CHAPTER 4

A Tour of the Cell

Objectives

Introduction Explain why art is so important to an understanding of biology.

Introduction to the World of the Cell

4.1 Compare the designs and images produced by a light microscope, scanning electron microscope, and transmission electron microscope. In addition, distinguish between magnification and resolving power.

4.1 Define cell theory and briefly describe the discoveries that led to its development.

4.2 Explain why cell size and shape varies.

4.2 Explain the relationships between nanometers, micrometers, millimeters, centimeters, and meters.

4.3 Explain why there are both upper and lower limits to cell size.

4.4 Distinguish between prokaryotic and eukaryotic cells.

4.5 Explain why compartmentalization is important in eukaryotic cells.

4.5 Compare the structures of plant and animal cells. Note the function of each cell part.

Organelles of the Endomembrane System

4.6–4.11, 4.13–4.14 Describe the structures and functions of the nucleus, endomembrane system, rough and smooth endoplasmic reticulum, Golgi apparatus, and lysosomes.

4.12 Explain how impaired lysosomal function can cause the symptoms of storage diseases.

Energy-Converting Organelles

4.15–4.16 Compare the structures and functions of mitochondria and chloroplasts.

The Cytoskeleton and Related Structures

4.17 Compare the structures and functions of microfilaments, intermediate filaments, and microtubules.

4.18 Explain how the structure of cilia and flagella relate to their functions.

Eukaryotic Cell Surfaces and Junctions

4.19 Compare the structures and functions of cell surfaces and intercellular junctions of plant and animal cells.

Functional Categories of Organelles

4.20 Describe the four functional categories of eukaryotic organelles, noting which organelles are in each group.

4.21 Describe the properties we would expect to find in extraterrestrial life.

Key Terms

light microscope (LM)
micrograph
magnification
resolving power
cell theory
electron microscope (EM)
scanning electron microscope (SEM)
transmission electron microscope (TEM)
prokaryotic cell
eukaryotic cell
nucleoid region
ribosome
plasma membrane
prokaryotic cell wall
capsule
pilus
prokaryotic flagellum
cytoplasm
organelle
cellular metabolism
nucleus
chromatin
chromosome
nuclear envelope
nucleolus
endomembrane system
endoplasmic reticulum (ER)
rough ER
secretory protein
glycoprotein
transport vesicle
smooth ER
Golgi apparatus
lysosome
lysosomal storage disease
vacuole
central vacuole
chloroplast
stroma
granum
mitochondrion
intermembrane space
mitochondrial matrix
crista
cytoskeleton
microfilament
intermediate filament
microtubule
cilium
flagellum
basal body
centriole
dynein arm
cell junction
plasmodesma
extracellular matrix
tight junction
anchoring junction
communicating junction

Word Roots

chloro- = green (*chloroplast:* the site of photosynthesis in plants and eukaryotic algae)

endo- = inner (*endomembrane system:* the system of membranes within a cell that include the nuclear envelope, endoplasmic reticulum, Golgi apparatus, lysosomes, vacuoles, and the plasma membrane)

extra- = outside (*extracellular matrix:* the substance in which animal tissue cells are embedded)

flagell- = whip (*flagellum:* a long whiplike cellular appendage that moves cells)

glyco- = sweet (*glycoprotein:* a protein covalently bonded to a carbohydrate)

lyso- = loosen (*lysosome:* a membrane-bounded sac of hydrolytic enzymes that a cell uses to digest macromolecules)

micro- = small; **-tubul** = a little pipe (*microtubule:* a hollow rod of tubulin protein in the cytoplasm of almost all eukaryotic cells)

nucle- = nucleus; **-oid** = like (*nucleoid:* the region where the genetic material is concentrated in prokaryotic cells)

plasm- = molded; **-desma** = a band or bond (*plasmodesmata:* an open channel in a plant cell wall)

pro- = before; **karyo-** = nucleus (*prokaryotic cell:* a cell that has no nucleus)

trans- = across; **-port** = a harbor (*transport vesicle:* a membranous compartment used to enclose and transport materials from one part of a cell to another)

vacu- = empty (*vacuole:* sac that buds from the ER, Golgi, or plasma membrane)

Lecture Outline

Introduction *The Art of Looking at Cells*

A. The use of art to help illustrate difficult concepts being discussed has a long tradition in biology.

B. *Review:* All organisms are composed of cells (Module 1.4).

C. Cells are at a scale just below what humans can visibly perceive, but with a microscope, we can plainly see that all living things contain cells.

D. The focus of this chapter is on the structure and function of the cell and the **organelles** that are found inside the cell.

I. Introduction to the World of the Cell

Module 4.1 Microscopes provide windows to the world of the cell.

A. Images formed by microscopes represent the object "under" the microscope.

B. Magnification: the number of times larger the image appears than the true size of the object.

C. Resolution: clarity of the image (resolving power; the ability to distinguish two objects as separate).

D. Three types of microscopes that produced the images in the text form images in different ways. Each of these microscopes has advantages relative to the others, and a range of scales at which it functions best.

E. **Light microscopes (LM)** bend the light coming through an object. The bent light rays form larger images in the viewer's eyes. Well-resolved LM images are limited to 1000 to 2000 times larger than life size. The LM is particularly good for looking at living cells and tissues (Figure 4.1A).

F. **Scanning electron microscopes (SEM)** compose images on a TV screen, from electrons that bounce off the surfaces of the object. SEM images are usually about 10,000–20,000 times larger than life size. The SEM is particularly good for showing organismal and cellular surfaces under high magnification (Figure 4.1B).

G. **Transmission electron microscopes (TEM)** compose images on camera film, from electrons that have traveled through very thin slices of the object and have been bent by magnetic lenses. TEM images are usually about 100,000–200,000 times larger than life size. The TEM is particularly useful for showing the internal structures of cells (Figure 4.1C).

Module 4.2 Cell sizes vary with their function.

A. Review: the scales of life (compare with Figure 1.1) (Figure 4.2).

B. Nerve cells can be very long, to communicate between different parts of an animal's body.

C. Bird eggs are very large, mostly composed of food reserves.

D. Blood cells are very small, to allow them to flow through blood vessels, and to provide a large surface area for efficient gas exchange (Figure 4.3).

Module 4.3 Natural laws limit cell size.

A. Large cells have a smaller ratio of surface area to volume than small cells (Figure 4.3). The key to this discussion is the comparison of the surface: volume.

B. This fact imposes the upper limit on cell size (actually, cell volume) because materials have to flow across the surface to get to the inside. Larger cells require correspondingly greater surface area, which they do not have.

C. The small size of cells is limited by the total size of all the molecules required for cellular activity (DNA, ribosomes, life-process-governing proteins, etc.).

Module 4.4 Prokaryotic cells are small and structurally simple.

A. The two groups of **prokaryotic cells** are the Bacteria and the Archaea (Figure 4.4).
Preview: The Archaea are more closely related to eukaryotes than they are to the Bacteria (Module 15.14).

B. Prokaryotic cells are usually relatively small (2–8 μm in length).

C. Prokaryotic cells lack a nucleus: DNA is in direct contact with cytoplasm and is coiled into a **nucleoid region.**

D. Cytoplasm includes **ribosomes** (protein factories) suspended in a semifluid.

E. Prokaryotic cells are otherwise composed of a bounding **plasma membrane,** complex outer cell wall (a rigid container, often with a sticky outer coat), **pili,** and, sometimes, flagella.
Preview: The classification and evolution of the prokaryotes are discussed in Module 15.14 and Modules 16.7–16.10.

Module 4.5 Eukaryotic cells are partitioned into functional compartments.

A. Eukaryotic cells are usually relatively larger (10–100 μm or more) in diameter.

B. These cells are internally complex, with organelles of two types: membranous and nonmembranous.

C. Membranous organelles found in eukaryotic cells include the nucleus, endoplasmic reticulum, Golgi apparatus, mitochondria, lysosomes, and peroxisomes.

D. Nonmembranous organelles found in eukaryotic cells include ribosomes, microtubules, centrioles, flagella, and the cytoskeleton.

E. Animal cells are bounded by the plasma membrane alone, often have flagella, and lack a cell wall (Figure 4.5A).

F. Plant cells are bounded by both a plasma membrane and a rigid cell wall composed of cellulose (Figure 4.5B). In addition, plant cells usually have a central vacuole and chloroplasts, lack centrioles, and usually lack lysosomes and flagella.

G. Cells of eukaryotes in other kingdoms vary in structure and components (protists: Figures 4.13B, 16.20A–D, 16.23A, B; fungi: Figure 17.15A–C, 17.16B–D).

H. *Preview:* Membranes play an important role in defining many cellular structures. Introduce the phospholipid bilayer and the protein mosaic model of membrane structure, reminding students that a thorough discussion of the structure and function of membranes will come in Chapter 5 (Figure 5.12).

II. Organelles of the Endomembrane System

Module 4.6 The nucleus is the cell's genetic control center.

A. The **nuclear envelope** is a double membrane, perforated with pores through which material can pass into and out of the **nucleus,** which separates this organelle from the cytoplasm (Figure 4.6).

B. DNA can be seen as strands of **chromatin** dispersed inside the nucleus. Each strand of chromatin constitutes a **chromosome.**

C. During cell reproduction chromosomes coil up and become visible through a light microscope.

D. The **nucleolus,** also within the nucleus, is composed of chromatin, RNA, and protein. The function of nucleoli is the manufacture of ribosomes.

Module 4.7 Overview: Many cell organelles are related through the **endomembrane system.**

A. An extensive system of membranous organelles work together in the synthesis, storage, and export of molecules (Figures 4.11B and 4.14).

B. Each of these organelles is bounded by a single membrane. Some are in the form of flattened sacs, some are rounded sacs, and some are tube-shaped.

C. The major function of the endomembrane system is to divide the cell into compartments.

Module 4.8 Rough endoplasmic reticulum makes membrane and proteins.

A. **Rough ER** is composed of flattened sacs that often extend throughout the entire cytoplasm (Figure 4.6).

B. Ribosomes on rough ER make proteins, some of which are incorporated into the membrane; other proteins are packaged in membranous sacs that bud off the rough ER (Figure 4.8).

Module 4.9 Smooth endoplasmic reticulum has a variety of functions.

A. One job of **smooth ER** is to synthesize lipids (Figure 4.9).

B. In other forms of smooth ER, enzymes help process materials as they are transported from one place to another. An example of this function is the detoxification of drugs by smooth ER in liver cells.

C. Other functions of smooth ER include the storage of calcium ions that are required for muscle contraction.
NOTE: You may need to review the concept of enzymes as proteins functioning as biological catalysts (Module 3.11).

Module 4.10 The **Golgi apparatus** finishes, sorts, and ships cell products.

A. Transport vesicles from the ER fuse on one end of a Golgi stack to form flattened sacs (Figure 4.10).

B. These sacs move through the stack like a pile of pancakes added at one end and eaten from the other. Molecular processing occurs in the sacs as they move through the Golgi.

C. At the far end, modified molecules are released in transport vesicles.

Module 4.11 Lysosomes digest the cell's food and wastes (Figure 4.11B).

A. **Lysosomes** are one kind of vesicle produced at the far end of the Golgi.

B. These vesicles contain hydrolytic enzymes that break down the contents of other vesicles, damaged organelles, or bacteria with which they fuse (Figure 3.3B).

Module 4.12 Connection: Abnormal lysosomes can cause fatal diseases.

A. **Lysosomal storage diseases** result from an inherited lack of one or more hydrolytic enzymes from lysosomes.

B. In Pompe's disease, lysosomes lack glycogen-digesting enzyme. In Tay-Sachs disease, lysosomes lack lipid-digesting enzymes.

Module 4.13 Vacuoles function in the general maintenance of the cell.

A. **Vacuole** is the general term given to other membrane-bounded sacs.

B. Plants have **central vacuoles** that function in storage, play roles in plant cell growth, and may function as large lysosomes (Figures 4.13A, 4.5B).

C. Contractile vacuoles in cells of freshwater protists (both protozoans and algae) function in water balance (Figure 4.13B).

Module 4.14 A review of the endomembrane system.

A. Discuss the structural connections between the various organelles in this system. The red arrows show the functional connections (Figure 4.14).

B. Vesicles can fuse with the plasma membrane and deliver the content to the extracellular environment without the content actually crossing the plasma membrane.

III. Energy-Converting Organelles

Module 4.15 Chloroplasts convert solar energy to chemical energy.

A. **Chloroplasts** are found in most cells of plants and in cells of photosynthetic protists (algae) (Figure 4.15).

B. Chloroplasts are double-membrane-bounded.

C. Chloroplasts are the site of photosynthesis.

D. The structure of the organelle fits its function. As we will see, the capturing of light and electron energizing occur on the **grana,** and chemical reactions that form food-storage molecules occur in the **stroma.**

E. *Preview:* Photosynthesis is covered in detail in Chapter 7 and the origin of chloroplasts is discussed in Module 16.18.

Module 4.16 Mitochondria harvest chemical energy from food.

A. **Mitochondria** are found in all cells of eukaryotes, except a few anaerobic protozoans (Figure 4.16).

B. Mitochondria are double-membrane-bounded.

C. Mitochondria are the site of cellular respiration.

D. The structure of the organelle fits its function. As we will see, the ATP-generating electron transport system is embedded in the inner membrane **(cristae),** and chemical reactions occur in compartments between membranes.

E. *Preview:* Cellular respiration is covered in detail in Chapter 6 and the origin of mitochondria is discussed in Module 16.18.

IV. The Cytoskeleton and Related Structures

Module 4.17 The cell's internal skeleton helps organize its structure and activities.

A. The organelles discussed up to this point, particularly the endomembrane system, provide cells with some support.

B. The **cytoskeleton** adds to this support, plays a role in cell movement, and may have a role in cell signaling (Figure 4.17A).

C. The cytoskeleton is a three-dimensional meshwork of fibers: microfilaments, intermediate filaments, and microtubules (Figure 4.17B).

D. **Microfilaments** are solid rods composed of globular proteins. They play a role in cell movement, including contraction (discussed more in Chapter 30).

E. **Intermediate filaments** are ropelike strands of fibrous proteins. These structures are tension-bearing and anchor some organelles.
NOTE: The cytoskeletal fibers of anchoring junctions are intermediate filaments (Module 4.19).

F. **Microtubules** are hollow tubes composed of globular proteins. Microtubules guide the movement of organelles through the cell, and are the basis of ciliary and flagellar movement.

Module 4.18 Cilia and flagella move when microtubules bend.

A. Although the terms *cilium* and *flagellum* refer to similar structures, the structures were named when their internal similarities were not appreciated. **Cilia** are short, numerous, and usually complexly organized. **Flagella** are longer, fewer, and less complexly organized.

B. In both cases, these nonmembranous organelles are minute, tubular extensions of the plasma membrane that surround a complex arrangement of microtubules (Figure 4.18A).

C. Cilia and flagella function to move whole cells or to move materials across or into cells.

D. The underlying structure consists of nine microtubule doublets arranged in a cylinder around a central pair of microtubules. At the base within the cell body **(basal body),** the structure is slightly different (Figure 4.18A).

E. Various types of whipping movements of a whole flagellum or cilium occur when the microtubule doublets move relative to neighboring doublets. The connecting dynein arms apply the force (Figure 4.18B).

F. *Preview:* Basal bodies are in the cytoplasm below these external extensions. They are identical in cross section to centrioles, which function in cell division (Figure 4.5A, Module 8.6, Figure 8.6).

V. Eukaryotic Cell Surfaces and Junctions

Module 4.19 Cell surfaces protect, support, and join cells.

A. Prokaryotic cells and eukaryotic cells of many protists function independently of one another and relate directly to the outside environment.

B. In multicellular plants, cell walls protect and support individual cells and join neighboring cells into interconnected and coordinated groups (tissues) (Figure 4.19A).
Preview: Plant cells and tissues (Module 31.5).

C. Plant cell walls are multilayered and are composed of various mixtures of polysaccharides and proteins. The dominant polysaccharide in plant cells is cellulose.

D. **Plasmodesmata** are channels through the cell walls connecting the cytoplasm of adjacent plant cells.

E. In multicellular animals, cells secrete and are embedded in sticky layers of glycoproteins, the **extracellular matrix,** which can protect and support the cell, as well as regulate cell activity (Figure 4.19B).

F. In animal tissues, cells are joined by several types of junctions. **Tight junctions** provide leak-proof barriers; **anchoring junctions** join cells to each other, or to the extracellular matrix, but allow passage of materials along the spaces between cells or attach cells to an extracellular matrix; **communicating junctions** provide channels between cells for the movement of small molecules.
Preview: Epithelial tissue is attached to the underlying extracellular matrix by cell junctions (Module 20.4).

NOTE: Provide examples of the importance of these cell junctions for the human body. For example: the role of tight junctions in the gastrointestinal tract, the role of anchoring junctions in keeping skin cells attached to each other and to the body (mention epidermolysis bullosa, a disease in which there is an inherited defect in anchoring junctions; ask what the result would be), and the role of communicating junctions in cardiac muscle contraction.

VI. Functional Categories of Organelles

Module 4.20 Eukaryotic organelles comprise four functional categories (Table 4.20).

A. Manufacture: synthesis of macromolecules and transport within the cell.

B. Breakdown: elimination and recycling of cellular materials.

C. Energy processing: conversion of energy from one form to another.

D. Support, movement, and communication: maintenance of cell shape, anchorage and movement of organelles, and relationships with extracellular environments.

E. Within each of the four categories there are structural similarities that underlie their functions.

F. All four categories work together as an integrated team, producing the emergent properties at the cellular level.

Module 4.21 Connection: Extraterrestrial life forms may share features with life on Earth.

A. *Review:* The concept of the fundamental similarity of life is first discussed in Module 1.5.

B. Cells are highly structured units.

C. Cell structure and function are related at the cellular and subcellular (and supracellular) levels.

D. Cells are set off from their external environment by membranes.

E. Each cell has DNA as the genetic material.

F. Each cell carries out metabolism.

G. These features that are likely to be characteristic of other life forms may have evolved in our universe, although the materials and structures involved might be modified from the pattern seen on Earth.

Class Activities

1. As time and resources permit, present views of living cells doing dynamic things. Protozoans, algae in pond water, and cheek cells are good examples of dynamic cells as opposed to the dead, stained, static cells students usually see.
2. After giving your cell tour lectures and reviewing the various cell organelles and their functions, show students a few previously unseen illustrations of cells of various types. Let the students describe and name the dominant organelles they observe. Continue this activity as you proceed through the course, to help add some depth to the understanding of tissue and cell types in animals, plants, and other organisms.
3. Ask students to consider how chloroplast (Module 4.15) and mitochondrial (Module 4.16) structure reflect their prokaryotic origins.

4. Ask your students to make correlations between organelle function and analogous organ function. Also, analogies can be made between relationships among organelles and those of the components of a factory.

Transparency Acetates

Figure 4.1A	Light microscope (LM)
Figure 4.2	The sizes of cells and related objects
Table 4.2	Measurement equivalents
Figure 4.3	Effect of cell size on surface area
Figure 4.4 A	prokaryotic cell (35,000x)
Figure 4.5A	An animal cell (8,000x)
Figure 4.5B	A plant cell (8,000x)
Figure 4.6	The nucleus and rough endoplasmic reticulum
Figure 4.8	Synthesis and packaging of a secretory protein by the rough ER
Figure 4.9	Smooth and rough endoplasmic reticulum
Figure 4.10	The Golgi apparatus
Figure 4.11A	Lysosomes in a white blood cell
Figure 4.11B	Lysosome formation and functions (Layer 1)
Figure 4.11B	Lysosome formation and functions (Layer 2)
Figure 4.11B	Lysosome formation and functions (Layer 3)
Figure 4.13A	Central vacuole in a plant cell
Figure 4.13B	Contractile vacuoles in a protist *(combined with Figure 4.13A)*
Figure 4.14	Connections among the organelles of the endomembrane system
Figure 4.15	The chloroplast
Figure 4.16	The mitochondrion
Figure 4.17B	Fibers of the cytoskeleton
Figure 4.18A	Structure of a eukaryotic flagellum or cilium
Figure 4.18B	The mechanism of microtubule bending in cilia and flagella
Figure 4.19A	Plant cell walls and cell junctions
Figure 4.19B	Animal cell surfaces and cell junctions
Table 4.20	Eukaryotic organelles and their functions

Media

See the beginning of this book for a complete description of all media available for instructors and students. Animations and videos are available in the Campbell Image Presentation Library. Media Activities and Thinking as a Scientist investigations are available on the student CD-ROM and web site.

Animations and Videos	File Name
Cytoplasmic Streaming Video	04-05B-CytoplasmStreVideo-B.mov
Cytoplasmic Streaming Video	04-05B-CytoplasmStreVideo-S.mov

Lysosome Formation Animation	04-11B-LysosomeFormAnim.mov
Paramecium Vacuole Video	04-13B-ParameciumVacVideo-B.mov
Paramecium Vacuole Video	04-13B-ParameciumVacVideo-S.mov
Endomembrane System Animation	04-14-EndomembraneSysAnim.mov
Paramecium Cilia Video	04-18-ParamecCiliaVideo-B.mov
Paramecium Cilia Video	04-18-ParamecCiliaVideo-S.mov
Cilia and Flagella Animation	04-18-CiliaFlagellaAnim.mov
Anchoring Junctions Animation	04-19B-AnchorJunctionsAnim.mov
Communicating Junctions Animation	04-19B-CommJunctionsAnim.mov
Tight Junctions Animation	04-19B-TightJunctionsAnim.mov

Activities and Thinking as a Scientist	**Module Number**
Web/CD Activity 4A: *Metric System Review*	4.2
Web/CD Thinking as a Scientist: *Connection: What Is the Size and Scale of Our World?*	4.2
Web/CD Activity 4B: *Prokaryotic Cell Structure and Function*	4.4
Web/CD Activity 4C: *Comparing Prokaryotic and Eukaryotic Cells*	4.5
Web/CD Activity 4D: *Build an Animal Cell and a Plant Cell*	4.5
Web/CD Activity 4E: *Overview of Protein Synthesis*	4.8
Web/CD Activity 4F: *The Endomembrane System*	4.14
Web/CD Activity 4G: *Build a Chloroplast and a Mitochondrion*	4.16
Web/CD Activity 4H: *Cilia and Flagella*	4.18
Web/CD Activity 4I: *Cell Junctions*	4.19
Web/CD Activity 4J: *Review: Animal Cell Structure and Function*	4.20
Web/CD Activity 4K: *Review: Plant Cell Structure and Function*	4.20
Web/CD Thinking as a Scientist: *Connection: How Are Space Rocks Analyzed for Signs of Life?*	4.21