2.3 ATP and Coupled Reactions

EXPECTATIONS

- **Identify how ATP molecules function within energy transformations in the cell.**
- **Describe the importance of ATP molecules in technological applications.**

Coupled Reactions and ATP

Enzymes are crucial for both endothermic and exothermic metabolic reactions. Many reactions in cells are endothermic, such as protein synthesis. The energy released by an exothermic reaction can be used to drive an endothermic one. Such a combination of reactions is called a **coupled reaction**. The energy used by endothermic reactions comes from the breakdown of ATP molecules, which is an exothermic reaction (shown in Figure 2.14). **ATP**, adenosine triphosphate, is the molecule that all cells use as an energy source. The process of cellular respiration converts energy (for example, the energy stored in the chemical bonds of fats and starch) into chemical energy stored in ATP molecules. As you will soon discover, all organisms can produce ATP via a process called glycolysis, the first step in cellular respiration. Cellular respiration is dealt with extensively in Chapter 3.

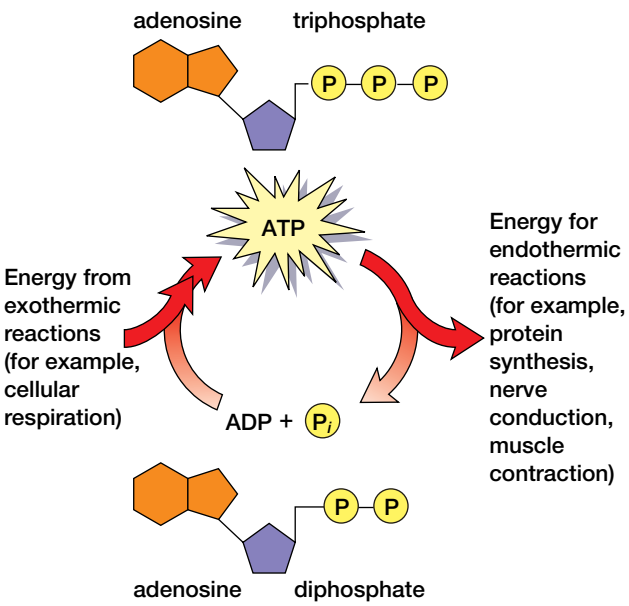

Figure 2.14 In the ATP cycle, hydrolysis removes a phosphate group from ATP, resulting in a release of energy used for various metabolic processes.

Figure 2.15 Like you, this Arctic fox uses ATP molecules to fuel cellular reactions.

ATP is a molecule composed of the sugar ribose, the base adenine, and three phosphate groups, as shown in Figure 2.16 on the next page. The sugar ribose and the base adenine together are called adenosine. Ribose is a five-carbon sugar that makes up the core of the molecule. Adenine is an organic molecule, composed of two carbon–nitrogen rings. Because of this, adenine is referred to as a nitrogenous base. As you may recall, adenine is also one of the four nitrogenous bases that make up RNA. The ribose and adenine molecules, together with one phosphate group, form a molecule called AMP (adenosine monophosphate). AMP is a component in the coenzyme, NAD^+, which is important in cellular respiration.

The final component that completes ATP is two more phosphate groups, linked by covalent bonds in a chain formation. The covalent bonds that join these phosphate groups to the rest of the molecule are often called high-energy bonds, because 31 kJ/mol (7.3 kcal/mol) of energy is released when

the exothermic reaction of ATP hydrolysis occurs. This energy value was determined in a laboratory. The high-energy bonds of ATP do not require a large quantity of activation energy to break, so little energy is required to initiate hydrolysis. In the hydrolysis of ATP, a typical metabolic reaction, only the outer high-energy bond is broken, releasing the end phosphate group. Figure 2.17 shows that the products of this reaction are ADP (adenosine diphosphate), P_i (an inorganic phosphate molecule), and the release of 31 kJ/mol of energy.

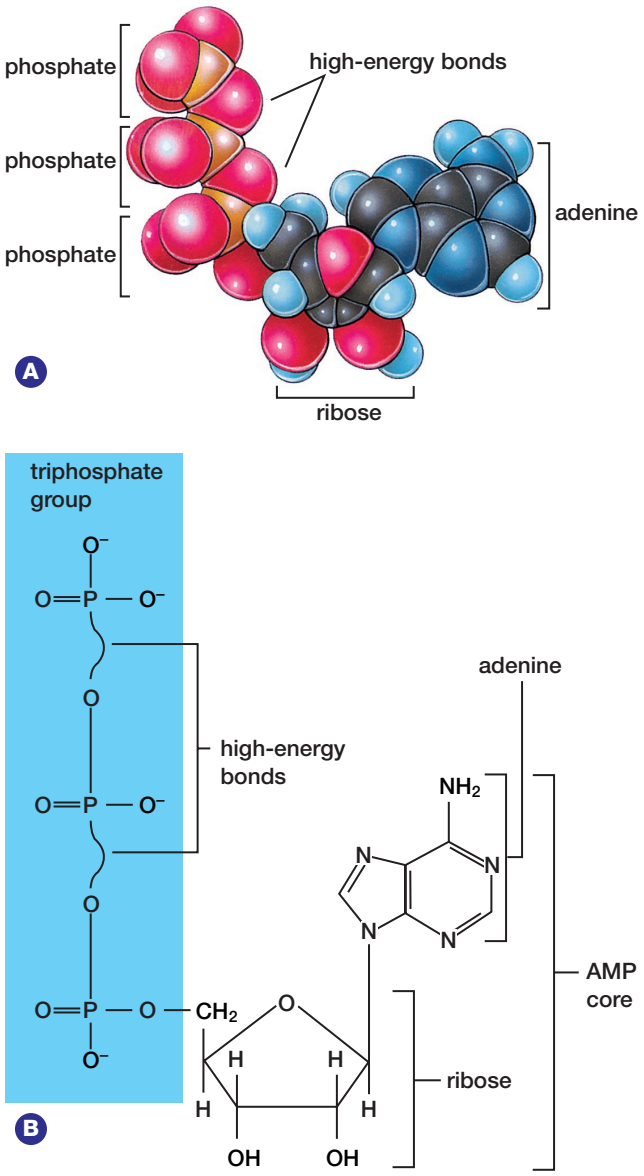

Figure 2.16 Diagram of the ATP molecule (A) and its chemical structure (B). ATP is composed of a ribose sugar, adenine, and a triphosphate group. High-energy bonds link the three phosphate groups. Energy is released from the molecule when these bonds are broken. AMP is adenosine monophosphate.

When cells require energy, they use ATP. Much ATP is needed as fuel for cellular work. A person who consumes 10.46 MJ (2500 Calories or 2500 kcal) per day manufactures and uses about 180 kg of ATP per day. ATP is constantly being generated from ADP and P_i. Consequently, cells do not keep a stockpile of ATP; it is more efficient for them to make ATP as the need arises.

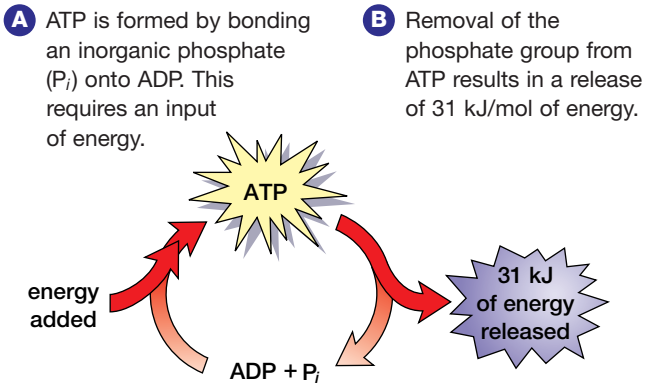

Figure 2.17 The ATP/ADP + P_i cycle

BIO FACT

Recent research indicates the molecule adenosine can induce sleep. Adenosine binds to specific receptors on the surface of nerve cells in the brain that promote sleep. The action of adenosine can be interrupted by caffeine, a stimulant found in foods, which blocks receptors on the nerve cells. As a result, a drink containing caffeine can make you feel more alert. Some researchers are investigating if sleep is influenced by ATP molecules, which are composed of an adenosine molecule and phosphate groups.

ATP Working Inside and Outside Cells

There are at least three distinct uses for ATP in cells:

1. **Chemical work** ATP supplies the energy needed to synthesize the macromolecules that comprise the cell.
2. **Mechanical work** ATP supplies the energy needed to permit muscles to contract, cilia and flagella to beat, chromosomes to move, and other functions.
3. **Transport work** ATP supplies the energy cells need to pump substances across the cell membrane.

Although some compounds (such as water) can move easily across the cell membrane, other substances require energy to move into the cell. This process is called **active transport**, and it requires the help of special proteins (often called pumps) and ATP. While facilitated diffusion and diffusion move particles along a concentration gradient, active transport moves particles *against* a concentration gradient — a process that requires energy. A common example of such a process is the **sodium-potassium pump**. This pump, which involves special carrier proteins, maintains an imbalance of sodium and potassium in cells, particularly nerve and muscle cells. The pump moves potassium ions to the inside of the cell and sodium ions to the outside of the cell. Study Figure 2.18 to learn how ATP and carrier proteins work in the sodium-potassium pump.

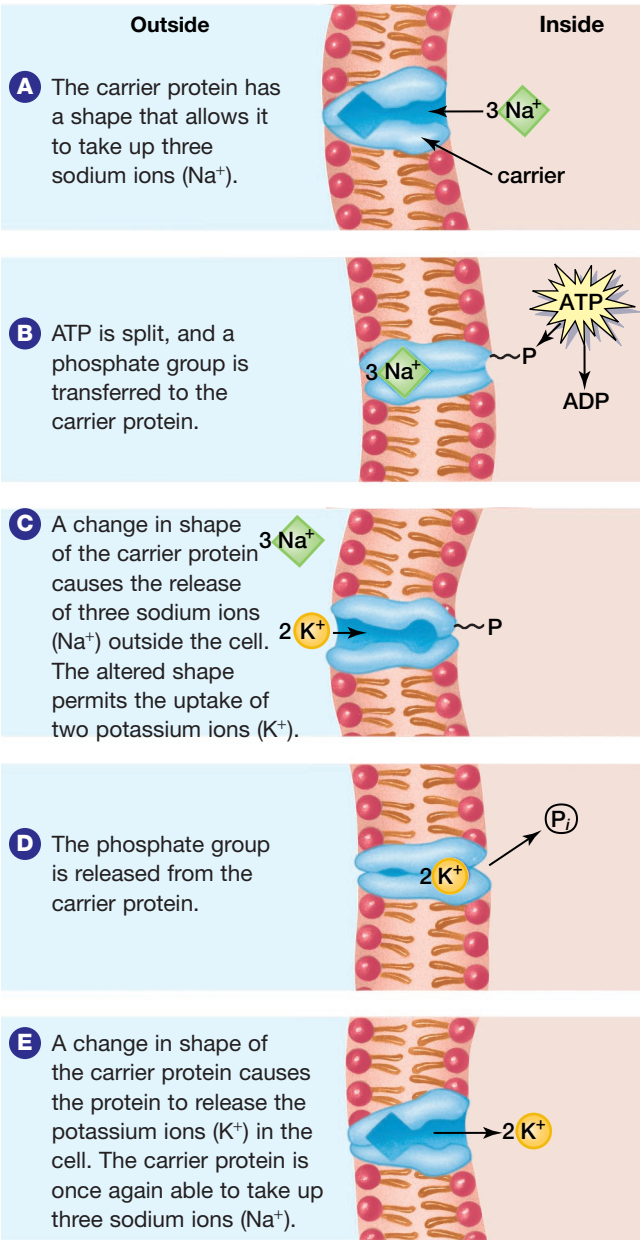

Figure 2.18 The sodium-potassium pump uses a carrier protein to move three sodium ions (Na^+) outside of the cell for every two potassium ions (K^+) moved inside the cell. Energy from ATP is required to accomplish this task.

ATP in Medicine and Industry

While ATP is important in cellular processes, it has also found a place in medical and industrial applications. Injections of ATP have helped some lung cancer patients by slowing down weight loss due to radiation therapy and helping to arrest the growth of tumours. Anesthetists use low doses of ATP in anesthesia to reduce pain, in much the same way as they administer morphine following surgery. Medical researchers also use ATP to treat patients with pulmonary hypertension, which is characterized by abnormally high blood pressure in the arteries of the lungs. Injections of ATP dilate the arteries, thereby lowering the blood pressure.

Food industries can monitor ATP to ensure food quality. ATP is only made by living organisms and can be found in low concentrations in nature (having leaked from living cells). The food industry scans food for abnormally high concentrations of ATP, which could indicate the presence of micro-organisms such as bacteria. Quality control technicians can make sure that foods with increased levels of ATP are not shipped to stores to be sold.

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To learn more about the transport of substances across cell membranes, go to your Electronic Learning Partner now.

WEB LINK

www.mcgrawhill.ca/links/biology12

In the mid-1980s, researchers discovered the enzyme kinesin, a motor protein that converts the energy of ATP into mechanical work. Kinesin and other motor proteins that have been identified are found in most eukaryotes. Motor proteins are responsible for such work as mechanical transport and chromosome movement during meiosis and mitosis. To learn more about kinesin and related motor proteins, go to the web site above, and click on **Web Links**. Select a motor protein and prepare an abstract outlining its function.

Figure 2.19 ATP therapy has great potential to help people overcome diseases such as cancer.

Advantages of ATP

Within the cell, the use of ATP as a carrier of energy is advantageous for several reasons:

1. ATP is the energy-rich molecule found in all cells and is used in many different cellular chemical reactions.
2. When ATP is broken down to ADP + P_i, some of the energy released is used in reactions to make more ATP.
3. ATP breakdown is coupled with endothermic reactions in such a way that energy loss is minimized. Some of the energy released is used in endothermic reactions, such as protein synthesis, muscle contraction, and nerve conduction.

As you have learned, ATP is essential for the endothermic and exothermic reactions that make up the metabolic processes in all cells. In the next chapter, you will study the two metabolic processes common to life on Earth: cellular respiration and photosynthesis. You will apply the principles of thermodynamics and your knowledge of enzymes to these essential metabolic processes. Exothermic and endothermic reactions in cells would not be possible without enzymes and ATP.

SECTION REVIEW

1. K/U Define the term "coupled reaction."
2. C How do coupled reactions work? In your explanation, include a diagram that demonstrates a coupled reaction.
3. K/U What are the advantages of using the same energy source, ATP, in all cells?
4. C Draw a diagram of ATP. Compose a paragraph detailing its structure and function.
5. K/U ATP molecules have three main purposes in the cell. Aside from transport work such as the sodium-potassium pump, what are two examples of how ATP is used to do work in cells?
6. MC ATP scanners can be used to detect biochemical activity. The beef industry uses this technology to detect bacterial growth in meat. Describe another possible application of this technology in industry.
7. C How is chemical energy in an ATP molecule transformed into energy that can be used to do work? Explain your answer.
8. I How could you speed up a coupled reaction? Outline an experiment to test your hypothesis.

UNIT INVESTIGATION PREP

How can the energy from one reaction be used to fuel another reaction? When designing your experiment for the end-of-unit investigation, think about how reactions are related and how some reactions are dependent on other reactions.