Introduction

- When *On the Origin of Species* was published (1859), there was no evidence for life older than the Cambrian (about 550 million years ago).
- At the turn of the twentieth century evidence for fossilized clumps of algae in rocks was found at the base of the Grand Canyon.
- Nearly a century later, geologist J. William Schopf found fossilized chains of cylindrical objects, similar in size and shape to cyanobacteria, in rocks in Western Australia. These fossils were dated at 3.5 billion years old.
- Life requires a structural compartment separate from the external environment in which macromolecules can perform unique functions in a relatively constant internal environment.
- These "living compartments" are cells.

The Cell: The Basic Unit of Life

- The cell theory states that cells are the fundamental units of life, that all organisms are composed of cells, and that all cells come from preexisting cells. The study of cell biology is the basis for studying all life, whether single-celled or multicellular.

Cells may have come from stable bubbles

- Protobionts are aggregates produced from molecules made in prebiotic synthesis experiments. They can maintain internal chemical environments that differ from their surroundings. (See Figure 4.1.)
  - In the 1920s, the Russian scientist Alexander Oparin formed unique bubbles by mixing a large protein and a polysaccharide in solution and agitating the mixture.
    - The interiors of these bubbles had concentrations of the macromolecules that were higher than those of their surroundings.
    - The bubbles also were able to catalyze chemical reactions and exert some control over what was transferred between them and the environment.
    - These bubbles were protobionts.
  - Other researchers showed that lipids mixed in an aqueous environment will spontaneously arrange themselves into droplets surrounded by a bilayer.
  - These experiments suggest a bubble theory for the origin of cells.

Cell size is limited by the surface area-to-volume ratio

- Most cells are tiny, with diameters in the range of 1 to 100 μm. (See Figure 4.2.)
- The surface of a cell is the area that interfaces with the cell's environment. The larger the surface area of a cell, the faster a cell can take in substances and remove waste products.
- The volume of a cell is a measure of the space inside a cell. The larger the volume of a cell, the more chemical activity it can have.
- Surface area-to-volume ratio is defined as the surface area divided by the volume. For any given shape, increasing volume decreases the surface area-to-volume ratio. (See Figure 4.3.)
- Shape also influences surface area-to-volume ratios.
  - *A sphere has the least surface area-to-volume ratio of any shape.*
  - *Imagine you have a lump of clay. Fashioning it into a sphere minimizes the surface area.*
  - *If you flatten the ball of clay to make a pancake shape, the surface area increases, while the volume remains the same. Cells such as red blood cells flatten into a pancake shape to increase surface area.*
  - *Fashioning the clay into a thin string also increases the surface area without increasing the volume. Nerve cells have this shape, which allows some of them to be a meter long or more.*
  - *If the clay is spherical but the surface is irregular with many fine projections coming off the surface, surface area is greatly increased. In epithelial cells, such projections are called microvilli.*

Microscopes are needed to visualize cells

- The small size of cells makes the use of microscopes necessary to view them. (Figure 4.2 shows the relative sizes of biological objects ranging from atoms to trees.)
- If two objects are too close together, they start to look like one object. With normal human vision the smallest objects that can be resolved (i.e., distinguished from one another) are about 200 μm (0.2 mm) in size.

- Light microscopes use glass lenses and visible light and typically have a resolving power of 0.2 µm (0.2×10^{-6} m). Resolution depends on the wavelength of the illuminating light, but in general, resolution is about 1000 times better than that of an unaided human eye. Living or killed and fixed cells may be viewed with light microscopes.
- Electron microscopes have magnets, rather than glass lenses, to focus an electron beam.
  - The wavelength of the electron beam is far shorter than that of light, and the resulting image resolution is far greater.
  - This image is not visible without the use of either film or a fluorescent screen.
  - Resolution is about 0.5 nm or 400,000 times finer than that of the human eye.
  - Subcellular features can be seen only if the cells are killed and fixed with special fixatives and stains.
  - *The electron beam does not carry color information. All electron micrographs are black and white, though false color is often added for clarity.*
- *Cells are also studied using molecular separation techniques, cell culture, radioisotope labeling, and other technologies.*
- (See Figure 4.4 for examples of micrographs.)

Cells are surrounded by a plasma membrane

- Every cell has a plasma membrane, a continuous membrane that surrounds the fluids and other structures of a cell.
- The membrane is composed of a lipid bilayer with proteins floating within it and protruding from it.
  - Some proteins associate with the membrane.
  - Some proteins traverse the membrane, with one part exposed on the inner cytoplasmic side and the other on the outer face of the cell.
- The plasma membrane acts as a selectively permeable barrier. Some substances can diffuse in and out; others cannot.
- The plasma membrane is an interface for cells where information is received from adjacent cells and extracellular signals.
- The membranes allow the cell to maintain a rather constant internal environment as well as separate and distinct chemical and structural environments.
- The plasma membrane often has molecules protruding from it that are responsible for binding and adhering to adjacent cells.
- (See Videos 4.1 and 4.2.)

Cells show two organizational patterns

- Living organisms can be classified into one of two major categories based on the location within the cell where the most genetic material is stored.
- Prokaryotes have no nucleus or other membrane-bounded compartments. They lack distinct organelles, although some do have invaginated membrane structures.
- Eukaryotes have a membrane-bounded nucleus and usually have other membrane-bounded compartments or organelles as well.

Prokaryotic Cells

- Prokaryotes inhabit the widest range of environmental extremes.
- They can be found at thermal vents deep in the ocean, living at temperatures above boiling. They also occur in extremely salty environments.
- *Some have been found deep in Earth's crust, far away from the sun, photosynthesizing organisms, and oxygen. These prokaryotes use inorganic reduced chemicals as an energy source.*

Prokaryotic cells share certain features

- All have a plasma membrane.
- All have a region called the nucleoid where the DNA is concentrated.
- The cytoplasm (the plasma membrane-enclosed region) consists of the nucleoid, ribosomes (the molecular protein synthesis machines), and a liquid portion called the cytosol.

Some prokaryotic cells have specialized features

- Most prokaryotic cells have a cell wall just outside the plasma membrane. (See Figure 4.5.)
  - *The cell wall functions to prevent plasma membrane lysis (bursting) when cells are exposed to solutions with lower solute concentrations than the cell interior. It also protects the membrane.*

  - In most bacteria (but not in archaea) the cell wall is made of a polymer of amino sugars called peptidoglycan, which is covalently cross-linked to form one giant molecule around the entire cell.
- Some bacteria have another membrane outside the cell wall, a polysaccharide-rich phospholipid membrane. This membrane has embedded proteins that make it more permeable than the interior membrane.
- Some bacteria have another layer in addition to a plasma membrane, a cell wall, and an outer membrane. The outermost slimy layer is made of polysaccharides and is referred to as a capsule.
  - For some bacteria, this capsule provides a means to escape detection by the immune systems of the animals they infect.
  - The capsule can prevent drying out of the cell and help the bacterium attack other cells.
  - The capsule is not essential to cell life; if the cell loses the capsule, it can survive.
- Some bacteria, including cyanobacteria, can carry on photosynthesis; that is, they have the ability to collect solar energy.
  - Cyanobacteria have chlorophyll in the infolded plasma membrane for this purpose.
  - In eukaryotes, separate organelles have specialized membranes for this process.
- Some bacteria have mesosomes, which are involved in cell division or in certain energy-releasing reactions.
  - Like the photosynthetic membrane system, they are formed from plasma membrane infolding.
  - Eukaryotes use mitochondria, separate membrane-bounded organelles, for energy release.
- Some bacteria have flagella, locomotary structures shaped like a corkscrew. They spin like a propeller to move the bacteria. The flagella bear no structural similarity to the flagella found in eukaryotic cells, such as sperm cells. (See Figure 4.6.)
- Some bacteria have pili, threadlike structures that help bacteria adhere to one another during mating or to other cells for food and protection.
- Recent evidence suggests that some prokaryotes have an internal filamentous helical structure just below the plasma membrane. The proteins that make up this structure are similar to actin, a major component of the eukaryotic cytoskeleton.

Eukaryotic Cells

- Animals, plants, fungi, and protists have a membrane-bounded nucleus in each of their cells and are classified as eukaryotes.
- Eukaryotic cells tend to be larger than prokaryotic cells.
- Eukaryotic cells have a variety of membrane-bounded compartments called organelles. (See Animated Tutorial 4.1.)
- Eukaryotes have a protein scaffolding called the cytoskeleton, which provides shape and structure to cells, among other functions.
- Figure 4.7 shows the different structures and organelles of eukaryotic cells.

Compartmentalization is the key to eukaryotic cell function

- The subunits, or compartments, within eukaryotic cells are called organelles.
- The nucleus contains most of the cell's genetic material (DNA).
- The mitochondrion is a power plant and industrial park for the storage and conversion of energy.
- The endoplasmic reticulum and Golgi apparatus make up a compartment where proteins are packaged and sent to appropriate locations in the cell.
- The lysosome and vacuole are cellular digestive systems where large molecules are hydrolyzed into usable monomers.
- The chloroplast performs photosynthesis.
- Membranes surrounding these organelles keep away inappropriate molecules that might disturb organelle function. They also act as traffic regulators for raw materials into and out of the organelle.

Organelles can be studied by microscopy or isolated for chemical analysis

- Cell organelles were first detected by light and electron microscopy.
- Figure 4.21 shows how stains that target specific macromolecules can be used to determine the chemical composition of organelles.
- Figure 4.8 shows the process of cell fractionation, another means by which cells can be examined.
- Microscopy and cell fractionation can be used as complements to each other, giving a complete picture of the structure and function of each organelle.

Organelles that Process Information

- In eukaryotic cells, most DNA, the information-storage molecule, is found in the nucleus.

- Information is translated from the language of DNA into the language of proteins at the ribosomes.

The nucleus contains most of the cell's DNA

- The nucleus, usually the largest organelle in a cell, is the site of DNA duplication to support cell reproduction.
- The nucleus also plays a role in DNA control of cell activities.
- Within the nucleus is a specialized, non-membrane-bounded region called the nucleolus, where ribosomes, the molecular protein synthesis machinery, are initially assembled.
- Two lipid bilayers form the nuclear envelope.
- The nuclear envelope is perforated with nuclear pores. (See Figure 4.9.)
- Each pore is about 9 nm in diameter. The nuclear pores connect the interior of the nucleus with the rest of the cytoplasm.
- Outer and inner membranes are continuous at these pores.
- A pore complex, consisting of eight very large protein granules arranged in an octagon, surrounds each pore.
- RNA and proteins must pass through these pores to enter or leave the nucleus.
  - *The DNA of the nucleus is the information molecule that provides the instructions needed for cellular and organismal life.*
  - *RNA, which is generated by using DNA as a template, actually determines the construction of proteins.*
  - *RNA is made in the nucleus, but all proteins are made outside the nucleus. Therefore, the nucleus isolates these two processes.*
- At certain sites the nuclear envelope is continuous with another organelle, the endoplasmic reticulum.
- *Molecules that are small can enter and leave the nucleus by simple diffusion, but traffic of large molecules is regulated.*
- The chromatin consists of diffuse or very long, thin fibers in which DNA is bound to proteins. (See Figure 4.10.)
- *In human cells (with the exception of the sex cells), there are 46 separate strands of chromatin in each nucleus.*
- Prior to cell division these condense and organize into structures recognized as chromosomes.
- Surrounding the chromatin is the nucleoplasm within which a network of proteins, the nuclear matrix, organizes the chromatin.
- The nuclear lamina is a meshwork of proteins generated by (reversible) polymerization, which maintains the shape of the nuclear envelope and the nucleus.
  - When the cell is about to divide, the nuclear envelope fragments into pieces of membrane with pore complexes because the nuclear lamina depolymerizes.
  - At the end of cell division a nucleus re-forms in each of the daughter cells.
- (See Videos 4.3 and 4.4.)

Ribosomes are the sites of protein synthesis

- Compared to organelles, ribosomes are tiny granules, but they are huge compared to proteins.
- In eukaryotes, functional ribosomes are found free in the cytoplasm, in mitochondria, bound to the endoplasmic reticulum, and in chloroplasts.
- Ribosomes are the sites of protein synthesis.
- They consist of a certain type of RNA, called ribosomal RNA, and more than 50 other proteins.

The Endomembrane System

- The membrane of eukaryotic cells is synthesized by the endoplasmic reticulum (ER). (See Figure 4.11.)
- There are continuities between this membrane and the nuclear envelope, as well as connections via small vesicles to the Golgi apparatus, lysosomes, and plasma membrane.
- These structures together constitute the endomembrane system.

The endoplasmic reticulum is a complex factory

- The ER is a network of interconnecting membranes distributed throughout the cytoplasm.
- The internal compartment, called the lumen, is a separate part of the cell with a distinct protein and ion composition.
- Most of the membrane of the cell is found in the ER.
- Approximately 15 percent of the entire fluid volume of the cell is inside the ER.
- The ER's folding generates a surface area much greater than that of the plasma membrane.
- At certain sites, the ER membrane is continuous with the outer nuclear envelope membrane.

- The rough ER (RER) has ribosomes attached, which actively synthesize proteins destined for the ER interior or incorporation into the membrane of the ER.
  - Some of these membrane and lumen proteins stay with the ER, some are transported to other points of the endomembrane system.
  - Some of the proteins that enter the lumen or face the lumen interior get folded, shaped by disulfide bridges, or get carbohydrate groups added.
  - Some of the proteins that enter the ER have address information, which determines their final destination. *By default, those with no address information are transported out of the cell.*
- There is a ribosome-free region of the ER called the smooth endoplasmic reticulum (SER).
- The SER of liver cells is the site for the synthesis and hydrolysis of glycogen.
- SER of the liver is also the site for drug detoxification (including alcohol) and cholesterol and steroid synthesis.
- Cells that are specialized for synthesizing proteins for extracellular export have extensive endomembrane systems. Examples are the cells of glands.
- (See Video 4.5.)

The Golgi apparatus stores, modifies, and packages proteins

- *The Golgi apparatus is difficult to see using standard light microscopy, but it is clearly visible with the electron microscope. (See Figure 4.12.)*
- *The Golgi receives its lipid membrane from vesicles that bud off the ER. Proteins are carried within them.*
- The organization of the Golgi varies in different organisms but it always consists of compartments, or cisternae, and small membrane-bounded vesicles.
- In organisms other than vertebrates, compartments are separate and scattered.
- In vertebrates, the Golgi is stacked like pancakes.
  - The compartment closest to the nucleus is called the cis region.
  - The middle compartment is the *medial* region.
  - The compartment closest to the plasma membrane is the *trans* region.
- These three parts have different functions and different associated enzymes.
  - Vesicles from the ER fuse to the *cis* region. Vesicles from the *cis* compartment move to the next compartment, the medial region, and then to the *trans* compartment. (See Animated Tutorial 4.2.)
  - *Modifications and sorting occur during this process. Chemical signals inform the system about the appropriate destinations for the products.*
  - Some vesicles fuse with the cytoplasmic face of the plasma membrane. (This is where the plasma membrane originates.) The contents of the vesicles are released to the outside of the cell.
- *The entire phenomenon of shipping into and out of vesicles is called vesicular trafficking. It is somewhat analogous to a conveyer belt flow of materials.*
- (See Videos 4.6 and 4.7.)

Lysosomes contain digestive enzymes

- Lysosomes are organelles that come in part from the Golgi. They are approximately 1 μm in diameter. (See Figure 4.13.)
  - The Golgi creates primary lysosomes, vesicles containing digestive enzymes.
  - Food and foreign objects are brought into the cytoplasm through a process called phagocytosis. The resulting phagosomes are vesicles that contain the foreign material.
  - Primary lysosomes created by the Golgi fuse with phagosomes to create secondary lysosomes.
  - Within the secondary lysosomes, the digestive enzymes hydrolyze macromolecules such as nucleic acids, proteins, lipids, and polysaccharides into monomers. These small molecules diffuse through the lysosome's membrane into the cytoplasm.
  - The remaining undigested material is expelled from the cell when the "used" secondary lysosome fuses with the plasma membrane and releases the undigested contents.
- Lysosomes are also the sites where digestion of spent cellular components occurs, a process called autophagy.
- Lysosomal storage diseases occur when cells lack the ability to hydrolyze one or more macromolecules. These then accumulate in the lysosomes with harmful consequences.
- *Cells can take up large molecules and sometimes whole cells in a process called endocytosis. There are three different types of endocytosis.*
  - *In phagocytosis ("cell eating"), the cell envelops another cell with its own membrane as it invaginates around it. Not all cells can do this, but it is very common among protists.*

- *Pinocytosis ("cell drinking") is a means of fluid uptake.*
- *In receptor-mediated endocytosis, the vesicles are small, but cell surface receptors are involved.*
- *Cells may also give up water, wastes, and manufactured products (such as hormones) by a process called exocytosis.*

Organelles that Process Energy

Mitochondria are energy transformers

- Mitochondria are small organelles less than 1.5 μm in diameter and 2 to 8 μm in length. (See Figure 4.14.)
- The primary function of mitochondria is to convert the potential energy of fuel molecules into a form that the cell can use.
- Mitochondria have an outer lipid bilayer and a highly folded inner membrane.
- *The space between the outer and inner membrane is called the intermembrane space.*
- Within the inner membrane is the mitochondrial matrix.
- Mitochondria have a small amount of DNA and some ribosomes located within this matrix.
- The inner deeply-folded membrane has embedded proteins, which are important to the functioning of the organelle. The folding gives this membrane a greater surface area on which chemical reactions can occur.
- Mitochondria use simple energy molecules and oxygen to generate ATP from ADP. Most of the oxygen taken in by eukaryotic organisms is used directly by mitochondria.
- (See Video 4.8.)

Plastids photosynthesize or store materials

- Plastids are organelles of several types found in eukaryotic plants and some protists.
- Chloroplasts, the sites where photosynthesis (conversion of light energy to chemical energy) occurs, are one type of plastid. (See Figure 4.15.)
- *Structurally, chloroplasts are remarkably similar to mitochondria.*
- Chloroplasts have special pigments embedded in the membranes of the thylakoid vesicles.
- The chloroplast has the following structure:
  - An outer lipid bilayer; and an inner membrane. As with mitochondria, the space between these is the intermembrane space.
  - Next is the stroma, which is the fluid-filled area of the inner membrane. Inside the stroma are the membrane-bounded thylakoids. This is where chlorophyll and other pigments for photosynthesis are embedded.
- Chloroplasts have a small amount of DNA and some ribosomes in the stroma.
- Other plastids found in plants include chromoplasts, such as those that cause the red color of tomatoes, or leucoplasts, which are specialized for storage of starch and fats.
- (See Videos 4.9, 4.10 and 4.11.)

Endosymbiosis may explain the origin of mitochondria and chloroplasts

- Organelles with their own DNA? Where did chloroplasts and mitochondria come from?
- According to the endosymbiosis theory, both organelles were formerly prokaryotic organisms that somehow became incorporated into a larger cell. This structure provided benefits for both partners, and a symbiotic system evolved.
- Today, both mitochondria and chloroplasts are self-duplicating organelles.
- In chloroplasts and mitochondria, the DNA, ribosomes, and gene reproduction on the organelle level all seem to resemble those of prokaryotes.
- (See Videos 4.12 and 4.13.)

Other Organelles

Peroxisomes house specialized chemical reactions

- Peroxisomes, also called microbodies, are small organelles (0.2 to 1.7 μm in diameter) that are specialized to compartmentalize toxic peroxides and break them down. (See Figure 4.19.)
- Glyoxysomes are structurally similar organelles found in plants.

Vacuoles are filled with water and soluble substances

- Vacuoles, found in plants and protists, are filled with an aqueous solution and are used to store wastes and pigments. Poisonous or distasteful waste materials deter animals from eating the plants, while pigments attract animals for assistance in pollination and/or seed dispersal. (See Figure 4.20.)

- Vacuoles may develop turgor pressure, a swelling that helps the plant cell maintain support and rigidity.
  - Water enters the vacuole because of dissolved substances in the vacuole, which cause it to swell and press against the cell wall.
- Food vacuoles are formed in single-celled protists. They are similar to the phagosomes mentioned above.
- The cytoplasm of freshwater protists is generally higher in salt concentration than the freshwater environment; as a result, water tends to move into the cytoplasm. Many freshwater protists have a contractile vacuole that helps eliminate excess water and restore the proper salt balance in the cytoplasm.
- (See Videos 4.1, 4.3, 4.5, and 4.14.)

The Cytoskeleton

- The cytoskeleton maintains cell shape and support, provides the mechanisms for cell and organismally controlled movement, and acts as tracks for "motor proteins" that help move materials within cells.
- There are three major types of cytoskeletal components: the microfilaments, intermediate filaments, and microtubules. (See Figure 4.21.)

Microfilaments function in support and movement

- Microfilaments may exist as single filaments, in bundles, or in networks. Each is 7 nm in diameter and several mm long.
- A single strand of actin polymer interacts with another to create a double helical microfilament.
- Microfilaments are needed for cell contraction, as in muscle cells.
- Microfilaments add structure to the plasma membrane and shape to cells.
- They are involved in the flowing movement of cell fluids bearing specific organelles and proteins, a process called cytoplasmic streaming.
- They also are involved in the formation of pseudopodia, cellular extensions seen in the amoeboid protists and human white blood cells.
- Microvilli are very fine plasma membrane-covered projections that increase the surface area of some cells. Their core is protein cross-linked actin bundles. (See Figure 4.22.)
- (See Videos 4.1, 4.2, 4.3, and 4.14.)

Intermediate filaments are tough supporting elements

- Intermediate filaments, found only in multicellular organisms, are ropelike assemblages 8 to 12 nm in diameter. (See Figure 4.21.)
- *These fibrous keratin proteins interact with each other and with other cellular components, particularly those of cell adhesion molecules.*
- They have two major structural functions: They stabilize the cell structure, and they resist tension.
- In some cells, intermediate filaments maintain the positions of the nucleus and other organelles in the cell.

Microtubules are long and hollow

- Microtubules are hollow cylinders 25 nm thick; they can be several μm in length. (See Figure 4.21.)
- Microtubules provide a rigid intracellular skeleton for some cells, and they function as tracks that motor proteins can move along in the cell. (See Figure 4.24.)
- Made from tubulin protein subunits, they regularly form and disassemble as the needs of the cell change.
- Tubulin is a globular protein made of α-tubulin and β-tubulin formed as a dimer (a polymer made up of only two monomers).
- Thirteen rows of tubulin dimers surround and define the central cavity.
- Each microtubule has a plus end and a minus end.
- Tubulin dimers can be added or subtracted at either end, but the plus end is more dynamic. (See Figure 4.24.)
- (See Video 4.15.)

Microtubules power cilia and flagella

- Microtubules are structurally essential parts of cilia and flagella, common locomotary appendages of cells.
- Cilia and flagella are plasma membrane-covered cell projections.
- Flagella typically are longer than cilia, and cells that have them usually only have one or two.
- Usually cilia are present in great numbers. (See Figure 4.23.)
- The microtubules in cilia and flagella are arranged in a 9 + 2 array.
- "Nine" are fused pairs of microtubules (called doublets) arranged to form an outer cylinder.
- "Two" are located in the center of the cylinder.

- At the base of each flagellum or cilium is a basal body. The nine pairs extend into the basal body, which may be the organizing area of these structures.
- In the basal body, there is no central microtubule and each of the nine pairs has an additional microtubule fused with it, making nine triplets instead of doublets.
- Centrioles are found in an organizing center near the cell nucleus.
  - Centrioles are similar to basal bodies, but are located toward the center of the cell.
  - Centrioles, like basal bodies, are made of nine sets of three fused microtubules.
  - The microtubules that radiate from centrioles help in the movement of chromosomes during cell division.
  - The microtubules also provide tracks for intracellular molecular trafficking and help maintain the positions of certain organelles within the cell.
- Most eukaryotic cells have centrioles; exceptions are flowering plants, pine trees and their relatives, and some protists.
- (See Videos 4.16–4.20.)

Motor proteins move along microtubules

- In both cilia and flagella, the microtubules are cross-linked by spokes of protein.
- Dynein is a motor protein that drives the cross-linked microtubule pairs past each other, resulting in the bending movement of cilia and flagella.
  - Dynein changes its shape when energy is released from ATP. Many dynein molecules associate along the length of the microtubule pair. (See Figure 4.24*a*.)
  - *Both the plasma membrane and other protein components limit the amount of dynein that can move along the microtubule, so the dynein spokes regulate the amount of cilia or flagella bending.*
- Dynein moves vesicles toward the minus end of the microtubule. Kinesin, another motor protein, moves them toward the plus end. (See Figure 4.24*b*.)

Extracellular Structures

- Extracellular structures are made by cells of multicellular organisms, but are outside the cell membrane.

The plant cell wall consists largely of cellulose

- The plant cell wall is composed of cellulose fibers embedded in a matrix of other complex polysaccharides and proteins. (See Figure 4.25.)
- The cell wall provides a rigid structure for the plasma membrane under turgor pressure, giving important support.
- It is a barrier to many fungi, bacteria, and other organisms that may cause plant diseases.
- (See Video 4.21.)

Animal cells have elaborate extracellular matrices

- Multicellular animals have an extracellular matrix composed of fibrous proteins such as collagen, and glycoproteins. (See Figure 4.26.)
- An example is the cartilage of kneecaps and the nose.
- Epithelial cells, which line the human body cavities, have a basement membrane of extracellular material called the basal lamina. *This is extracellular matrix that connects and separates different cells and provides strength.*
- Proteoglycan, one component of the extracellular matrix, is huge. One molecule can be as large as 100 million daltons and take up as much space as an entire prokaryotic cell.