9.1 ATP in a Molecule

A spring stores energy when it is compressed. When the compressed spring is released, energy is also released, energy that sends this smiley-face toy flying into the air. Like this coiled spring, chemical bonds store energy that can be released when the bond is broken. Just as some springs are tighter than others, some chemical bonds store more energy than others.

**Cell Energy**

Energy is essential to life. All living organisms must be able to produce energy from the environment in which they live, store energy for future use, and use energy in a controlled manner.

**Work and the need for energy**

You’ve learned about several cell processes that require energy. Active transport, cell division, movement of flagella or cilia, and the production and storage of proteins are some examples. The transport of proteins is shown in Figure 9.1. You can probably come up with other examples of biological work, such as muscles contracting during exercise, your heart pumping, and your brain...
Problem-Solving Lab 9-1

Recognizing Cause and Effect

Why is fat the choice?
Humans store their excess energy as fat rather than as carbohydrates. Why is this? From an evolutionary and efficiency point of view, fats are better for storage than carbohydrates. Find out why.

Analysis
The following facts compare certain characteristics of fats and carbohydrates:

A. When broken down by the body, each six-carbon molecule of fat yields 51 ATP molecules. Each six-carbon carbohydrate molecule yields 38 ATP molecules.

B. Carbohydrates bind and store water. The metabolism of water yields zero ATP. Fat has zero grams of water bound to it.

C. An adult who weighs 70 kg can survive on the energy derived from stored fat for 30 days without eating. The same person would have to weigh nearly 140 kg to survive 30 days on stored carbohydrates.

Thinking Critically
1. From an ATP production viewpoint, use fact B to make a statement regarding the efficiency of fats vs. carbohydrates.

2. Explain why the average weight for humans is close to 70 kg and not 140 kg.

The name of this energy molecule is adenosine triphosphate (uh DEN uh seen tri FAHIS fayt), or ATP for short. ATP is composed of an adenosine molecule with three phosphate groups attached. Recall that phosphate groups are charged molecules, and remember that molecules with the same charge do not like being too close to each other.

Forming and Breaking Down ATP

The charged phosphate groups act like the positive poles of two magnets. If like poles of a magnet are placed next to each other, it is difficult to force the magnets together. Likewise, bonding phosphate groups to adenosine requires considerable energy. When only one phosphate group is attached, a small amount of energy is required and the chemical bond does not store much energy. A molecule of this sort is called adenosine monophosphate (AMP). When a second phosphate is added, a more substantial amount of energy is required to force the two phosphate groups together. A molecule of this sort is called adenosine diphosphate, or ADP. When the third phosphate group is added, a tremendous amount of energy is required to force the third charged phosphate close to the two other phosphate groups. The third phosphate group is so eager to get away from the other two that, when that bond is broken, a great amount of energy is released.

The energy of ATP becomes available when the molecule is broken down. In other words, when the chemical bond between phosphate groups in ATP is broken, energy is released and the resulting molecule is ADP. At this point, ADP can reform

controlling your entire body. This work cannot be done without energy. Read the Problem-Solving Lab on this page and think about how the human body stores energy.

When you finish strenuous physical exercise, such as running cross country, your body wants a quick source of energy, so you may eat a candy bar. Similarly, there is a molecule in your cells that is a quick source of energy for any organelle in the cell that needs it. This energy is stored in the chemical bonds of the molecule and can be used quickly and easily by the cell.

228 ENERGY IN A CELL
ATP by bonding with another phosphate group. This creates a renewable cycle of ATP formation and breakdown. Figure 9.2 illustrates the chemical reactions that are involved in the cycle.

The formation/breakdown recycling activity is important because it relieves the cell of having to store all of the ATP it needs. As long as phosphate molecules are available, the cell has an unlimited supply of energy. Another benefit of the formation/breakdown cycle is that ADP can also be used as an energy source. Although most cell functions require the amount of energy in ATP, some cell functions do not require as much energy and can use the energy stored in ADP.

**How cells tap into the energy stored in ATP**

When ATP is broken down and the energy is released, cells must have a way to capture that energy and use it efficiently. Otherwise, it is wasted. ATP is a small compound. Cellular proteins have a specific site where ATP can bind. Then, when the phosphate bond is broken and the energy released, the cell can use the energy for activities such as making a protein or transporting molecules through the plasma membrane. This cellular process is similar to the way energy in batteries is used by a radio. Batteries sitting on a table are of little use if the energy stored within the batteries cannot be accessed. When the batteries are snapped into the holder on the radio, the radio then has access to the stored energy and can use it. Likewise, when the energy in the batteries has been used, the batteries can be taken out, recharged, and replaced in the holder. In a similar fashion in a cell, when ATP has been broken down to ADP, ADP is released from the binding site in the protein and the binding site may then be filled by another ATP molecule. ATP binding and energy release in a protein is shown in Figure 9.3.
Figure 9.4
ATP fuels the cellular activity that drives the organism.

A Nerve cells transmit impulses by using ATP to power the active transport of certain ions.

C Fireflies, some caterpillars, such as the one shown here, and many marine organisms produce light by a process called bioluminescence. The light results from a chemical reaction that is powered by the breakdown of ATP.

B Some organisms with cilia or flagella (left) use energy from ATP to move.

Uses of Cell Energy

You can probably think of hundreds of physical activities that require energy, but energy is equally important at the cellular level for nearly all of the cell's activities.

Making new molecules is one way that cells use energy. Some of these molecules are enzymes, which carry out chemical reactions. Other molecules build membranes and cell organelles. Cells use energy to maintain homeostasis. Kidneys use energy to move molecules and ions in order to eliminate waste substances while keeping needed substances in the bloodstream. Figure 9.4 shows several organisms and activities that illustrate ways that cells use energy.

Understanding Main Ideas
1. What processes in the cell need energy from ATP?
2. How does ATP store energy?
3. How can ADP be "recycled" to form ATP again?
4. How do proteins in your cells access the energy stored in ATP?

Thinking Critically
5. Phosphate groups in ATP repel each other because they have negative charges.

Skill Review
6. Observing and Inferring When animals shiver in the cold, muscles move almost uncontrollably. Suggest how shivering helps an animal survive in the cold. For more help, refer to Thinking Critically in the Skill Handbook.

230 ENERGY IN A CELL