

24.6

1 FOCUS

Objectives

24.6.1 Describe the function of ATP in cells.

24.6.2 Distinguish between catabolism and anabolism.

24.6.3 Describe the nitrogen cycle.

Guide for Reading

Build Vocabulary L2

Paraphrase Have students write definitions of *metabolism*, *catabolism*, and *anabolism* in their own words.

Reading Strategy L2

Monitor Your Understanding After students read about catabolism and anabolism, ask them to create a diagram that shows how carbon moves from one type of metabolism to the other. They should show where energy (ATP) comes into play.

2 INSTRUCT

Connecting to Your World

Ask, **What is metabolic rate?** (*how fast the body's chemical reactions are*) **Why is iodine important in controlling human metabolism?** (*It is a component of the hormone thyroxine, which controls metabolic rate.*)

ATP

Discuss L2

Have students compare the free energy changes associated with spontaneous and nonspontaneous processes. Energy released by a reaction that is available to do work is called free energy. Spontaneous processes, which favor formation of products, release free energy. Point out that it is the phosphate–oxygen anhydride bonds in ATP that store the chemical energy in ATP. When broken by water, these bonds release energy that is used to form new types of chemical bonds in other molecules.

24.6 Metabolism

Connecting to Your World

The body's metabolic rate is controlled by a hormone called thyroxine that is released by the thyroid gland. When a person's diet does not contain adequate iodine, the thyroid gland is unable to produce and release thyroxine. The gland begins to swell, forming a goiter. In this section, you will learn where some of the nutrients in a person's diet come from and how they are involved in metabolic reactions.



Guide for Reading

Key Concepts

- What is the function of ATP in living cells?
- How does a cell obtain the energy and building blocks needed for the construction of new biological compounds?
- What happens in a cell during anabolism?
- How do nitrogen-fixing bacteria provide plants with a useable form of nitrogen?

Vocabulary

adenosine triphosphate (ATP)
metabolism
catabolism
anabolism

Reading Strategy

Comparing and Contrasting

When you compare and contrast things, you examine how they are alike and different. As you read, list the similarities and differences between catabolism and anabolism.

ATP

All living things need energy to function properly. **Adenosine triphosphate (ATP)**, shown in Figure 24.23, is a molecule that transmits this energy in the cells of living organisms. The function of ATP can be compared to a belt connecting an electric motor to a pump. The motor generates energy capable of operating the pump. But if a belt does not connect the motor to the pump, the energy produced by the motor is wasted. You can think of ATP as the belt that couples the production and use of energy by cells. **In living cells, ATP is the energy carrier between the spontaneous reactions that release energy and nonspontaneous reactions that use energy.**

Recall that oxidation reactions, such as the combustion of methane in a furnace or the oxidation of glucose in a living cell, are spontaneous reactions that release energy. This energy can be captured when adenosine diphosphate (ADP) condenses with an inorganic phosphate group to become ATP. The addition of a phosphate group, called phosphorylation, occurs during certain biochemical oxidation reactions.

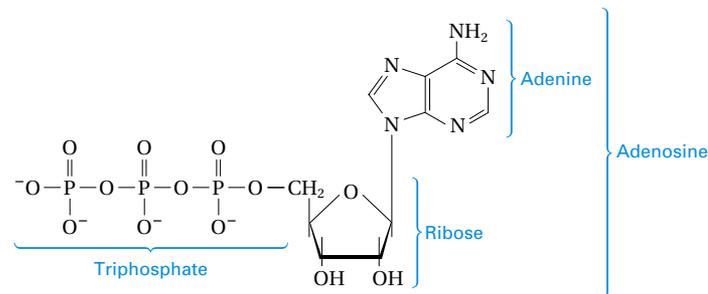


Figure 24.23 ATP is ADP that has been phosphorylated. ATP provides energy to muscles for moving the body. **Comparing and Contrasting** How is the structure of ATP similar to that of a DNA nucleotide?

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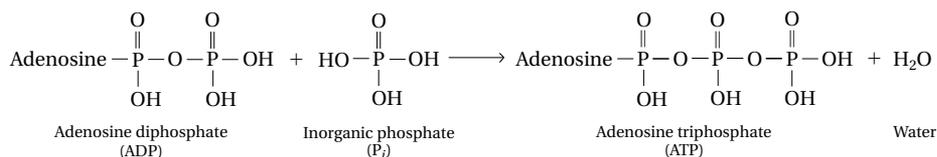
Section Resources

Print

- **Guided Reading and Study Workbook**, Section 24.6
- **Core Teaching Resources**, Section 24.6 Review, Interpreting Graphics
- **Transparencies**, T285

Technology

- **Interactive Textbook with ChemASAP**, Assessment 24.6
- **Go Online**, Section 24.6



The formation of ATP efficiently captures energy produced by the oxidation reactions in living cells. Every mole of ATP produced by the phosphorylation of ADP stores about 30.5 kJ of energy. The reverse happens when ATP is hydrolyzed back to ADP: Every mole of ATP that is hydrolyzed back to ADP releases about 30.5 kJ of energy. Cells use this released energy to drive processes that would ordinarily be nonspontaneous. Because of its ability to capture energy from one process and transmit it to another, ATP is sometimes referred to as a high-energy compound; however, the energy produced by the breakdown of ATP to ADP is not particularly high for the breaking of a covalent bond. ATP is important because it occupies an intermediate position in the energetics of the cell. It can be formed by using the energy obtained from a few higher-energy oxidation reactions. The energy that is contained in the bonds of ATP can then be used to drive other cellular processes.

Catabolism

Thousands of chemical reactions take place in the cells of a living organism. The entire set of chemical reactions carried out by an organism is known as the organism's **metabolism**. In metabolism, unneeded cellular components and the nutrients in food are broken down into simpler compounds by chemical reactions collectively called **catabolism**. Catabolic reactions release energy as well as produce simple compounds.  **The degradation of complex biological molecules such as carbohydrates, lipids, proteins, and nucleic acids during catabolism provides the energy and the building blocks for the construction of new biological compounds needed by the cell.** Through the formation of ATP, catabolic reactions provide the energy for such needs as body motion and the transport of nutrients to cells where they are required. The oxidation reactions of catabolism also provide energy in the form of heat. These reactions help keep your body temperature constant at 37°C. The need for energy and building blocks is the reason why all organisms, such as the field mouse shown in Figure 24.24, require food.

The complete oxidation of glucose to carbon dioxide and water is one of the most important energy-yielding processes of catabolism. Study Figure 24.25, which summarizes the major steps in the degradation of one glucose molecule to six molecules of carbon dioxide. The complete oxidation actually involves many reactions, which are not shown. As you can see in the figure, the major carbon-containing reactants and products are named, and they are also referred to according to the number of carbons they contain.

Figure 24.24 Organisms such as this mouse use the energy stored in the chemical bonds of food molecules to power their body processes.



Facts and Figures

Free Energy

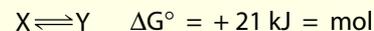
All living things require a continuous input of free energy for muscle contraction, transport of nutrients, and synthesis of biomolecules. More than 50% of the free energy released by cellular reactions is used to cause other

chemical changes. The rest is lost as heat. Compare this efficiency to that of the internal combustion engine. At most, 30% of the free energy of combustion is used to propel a car.

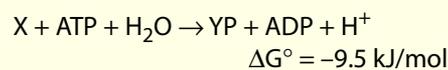
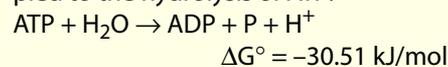
Discuss

L2

Use Hess's law of heat summation to show how the free energy of ATP hydrolysis can be harnessed by the cell to drive a nonspontaneous reaction. Consider the reversible, nonspontaneous reaction:



Normally, K_{eq} for this reaction is much less than 1, but if the reaction is coupled to the hydrolysis of ATP:



Conversion of X to Y is driven forward by high intracellular concentrations of ATP.

Catabolism

Relate

L2

In the human body, glycogen is stored in skeletal muscles and the liver. Liver glycogen is used to maintain normal blood sugar level. Muscle glycogen, however, is used solely for muscle work. Large amounts of carbohydrates, including glycogen, are used by the body during athletic events that require power or speed. The carbohydrates provide the necessary energy. Interval training, a technique that alternates rest and work phases, is designed as much to train biochemical energy pathways as to train the muscles used in an athletic activity. Proper training and diet can increase the amount of glycogen stored after a training session by more than a thousandfold.



Download a worksheet on **food as fuel** for students to complete, and find additional teacher support from NSTA SciLinks.

Answers to...

Figure 24.23 Like the nucleotides of DNA and RNA, ATP has a basic structure consisting of a phosphate group, a five-carbon sugar, and a nitrogen base. The sugar unit in both ATP and RNA is ribose.

Anabolism

Use Visuals

L1

Figure 24.26 Ask, **Are there any inputs (created by catabolism) that aren't reflected in outputs?** (no) Discuss why this is so for an animal, for example. (We need all these things to live, and there has to be a way to break them down and use them to build a body.)

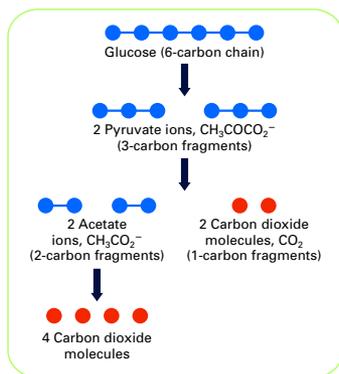


Figure 24.25 The breakdown of glucose to carbon dioxide and water is one of the most important energy-yielding processes of catabolism. **Making Generalizations** What happens to the number of carbon-carbon bonds from one step to the next?

The combustion of 1 mole of glucose to 6 moles of carbon dioxide and 6 moles of water, either by fire or by oxidation in a living cell, produces 2.82×10^3 kJ of energy. Cells that use oxygen may produce up to 38 moles of ATP by capturing the energy released by the complete oxidation of a single mole of glucose! The large amount of ATP produced from the oxidation of glucose makes it the likeliest mode of energy production for most kinds of cells. In fact, if glucose is available, brain cells use no other source of carbon compounds for energy production.

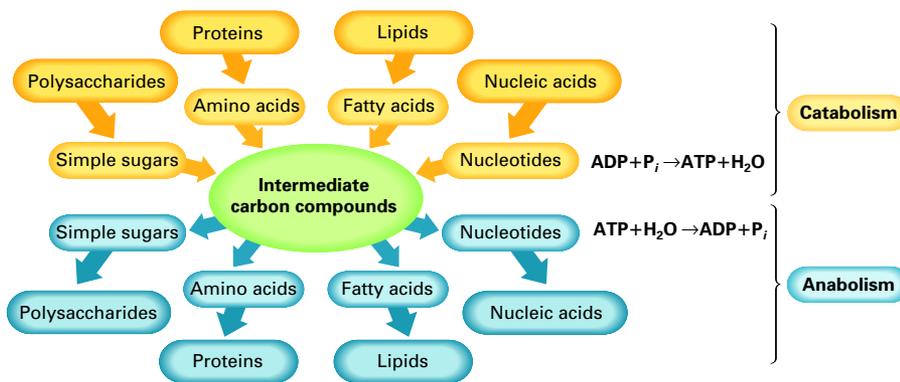
Checkpoint How much energy is released by the complete combustion of 1 mole of glucose?

Anabolism

Some of the simple compounds produced by catabolism are used to synthesize more-complex biological molecules—carbohydrates, lipids, proteins, and nucleic acids—necessary for the health and growth of an organism. The synthesis reactions of metabolism are called **anabolism**. Unlike catabolism, which releases energy, anabolism uses energy.

Figure 24.26 gives an overview of the relationship between catabolism and anabolism. Nutrients and unneeded cell components are degraded to simpler components by the reactions of catabolism. The oxidative reactions of catabolism yield energy captured in the formation of ATP. **In anabolism, the products and the energy of catabolism are used to make new cell parts and compounds needed for cellular life and growth.** You already know that energy produced by physical and chemical processes is of little value unless the energy can be captured to do work. If it is not captured, the energy is lost as heat. The chemical energy produced by catabolism must have some means of being used for the chemical work of anabolism. The ATP molecule is that means of transmitting energy.

Figure 24.26 Simple compounds produced by catabolism are used in the synthesis reactions of anabolism. **Applying Concepts** What part of metabolism releases energy? What part uses energy?



Differentiated Instruction

Less Proficient Readers

L1

Have students create cards for the steps in glucose breakdown, shown in Figure 24.26. They should expand on the shorthand version in the visual, using words or chemical

structures, so that each step makes sense to them. They can shuffle their cards and have another student put them into the correct sequence.

The Nitrogen Cycle

You have learned that the biological molecules taken into an organism's body as nutrients in food are broken down during catabolism. Food contains carbohydrates, proteins, lipids, nucleic acids, vitamins, and minerals. These nutrients are composed mainly of carbon, hydrogen, and oxygen atoms. Many biological compounds, such as proteins, contain nitrogen as well. Although Earth's atmosphere is 78% nitrogen gas, no animals and only a few plants can use this form of nitrogen to make nitrogen-containing compounds. However, certain bacteria can convert nitrogen gas into useable forms in a process called nitrogen fixation. 🔄 **Nitrogen-fixing bacteria reduce atmospheric nitrogen ($N_2(g)$) to ammonia ($NH_3(g)$), a water-soluble form of nitrogen that can be used by plants.** In soil and biological fluids, most ammonia is present as ammonium ions.

Plants incorporate ammonia into biological nitrogen compounds such as proteins, nucleic acids, and ATP. Because animals cannot synthesize these compounds, they get them by eating plants or other animals that eat plants. When these plants and animals die, they decay with the aid of bacteria. Decaying matter returns nitrogen to the soil as ammonia, nitrite ions (NO_2^-), or nitrate ions (NO_3^-). Moreover, some nitrogen gas is returned to the atmosphere. This flow of nitrogen between the atmosphere and Earth and its living creatures is the nitrogen cycle, shown in Figure 24.27.

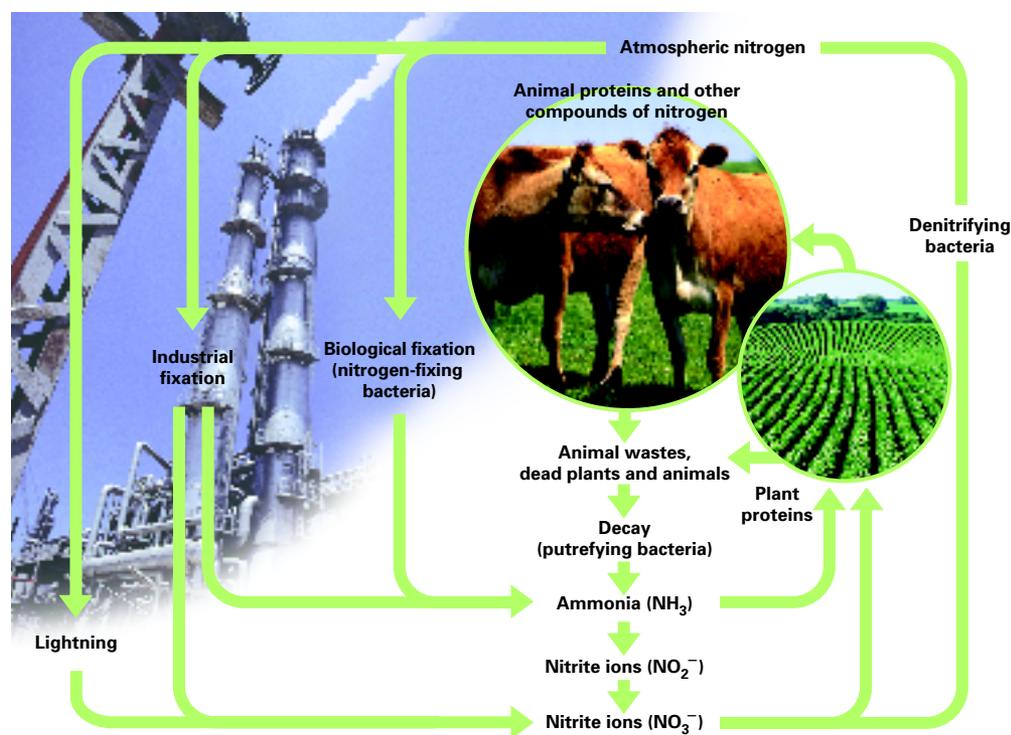


Figure 24.27 Nitrogen moves between the atmosphere and the biosphere in the nitrogen cycle.

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The Nitrogen Cycle

Relate

L2

Nitrogen often is the limiting factor in how many plants can grow to maturity in a system. Some plants specialize in low-nitrogen settings, which prevent faster growing plants from taking over the habitat. Release of extraordinary nitrogen from fertilizers allows these other plants to outcompete the low-nitrogen specialists and may eliminate them from the habitat.

Answers to...

Figure 24.25 The number of C—C bonds decreases.

Figure 24.26 Catabolism releases energy; anabolism uses energy.



Checkpoint

2.82×10^3 kJ

Section 24.6 (continued)

3 ASSESS

Evaluate Understanding L2

Ask students to compare the carbon cycle to the nitrogen cycle. Ask, **Where does energy come into play? What is its source?**

Reteach L1

Draw a schematic diagram on the board that illustrates the exchange of energy between anabolic and catabolic reactions. Connect the terms ATP and ADP by upper and lower arrows. Label the upper arrow “anabolism”. In anabolic reactions, small molecules are put together to form larger ones. These nonspontaneous processes must be coupled to the free energy of ATP hydrolysis; thus, ADP is produced during anabolic reactions. Label the lower arrow “catabolism”. In catabolic reactions, large molecules are broken down. Catabolic reactions most often release energy that can be used to drive the synthesis of ATP.

Writing Activity

The nitrogen cycle is the flow of nitrogen between the atmosphere and biosphere. Atmospheric nitrogen is converted to ammonia and ammonium ions by nitrogen-fixing bacteria. Plants, and then plant-eating organisms, synthesize nitrogen-containing compounds. The decay of these plants and animals returns nitrogen to the atmosphere.

Interactive Textbook

If your class subscribes to the Interactive Textbook, use it to review key concepts in Section 24.6.

with **ChemASAP**

Figure 24.28 The bumps on these plant roots contain bacteria, which live in a symbiotic relationship with the plant. The plant gets nitrogen in a form it can use, and the bacteria get food in the form of sugars that the plant makes during photosynthesis.



Biological Nitrogen Fixation Nitrogen-fixing bacteria are of two types: free-living and symbiotic. Free-living bacteria lead an independent existence in soil. Symbiotic bacteria, such as *Rhizobium*, live in a mutually beneficial arrangement with plants. Symbiotic bacteria live in nodules on the roots of legumes, such as alfalfa, clover, peas, and beans. These root nodules are shown in Figure 24.28. Soil fertility can be improved by plowing nitrogen-rich legumes back into the ground instead of harvesting them.

Industrial Nitrogen Fixation Modern agriculture uses an enormous quantity of nitrogen, which plays a role in the nitrogen cycle. For the past several years, the daily amount of atmospheric nitrogen fixed by industrial processes in the production of fertilizers has probably exceeded the amount fixed by living organisms in Earth's forests and oceans. Nitrogen fertilizers enter the biosphere when they are taken up by plants. In addition, a small amount of atmospheric nitrogen is fixed by lightning discharges, which produce the soluble nitrogen oxides (NO , NO_2 , N_2O_4 , N_2O_5).

24.6 Section Assessment

32. **Key Concept** What is the role of ATP in energy production and energy use in living cells?
33. **Key Concept** What is the function of catabolism in the cells of living organisms?
34. **Key Concept** How does anabolism make use of the products of catabolism?
35. **Key Concept** What form of nitrogen is supplied to plants by nitrogen-fixing bacteria?
36. How many moles of ATP are formed from the complete oxidation of 1 mol of glucose in a cell that uses oxygen?

Writing Activity

Explain a Process Review the diagram of the nitrogen cycle in Figure 24.27. Write a paragraph that describes how nitrogen moves between the atmosphere and the biosphere. (*Hint:* Use atmospheric nitrogen as the starting point in your description of the process.)

Interactive Textbook

Assessment 24.6 Test yourself on the concepts in Section 24.6.

with **ChemASAP**

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Section 24.6 Assessment

32. ATP transmits energy in the body. Energy is released and captured in the bonds of ATP when the bonds of ATP are broken.
33. Catabolism is the subset of metabolic reactions that involve degradation of complex molecules and production of energy.
34. Catabolic reactions provide the energy and the building blocks for the construction of new compounds needed by the cell in anabolism.
35. Atmospheric nitrogen is converted to ammonia and ammonium ions.
36. as many as 38 moles of ATP

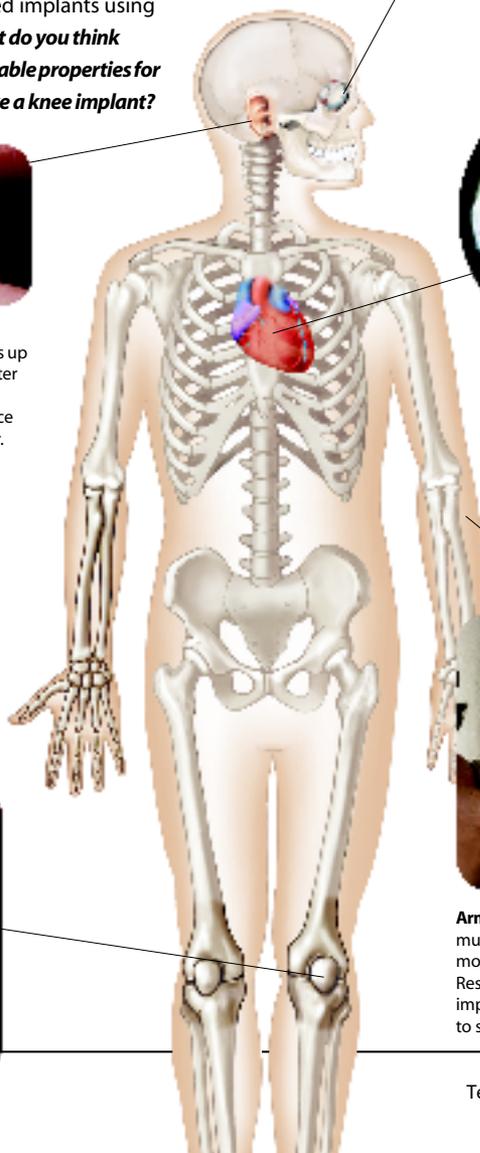
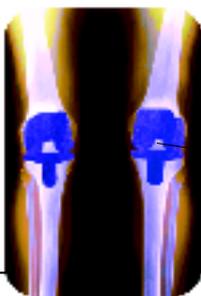
Biomedical Implants

Science, medicine, and technology have combined to create artificial limbs, artificial organs, and other parts for the human body. Some are mechanical devices, some have batteries, and some even contain computers. Scientists are developing replacement wrists and shoulders, researching ways to extend the life of implants, and creating sophisticated implants using robotics. **Inferring** *What do you think would be considered desirable properties for the materials used to make a knee implant?*



Cochlear implants An external microphone picks up sound, and a mini-computer translates the sound into signals received by a device implanted in the inner ear.

Knee implants Made of metal and plastic, the first implants used a hinge design. Newer models more closely emulate the complex movements of a knee.



Eye implants Small acrylic disks or rings reshape the eye to correct nearsightedness. Plastic or acrylic lens implants are used to treat patients with cataracts.



Heart valve implants Heart valves control blood flow through the heart. Implants replace valves damaged by age or disease.



Arm implants Signals from muscles switch motors on or off to move the hand, wrist, or elbow. Researchers hope to develop arm implants that will respond directly to signals from the brain.

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Biomedical Implants

Implants require the efforts of many professionals, including materials scientists, mechanical engineers, surgeons, and biomedical engineers. After implant surgery, follow-up is essential to make it work, which involves therapists working in a variety of fields. The cochlear implant, for example, requires the help of speech and hearing specialists for many hours to train people to recognize speech and other sounds. Implants don't last forever. For example, knees and hips produce debris during wear. The debris level builds up and causes joint loosening, discomfort, and the need for repair or replacement surgery.

Students can find a variety of Web sites about biomedical implants. The sites range from information for surgeons, to how to make a decision on whether to get an implant, to support groups for people living with an implant.

Answers to...

Inferring It should have strength, good range of motion, and smooth joint surfaces.