THE CELL

A Tour of the Cell
(Chapter 6)

YOU MUST KNOW…

- Three differences between prokaryotic and eukaryotic cells.
- The structure and function of organelles common to plant and animal cells.
- The structure and function of organelles found only in plant cells or only in animal cells.
- How different cell types show differences in subcellular components.
- How internal membranes and organelles contribute to cell functions.
- How cell size and shape affect the overall rate of nutrient intake and waste elimination.

Eukaryotic cells have internal membranes that compartmentalize their functions (6.2)

- Prokaryotic cells are found in the domains Bacteria and Archaea. Eukaryotic cells belong to the domain Eukarya and include animals, fungi, plants, and protists.
- Three key details to remember about prokaryotes include:
    - The single circular chromosome is found on a region called the nucleoid, but there is no nuclear membrane and therefore no true nucleus.
    - No membrane-bounded organelles are found in the cytosol. (Ribosomes are found, but they are not membrane bound.)
    - From the preceding table, notice how much smaller prokaryotes are than eukaryotes.
- Three corresponding details about eukaryotic cells:
    - A membrane-enclosed nucleus contains the cell’s linear chromosomes.
    - Many membrane-bound organelles are found in the cytoplasm.
    - On average, eukaryotes are much larger than prokaryotes.
- Use Figure 6.8 to locate each component of a plant or animal cell as they are reviewed. Notice if the cell structure is found only in animal cells, only in plant cells, or both plant and animal cells.
- The **plasma membrane** forms the boundary for a cell. It is selectively permeable and permits the passage of materials into and out of the cell.
- The plasma membrane is made up of *phospholipids*, *proteins*, and associated *carbohydrates*. These molecules determine the functions of the membrane.

- The *surface area-to-volume ratio* becomes less favorable as a cell increases in size. The total volume grows proportionately more than the surface area. Because a cell acquires resources through the plasma membrane, cell size is limited.

> **CONNECT WITH THE CURRICULUM**
>
> **Big Idea 2**
>
> Be able to calculate surface area-to-volume ratios for various cell sizes and shapes. Can you use this information to predict relative rates of diffusion into/out of the cell? How do the following structures enhance exchange: root hairs, microvilli, cristae of mitochondria?

The Eukaryotic cell's genetic instructions are housed in the nucleus and carried out by the ribosomes (6.3)

- The **nucleus** has the following key characteristics:
    - The nucleus contains most of the cell's DNA. It is in the nucleus where DNA is used as the template to make messenger RNA (mRNA), which contains the code to produce a protein. Because the nucleus contains the genetic information, it is referred to as the control center of the cell.
    - The nucleus is the most noticeable organelle in the cell because of its large relative size. The nucleus is surrounded by a double membrane, the **nuclear envelope**. Note that the nuclear envelope is continuous with the rough endoplasmic reticulum. The nuclear envelope contains **nuclear pores** that control what may enter or leave the nucleus.
    - **Chromatin** is the complex of DNA and protein housed in the nucleus that is formed from the chromosomes. As a cell gets ready for cell division, the diffuse threads of chromatin condense back into visible chromosomes.
    - The **nucleolus** is a region of the nucleus where ribosomal RNA (rRNA) complexes with proteins to form ribosomal subunits.
- **Ribosomes** are protein factories. They are composed of rRNA and proteins and are sites of protein synthesis in the cell. Each ribosome consists of a large and a small subunit.
    - *Free ribosomes* are found floating in the cytosol and generally produce proteins that are used within the cell.
    - *Bound ribosomes* are attached to the endoplasmic reticulum and make proteins destined for export from the cell.

> **CONNECT WITH THE CURRICULUM**
>
> **Big Idea 2**
>
> Consider what cell features might be present in abundance or absent in certain cells based on their functions.

The endomembrane system regulates protein traffic and performs metabolic functions in the cell (6.4)

- **Endoplasmic reticulum (ER)** makes up more than half the total membrane structure in many cells. The ER is a network of membranes and sacs whose internal area is called the *cisternal space*. There are two types of ER:
    - **Smooth ER** has three primary functions: synthesis of lipids, metabolism of carbohydrates, and detoxification of drugs and poisons.
    - **Rough ER** is so called because its associated ribosomes make the structure appear rough under the microscope. Ribosomes associated with ER synthesize proteins that are generally secreted by the cell. As the proteins are produced by the ER-bound ribosomes, the polypeptide chains travel across the ER membrane and into the cisternal space. Within the cisternal space the proteins are packaged into *transport vesicles*, which bud off the ER and move toward the Golgi apparatus.
- The **Golgi apparatus** operates something like the postal system – proteins from the transport vesicles are modified, stored, and shipped. As Figure 6.12 shows, the Golgi apparatus consists of flattened sacs of membranes called cisternae, arranged in stacks. Golgi stacks have polarity – the *cis* face receives vesicles, whereas the *trans* face ships vesicles. Products of the ER are modified here, and the Golgi apparatus is extensive in cells specialized for secretion.
- **Lysosomes** are membrane-bound sacs of hydrolytic enzymes that can digest large molecules, including proteins, polysaccharides, fats, and nucleic acids. They have digestive enzymes that break down macromolecules to organic monomers that are released into the cytosol and thus recycled by the cell. The digestive or hydrolytic enzymes work best in the acidic environment found in lysosomes. If a lysosome breaks open or leaks, the enzymes are not very active in the neutral pH of the cell. This is a good example of the importance of cell compartmentalization.
- **Vacuoles** are membrane-bound vesicles. *Food vacuoles* such as those formed by phagocytosis of protists are one example, as are the *contractile vacuoles* that maintain water balance in *Paramecia* and other protists.
- **Central vacuoles** in plant cells may concentrate and contain compounds not found in the cytosol. A large central vacuole is one of the striking differences between plant and animal cells. In plants, a vacuole can make up as much as 80% of the cell.

Mitochondria and chloroplasts change energy from one form to another (6.5)

- **Mitochondria** are the sites of cellular respiration, the metabolic process that uses oxygen to generate ATP by extracting energy from sugars, fats, and other fuels. Mitochondria are found in both plant and animal cells. Study Figure 6.7a to learn the structure.
    - Mitochondria consist of an *outer* and *inner membrane*. The inner membrane is highly folded. These *cristae* (folds) increase the surface area, enhancing the productivity of cellular respiration.
    - The inner compartment, the *mitochondrial matrix*, is fluid-filled and many of the reactions of cellular respiration occur here.

  - The mitochondrial matrix contains mitochondrial DNA separate from nuclear DNA as well as ribosomes.
- **Chloroplasts**, found in plants and algae, are the sites of photosynthesis.
- The *endosymbiont theory* proposes that both mitochondria and chloroplasts share a similar origin. This theory states that these organelles descended from prokaryotic cells once engulfed by ancestors of eukaryotic cells. There are several lines of evidence for this:
  - Both organelles have a double-membrane structure.
  - Both organelles have their own ribosomes and circular DNA molecules.
  - Both reproduce independently within the cell.
- **Peroxisomes** are single-membrane-bound compartments in the cell responsible for various metabolic functions that involve the transfer of hydrogen from compounds to oxygen, producing hydrogen peroxide (H_2O_2). Peroxisomes break down fatty acids to be sent to the mitochondria for fuel and detoxify alcohol by transferring hydrogen from the poison to oxygen.
- This is an excellent example of how the cell's compartmental structure is crucial to its functions: The enzymes that produce hydrogen peroxide and those that dispose of this toxic compound are separate from other cellular components that could be damaged.

The cytoskeleton is a network of fibers that organizes structures and activities in the cell (6.6)

- The **cytoskeleton** is a network of protein fibers that runs throughout the cytoplasm, where it is responsible for support, motility, and regulating some biochemical activities. Three types of fibers make up the cytoskeleton:
  - **Microtubules**, made of the protein tubulin, are the largest of the cytoskeleton fibers. Microtubules shape and support the cell and also serve as tracks along which organelles equipped with *motor molecules* can move. They also separate chromosomes during mitosis and meiosis (forming the spindle) and are the structural components of cilia and flagella (found primarily in animal cells).
  - **Microfilaments** are composed of the protein actin. Much smaller than microtubules, microfilaments function in smaller-scale support. When coupled with the motor molecule myosin, microfilaments can be involved with movement. *Examples*: amoeboid movement, cytoplasmic streaming, and contraction of muscle cells.
  - **Intermediate filaments** are slightly larger than microfilaments and smaller than microtubules. Intermediate fibers are more permanent fixtures in the cell, where they are important in maintaining the shape of the cell and fixing the position of certain organelles.
- **Centrosomes** are a region located near the nucleus from which microtubules grow (the area is also called the microtubule-organizing center). Centrosomes contain centrioles in animal cells.
- **Centrioles** are located within the centrosomes of animal cells, where they replicate before cell division.
- A specialized arrangement of microtubules is responsible for the beating of flagella and cilia.

- **Flagella** are usually long and few in number. Many unicellular eukaryotic organisms are propelled through the water by flagella, as are the sperm of animals, algae, and some plants.
- **Cilia** are usually much shorter and more numerous than flagella. Cilia can also be used in locomotion or, when held in place as part of a tissue layer, they can move fluid over the surface of the tissue. For example, the lining of the trachea moves mucus-trapped debris out of the lungs in this manner.

- Although different in length, number per cell, and beating pattern, cilia and flagella share a common ultrastructure. Nearly all eukaryotic cilia and flagella have nine pairs of microtubules surrounding a central core of two microtubules. This arrangement is referred to as the "9+ 2"pattern.

Extracellular components and connections between cells help coordinate cellular activities (6.7)

- The **cell wall** of a plant protects the plant and helps maintain its shape. It is outside the plasma membrane. The primary component of cell walls is the carbohydrate *cellulose*.
- Prokaryotes and fungi also have cell walls, although not formed of cellulose.
- **Plasmodesmata** are channels that perforate adjacent plant cell walls and allow the passage of some molecules from cell to cell.
- **Extracellular matrix (ECM)** of animal cells is situated just external to the plasma membrane; it is composed of glycoproteins secreted by the cell (most prominent of which is collagen). The ECM greatly strengthens tissues and serves as a conduit for transmitting external stimuli into the cell, which can turn genes on and modify biochemical activity.
- Animal cells have three types of intercellular junctions:
    - **Tight junctions** are sections of animal cell membrane where two neighboring cells are fused, making the membranes watertight.
    - **Desmosomes** fasten adjacent animal cells together, functioning like rivets to fasten cells into strong sheets.
    - **Gap junctions** provide channels between adjacent animal cells through which ions, sugars, communication molecules, and other small molecules can pass.

STUDY TIP

Know the structure and function of each organelle and whether it is found in a plant cell or an animal cell, or both. Be able to predict and justify how a change in a cellular organelle would affect the function of the entire cell or organism.

Membrane Structure and Function
(Chapter 7)

YOU MUST KNOW…

- Why membranes are selectively permeable.
- The role of phospholipids, proteins, and carbohydrates in membranes.
- How water will move if a cell is placed in an isotonic, hypertonic, or hypotonic solution and be able to predict the effect of different environments on the organism.
- How electrochemical gradients and proton gradients are formed and function in cells.

Cellular membranes are fluid mosaics of lipids and proteins (7.1)

- The cell or **plasma membrane** is **selectively permeable**; that is, it allows some substances to cross it more easily than others.
- Membranes are predominantly made of phospholipids and proteins held together by weak interactions that cause the membrane to be fluid. The *fluid mosaic model* of the cell membrane describes the membrane as fluid, with proteins embedded in or associated with the phospholipid bilayer. Figure 7.3 shows the current model of an animal cell's plasma membrane. Find each part of the membrane as the three primary organic molecules of the membrane are described:
    - The hydrophilic phosphate portions of the phospholipids are oriented toward the aqueous inside and outside environments of cells, whereas the hydrophobic fatty acids face each other in a double layer (the *bilayer*) in the interior.
    - The **phospholipids** in the membrane provide a hydrophobic barrier that separates the cell from its liquid environment. Hydrophilic molecules cannot easily enter the cell, but hydrophobic molecules can enter much more easily; hence, the selectively permeable nature of the membrane.
    - There are **proteins** completely embedded in the membrane, including some that span the membrane completely. These may serve as transport channels to movematerials across the hydrophobic interior of the phospholipid bilayer, or as molecular receptors to bind to signaling molecules (ligands). Peripheral proteins are loosely bound to the membrane's surface. An example would be a G protein, which can move along the membrane when a ligand binds a G protein-coupled receptor.
    - **Carbohydrates** on the membrane are crucial in cell-cell recognition (which is necessary for proper immune function) and in developing organisms (for tissue differentiation). Cell-surface carbohydrates vary from tissue to tissue and are the reason that blood transfusions must be type-specific.

Membrane structure results in selective permeability (7.2)

- Nonpolar molecules – such as hydrocarbons, carbon dioxide, and oxygen – are hydrophobic and can dissolve in the hydrophobic interior of the phospholipid bilayer and cross the membrane easily.
- The hydrophobic core of the membrane impedes the passage of ions and polar molecules, which are hydrophilic. However, hydrophilic substances can avoid the lipid bilayer by passing through **transport proteins** that span the membrane (see Figure 7.3).
- Perhaps the most important molecule to move across the membrane is water. Water moves through special transport proteins termed **aquaporins**. Aquaporins greatly accelerate the speed (3 billion water molecules per aquaporin per second!) at which water can cross membranes.

Passive transport is diffusion of a substance across a membrane with no energy investment (7.3)

- In **passive diffusion**, a substance travels from where it is more concentrated to where it is less concentrated, diffusing down its **concentration gradient**. Hydrocarbons, carbon dioxide, and oxygen (O_2) are hydrophobic substances that can pass easily across the cell membrane by passive diffusion. This type of diffusion requires that no work be done, and it relies only on the thermal motion energy intrinsic to the molecule in question. It is called "passive" because the cell expends no energy in moving the substances.
- The diffusion of water across a selectively permeable membrane is **osmosis**. A cell has one of three water relationships with the environment around it.
  - In an **isotonic solution** there will be no net movement of water across the plasma membrane. Water crosses the membrane but at the same rate in both directions.
  - In a **hypertonic solution** the cell will lose water to its surroundings. The *hyper*- prefix refers to more solutes in the water around the cell; hence, the movement of water to the higher (hyper-) concentration of solutes. In this case the cell loses water to the environment, will shrivel, and may die.
  - In a **hypotonic solution** water will enter the cell faster than it leaves. The *hypo*- prefix refers to fewer solutes in the water around the cell; hence, the movement of water into the cell where solutes are more heavily concentrated. In this case the cell will swell and may burst.
- Be sure to watch the wording: Is the cell hypertonic to the solution it is placed in, or is the surrounding solution hypertonic to the cell? In the first example water moves into the cell, whereas in the second water moves out of the cell. Remember this: Water moves *from* a hypotonic solution *to* a hypertonic solution. **Hypo → Hyper**
- **Ions** and **polar molecules** cannot pass easily across the membrane. The process by which ions and hydrophilic substances diffuse across the cell membrane with the help of transport proteins

is called **facilitated diffusion**. Transport proteins are specific (like enzymes) for the substances they transport. They work in one of two ways:
    - They provide a hydrophilic channel through which the molecules in question can pass.
    - They bind loosely to the molecules in question and carry them through the membrane.

Active transport uses energy to move solutes against their gradients (7.4)

- In **active transport**, substances are moved against their concentration gradient – that is, from the region where they are *less* concentrated to the region where they are *more* concentrated. This type of transport requires energy, usually in the form of ATP.
- A common example of active transport is the **sodium-potassium pump**. This transmembrane protein pumps sodium out of the cell and potassium into the cell. The sodium-potassium pump is necessary for proper nerve transmission and is a major energy consumer in your body as you read this.
- The inside of the cell is negatively charged compared with outside the cell. The difference in electric charge across a membrane is expressed in voltage and termed the **membrane potential**. Because the inside of the cell is negatively charged, a positively charged ion on the outside, like sodium, is attracted to the negative charge inside the cell. Thus, two forces drive the diffusion of ions across a membrane:
    - A *chemical force*, which is the ion's concentration gradient.
    - A *voltage gradient* across the membrane, which attracts positively charged ions and repels negatively charged ions.
- This combination of forces acting on an ion forms an **electrochemical gradient**.

Bulk transport across the plasma membrane occurs by exocytosis and endocytosis (7.5)

- Large molecules are moved across the cell membrane through exocytosis and endocytosis.
    - In **exocytosis**, vesicles from the cell's interior fuse with the cell membrane, expelling their contents.
    - In **endocytosis**, the cell forms new vesicles from the plasma membrane; this is basically the reverse of exocytosis, and this process allows the cell to take in macromolecules. Examples of endocytosis include the engulfing of foreign particles by white blood cells or amoebas.

Resource Acquisition and Transport in Vascular Plants
(Chapter 36)

YOU MUST KNOW…

- How passive transport, active transport, and cotransport function to move materials across plant cell membranes.
- The role of water potential in predicting movement of water in plants.
- How the transpiration cohesion-tension mechanism explains water movement in plants.

Adaptations for acquiring resources were key steps in the evolution of vascular plants (36.1)

- Study Figure 36.2 where you will see an overview of resource acquisition and transport. Take your time with the figure because it has much important information.

Different mechanisms transport substances over short or long distances (36.2)

- Transport begins with the movement of water and solutes across a cell membrane.
    - Solutes diffuse down their electrochemical gradients. Electrochemical gradients are the combined effects of the concentration gradient of the solute and the voltage or charge differential across the membrane.
    - If no energy is required to move a substance across the membrane, then the movement is termed *passive transport*. Diffusion is an example of passive transport.
    - If energy is required to move solutes across the membrane, it is termed *active transport*. Because most solutes cannot move across the phospholipid barrier of the membrane, a **transport protein** is required. The most important protein in plants is the **proton pump**.
    - A proton pump creates an electrochemical gradient by using the energy of ATP to pump hydrogen ions across the membrane. This potential energy can then be used in the process of **cotransport** – the coupling of the steep gradient of one solute (hydrogen in our example) with a solute like sucrose. The drop in potential energy experienced by the hydrogen ion pays for the transport of the sucrose.
- The uptake of water across cell membranes occurs through *osmosis*, the passive transport of water across a membrane.
    - Water moves from areas of high water potential to low water potential. **Water potential** includes the combined effects of solute concentration and physical pressure.
    - The water potential equation is $\Psi = \Psi s + \Psi p$, where Ψ is water potential, Ψs is solute potential, and Ψp is the pressure potential.
    - By definition the Ψs of pure water is 0. Adding solutes to pure water always lowers water potential. The solute potential of a solution is therefore always negative.

    - Pressure potential is the physical pressure on a solution. An example of positive Ψp occurs when the cell contents press the plasma membrane against the cell wall, a force termed *turgor pressure*. If the cell loses water, the pressure potential becomes more negative, resulting in wilting.
- **Aquaporins** are the transport proteins (channels) in the plant plasma membrane specifically for the passage of water.
- Long-distance transport in plants occurs through **bulk flow**, the movement of liquid in response to a pressure gradient. Bulk flow is always from regions of high pressure to regions of low pressure.

Transpiration drives the transport of water and minerals from roots to shoots via the xylem (36.3)

- Water and minerals from the soil enter the plant through the root epidermis, cross the body of the root, and then flow up the xylem.
- Once in the root xylem, water and minerals are transported long distances – to the rest of the plant – by bulk flow. The water and minerals, termed *xylem sap*, flow out of the root and up through the shoot, eventually exiting the plant, primarily through the leaves.
- **Transpiration** is the loss of water vapor from the leaves and other parts of the plant that are in contact with air. It plays a key role in the movement of water from the roots.
    - The **cohesion-tension hypothesis** describes how transpiration provides the pull for ascent of xylem sap, and the cohesion of water molecules transmits this pull along the entire length of the xylem from shoots to roots.
    - Water is lost through transpiration from the leaves of the plant due to the lower water potential of the air. The *cohesion* of water due to hydrogen bonding plus the *adhesion* of water to the plant cell walls enables the water to form a water column. Water is drawn up through the xylem as water evaporates from the leaves, each evaporating water molecule pulling on the one beneath it through the attraction of *hydrogen bonds*.

TIP FROM THE READERS

Hydrogen bonding plays a key role in cohesion-tension mechanisms. Be able to explain the importance of cohesion, adhesion (water hydrogen bonded to the xylem walls), and surface tension in this mechanism.

The rate of transpiration is regulated by stomata (36.4)

- Large leaf surface area increases photosynthesis but also increases water loss by the plant through stomata. Guard cells open and close the stomata, controlling the amount of water lost by transpiration, but also the amount of carbon dioxide available from the atmosphere for photosynthesis.

- Guard cells control the size of the stomata opening by changing shape, widening or closing the gap between them. When the guard cells take up K^+ from the surrounding cells, water potential in the guard cells is decreased, causing them to take up water. The guard cells then swell and buckle, increasing the size of the pore between them. When the guard cells lose K^+, the cells then lose water, become less bowed, and the pore closes. Follow this sequence of events as shown in Figure 36.13.
- Guard cells are stimulated to open by the presence of light, loss of carbon dioxide in the leaf, and by normal circadian rhythms. Notice the critical interactions between environmental stimuli and internal molecular changes. This area of study has many essay possibilities!
- Circadian rhythms are part of the plant's internal clock mechanism and cycle with intervals of about 24 hours. Even plants kept in the dark will open their stomata as dawn approaches.