UNIT 3

Photosynthesis and Cellular Respiration

General Outcomes

In this unit, you will

- relate photosynthesis to the storage of energy in organic compounds
- explain the role of cellular respiration in releasing potential energy from organic compounds

Unit 3 Contents

Chapter 5

Focussing Questions

1 How does light energy from the Sun enter living systems?

2 How is the energy from light used to synthesize organic matter?

3 How is the energy from organic matter released for use by living systems?

Unit PreQuiz ?

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This is a common view of the Great Plains—herds of animals grazing on a seemingly endless ocean of grasses. The interaction between producers and consumers is the way in which the Sun's energy enters, is transformed by, and exits living systems. At the same time, vital chemicals such as water, carbon, nitrogen, and sulfur cycle continuously, linking organisms with one another and with their environment.

Today, the Prairie landscape is punctuated by the products and practices of technology. The petroleum industry "taps into" long-buried stores of energy, in the form of crude oil and natural gas. These resources developed with the passage of time as natural chemical processes slowly changed the bodies of ancient producers and consumers into the compounds that fuel modern society and serve as building blocks for plastics and other synthetic materials.

In Unit 1, you explored the interactions between living and non-living systems at a macroscopic level. In this unit, you will consider the same interactions at a microscopic level. You will examine the cellular processes of photosynthesis and cellular respiration that provide the energy and matter all organisms need to survive.

UNIT 3 Preparation

Prerequisite Concepts

This unit builds on your knowledge of photosynthesis and cellular respiration, as well as the investigations you have conducted to explore them (Chapters 1 and 2).

Plant and Animal Cells

Plants and animals (as well as fungi and protists) are organisms that are made up of eukaryotic cells. These are cells that have a nucleus.

Cells are the microscopic components that make up all organisms. Cells exhibit the characteristics of life, but they can also be specialized for specific tasks.

The cells that make up plants and the cells that make up animals have some structures that distinguish one type from the other. For example, plant cells are surrounded by a rigid structure called a cell wall, while animal cells lack this feature.

Plant and animal cells also share several basic structural and functional similarities. For example, both types of cell contain organelles, which are structures that have a specific function in the cell. Many organelles are surrounded by a membrane. The various organelles work together as part of a cellular system that effectively carries out the essential life-related tasks of the cell. Figure P3.1 and P3.2 summarize and review the basic structures and functions of plant and animal cells.

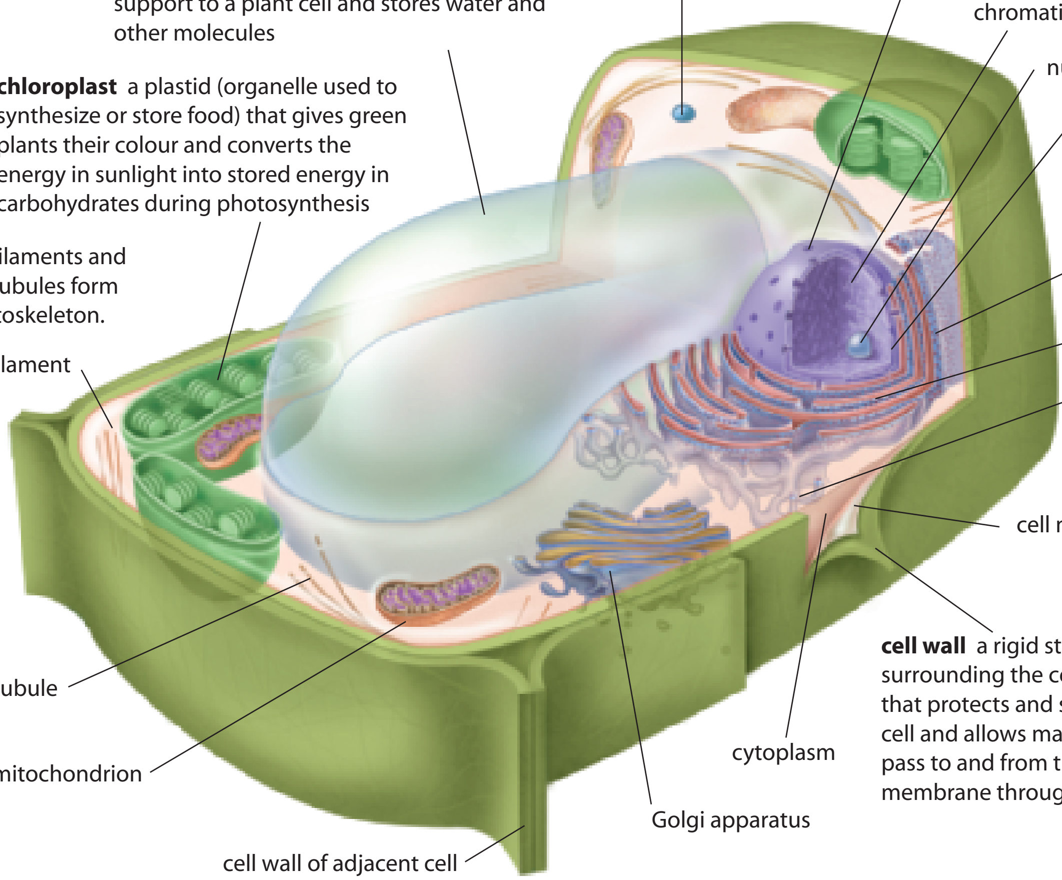

Figure P3.1 In general, plant cells are larger than animal cells. The most distinctive features that distinguish plant cells from animal cells are their cell wall and chloroplasts.

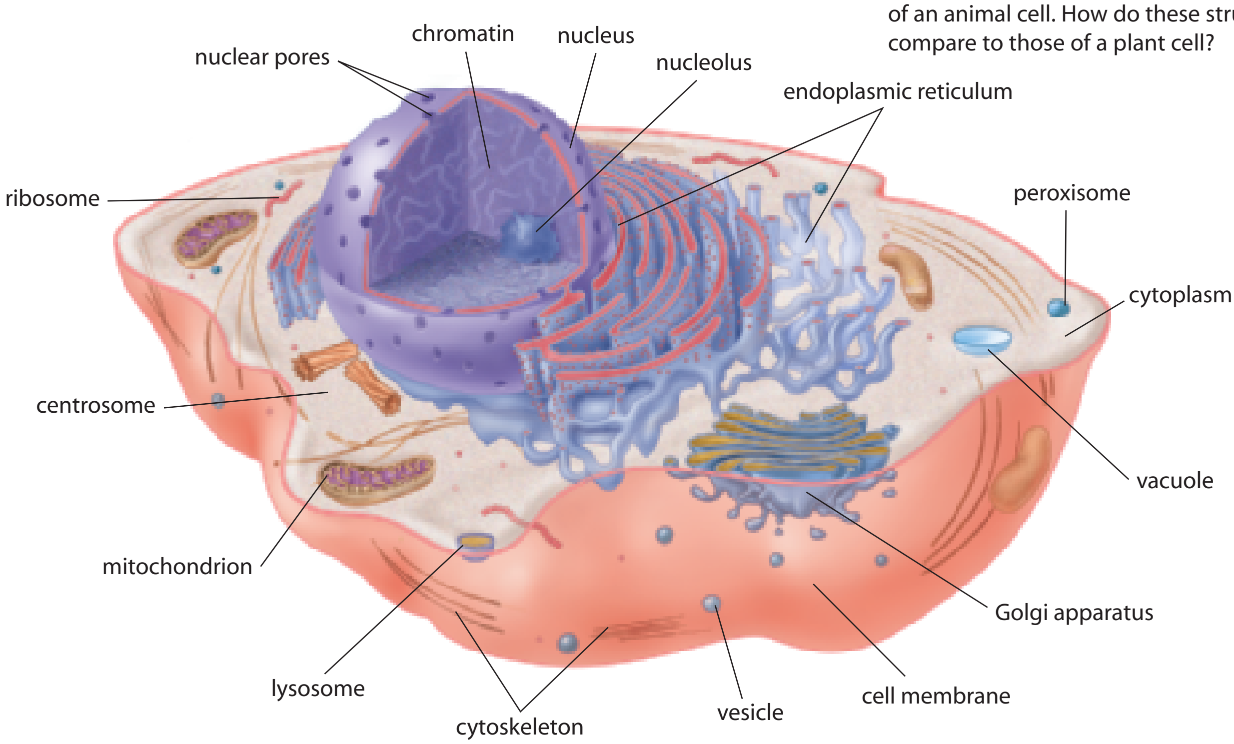

Figure P3.2 Structures that are typical of an animal cell. How do these structures compare to those of a plant cell?

- **cell membrane** a structure that separates the cell interior from the outside world and controls the movement of materials into and out of the cell
- **cytoplasm** a gel-like material consisting mostly of water that contains dissolved materials and creates the chemical environment in which the other cell structures work
- **nucleus** the command centre of the cell that contains the DNA blueprints for making proteins and is surrounded by a double membrane to protect the DNA from potentially damaging byproducts of biochemical reactions
- **nuclear pores** pores in the nuclear membrane large enough to allow macromolecules to enter and ribosomes to leave the nucleus
- **chromatin** uncoiled chromosomes (DNA)
- **nucleolus** a specialized area of chromatin inside the nucleus responsible for producing ribosomes
- **ribosome** tiny two-part structures found throughout the cytoplasm that help put together proteins
- **endoplasmic reticulum (ER)** a system of flattened membrane-bound sacs and tubes continuous with the outer membrane of the nuclear envelope that has two types of membrane: rough ER, which is studded with ribosomes and synthesizes proteins, and smooth ER, which synthesizes phospholipids and packages macromolecules in vesicles for transport to other parts of the cell
- **Golgi apparatus** a stack of flattened membrane-bound sacs that receive vesicles from the ER, contain enzymes for modifying proteins and lipids, package finished products into vesicles for transport to the cell membrane (for secretion out of the cell) and within the cell as lysosomes
- **mitochondrion** the powerhouse of the cell where organic molecules, usually carbohydrates, are broken down inside a double membrane to release and transfer energy
- **lysosome** a membrane-bound vesicle filled with digestive enzymes that can break down worn-out cell components or materials brought into the cell
- **peroxisome** a membrane-bound vesicle containing enzymes that break down lipids and toxic waste products, such as alcohol
- **centrosome** an organelle located near the nucleus that organizes the cell's microtubules, contains a pair of centrioles (made up of microtubules), and helps to organize the even distribution of cell components when cells divide
- **vesicle** a small membrane-bound transport sac
- **vacuole** a large membrane-bound, fluid-filled sac for the temporary storage of food, water, or waste products
- **cytoskeleton** a network of three kinds of interconnected fibres that maintain cell shape and allow for movement of cell parts: actin filaments, intermediate filaments, and microtubules

The Cell Membrane

The cell membrane is a boundary that separates the internal environment of a cell from its external environment. Cell membranes are composed mainly of a double layer of phospholipid molecules, which are a type of lipid. (Lipids are organic compounds that do not dissolve in water, such as fats, oils, and steroids like cholesterol.) Each phospholipid molecule has a shape with a distinctive head region at one end and a tail region at the other. These two ends have different chemical compositions that cause them to interact differently with water. The head end dissolves easily in water, while the tail end is insoluble in water.

Because of these different responses to water, phospholipid molecules arrange themselves spontaneously in water into a two-layered, sandwich-like structure. In this structure, the head ends are on the outside layers, where they are exposed to the watery fluid outside and inside the cell. The tail ends face each other on the inside of the structure, away from water.

As shown in Figure P3.3, cell membranes are composed of these double-layer phospholipids as well as various proteins and other molecules that are embedded within them and that extend from them. Some of the embedded proteins create passageways through which water-soluble molecules and ions can pass. Other proteins help transport substances across the membrane.

Passive Transport: Diffusion and Osmosis

The cell membrane is *selectively permeable* (or semi-permeable), which means that it allows some molecules to pass through it while preventing others

Figure P3.3 A model of cell membrane structure. Note the two layers of phospholipids (called a phospholipids bilayer), with the distinctive head-and-tail shape of the phospholipid molecules. Inside the cell, parts of the cell's "skeleton" (called the cytoskeleton) support the membrane.

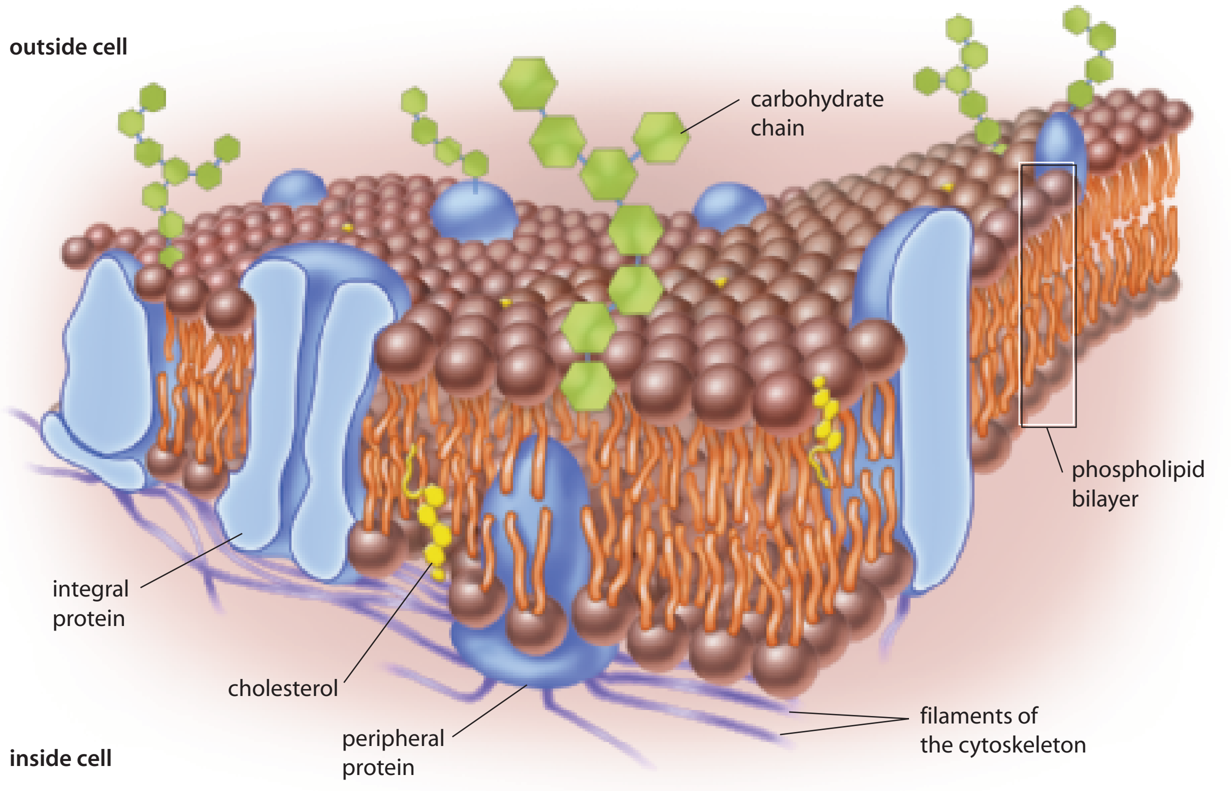

Figure P3.4 Diffusion is a spontaneous process in which molecules move down their concentration gradient—that is, from an area of higher concentration to an area of lower concentration. In this photograph, for example, the ink particles will become dispersed evenly as time passes due to diffusion.

from doing so. One method by which small molecules and ions move through the cell membrane is diffusion. *Diffusion* is the natural movement of molecules or ions from a region where they are more concentrated to one where they are less concentrated (Figure P3.4).

Many molecules—especially small, uncharged ones such as oxygen—can move easily through the cell membrane by diffusion. The cell membrane cannot prevent this movement of certain molecules and ions, because it is permeable to them. Thus, diffusion is a passive process that does not require energy from the cell.

The natural tendency of a substance to move from an area of high concentration to an area of lower concentration is often described as "moving down" or "following" its *concentration gradient*. A gradient is a general term that refers to a difference in some quality between two adjacent regions. Differences in concentration, in pressure, in electrical energy, and in pH all establish gradients.

Water inside the cell (intracellular fluid) and outside the cell (extracellular fluid) also diffuses freely through the cell membrane. The diffusion of a solvent (in this case, water) across a semi-permeable membrane that separates two solutions is called *osmosis*. The direction of osmosis depends on the relative concentration of water molecules on either side of the cell membrane.

- If the water concentration inside the cell equals the water concentration outside the cell, equal amounts of water move in and out of the cell at the same rate. (The cell is isotonic to the fluid surrounding it.)
- If the water concentration outside the cell is greater than that inside the cell, water moves into the cell. (The cell is hypotonic to the fluid surrounding it.)
- If the water concentration inside the cell is greater than that outside the cell, water moves out of the cell. (The cell is hypertonic to the fluid surrounding it.)

The cell membrane cannot prevent the movement of water, because it is permeable to water molecules. Thus, osmosis is a passive process that does not require energy from the cell.

Facilitated Diffusion

Substances such as water, oxygen, and carbon dioxide can pass through the cell membrane without assistance. However, other substances cannot do so without help. For example, a glucose molecule is too large to diffuse between the structural molecules of the cell membrane. Specialized transport proteins in the cell membrane help different kinds of substances move in and out of the cell.

The structure of these transport proteins makes them very selective. A particular transport protein will recognize and help to move only one type of dissolved molecule or ion based on its shape, size, and electrical charge.

A type of membrane protein called a carrier protein facilitates (helps) the movement of glucose molecules from where they are more concentrated to where they are less concentrated. A carrier protein will accept only a non-charged molecule with a specific shape (Figure 3.5A). However, carrier proteins allow molecules to move both in and out of the cell.

A different type of membrane protein called a channel protein transports charged particles across the membrane (Figure 3.5B). Channel proteins have a tunnel-like shape. To pass through, an ion in solution must be small enough to fit through the "tunnel." It must also have the right charge. In much the same way that like poles of two magnets repel each other, a positively charged channel protein repels positively charged ions, and a negatively charged channel protein repels negatively charged ions.

In diffusion, osmosis, and facilitated diffusion, any substances crossing the cell membrane follow their concentration gradient. No energy from the cell is required, regardless of whether the substance moves into or out of the cell.

Active Transport

Active transport uses energy to enable a cell to take in a substance that is more concentrated inside the cell than outside the cell. Energy for active transport often comes from a molecule called **a**denosine **trip**hosphate (ATP). (You will learn about this molecule and its importance to plants, animals, and other organisms in Chapter 5.)

When one of the three phosphates is split from ATP in a chemical reaction, energy is released that is harnessed to power a cellular function. Often, this function is to move a molecule through a membrane against its concentration gradient.

Endocytosis and Exocytosis

Some of the substances that a cell must take in or expel are too large to cross

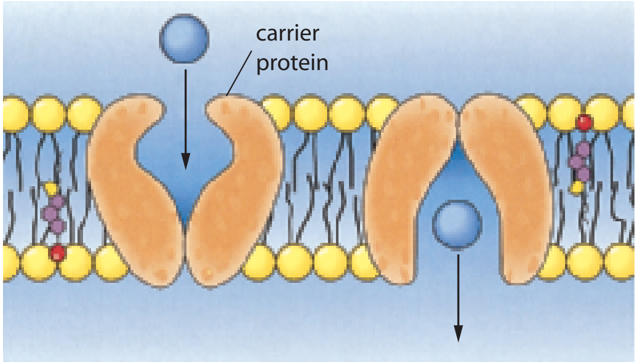

Figure P3.5A Carrier proteins change shape to allow certain molecules to cross the cell membrane.

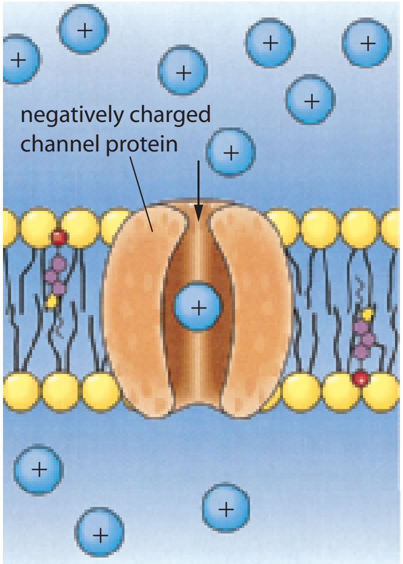

Figure P.3.5B Channel proteins provide water-filled passages through which small dissolved ions can diffuse.

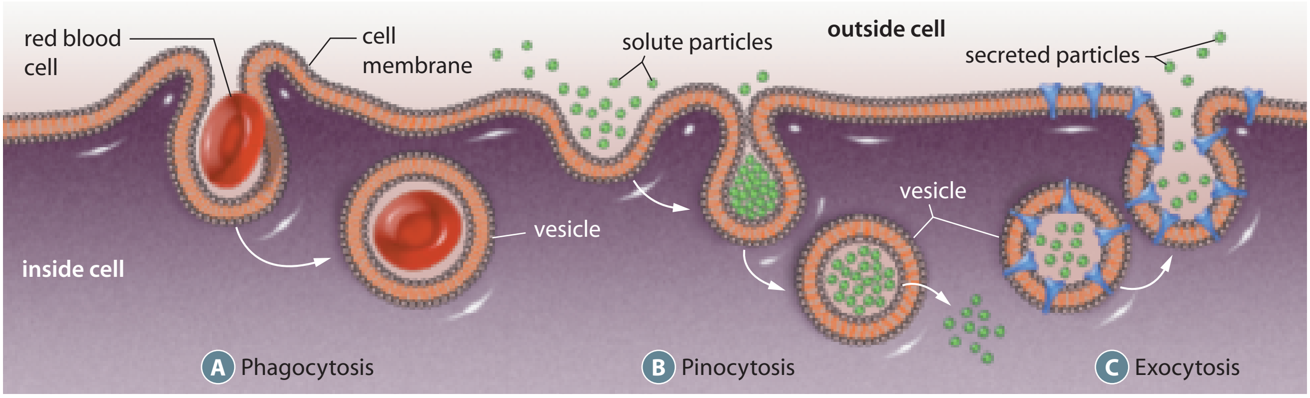

Figure P3.6 Examples of endocytosis and exocytosis

the cell membrane. Cholesterol is one example. The cell uses a specialized method to move such substances. It can fold in on itself to create a membrane-enclosed, bubble-like sac called a vesicle. The cell uses vesicles to "swallow" or expel various substances (Figure P3.6).

When the cell membrane folds inward, trapping and enclosing a small amount of matter from outside the cell, the process is called endocytosis. There are three forms of this process: pinocytosis, phagocytosis, and receptor-assisted endocytosis.

Pinocytosis involves the intake of a small droplet of extracellular fluid along with any dissolved substances or tiny particles that it may contain. This process occurs in almost all cell types nearly all of the time.

Phagocytosis involves the intake of a large droplet of extracellular fluid, often including bacteria or bits of organic matter. This process occurs only in specialized cells such as certain white blood cells of our immune system.

Receptor-assisted endocytosis involves the intake of specific molecules that attach to special proteins in the cell membrane. These membrane receptor proteins possess a uniquely shaped projection or cavity that fits the shape of only one specific molecule. Cholesterol is transported into cells using this process.

Exocytosis is the process for removing substances from the cell. In exocytosis, a vesicle from the inside the cell moves to the cell surface. There, the vesicle membrane fuses with the cell membrane. The contents of the outward-bound vesicle are secreted into the extracellular fluid. Exocytosis is important in cells that specialize in the secretion of cell products such as hormones.

Mechanisms for the Movement of Substances across the Cell Membrane

Membrane Transport Mechanism	Characteristics
diffusion	follows concentration gradient; no energy from the cell is required
osmosis	follows concentration gradient; no energy from the cell is required
facilitated diffusion	follows concentration gradient, assisted by channel proteins or carrier proteins; no energy from the cell is required
active transport	moves against concentration gradient, assisted by channel or carrier proteins and with the input of energy (usually from ATP molecules)
endocytosis (may be pinocytosis, phagocytosis, and receptor-assisted endocytosis)	membrane engulfs a substance and draws it into the cell in membrane-bounded vesicle
exocytosis	membrane-bounded vesicle fuses with cell membrane, releasing the cell's contents outside of the cell