Human Physiology From Cells to Systems 9th edition Sherwood Solutions Manual

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Chapter 2
Cell Physiology

CHAPTER OUTLINE

2.1 CELL THEORY AND DISCOVERY
The cell is the smallest structural and functional unit capable of carrying out life processes. Cells are the building blocks for all multicellular organisms including humans.
Cells of a hummingbird, a human, and a whale are all about the same size. Larger species have more cells, not larger cells.
The human body has about 200 different types of cells based on structure and specialization.

2.2 AN OVERVIEW OF CELL STRUCTURE
Most of the trillions of cells making up the human body share three major subdivisions:

The plasma membrane bounds the cell.
-The **plasma membrane** is composed of a bilayer of phospholipids containing proteins, carbohydrates, and cholesterol and functions to provide a semipermeable barrier around the cell. The membrane functions to prevent intracellular fluid from mixing with extracellular fluid (which separates the cell's contents from its surroundings), yet it functions to assist in the transport of life-sustaining substances into the cell and waste materials out of the cell.

The nucleus contains the DNA.
-The nucleus is bounded by the double-layer membrane (**nuclear envelope**) and contains deoxyribonucleic acid (DNA). The nucleus is the site for the synthesis of all types of RNA (transcription). The nuclear envelope is pierced by many **nuclear pores** that allow necessary traffic to move between the nucleus and the cytoplasm.

The cytoplasm consists of various organelles, the cytoskeleton, and the cytosol.
-The **cytoplasm** consists of the cytosol and both membranous and non-membranous organelles.

2.3 ENDOPLASMIC RETICULUM AND SEGREGATED SYNTHESIS
The rough ER synthesizes proteins for secretion and membrane construction.
The **endoplasmic reticulum (ER)** is a complex membrane system with two distinct, but connected, regions: rough (RER) and smooth endoplasmic reticulae (SER). The RER membrane is studded with ribosomes, which are the "workbenches" where protein synthesis takes place. In addition to these attached ribosomes, there are "free" ribosomes dispersed throughout the cytosol. Proteins synthesized in the RER are destined for export or used in construction of new cellular membrane. RER membranes contain enzymes necessary for lipid synthesis.

The smooth ER packages new proteins in transport vesicles.
The SER packages new proteins in portions of the SER membrane that have budded off to form **transport vesicles**, which are utilized to move newly synthesized protein to the Golgi complex. In some specialized cells, the SER is extensive and functions in lipid metabolism, aiding the RER in synthesizing steroids. Another function of SER is to detoxify harmful substances produced in the body by metabolism or substances that enter the body from the outside. These substances can include drugs or other foreign compounds.

RIBOSOMES CARRY OUT PROTEIN SYNTHESIS
Ribosomes coordinate the components that participate in translation of mRNA, allowing synthesis of proteins.
Ribosomes are "free" in the cytosol or attached to the membrane of the RER.

Misfolded proteins are destroyed by the ubiquitin-proteosome pathway.

2.4 GOLGI COMPLEX AND EXCOCYTOSIS
Transport vesicles carry their cargo to the Golgi complex for further processing.

The Golgi complex packages secretory vesicles for release by exocytosis.

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The Golgi complex is responsible for sorting and segregating products according to their function and final destination. This segregation of destination is accomplished by packaging the various products in membranes containing different surface proteins called **docking markers**. As a result of the specific docking marker, the vesicle can "dock" and unload its cargo only at the appropriate **docking-marker acceptor** proteins located at specific destinations within the cell—like a house address.

2.5 LYSOSOMES AND ENDOCYTOSIS

Lysosomes digest extracellular material brought into the cell by phagocytosis.

Lysosomes are small (0.2–0.5 μm) oval or spherical vesicles contain hydrolytic enzymes and serve as the "intracellular digestive system." Cells normally contain about 300 lysosomes.

Lysosomes remove worn-out organelles.

Lysosomes remove aged or damaged organelles (cellular debris) and foreign/extracellular materials (such as bacteria) brought into the cell by phagocytosis, pinocytosis, or receptor-mediated endocytosis.

2.6 PEROXISOMES AND DETOXIFICATION

Peroxisomes house oxidative enzymes that detoxify various wastes.

Peroxisomes are membranous organelles that produce and decompose hydrogen peroxide (H_2O_2). H_2O_2 is produced when the peroxisome's oxidative enzymes interact with various wastes produced in the cell or toxins such as alcohol that may have entered the cell. H_2O_2 is potentially destructive to the cell if allowed to accumulate; therefore, peroxisomes contain *catalase* to decompose the H_2O_2 into H_2O and O_2.

2.7 MITOCHONDRIA AND ATP PRODUCTION

Mitochondria are enclosed by two membranes.

Mitochondria are the *energy organelles or "power plants"* and generate about 90 percent of the ATP needed by the cells for survival. Mitochondria are rod-shaped or oval, and are about the size of bacteria. Mitochondria are thought to have originated as ancient bacteria that were engulfed, or invaded, by primitive cells early in evolutionary history, thus accounting for them possessing their own distinct DNA, **mitochondrial DNA (mtDNA)**.

Mitochondria form a mitochondrial reticulum in some cells.

In some cells mitochondria for interconnected networks, called the **mitochondrial reticulum**, increase the efficiency of distribution of substrates needed for ATP synthesis.

Mitochondria play a major role in generating ATP.

Mitochondria generate ATP using by-products from **glycolysis** (10 sequential enzyme-catalyzed reactions occurring in the cytosol) as substrates for the citric acid cycle (CAC; occurs in the mitochondrial matrix) and oxidative phosphorylation (occurs along the membrane of the cristae). The process involves oxidation of NADH and $FADH_2$ molecules via the **electron transport system**. ATP synthesis is powered by **chemiosmosis**.

The cell generates more ATP in aerobic than in anaerobic conditions.

The energy stored in ATP is used for synthesis, transport, and mechanical work.

Mitochondria play a key role in programmed cell death.

In addition to the role in ATP synthesis, mitochondria are essential for **apoptosis** (programmed cell death) as they rupture and leak **cytochrome c** into the cytosol, thus activating specific enzymes and causing them to slice the cell into small, disposable pieces.

2.8 VAULTS AS CELLULAR TRUCKS

Vaults may serve as cellular transport vehicles, moving specific substances from the nucleus to their destinations in the cell.

2.9 CYTOSOL: CELL GEL

The cytosol is important in intermediary metabolism, ribosomal protein synthesis, and nutrient storage.

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2.10 CYTOSKELETON: CELL "BONE AND MUSCLE"

Microtubules help maintain asymmetrical cell shapes and play a role in complex cell movements.
Microfilaments are important to cellular contractile systems and as mechanical stiffeners.
Intermediate filaments are important in cell regions subject to mechanical stress.
The cytoskeleton functions as an integral whole and links other parts of the cell together.

CENTROSOME, CENTRIOLES, AND MICROTUBULE ORGANIZATION

The centrosome consists of the centrioles surrounded by a mass of proteins. This structure functions as the cell's main microtubule-organizing center. Microtubules are components of the cytoskeleton. Microtubules are important in moving vesicles throughout the cytosol and function in the formation of cilia, flagella, and mitotic spindles.

LIST OF KEY TERMS

Cell structure
- cell/plasma membrane
- cytoplasm
- cytosol
- ectoplasm
- glycogen
- inclusions

Organelles
- nucleus
- nuclear envelope
- nuclear pores
- deoxyribonucleic acid (DNA)
- ribonucleic acid (RNA)
- vaults
- endoplasmic reticulum
- rough ER
- smooth ER
- Golgi bodies
- mitochondria
- matrix
- cristae
- lysosomes
- peroxisomes
- basal body
- transport vesicles

Cytoskeleton
- tubulin
- microtubules
- microfilaments
- actin

Cellular extensions
- flagellum
- microvilli
- cilia
- amoeboid movement
- pseudopod

Cellular processes
- metabolism
- aerobic
- anaerobic
- oxidative enzymes
- oxidative phosphorylation
- chemiosmotic mechanism
- autophagy
- phagocytosis
- pinocytosis
- exocytosis
- endocytosis
- receptor-mediated endocytosis
- endocytic vesicles
- guanosine diphosphate (GDP)
- guanosine triphosphate (GTP)
- adenosine diphosphate (ADP)
- adenosine triphosphate (ATP)
- molecular motors

Cellular molecules
- ATP synthase
- messenger RNA (mRNA)
- transfer RNA (tRNA)
- ribosomal RNA (rRNA)
- hydrogen peroxide
- catalase
- NAD^+
- FAD
- kinesin
- dynamin
- clathrin

Disease states of cellular origin
- amyotrophic lateral sclerosis (ALS)
- Lou Gehrig's disease
- cancers
- Tay-Sachs disease
- Charcot-Marie-Tooth type 2a

LECTURE HINTS AND SUGGESTIONS

1. Slides, transparencies, and electron micrographs are very useful for pointing out the major features of cells and organelles. These can be obtained from Carolina Biological Supply Company, Burlington, NC. Numerous online resources are also available, such as http://www.cellbio.com.

2. Demonstrate a model of a cell and the different organelles. Encourage students to think of cells as highly dynamic, three-dimensional entities.

3. Use online animations of active cellular events to drive home the concept of cellular functions.

4. Use a video microscope to show living cells or preserved specimens.

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5. If you have an internet connection in the classroom, a variety of video clips and slides are available at the sites listed below.

6. Students enjoy the "Cell Game" available from Carolina Biological Supply.

7. The importance of ATP in living systems can be easily demonstrated using fireflies. Kits are available from biological supply companies.

8. Have a student volunteer to do some form of physical exertion (e.g., jumping jacks or squat-thrusts) until they show signs of increased body heat, flushing of face, or sweat production. Use this as a demonstration of the use of cellular energy.

9. Be sure to remind students of the learning resources available on MindTap®.

AUDIOVISUAL AIDS

Videos/Films
The following are films that may be suitable for presentation in your class.

http://www.ffh.films.com

Cells – The Inside and Out, 2 parts, 29–33 min each.
These information-rich programs take an entertaining route in examining both the inner workings of the cell and the ways intercellular reactions occur. With extremely clear graphics and a witty narrative, the whole array of cellular organelles is presented, as well as the structure and function of the cell membrane.

Inside Cells: Cells and Their Organelles, 29 min.
Using electron microscope images and entertaining graphics, this program walks viewers through the basic components of a cell. The tour looks in detail at the structure and function of cellular organelles, including cell membranes, nuclei, mitochondria, chloroplasts, smooth and rough endoplasmic reticula, ribosomes, lysosomes, vacuoles, cytoplasm, cytosol and cytoskeleton, microtubules and microfilaments, and the Golgi complex. The program also covers the importance of internal cellular membranes and compares the relative sizes of the different organelles.

The Cell and Energy, 10 min.
The cell's energy molecule, glucose, is examined, and the process of extracting energy from glucose and transferring it to ATP in specific organelles—called mitochondria—is discussed. The structure, function, and evolution of these organelles are illustrated in relation to their role in cellular respiration.

http://www.ffh.films.com

Glycolysis I, 10 min.
This program begins with the discovery of the energy role played by the cell cytosol, the starting point of cellular respiration. Computer animation is used to follow the sequential breakdown of glucose through the process of glycolysis that leads to the production of ATP molecules.

Glycolysis II, 10 min.
Continuing with the second half of the glycolysis process, the energy intermediate molecule NADH is introduced. The glycolytic breakdown of glucose continues, ending with the production of the molecule pyruvate. The program also looks at how simple life-forms produce alcohol.

The Krebs Cycle, 10 min.
The chemical process known as the Krebs cycle is examined in detail. The cyclical metabolism of pyruvate and the subsequent generation of NADH inside the cell mitochondrion are illustrated in three-dimensional computer animation.

Oxidative Phosphorylation, 10 min.
Occurring across the inner membrane of the mitochondrion organelle, this process is shown to depend on the

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creation of a hydrogen gradient, which in turn drives the synthesis of ATP molecules. The program totals the ATPs produced from a single glucose molecule through the combined process of glycolysis, the Krebs cycle, and oxidative phosphorylation.

http://cambridge.films.com/

The Cell, 14 min.
This program explains the structure and function of the cell—the basic unit of life—and how it is studied using the compound and electron microscopes.

An Introduction to the Living Cell, 29 min.
This program shows subcellular organelles working together to meet the cell's needs. Full-motion computer animation, art, and microscopic images help guide students' understanding of the cell's inner workings.

Cancer Cell Research: The Way of All Flesh, 60 min.
This program examines the history of using HeLa cells in the study of cancer biology.

Cell Biology in the Cellular City, 30 min.
This DVD explores the membrane of the cell and of the organelles.

http://www.carolina.com

Glycolysis and Cellular Respiration: The Biology of Energy, 27 min.
This DVD explores the processes of glycolysis, fermentation, CAC, and oxidative phosphorylation, and the endosymbiotic theory of the origin of mitochondria.

Visualizing Cell Processes, 5 videos, each 15 min.
These VHS video explore: (1) the biochemistry of the chloroplast and the mitochondria; (2) the structures and processes of cell movement and transport of materials in the cell; (3) cellular anatomy and the molecules of the cell; (4) replication, mitosis, and cellular reproduction; and (5) the genetic code.

http://www.evndirect.com

Understanding the Cell, 17 min.
This DVD/VHS program uses computer animation and videomicroscopy to detail the structure of prokaryotic and eukaryotic cells.

Understanding Cell Membranes, 32 min.
This DVD/VHS provides computer animation for the study of the basic anatomy of the cell membrane.

DNA: The Amazing Double Helix, 21 min.
This DVD/VHS provides students with state-of-the-art computer animations for the study of the structure and function of DNA and practical application of genetic engineering.

The Cell: Basic Unit of Life, 18 min.
This DVD provides a basic overview of the structure of the cell and an explanation of the function of organelles.

Software

Cells: An Interactive Exploration. (http://ffh.films.com/id/11557/Cells_An_Interactive_Exploration.htm)
-an interactive CD exploring the structures and functions common to all cell types.
Cells alive! QG, a CD that explores cell structure in video and animations.
Cell Biology Biodiscs CD, BIO, a series of 13 CDs on cell biology.
Cell City, CE, an innovative CD that explains the operations of a cell.
Cell Structure and Function, EI, presents an overview of the animal cell.
Cell Structure and Function, CY, an interactive CD.
Cell Structure and Specialization Set, CBS, five CDs covering cells.
Cells, CBS, covers the cell theory and differences between plant and animal cells.

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Cellular Respiration, CY, an interactive CD.
Cellular Respiration, PLP, an interactive CD.
Energy and the Chemistry of Life, CBS, CD Mac/Win.
Inside the Cell, Cyber Ed, http://www.cyber-ed.com.
Learning about Cells and Biology, EDI, an illustrated CD on cell structure and function.
The Plasma Membrane & Cellular Transport, CY, an interactive CD.
The Study of the Cell, PLP, an interactive CD.

Relevant Educational Websites

http://www.biology.arizona.edu/cell_bio/tutorials/cytoskeleton/main.html
This jump-off page lists links for tutorials and images dealing with cellular movements.

http://ajpcon.physiology.org/
Home page for the American Journal of Physiology. Provides essays on the APS classic papers.

http://www.nrcam.uchc.edu/ (National Resource for Cell Analysis and Modeling)
Home page for the Virtual Cell, an online cell-modeling program.

http://www.interscience.wiley.com/jpages/0021-9541/
Interface for the Journal of Cellular Physiology.

http://www.cellsalive.com
Jump-off page for interactive study of cells, mitosis, meiosis, etc. Also available are downloads of videos and photographic images of cells.

http://www.cell.com
Jump-off page for downloadable papers and animations of cellular processes.

http://www.cellbio.com (Cell and Molecular Biology Online)
Homepage for Cell and Molecular Biology Online. Provides hyperlinks to videos, papers, books, and interactive demonstrations of the function of cells.

http://www.biology.arizona.edu/cell_bio/cell_bio.html
Hyperlinks to The Biology Project. Activities include animations and online problem sets designed to help the student learn cell biology.

Relevant Organizations Providing Educational Resources

American Society for Biochemistry and Molecular Biology
9650 Rockville Pike
Bethesda, MD 20814-3996
http://www.asbmb.org

American Society for Cell Biology
8120 Woodmont Ave, Suite 750
Bethesda, MD 20814-2762
http://www.ascb.org

American Society of Cytopathology
400 West 9th Street, Suite 201
Wilmington, Delaware 19801
http://www.cytopathology.org/

British Society for Cell Biology
c/o M. Clements, Department of Zoology
Downing St., Cambridge CB2 3EJ, UK
http://www.bscb.org

Chapter Two

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Canadian Society of Biochemistry and Molecular and Cell Biology
http://www.csbmcb.ca/

International Federation for Cell Biology
http://www.ifcbiol.org/

International Society for Analytical Cytology
60 Revere Drive, Suite 500
Northbrook, IL 60062-1577
(847) 205-4722
http://www.isac-net.org/

Answers to End of Chapter Essays

1. An advantage of organelle compartmentalization is that it allows organelles to have a distinct internal compartment that contains specialized chemicals for carrying out particular functions.

2. Membranous organelles include: endoplasmic reticulum, Golgi complex, lysosomes, peroxisomes, and mitochondria. Non-membranous organelles include: ribosomes, vaults, and centrioles.

3. Endoplasmic reticulum (ER) is a fluid-filled membranous system distributed throughout the cytosol. Rough ER consists of flattened interconnected sacs, and the outer surface of the rough ER contains ribosomes. These ribosomes synthesize and release proteins into the ER lumen, where they undergo transport within or outside the cell. Smooth ER is a meshwork of interconnected tubules and lacks ribosomes, thus the name *smooth*. The smooth ER collects proteins and lipids from the rough ER and packages them for distribution throughout the cell.

4. Exocytosis is the mechanism by which materials from the inside of the cell are released to the exterior. During exocytosis cells secrete materials into the ECF. Endocytosis is the opposite of exocytosis. It is the internalization of extracellular material by the cell. There are three forms of endocytosis depending on what is being internalized. Pinocytosis is a process by which a droplet of ECF is non-selectively internalized. Phagocytosis is a process by which large multi-molecular particles are internalized. Receptor-mediated endocytosis is a selective process that enables cells to internalize specific large molecules from its environment.

5. Lysosomes serve as the intracellular digestive system. They contain hydrolytic enzymes and, in addition to breaking down raw ingredients, they also remove worn-out organelles.

6. Peroxisomes contain oxidative enzymes and perform detoxifying activities by removing hydrogen atoms from certain organic molecules. Lysosomes serve as the intracellular digestive system. They contain hydrolytic enzymes, and in addition to breaking down raw ingredients, they also remove worn-out organelles.

7. Cellular respiration refers to the collection of intracellular reactions in which nutrient molecules are broken down to form ATP. During the process, oxygen is utilized and carbon dioxide is produced. Oxidative phosphorylation is the process by which ATP is synthesized using the energy released by electrons as they are transferred to oxygen; it takes place at the mitochondrial inner membrane. Chemiosmosis encompasses the last steps of oxidative phosphorylation and involves the production of ATP via the activation of ATP synthase. This enzyme is activated as H+ moves into the mitochondrial matrix.

8. Mitochondria are enclosed by a double membrane—an outer membrane that surrounds the organelle, itself, and an inner membrane that contains numerous folds, called cristae. The innermost cavity formed by the cristae is called the matrix and is filled with a gel-like solution. These organelles play a major role in ATP production. Citric acid cycle reactions occur in the matrix, and oxidative phosphorylation reactions take place on the inner membrane.

9. Oxidative enzymes in the peroxisome utilize oxygen for detoxification. Oxidative enzymes in the mitochondria utilize oxygen in the process of synthesizing ATP.

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10. Cells expend energy on synthesis of new chemical compounds, membrane transport processes, and mechanical work.

11. The cytoskeleton is composed of microtubules, microfilaments, and intermediate filaments. Microtubules serve a variety of functions including maintaining the shape of cells, coordinating complex intracellular movements, and serving as the main structural component of cilia and flagella. Microfilaments play a major role in cellular contractile systems, including muscle contraction. Intermediate filaments resist mechanical stress placed on cells.

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Human Physiology – From Cells to Systems | 9e
Lauralee Sherwood

2

Cell Physiology

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2.1 Cell Theory and Discovery

TABLE 2-1 Principles of the Cell Theory

- The cell is the smallest structural and functional unit capable of carrying out life processes.
- The functional activities of each cell depend on the specific structural properties of the cell.
- Cells are the living building blocks of all multicellular organisms.
- An organism's structure and function ultimately depend on the collective structural characteristics and functional capabilities of its cells.
- All new cells and new life arise only from preexisting cells.
- Because of this continuity of life, the cells of all organisms are fundamentally similar in structure and function.

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2.2 An Overview of Cell Structure

- Major cell subdivisions
  - Plasma membrane: bounds the cell
  - Nucleus: contains DNA
    - Important concepts: roles of RNA, human genome and proteome, epigenetics, and lipidome
  - Cytoplasm: consists of various organelles, the cytoskeleton, and the cytosol
    - Cytoplasm is the portion of the cell interior not occupied by the nucleus

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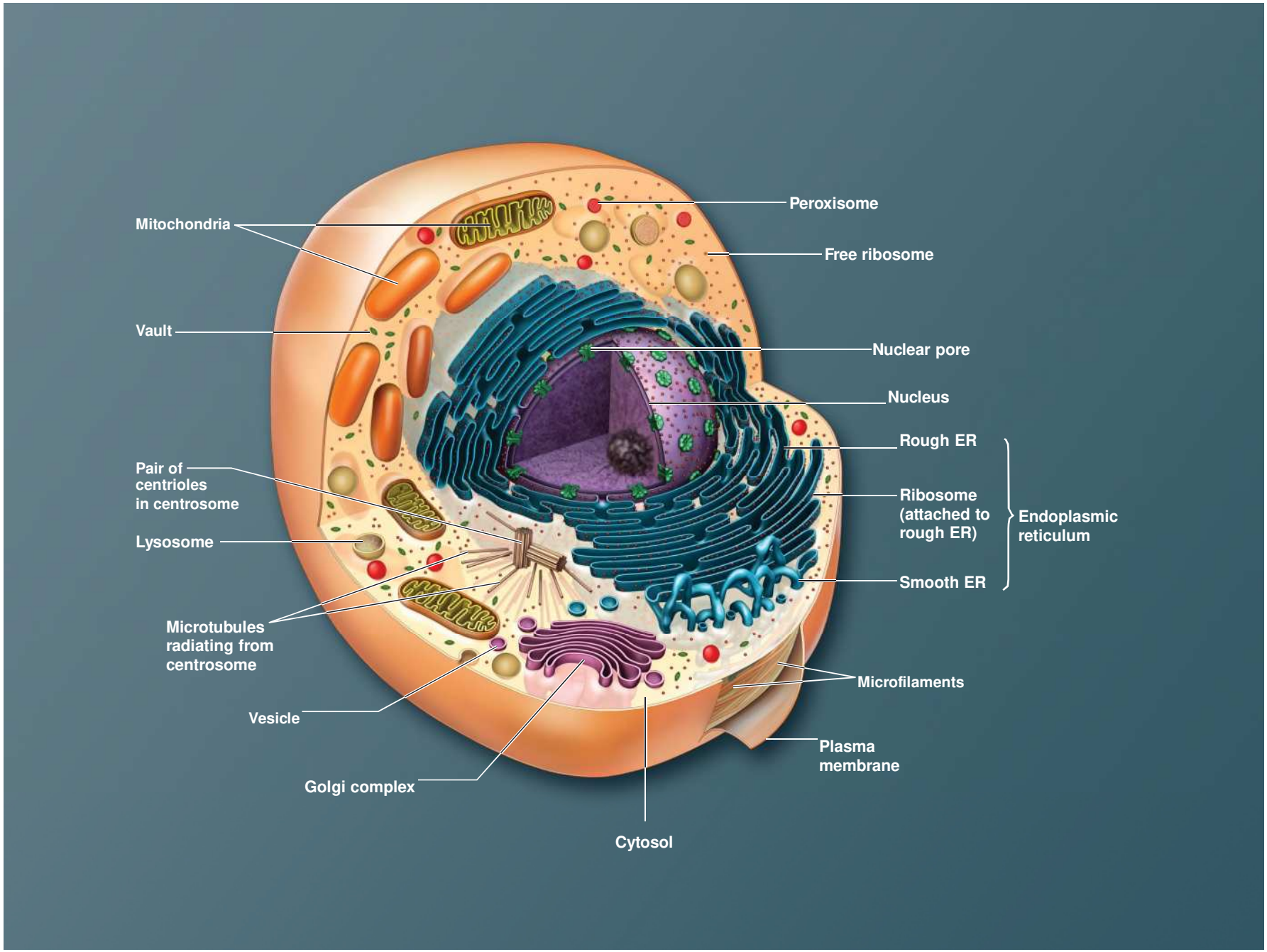

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2.3 Endoplasmic Reticulum and Segregated Synthesis

- Endoplasmic reticulum (ER) is an elaborate fluid-filled membranous system
  - Distributed extensively throughout the cytosol
  - Primary function: produce proteins and lipids
  - Rough-ER synthesizes proteins for secretion and membrane construction
  - Smooth ER packages new proteins in transport vesicles

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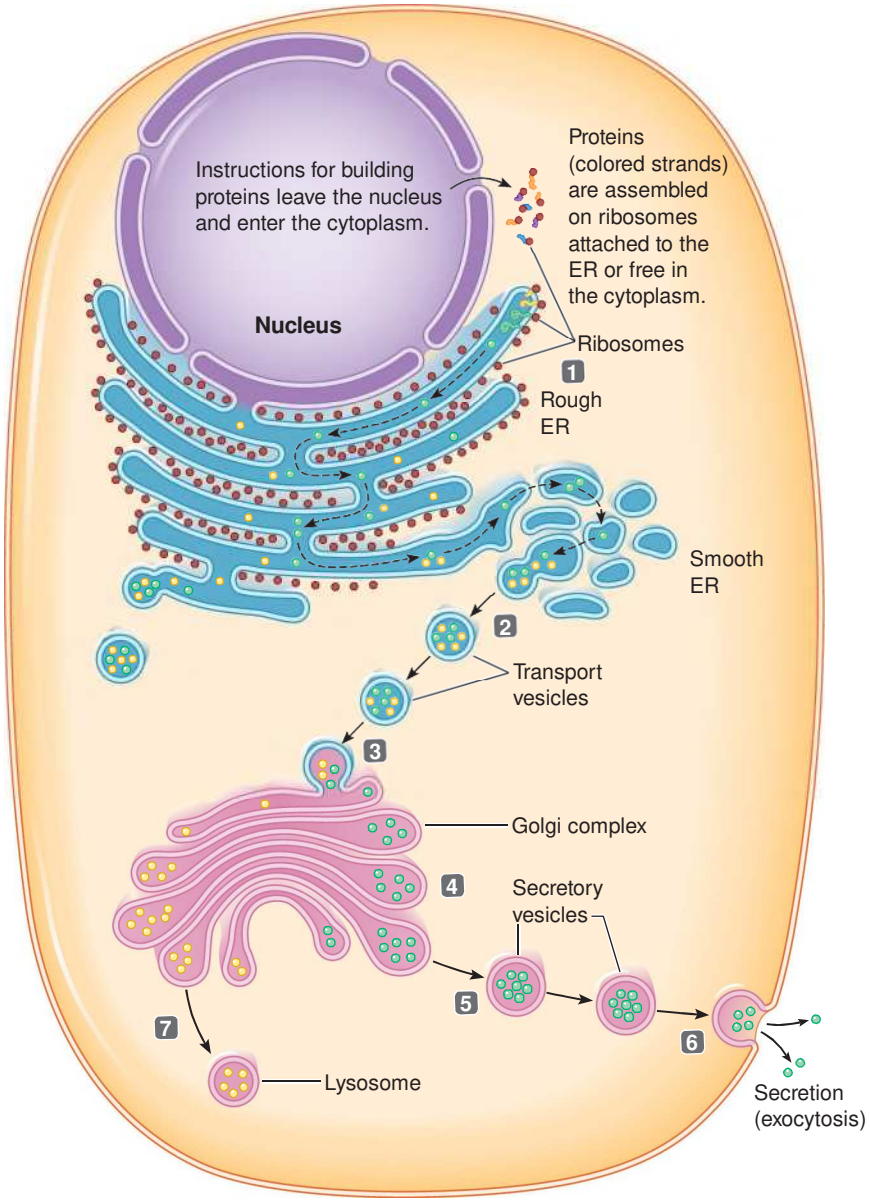

1 The rough ER synthesizes proteins to be secreted to the exterior or to be incorporated into plasma membrane or other cell components.

2 The smooth ER packages the secretory product into transport vesicles, which bud off and move to the Golgi complex.

3 The transport vesicles fuse with the Golgi complex, open up, and empty their contents into the closest Golgi sac.

4 The newly synthesized proteins from the ER travel by vesicular transport through the layers of the Golgi complex, which modifies the raw proteins into final form and sorts and directs the finished products to their final destination by varying their wrappers.

5 Secretory vesicles containing the finished protein products bud off the Golgi complex and remain in the cytosol, storing the products until signaled to empty.

6 On appropriate stimulation, the secretory vesicles fuse with the plasma membrane, open, and empty their contents to the cell's exterior. Secretion has occurred by exocytosis, with the secretory products never having come into contact with the cytosol.

7 Lysosomes also bud from the Golgi complex.

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Endoplasmic Reticulum and Segregated Synthesis (cont'd.)

- Misfolded proteins are destroyed by the ubiquitin–proteasome pathway
  - They are tagged with ubiquitin, a small protein "doom tag"
    - Labels those flawed proteins for destruction
    - Also labels other damaged or unneeded intracellular proteins for degradation in proteasomes

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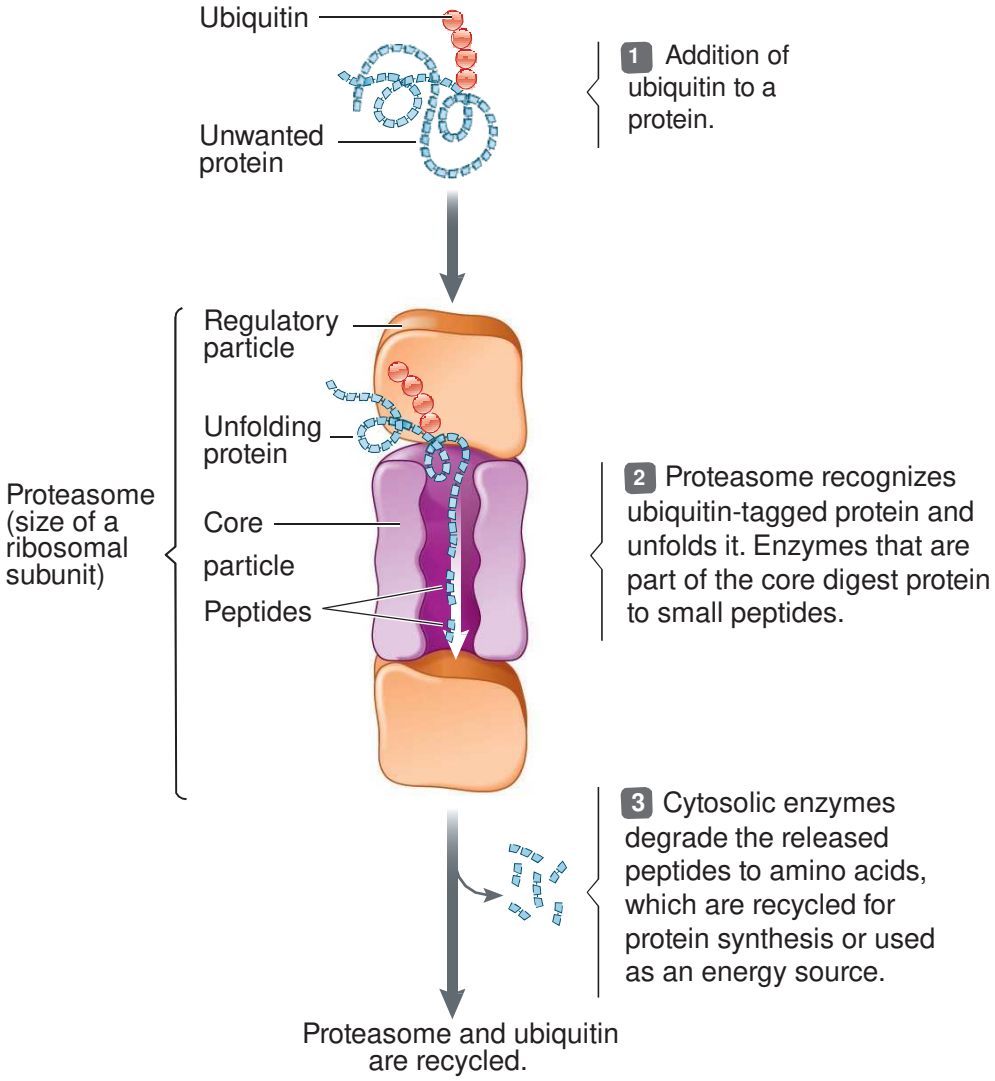

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2.4 Golgi Complex and Exocytosis

- Golgi complex
  - Consists of a stack of flattened, slightly curved, membrane-enclosed sacs
    - Do not come into contact with one another
  - Vesicular transport from one Golgi sac to the next: accomplished through action of membrane-curving coat protein I (COPI)
  - In secretory cells, the Golgi complex packages proteins for export by exocytosis

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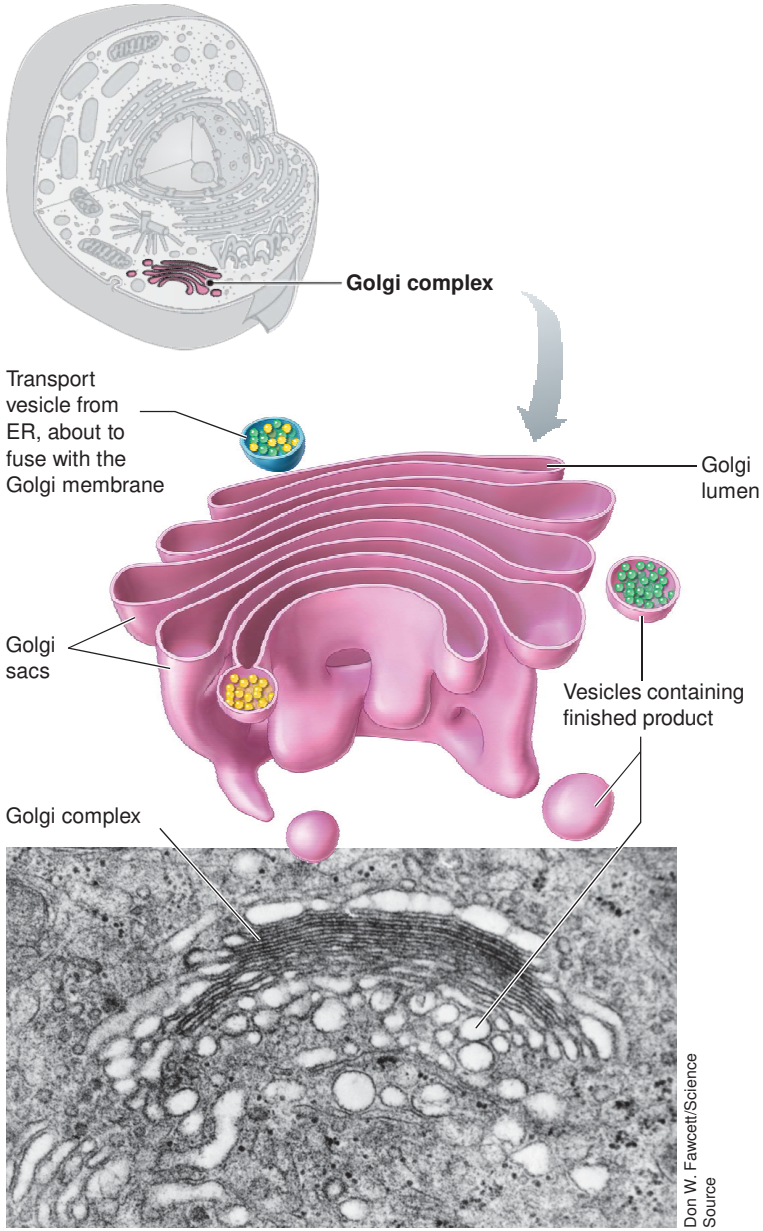

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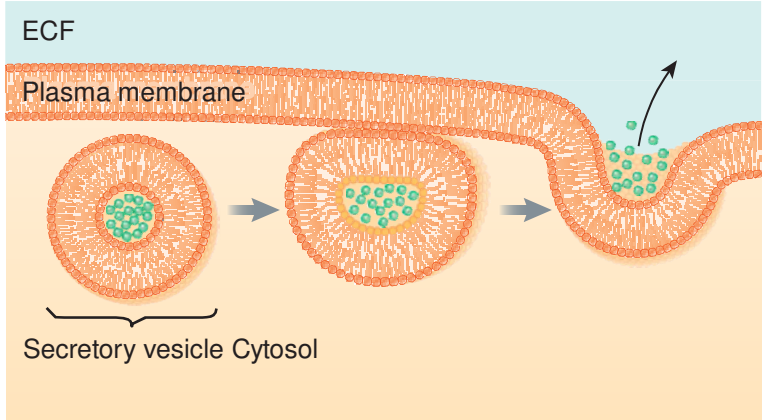
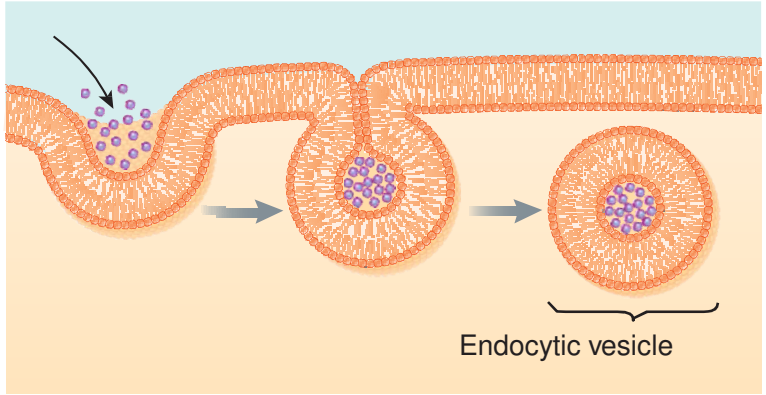


(a) Exocytosis: A secretory vesicle fuses with the plasma membrane, releasing the vesicle contents to the cell exterior. The vesicle membrane becomes part of the plasma membrane.



(b) Endocytosis: Materials from the cell exterior are enclosed in a segment of the plasma membrane that pockets inward and pinches off as an endocytic vesicle.

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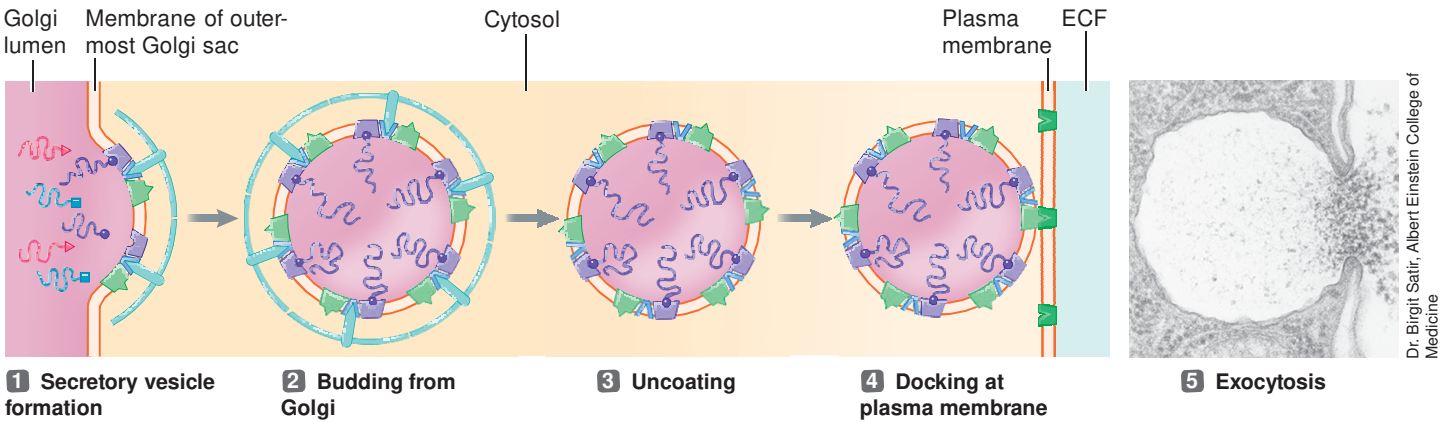

KEY

- Recognition marker
- Coat-protein acceptor
- v-SNARE (docking marker)
- Sorting signal
- Cargo proteins
- Coatomer (coat protein that causes membrane to curve)
- t-SNARE (docking-marker acceptor)

1 Recognition markers in the membrane of the outermost Golgi sac capture the appropriate cargo from the Golgi lumen by binding only with the sorting signals of the protein molecules to be secreted. The membrane that will wrap the vesicle is coated with coatomer, which causes the membrane to curve, forming a bud.

2 The membrane closes beneath the bud, pinching off the secretory vesicle.

3 The vesicle loses its coating, exposing v-SNARE docking markers on the vesicle surface.

4 The v-SNAREs bind only with the t-SNARE docking-marker acceptors of the targeted plasma membrane, ensuring that secretory vesicles empty their contents to the cell's exterior.

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2.5 Lysosomes and Endocytosis

- Lysosomes: small, membrane-enclosed, degradative organelles
  - Digest extracellular material brought into the cell by phagocytosis and remove worn-out organelles
  - Endocytosis: internalization of extracellular material within a cell
    - Processes: pinocytosis, receptor-mediated endocytosis, and phagocytosis

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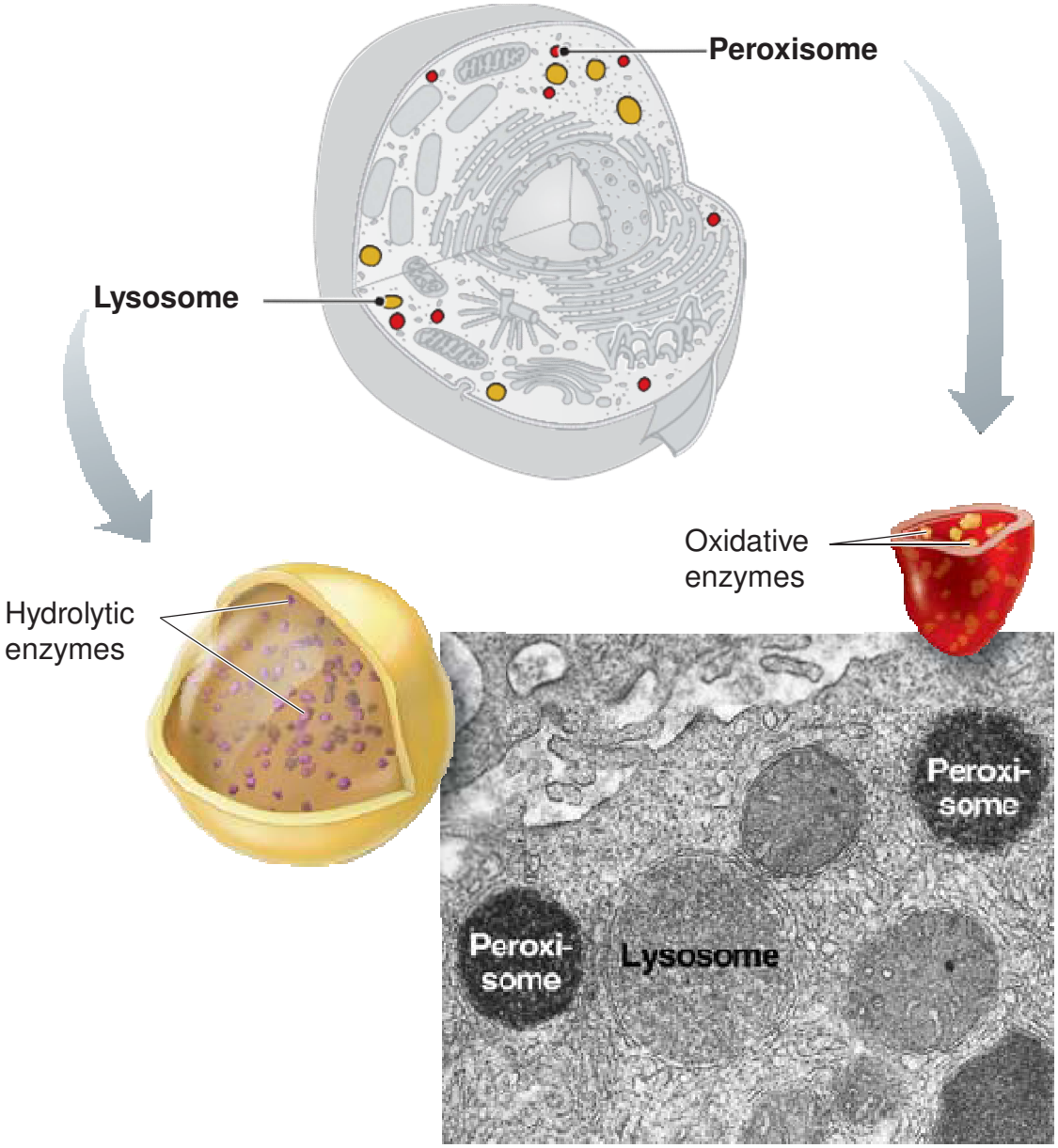

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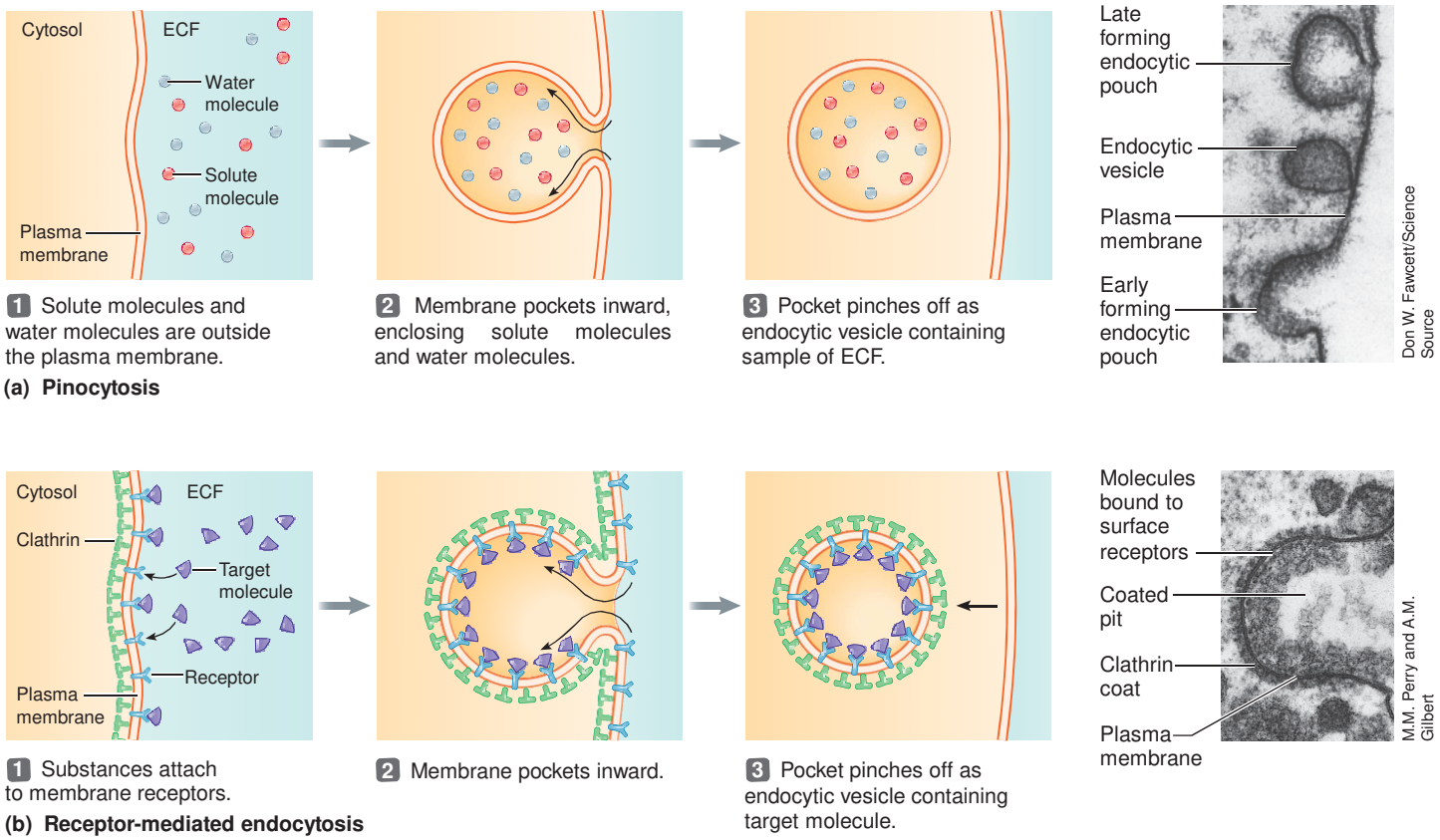

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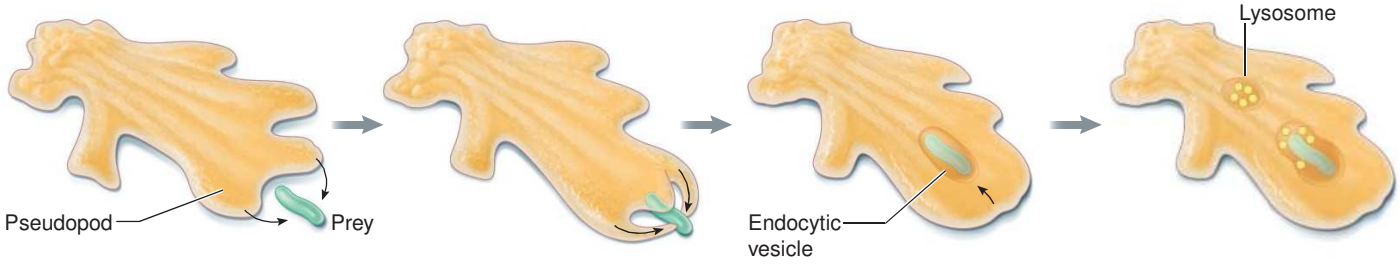
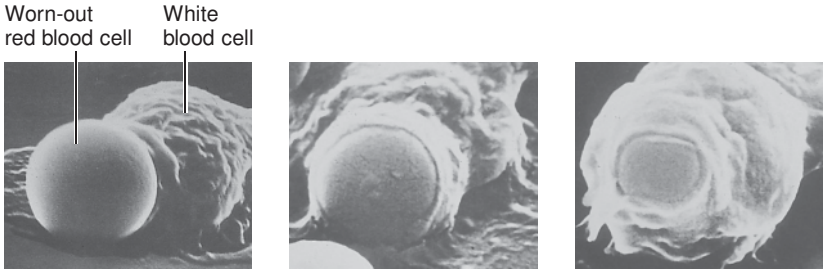


1 Pseudopods begin to surround prey.

2 Pseudopods close around prey.

3 Prey is enclosed in endocytic vesicle (phagosome) that sinks into cytoplasm.

4 Lysosome fuses with vesicle, releasing enzymes that attack material inside vesicle.



Source Prof. Marcel Bessis/Science

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2.6 Peroxisomes and Detoxification

- Peroxisomes: membranous organelles
  - Produce and decompose hydrogen peroxide (H_2O_2) while degrading potentially toxic molecules
  - House oxidative enzymes that detoxify various wastes
    - Oxidative enzymes use oxygen (O_2) to strip hydrogen from certain organic molecules

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2.7 Mitochondria and ATP Production

- Mitochondria: energy organelles of the cell
  - Extract energy from food nutrients and transform it into a usable form for activities
  - Enclosed by two membranes that form the cristae
  - Form a mitochondrial reticulum in some cell types
  - Play a major role in generating ATP
    - Processes: glycolysis, citric acid cycle, oxidative phosphorylation

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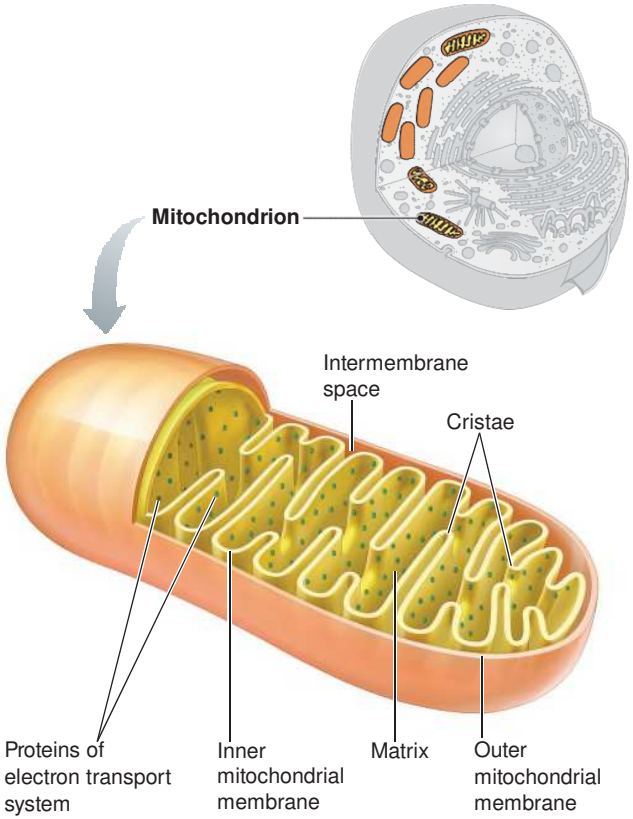

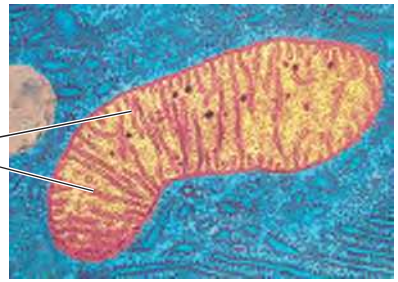

(a) Mitochondrion

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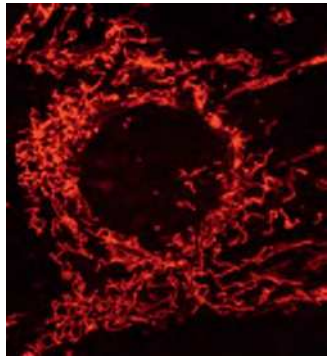

(b) Mitochondrial reticulum

Courtesy of Xiying Fan

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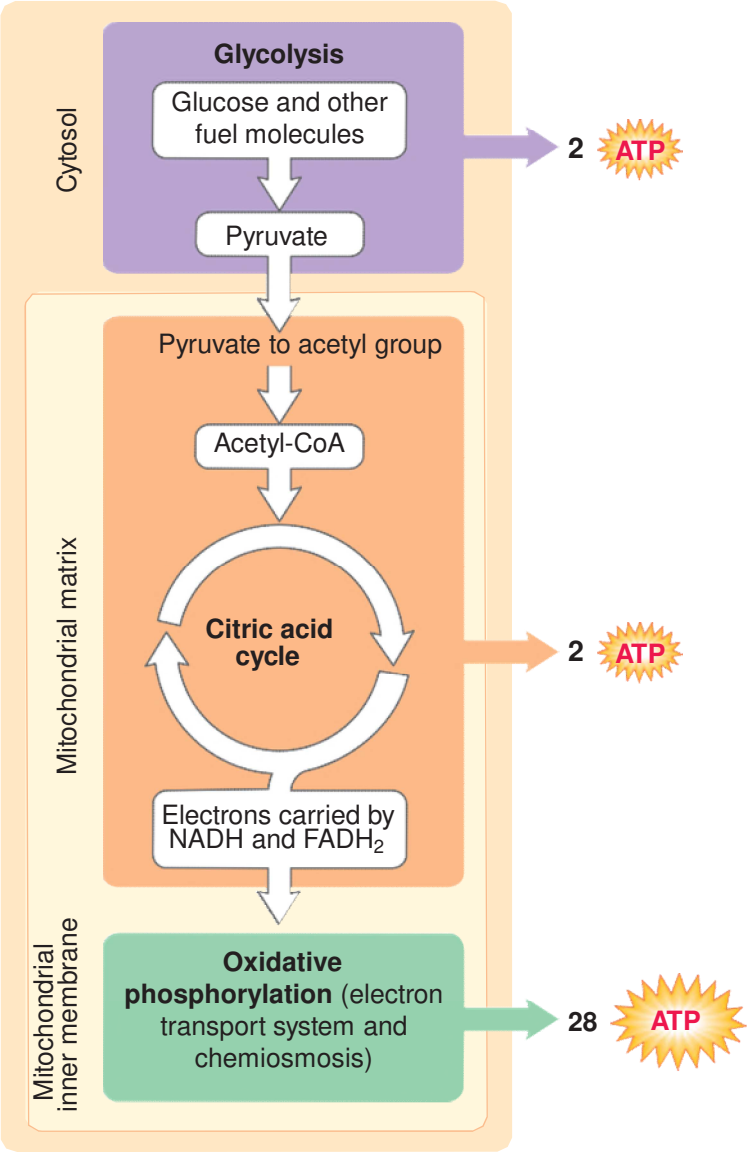

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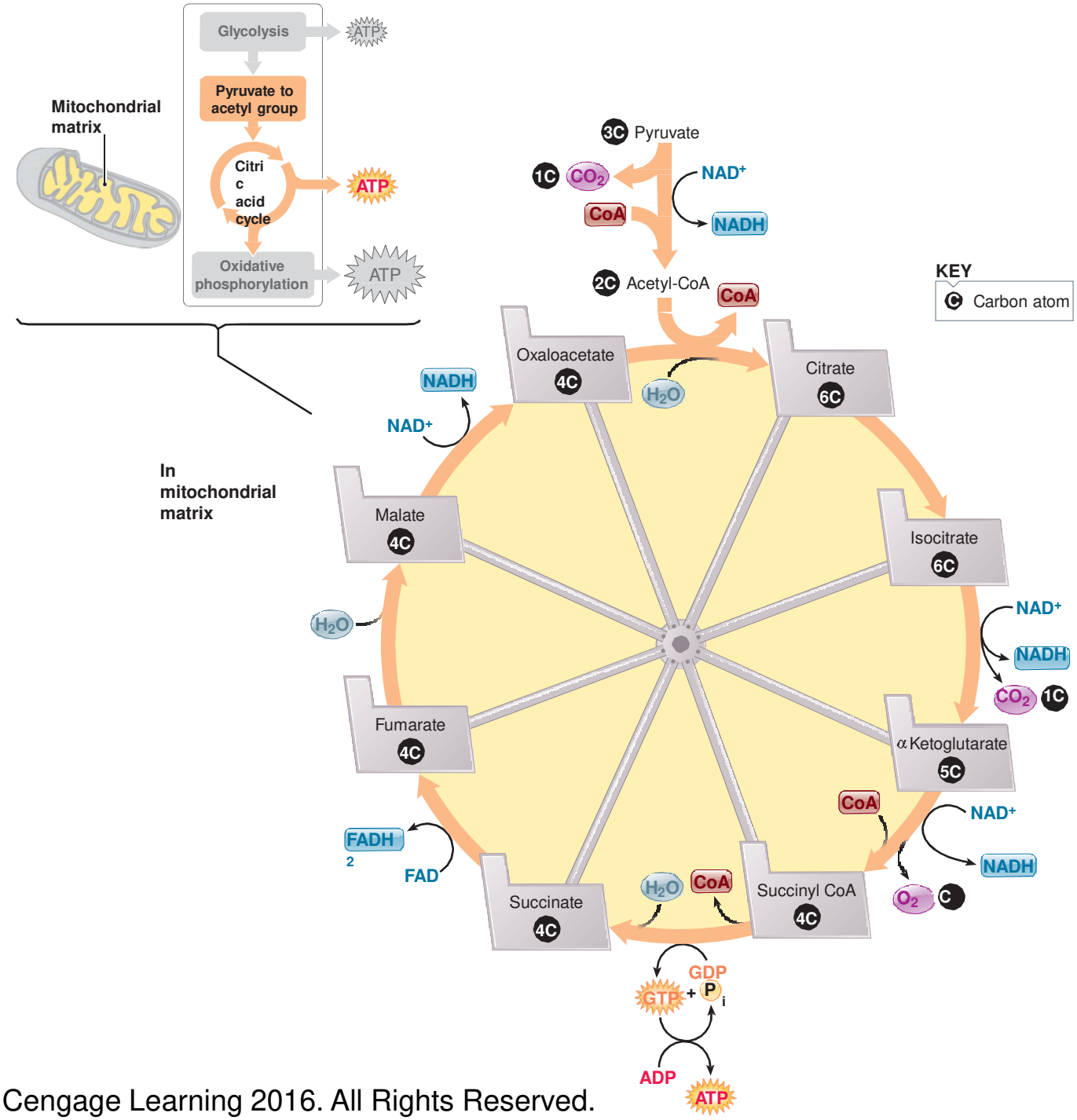

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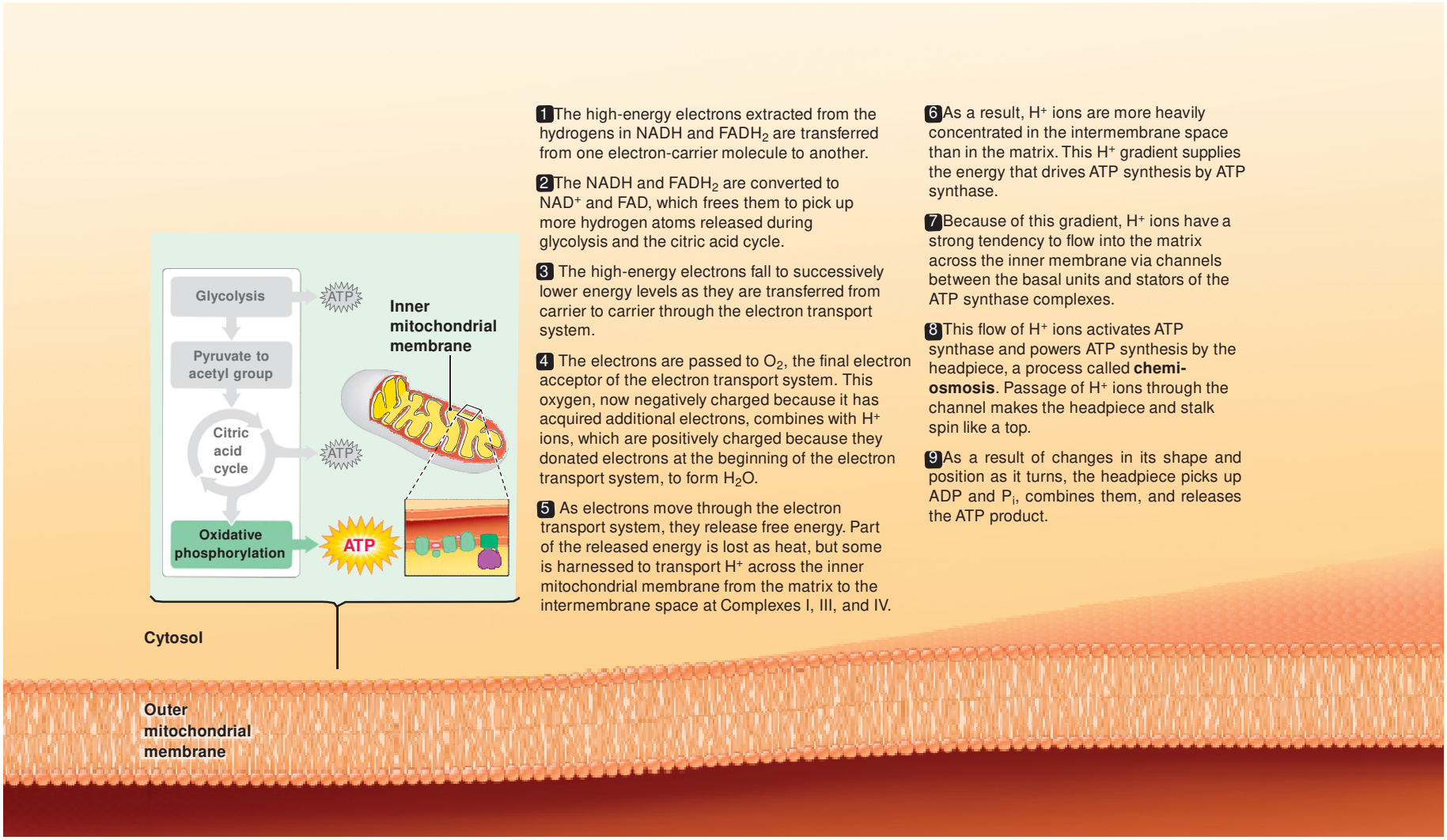

1 The high-energy electrons extracted from the hydrogens in NADH and $FADH_2$ are transferred from one electron-carrier molecule to another.

2 The NADH and $FADH_2$ are converted to NAD^+ and FAD, which frees them to pick up more hydrogen atoms released during glycolysis and the citric acid cycle.

3 The high-energy electrons fall to successively lower energy levels as they are transferred from carrier to carrier through the electron transport system.

4 The electrons are passed to O_2, the final electron acceptor of the electron transport system. This oxygen, now negatively charged because it has acquired additional electrons, combines with H^+ ions, which are positively charged because they donated electrons at the beginning of the electron transport system, to form H_2O.

5 As electrons move through the electron transport system, they release free energy. Part of the released energy is lost as heat, but some is harnessed to transport H^+ across the inner mitochondrial membrane from the matrix to the intermembrane space at Complexes I, III, and IV.

6 As a result, H^+ ions are more heavily concentrated in the intermembrane space than in the matrix. This H^+ gradient supplies the energy that drives ATP synthesis by ATP synthase.

7 Because of this gradient, H^+ ions have a strong tendency to flow into the matrix across the inner membrane via channels between the basal units and stators of the ATP synthase complexes.

8 This flow of H^+ ions activates ATP synthase and powers ATP synthesis by the headpiece, a process called **chemi-osmosis**. Passage of H^+ ions through the channel makes the headpiece and stalk spin like a top.

9 As a result of changes in its shape and position as it turns, the headpiece picks up ADP and P_i, combines them, and releases the ATP product.

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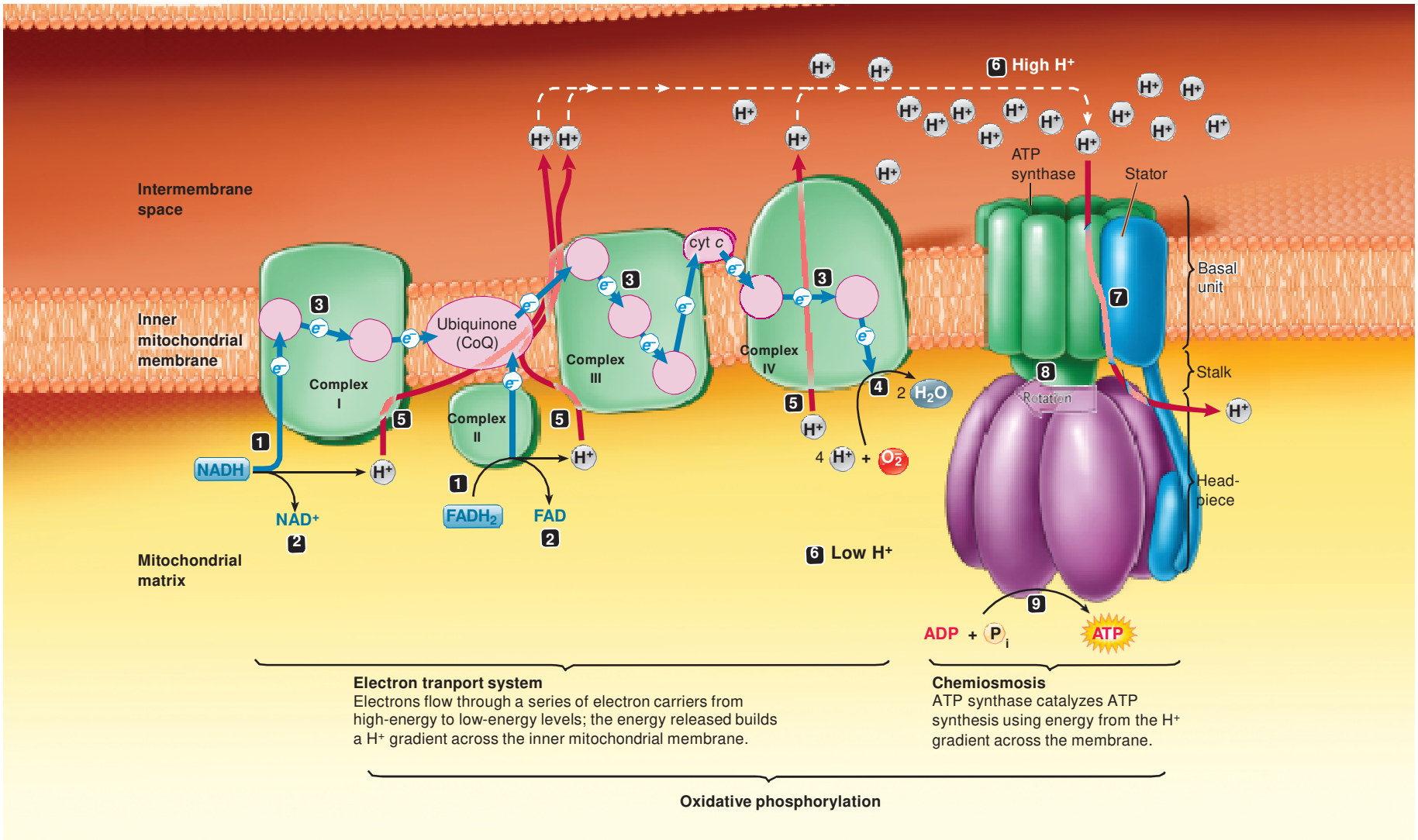

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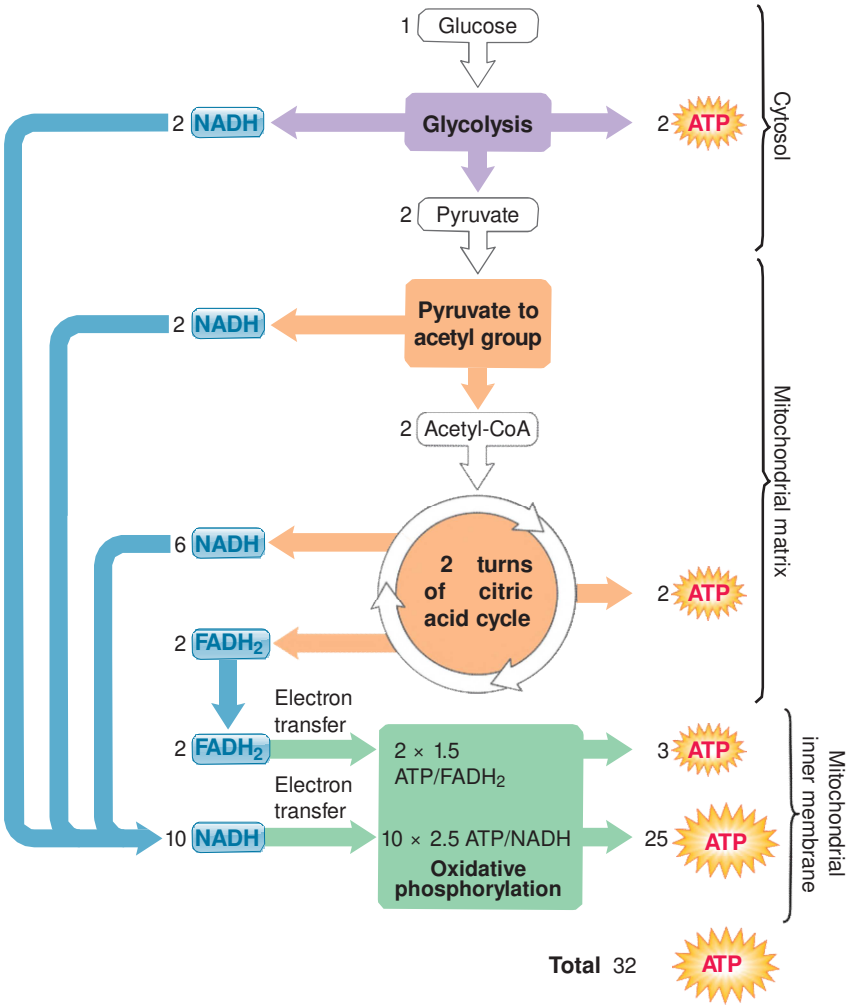

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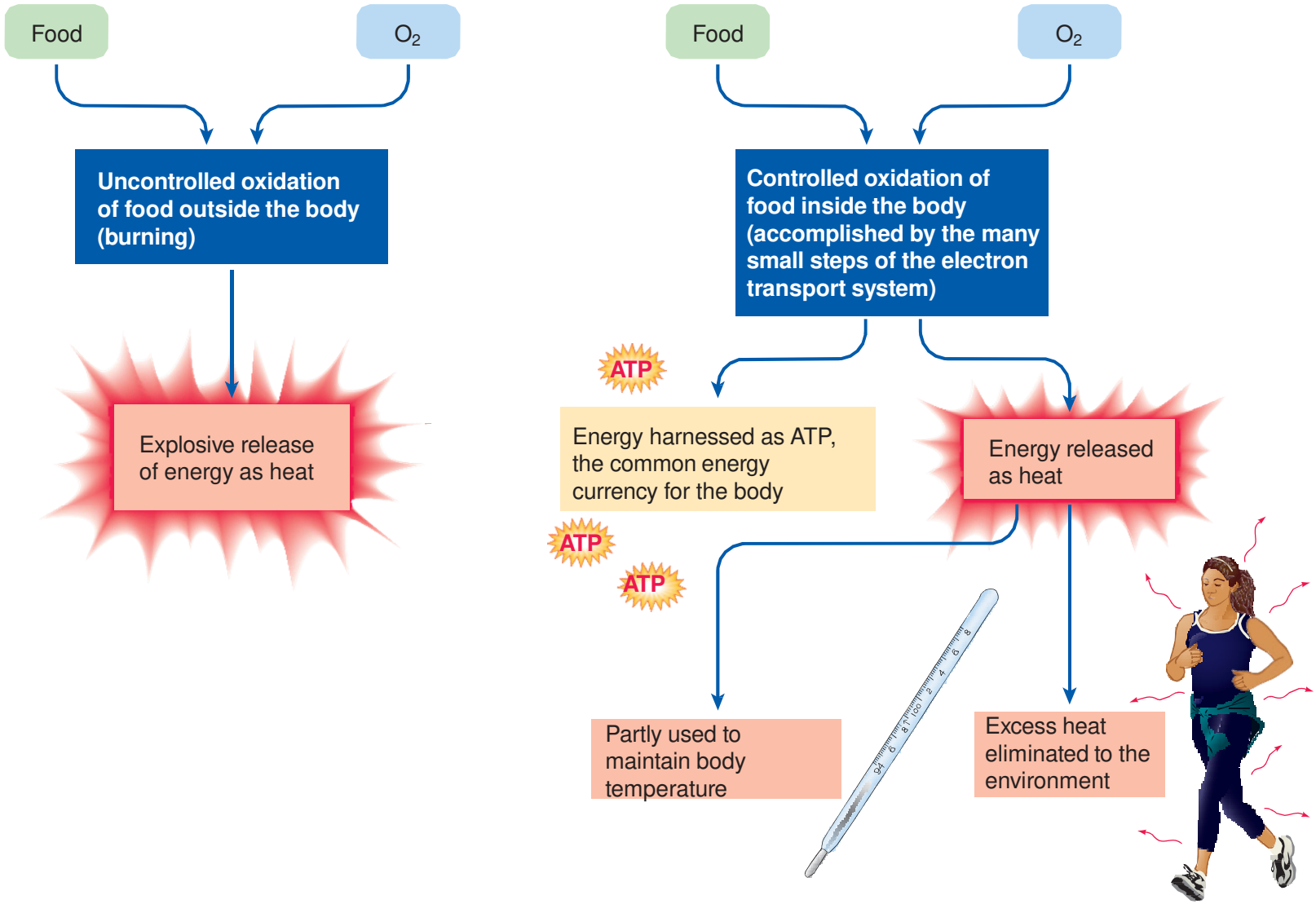

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Mitochondria and ATP Production (cont'd.)

- Aerobic conditions
  - More energy is generated in these conditions than in anaerobic conditions
- Energy stored within ATP
  - Used for synthesis, transport, and mechanical work
- Programmed cell death
  - Mitochondria plays a key role

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2.8 Vaults as Cellular Trucks

- Vaults: nonmembranous organelles
  - Shaped like octagonal barrels and have a hollow interior
  - May serve as cellular transport vehicles
  - Believed to pick up nucleus molecules and transport elsewhere in the cell
  - May transport mRNA from nucleus to ribosomal sites for protein synthesis
  - May play an undesirable role in bringing about multidrug resistance displayed by cancer cells

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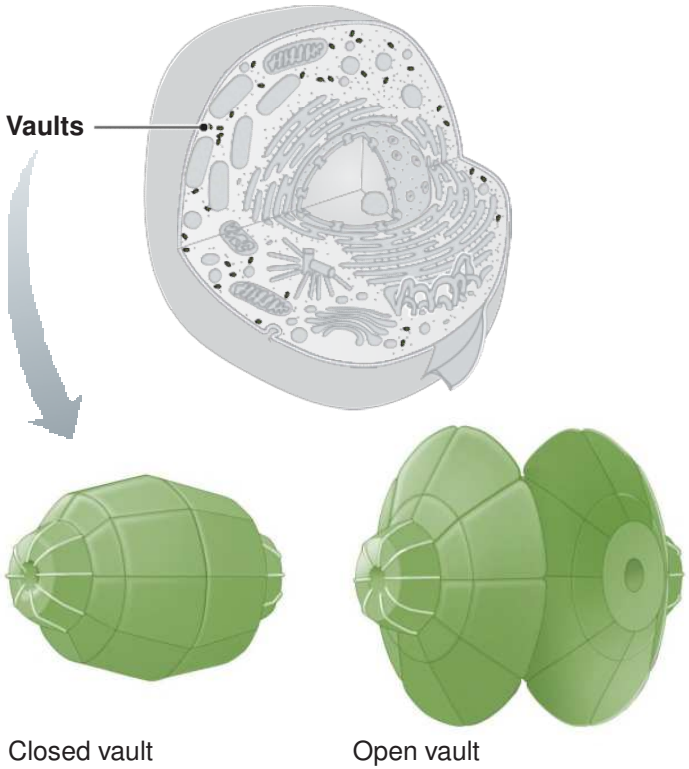

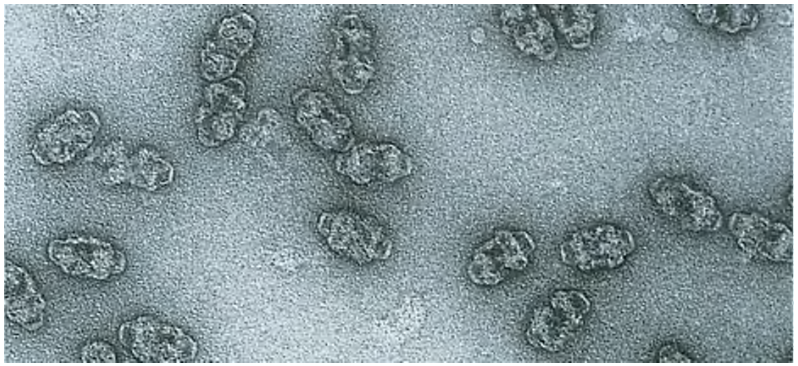

Dr. Leonard H. Rome/UCLA School of Medicine

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2.9 Cytosol: Cell Gel

- Cytosol: semiliquid portion of cytoplasm that surrounds organelles
  - Categories of activities associated with cytosol
    - Enzymatic regulation of intermediary metabolism
    - Ribosomal protein synthesis
    - Storage of fat, carbohydrate, and secretory vesicles

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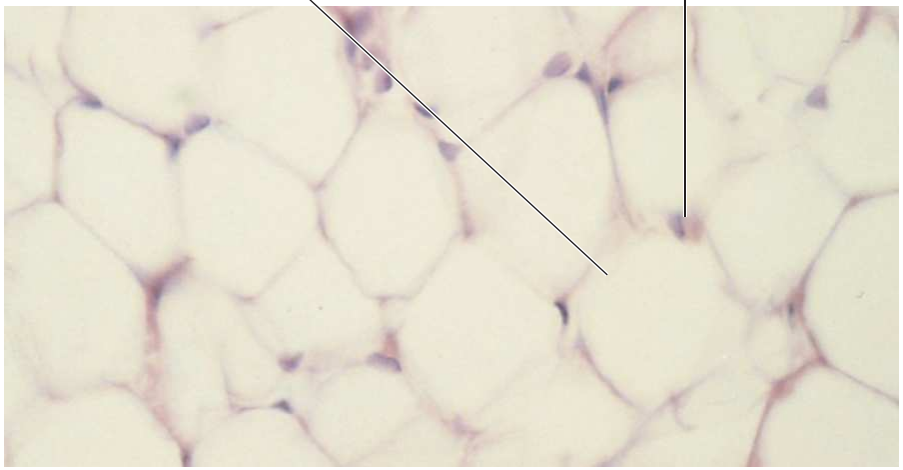
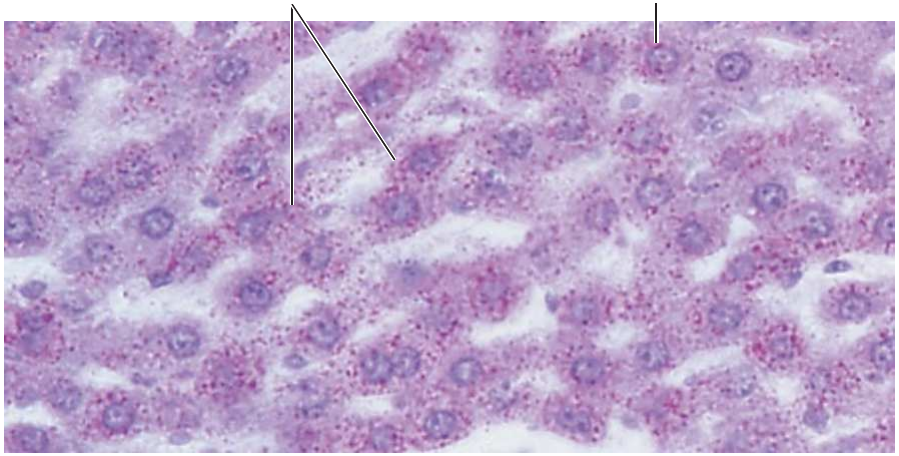


West Virginia University, School of Medicine (WVU)

(a) Fat storage in adipose cells



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(b) Glycogen storage in liver cells

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2.10 Cytoskeleton: Cell “Bone and Muscle”

- Cytoskeleton: complex protein network that acts as “bone and muscle” of cell
  - Distinct elements
    - Microtubules: help maintain asymmetric cell shapes and play a role in complex cell movements
    - Microfilaments: important to cellular contractile systems and as mechanical stiffeners
    - Intermediate filaments: important in cell regions subject to mechanical stress

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TABLE 2-2 Summary of Cytoplasm Components

Cytoplasm Component	Structure	Function
Membranous organelles		
Endoplasmic reticulum	Extensive, continuous membranous network of fluid-filled tubules and flattened sacs, partially studded with ribosomes	Forms new cell membrane and other cell components and manufactures products for secretion
Golgi complex	Sets of stacked, flattened, membranous sacs	Modifies, packages, and distributes newly synthesized proteins
Lysosomes	Membranous sacs containing hydrolytic enzymes	Serve as cell's digestive system, destroying foreign substances and cellular debris
Peroxisomes	Membranous sacs containing oxidative enzymes	Perform detoxification activities
Mitochondria	Rod- or oval-shaped bodies enclosed by two membranes, with the inner membrane folded into cristae that project into an interior matrix	Act as energy organelles; major site of ATP production; contain enzymes for citric acid cycle, proteins of electron transport system, and ATP synthase

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Nonmembranous organelles		
Ribosomes	Granules of RNA and proteins—some attached to rough ER, some free in cytosol	Serve as workbenches for protein synthesis
Proteasomes	Cylindrical protein complexes consisting of a hollow core particle capped on both ends by a regulatory particle	Degrade unwanted intracellular proteins that have been tagged for destruction by ubiquitin
Vaults	Shaped like hollow octagonal barrels	Serve as cellular trucks for transport from nucleus to cytoplasm
Centrioles	A pair of cylindrical structures at right angles to each other	Form and organize microtubules during assembly of the mitotic spindle during cell division and form cilia and flagella
Cytosol		
Intermediary metabolism enzymes	Dispersed within the cytosol	Facilitate intracellular reactions involving degradation, synthesis, and transformation of small organic molecules
Transport, secretory, and endocytic vesicles	Transiently formed, membrane-enclosed products synthesized within or engulfed by the cell	Transport or store products being moved within, out of, or into the cell, respectively
Inclusions	Glycogen granules, fat droplets	Store excess nutrients

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Cytoskeleton		As an integrated whole, serves as the cell's "bone and muscle"
Microtubules	Long, slender, hollow tubes composed of tubulin molecules	Maintain asymmetric cell shapes and coordinate complex cell movements, specifically serving as highways for transport of secretory vesicles within cell, serving as main structural and functional component of cilia and flagella, and assembling into mitotic spindle
Microfilaments	Intertwined helical chains of actin molecules; microfilaments composed of myosin molecules also present in muscle cells	Play a vital role in various cellular contractile systems, including muscle contraction and amoeboid movement; serve as a mechanical stiffener for microvilli
Intermediate filaments	Irregular, threadlike proteins	Help resist mechanical stress

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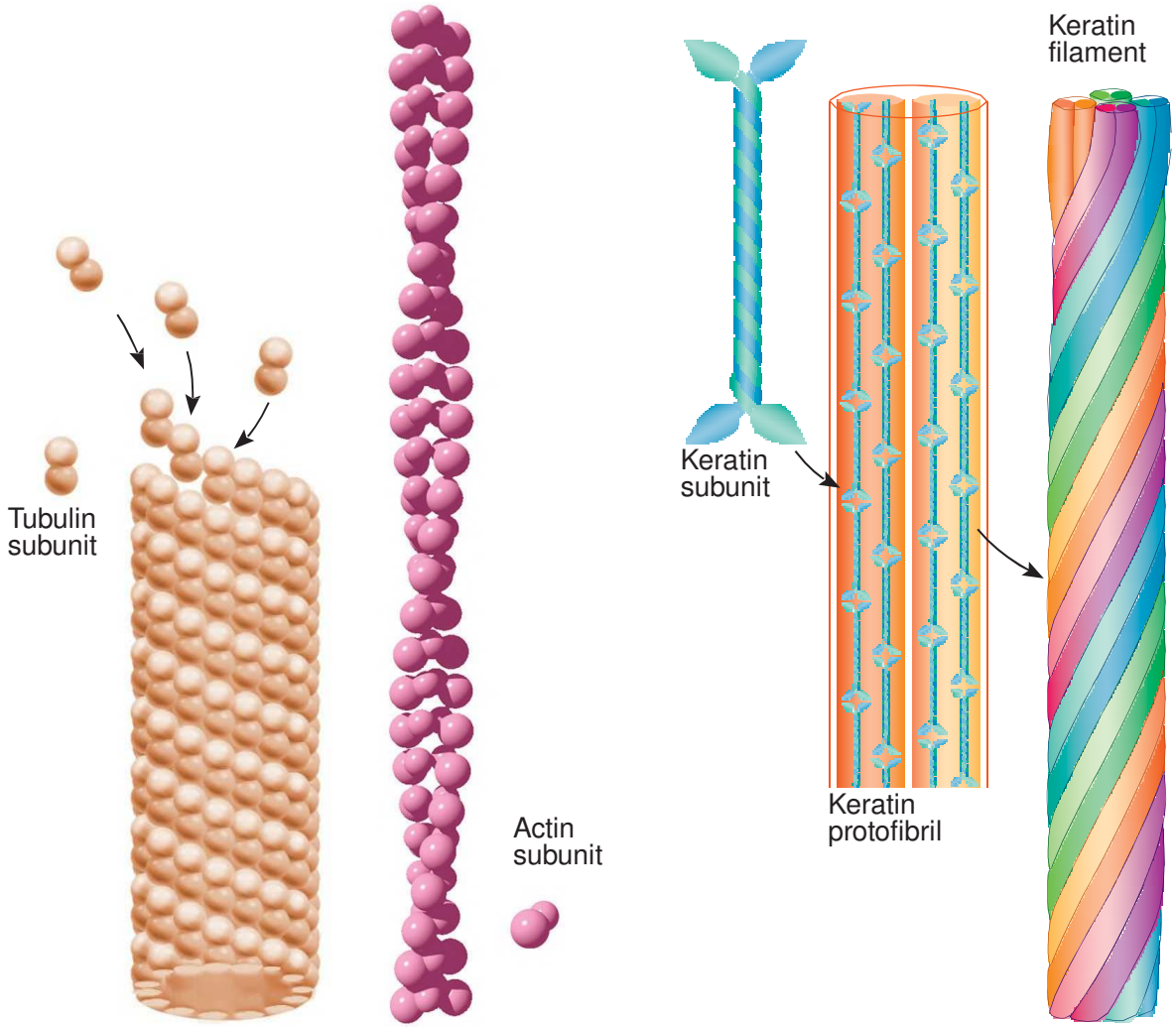

(a) Microtubule **(b)** Microfilament **(c)** Keratin, an intermediate filament

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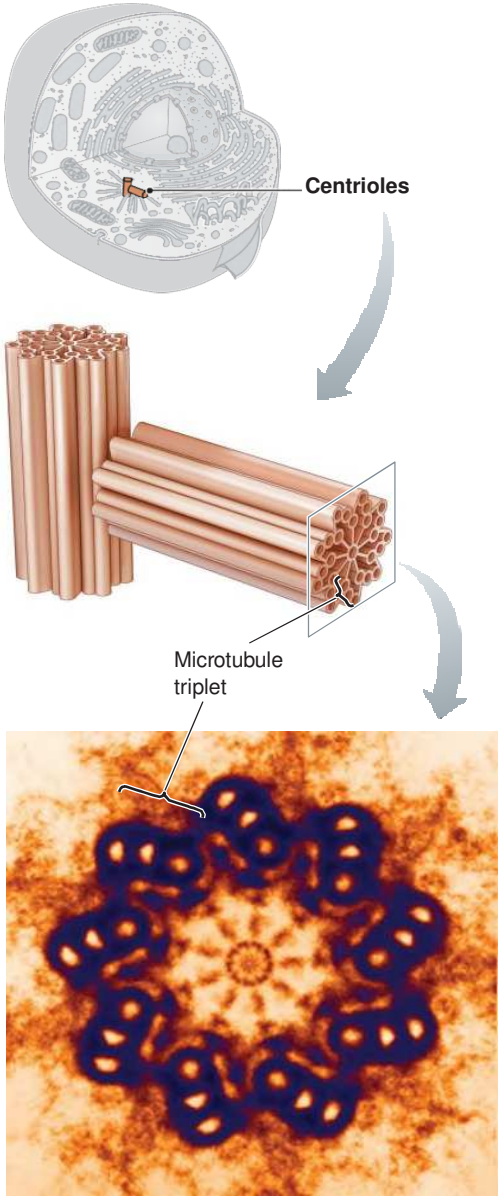

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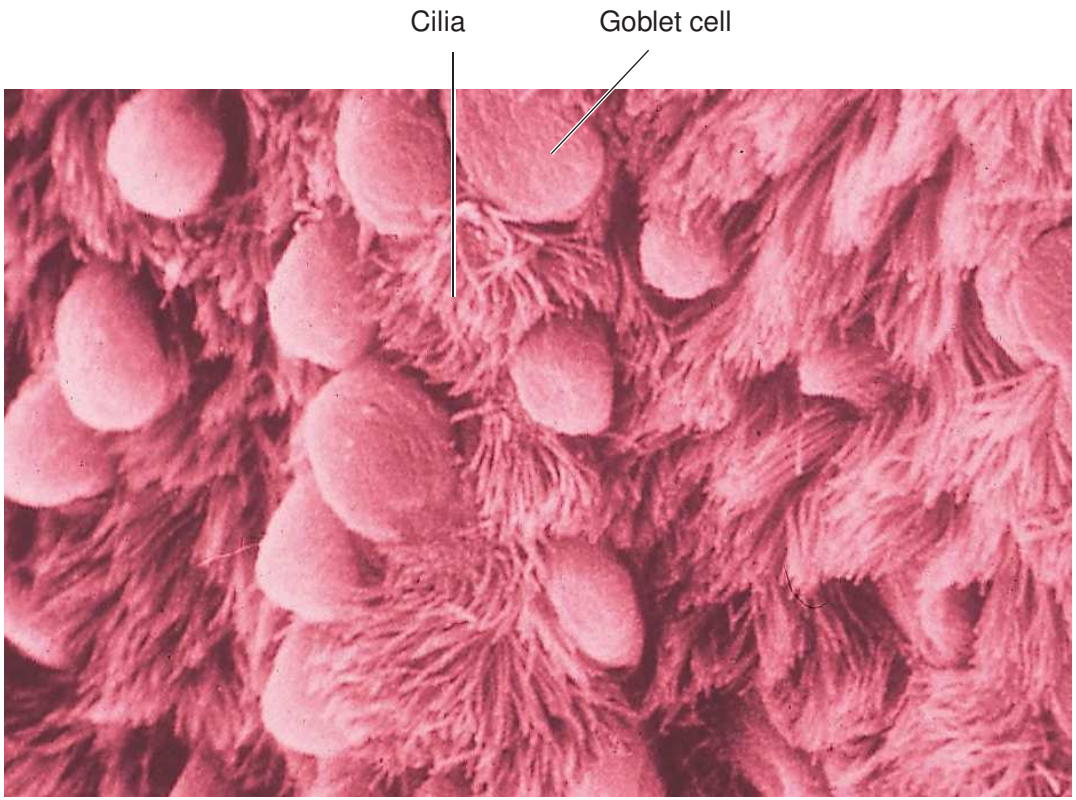

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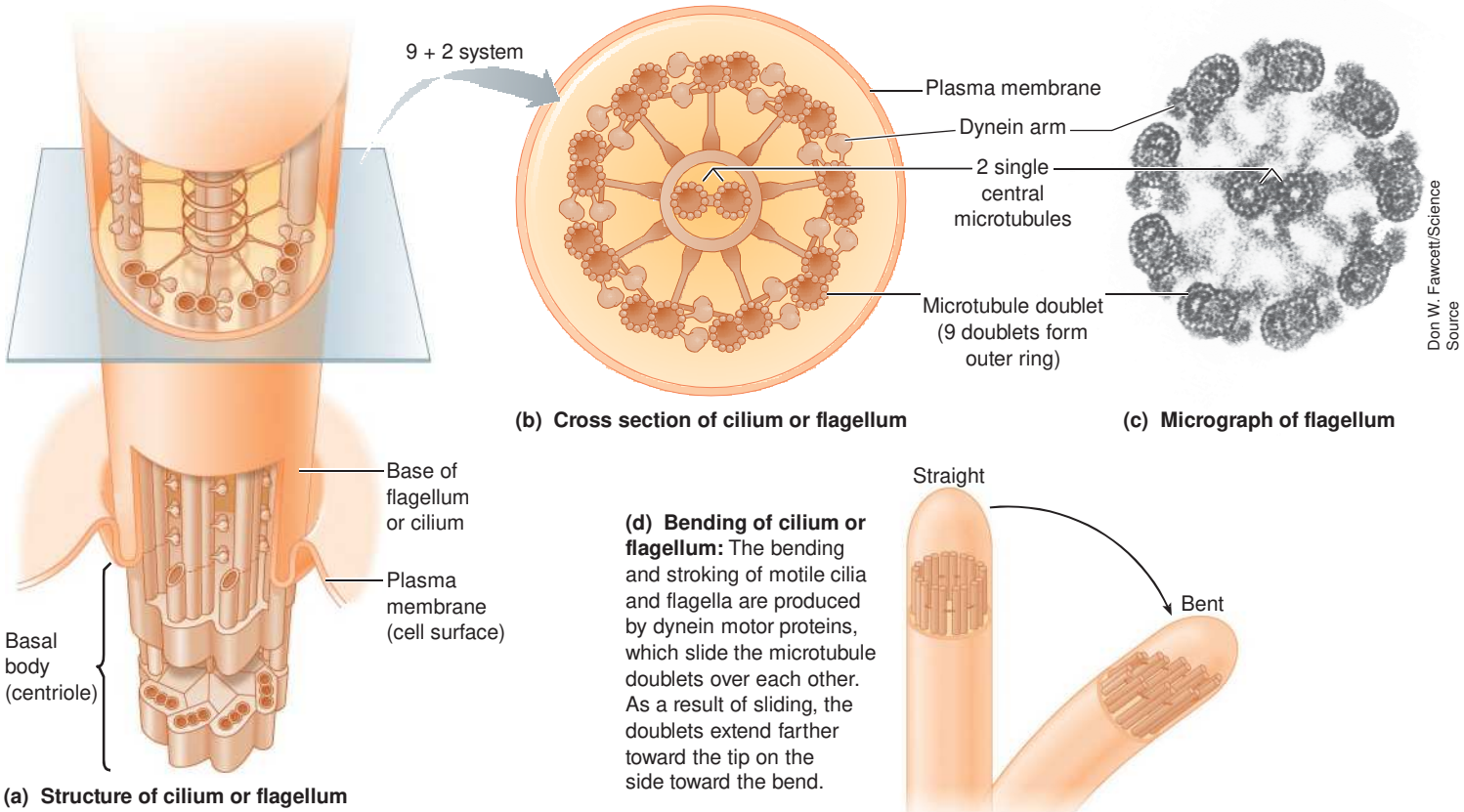

(a) Structure of cilium or flagellum

(b) Cross section of cilium or flagellum

(c) Micrograph of flagellum

(d) Bending of cilium or flagellum: The bending and stroking of motile cilia and flagella are produced by dynein motor proteins, which slide the microtubule doublets over each other. As a result of sliding, the doublets extend farther toward the tip on the side toward the bend.

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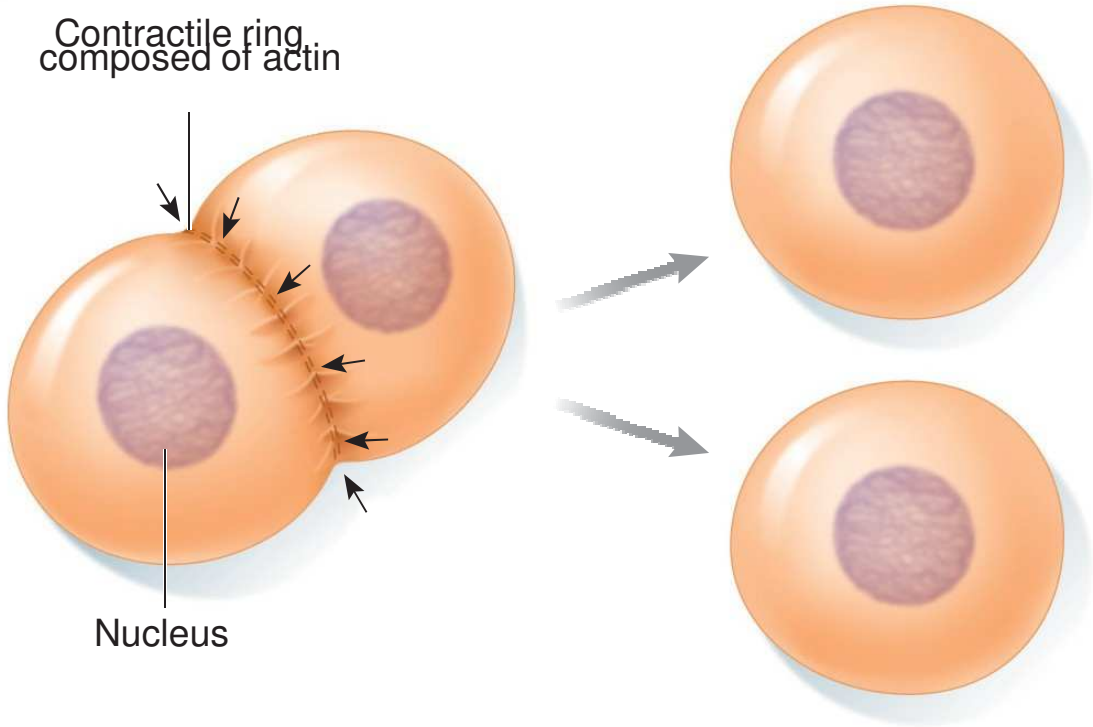

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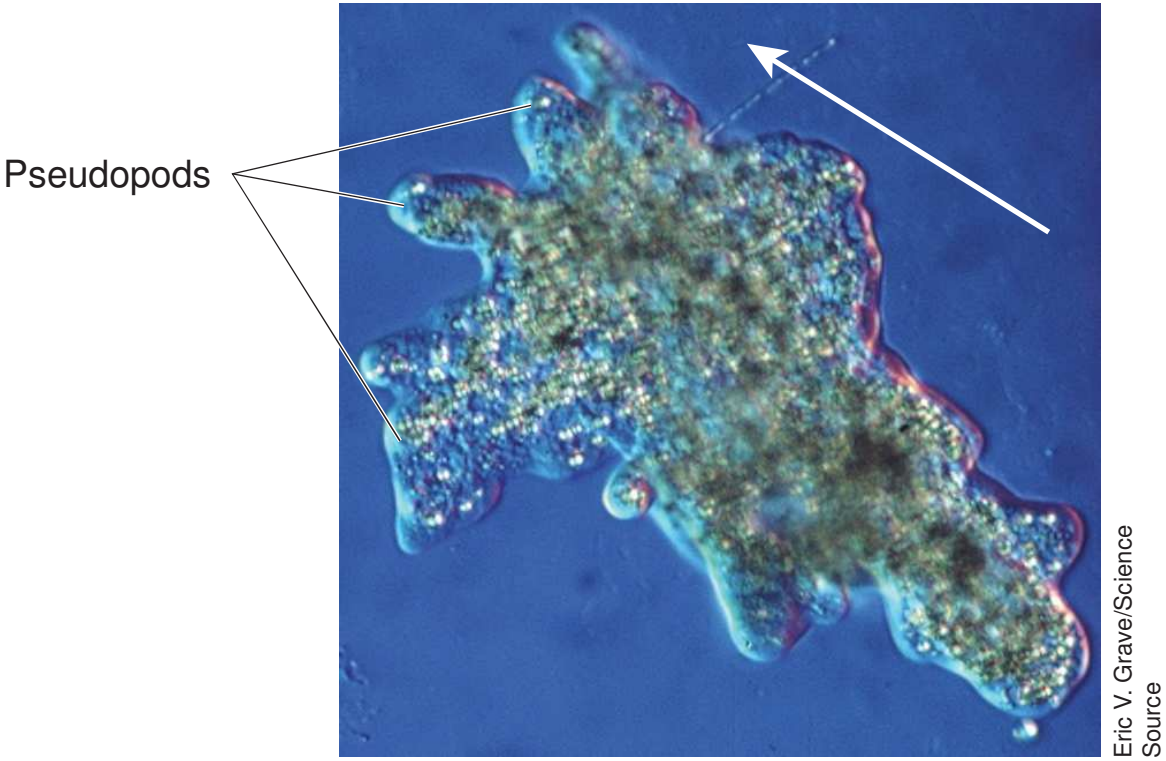

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Cytoskeleton: Cell “Bone and Muscle” (cont’d.)

- Cytoskeleton functions as an integrated whole
  - Links parts of the cell
    - Responsible for the particular shape, rigidity, and spatial geometry of each different cell type
    - Serves as a lattice to organize groups of enzymes for many cellular activities
    - May serve as a mechanical communications system
    - Responsible for directing intracellular transport and for regulating numerous cellular movements

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Points to Ponder

- What basic cellular functions are essential to a cell's survival?
- What are some examples of specialized cellular tasks that promote homeostasis?
- What are the stages of cellular respiration, and where is each accomplished?

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