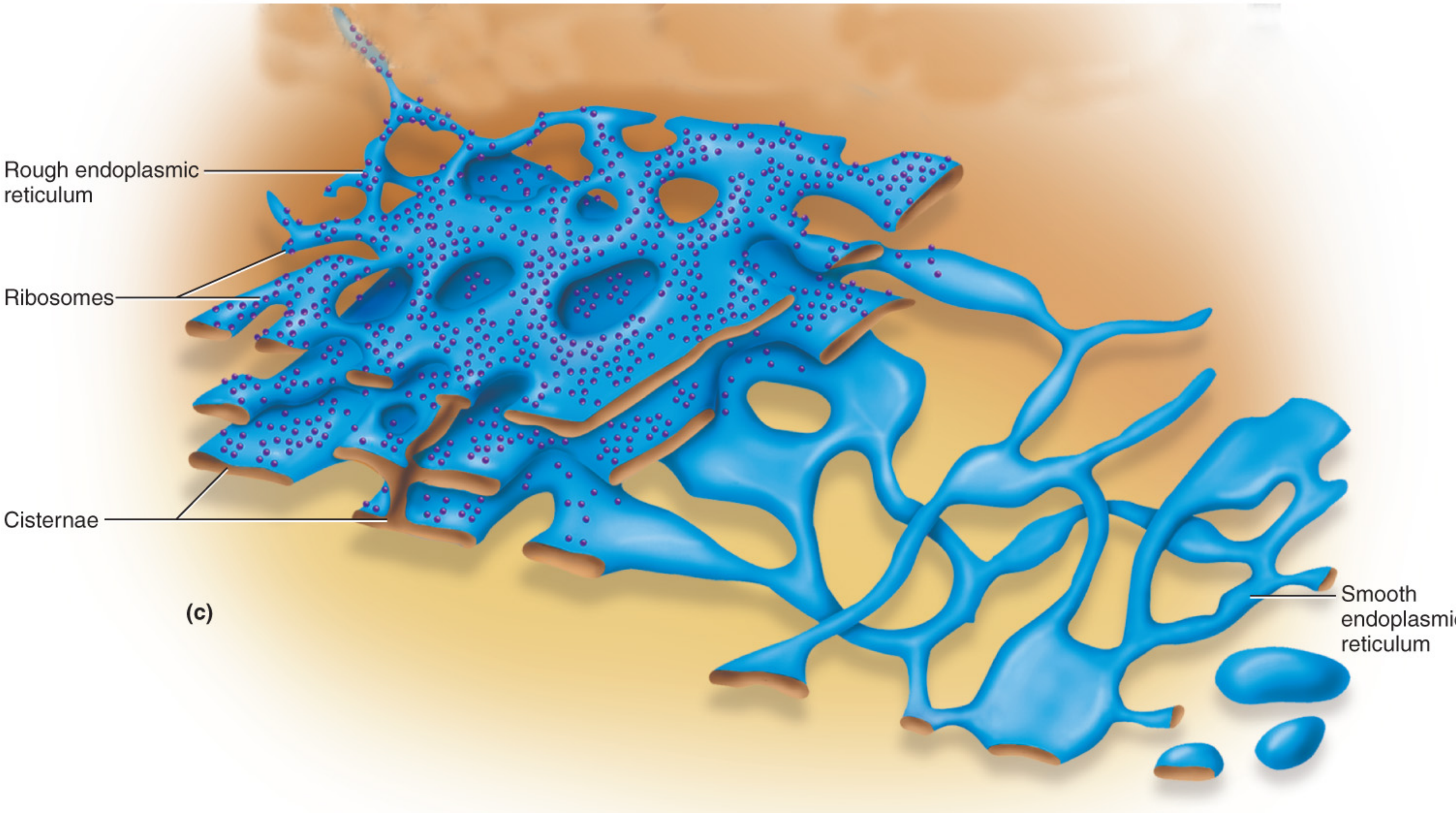
Endoplasmic Reticulum

- **endoplasmic reticulum** - system of interconnected channels called **cisternae** enclosed by unit membrane
- **rough endoplasmic reticulum** – composed of parallel, flattened sacs covered with **ribosomes**
  - continuous with outer membrane of nuclear envelope
  - adjacent cisternae are often connected by perpendicular bridges
  - produces the phospholipids and proteins of the plasma membrane
  - synthesizes proteins that are packaged in other organelles or secreted from cell

Endoplasmic Reticulum

- **smooth endoplasmic reticulum**
  - lack ribosomes
  - cisternae more tubular and branching
  - cisternae are thought to be continuous with those of rough ER
  - synthesizes steroids and other lipids
  - detoxifies alcohol and other drugs
  - manufactures all membranes of the cell
- rough and smooth ER are functionally different parts of the same network


Cisternae of rough ER
Nucleus
Ribosomes of rough ER
Oil droplet (inclusion)
Smooth endoplasmic reticulum
(a)
1 µm
(b)
1 µm


Rough endoplasmic reticulum
Ribosomes
Cisternae
Smooth endoplasmic reticulum

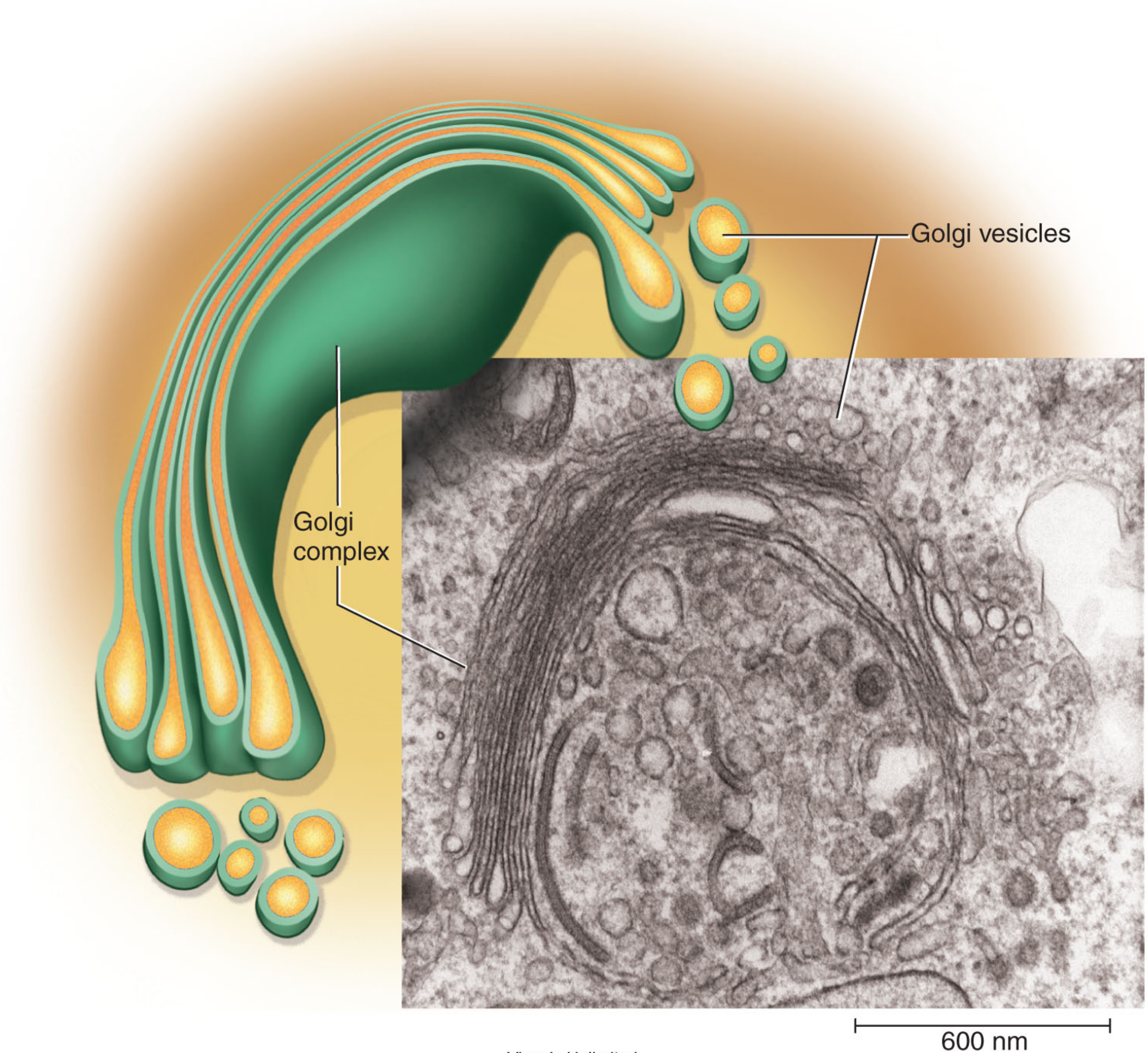
(c)

Ribosomes

- **Ribosomes** - small granules of **protein and RNA**
  - found in nucleoli, in cytosol, and on outer surfaces of rough ER, and nuclear envelope
- they ‘read’ coded genetic messages (**messenger RNA**) and assemble amino acids into proteins specified by the code

Golgi Complex

- **Golgi complex** - a small system of cisternae that synthesize carbohydrates and put the finishing touches on protein and glycoprotein synthesis
  - receives newly synthesized proteins from rough ER
  - sorts them, cuts and splices some of them, adds carbohydrate moieties to some, and packages the protein into membrane-bound **Golgi vesicles**
    - some become lysosomes
    - some migrate to plasma membrane and fuse to it
    - some become secretory vesicles for later release



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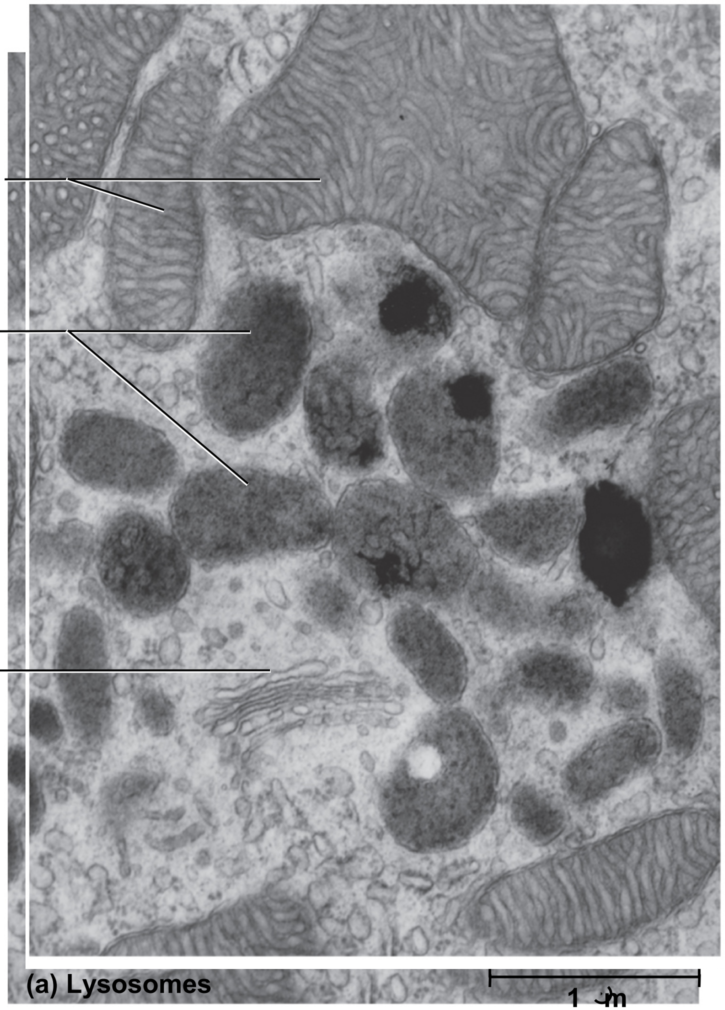
Lysosomes

- **Lysosomes** - package of enzymes bound by a single unit membrane
  - extremely variable in shape
- **Functions**
  - intracellular hydrolytic digestion of proteins, nucleic acids, complex carbohydrates, phospholipids, and other substances
  - **autophagy** – digest and dispose of worn out mitochondria and other organelles
  - **autolysis** – ‘cell suicide’ – some cells are meant to do a certain job and then destroy themselves

Lysosomes and Peroxisomes



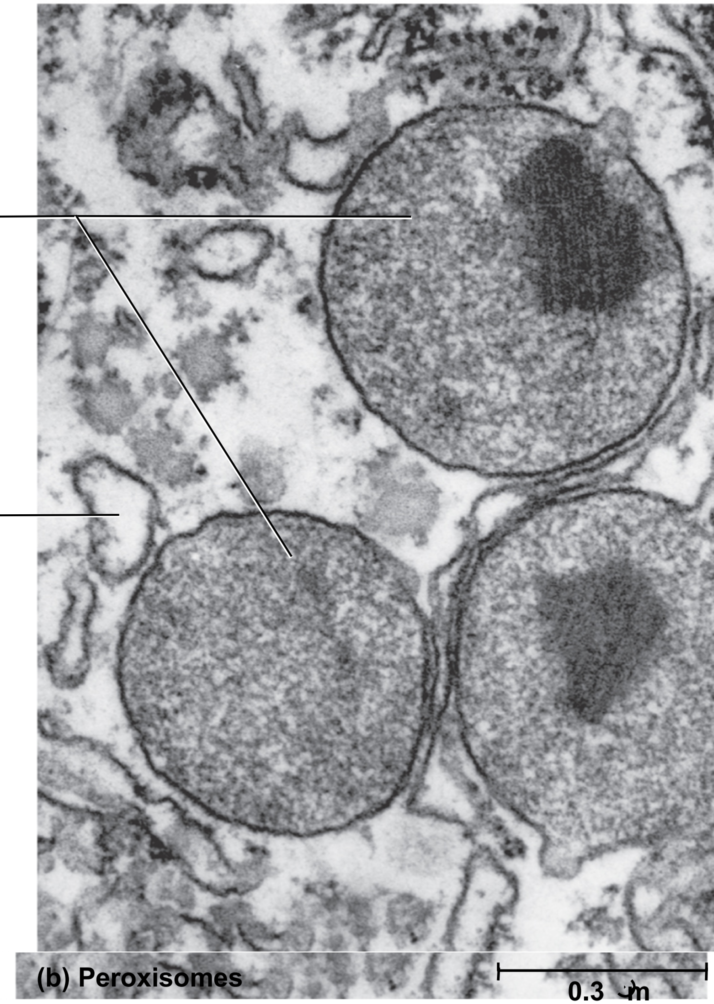


Figure 3.28a

Figure 3.28b

Peroxisomes

- **Peroxisomes** - resemble lysosomes but contain different enzymes and are not produced by the Golgi complex
- General function is to use molecular oxygen to oxidize organic molecules
  - these reactions produce hydrogen peroxide (H_2O_2)
  - **catalase** breaks down excess peroxide to H_2O and O_2
  - neutralize free radicals, detoxify alcohol, other drugs, and a variety of blood-borne toxins
  - breakdown fatty acids into acetyl groups for mitochondrial use in ATP synthesis
- In all cells, but abundant in liver and kidney

Mitochondrion

- **mitochondria –** organelles specialized for synthesizing **ATP**
- variety of shapes – spheroid, rod-shaped, kidney bean-shaped, or threadlike
- surrounded by a double unit membrane
  - inner membrane has folds called **cristae**
  - spaces between cristae are called **matrix**
    - matrix contains ribosomes, enzymes used for ATP synthesis, small circular DNA molecule – mitochondrial DNA (mtDNA)
- "Powerhouses" of the cell
  - energy is extracted from organic molecules and transferred to ATP

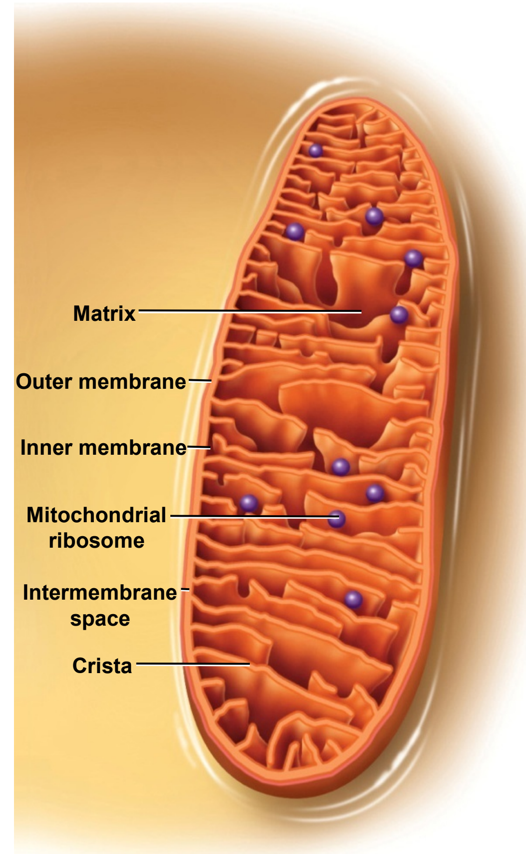


Figure 3.29b

Mitochondrion

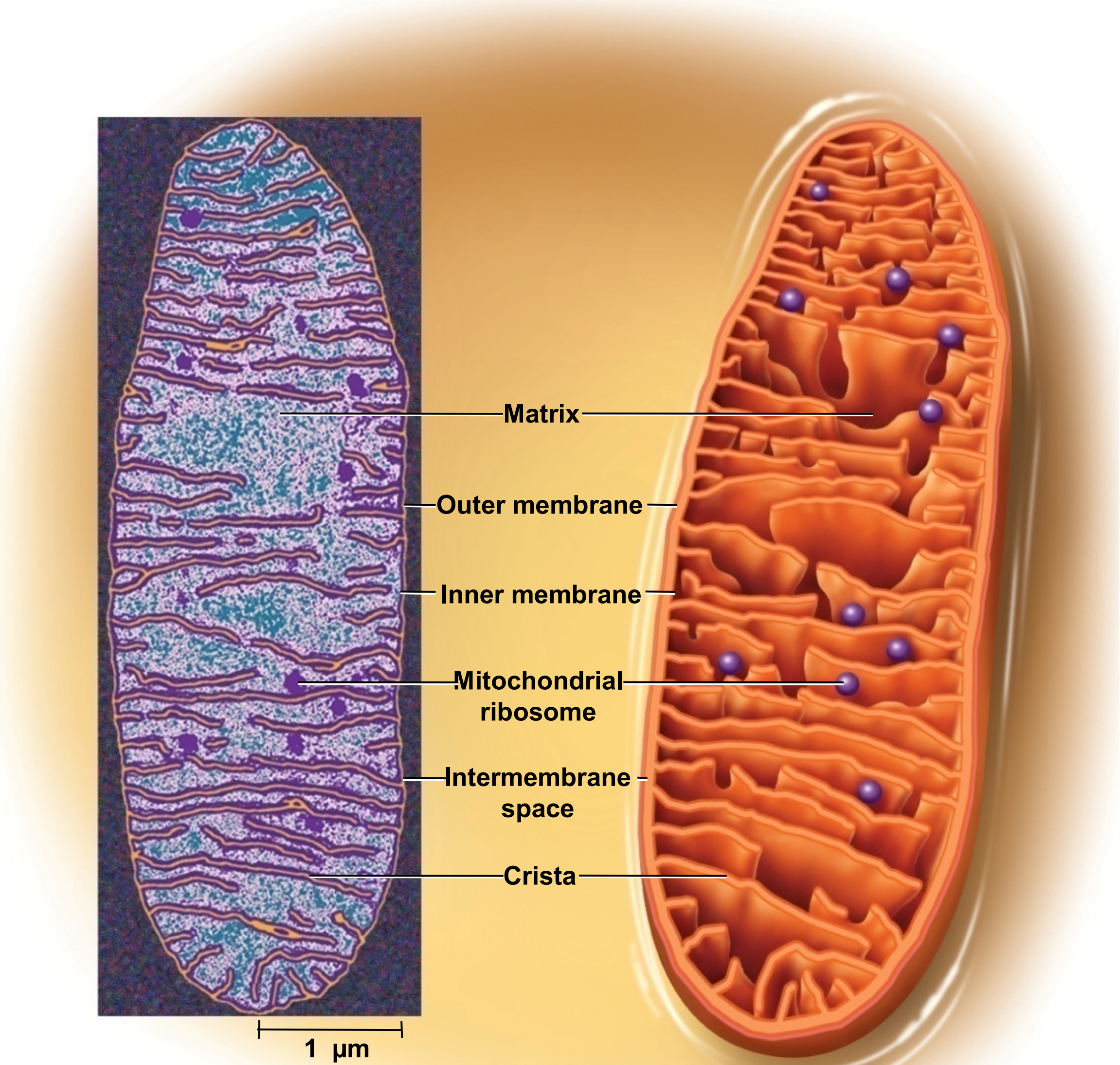


Figure 3.29a,b

(Left): Dr. Donald Fawcett & Dr. Porter/Visuals Unlimited

Evolution of Mitochondrion

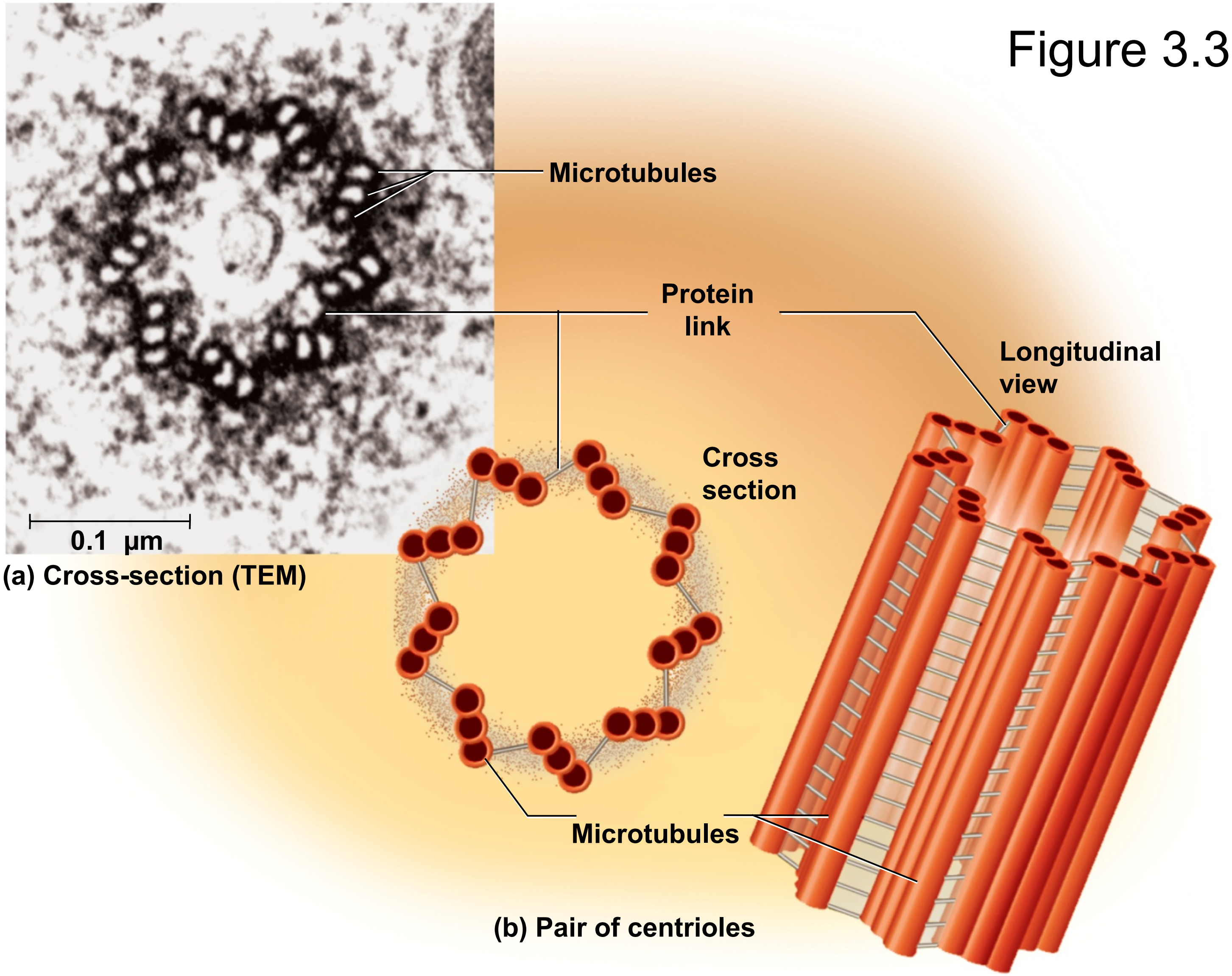
- It is a virtual certainty that mitochondria evolved from bacteria that invaded another primitive cell, survived in the cytoplasm, and became permanent residents
  - its two unit membranes suggests that the original bacterium provided the inner membrane, and the host cell's phagosome provided the outer membrane
  - mitochondrial ribosomes more like bacterial ribosomes
  - has its own mtDNA
    - small circular molecule resembling bacterial DNA
    - replicates independently of nuclear DNA
  - when a sperm fertilizes the egg, any mitochondria introduced by the sperm are usually destroyed, and only those provided by the egg are passed on to the developing embryo
    - mitochondrial DNA is almost exclusively inherited through the mother
  - mutates more readily than nuclear DNA
    - no mechanism for DNA repair
    - produces rare hereditary diseases
    - mitochondrial myopathy , mitochondrial encephalomyopathy, and others

Centrioles

- **centriole** – a short cylindrical assembly of microtubules arranged in nine groups of three microtubules each
- two centrioles lie perpendicular to each other within a small clear area of cytoplasm - **centrosome**
  - play role in cell division
- **cilia and flagella formation**
  - each **basal body** of a cilium or flagellum is a single centriole oriented perpendicular to plasma membrane
  - basal bodies originate in *centriolar organizing center*
    - migrates to plasma membrane
  - two microtubules of each triplet elongate to form the nine pairs of peripheral microtubules of the **axoneme**
  - cilium reaches full length in less than one hour

Centrioles

Figure 3.30a,b



(a) Cross-section (TEM)

(b) Pair of centrioles

a: From: Manley McGill, D.P. Highfield, T.M. Monahan, and B.R. Brinkley *Effects of Nucleic Acid Specific Dyes on Centrioles of Mammalian Cells*, published in the Journal of Ultrastructure Research 57, 43-53 (1976), pg. 48, fig. 6, with permission from Elsevier

Cytoskeleton

- **Cytoskeleton** - collection of filaments and cylinders
  - determines shape of cell, lends structural support, organizes its contents, directs movement of substances through the cell, and contributes to the movements of cell as a whole.
- Composed of:
  - **microfilaments** – made of protein **actin**
    - form network on cytoplasmic side of plasma membrane called the **terminal web**
      - provides physical support for phospholipid bilayer
      - actin supports microvilli and produces cell movements
  - **intermediate fibers** – thicker and stiffer than microfilaments
    - resist stresses placed on cell
    - participate in junctions that attach some cells to their neighbors
    - line nuclear envelope and form cagelike nuclear lamina that encloses DNA

Microtubules

- **microtubule made of the protein tubulin**
- microtubules radiate from centrosome and hold organelles in place, form bundles that maintain cell shape and rigidity, and act somewhat like railroad tracks
  - motor proteins ‘walk’ along these tracks carrying organelles and other macromolecules to specific locations in the cell
- not permanent structures, they come and go moment by moment

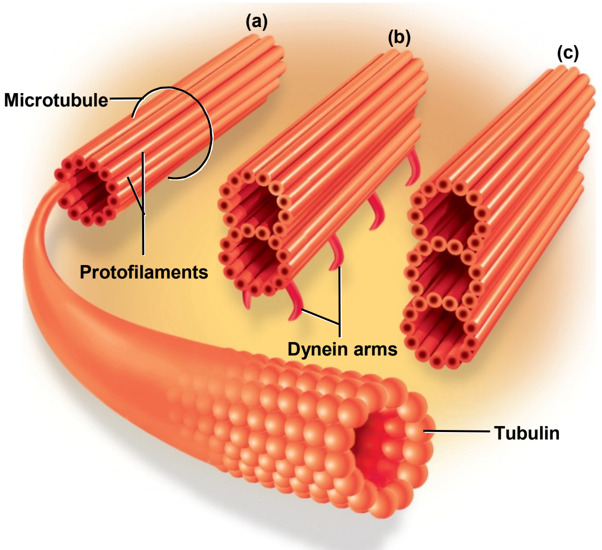


Figure 3.32

Cytoskeleton

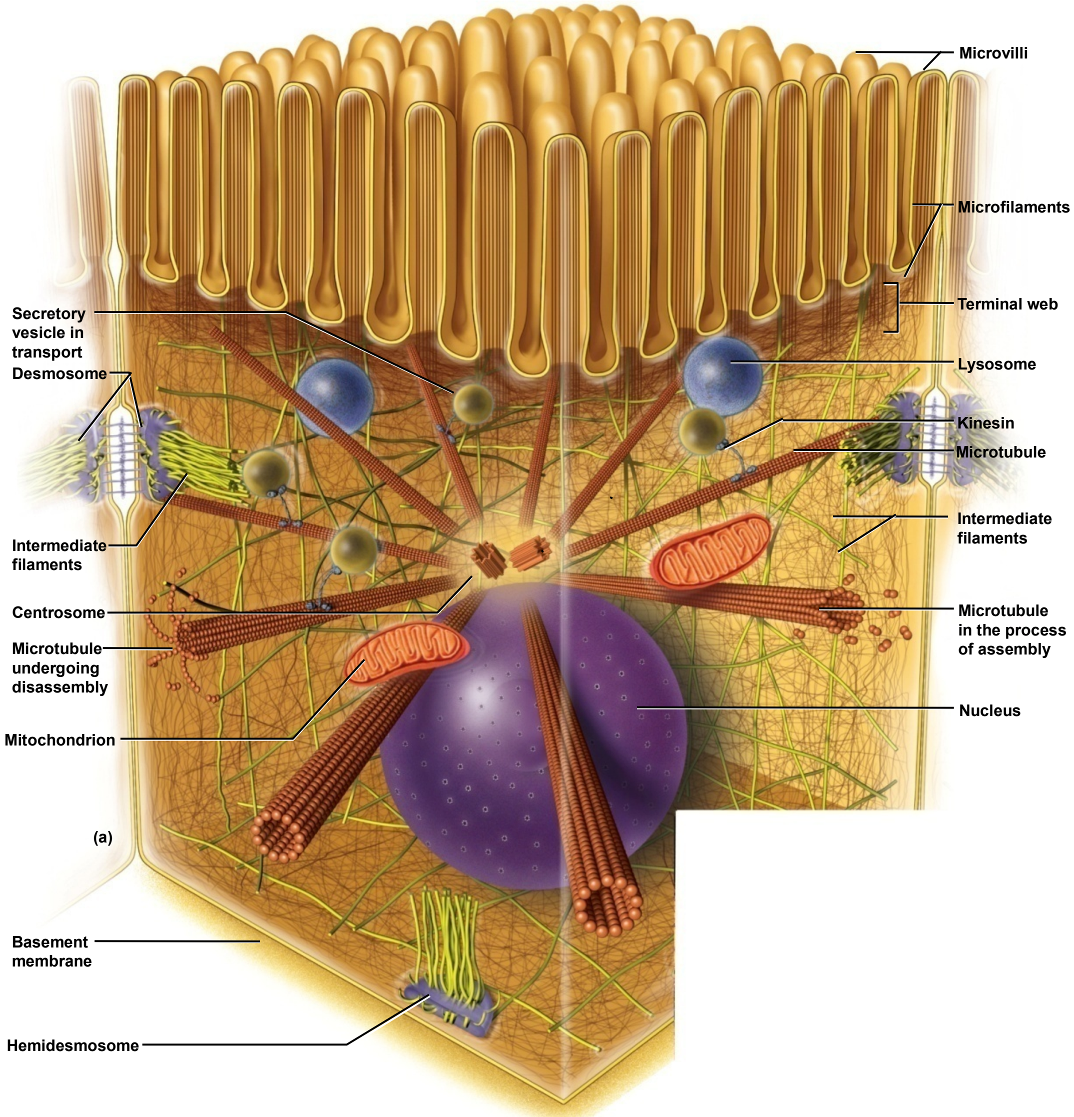
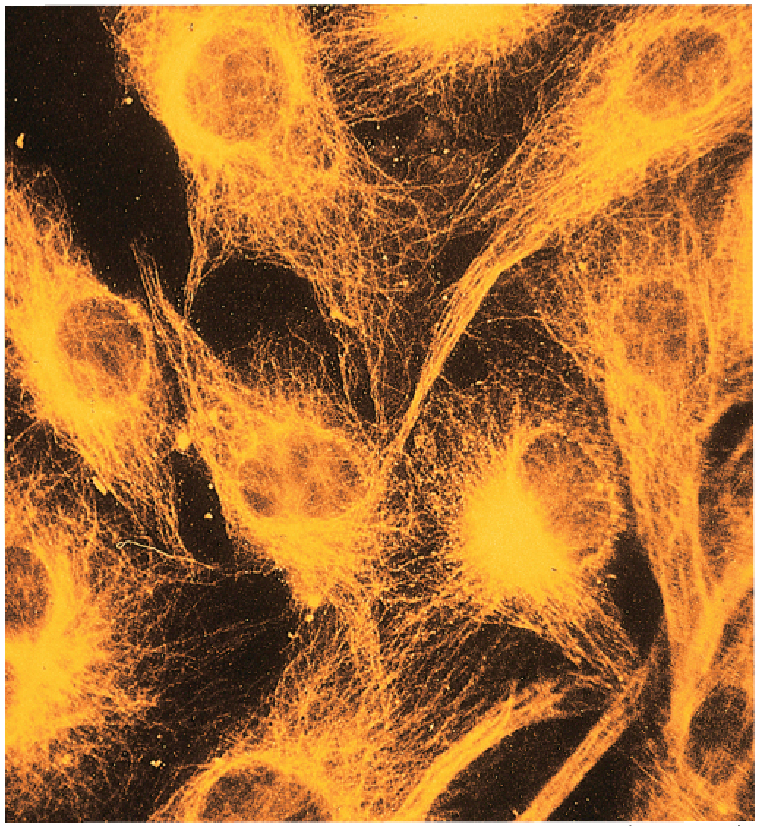


Figure 3.31a

EM and Fluorescent Antibodies demonstrate Cytoskeleton

(b)



15 µm

Figure 3.31b