



Figure 5-1 From potential energy to kinetic energy

The body of a diver on the platform has potential energy, because the heights of the platform and the pool are different. As he dives, the potential energy is converted to the kinetic energy of motion of his body. Finally, some of this kinetic energy is transferred to the water, which itself is set in motion.

Energy Cannot Be Created or Destroyed

The laws of thermodynamics describe the basic properties and behavior of energy. The **first law of thermodynamics**, often called the law of conservation of energy, states that energy can neither be created nor destroyed, so the total amount of energy remains constant. Energy can, however, change its form. For example, a car converts the potential chemical energy of gasoline into the kinetic energy of movement and heat. Similarly, a runner converts the potential chemical energy of food into the kinetic energy of movement plus heat. In both of these cases, potential energy changes form, but the total amount of energy remains unchanged.

Energy Tends to Become Distributed Evenly

The **second law of thermodynamics** states that whenever energy is converted from one form to another, the amount of energy that is in useful forms decreases. All spontaneous changes result in a more even distribution of energy, which reduces the energy differences that are

required to do work. In other words, energy tends to be converted from more useful into less useful forms.

To illustrate the second law, let's examine a car engine burning gasoline. In a moving vehicle, the kinetic energy of movement is much smaller than the amount of chemical energy in the gasoline that was burned to generate the movement. The first law tells us that energy cannot be destroyed, so where is the "missing" energy? It has been transferred to the car's materials and surroundings. The burning gas not only moved the car but also heated up the engine, the exhaust system, and the air around the car. In addition, the friction of tires on the pavement slightly heated the road. No energy is missing. However, the energy that was released as heat has been converted to a less useful form; it merely heated the engine, the road, and the air. The second law tells us that all conversions of energy entail a loss of usefulness; no process is 100% efficient.

Matter Tends to Become Less Organized

Regions in which energy is concentrated tend to be more organized than regions with less energy. For example, the eight carbon atoms in a single molecule of gasoline have a much more orderly arrangement than do the eight carbon atoms in the eight separate, randomly moving molecules of carbon dioxide that are formed when the gasoline molecule burns. Therefore, we can also phrase the second law in terms of the organization of matter: processes that proceed spontaneously lead to increasing randomness and disorder. This randomness and disorder is called **entropy**. Entropy always tends to increase, a tendency that can be overcome only by adding energy.

We all experience the tendency toward entropy in our homes. Frequent inputs of energy are required to keep debris confined to the trash can, newspapers to folded stacks, books to their shelves, and clothes to drawers and closets. Without our energetic cleaning and organizing efforts, these items tend to end up in their lowest-energy state—a state of disorder. When the ecologist G. Evelyn Hutchinson said, "Disorder spreads through the universe, and life alone battles against it," he was making an eloquent reference to entropy and the second law of thermodynamics.

Living Things Use the Energy of Sunlight to Create Low-Entropy Conditions

If you think about the second law of thermodynamics, you may wonder how life can exist at all. All chemical reactions, including those inside living cells, cause the amount of usable energy to decrease. Matter tends toward increasing randomness and disorder. Given these facts, how can organisms accumulate the concentrated energy and precisely ordered molecules that characterize living things? The answer is that living things use a



continuous input of solar energy to construct complex molecules and maintain orderly structures—to “battle against disorder.” This solar energy arrives on Earth in the form of sunlight, which is produced by nuclear reactions in the sun. These reactions produce huge increases in entropy, so the highly organized, low-entropy systems of life do not violate the second law; the increased order of living things is achieved at the expense of an enormous loss of order in the sun. The entropy of the solar system as a whole constantly increases.

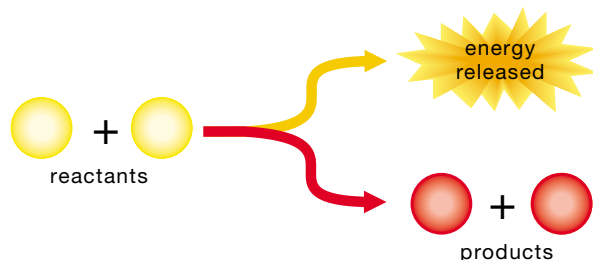
The Big Picture

Life operates within constraints imposed by the laws of physics. None of life’s processes may violate these laws, and knowledge of them can help us understand why organisms operate as they do.

2 How Does Energy Flow in Chemical Reactions?

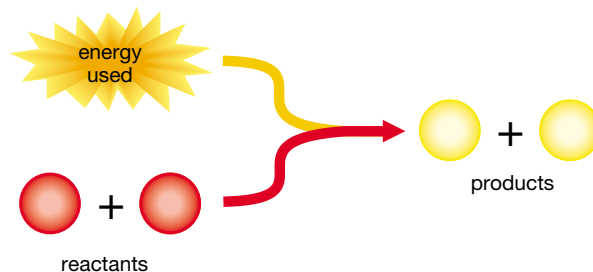
A **chemical reaction** converts one set of chemical substances, the **reactants**, into another set, the **products**. Some chemical reactions release energy; others consume it. A reaction that releases energy is classified as an **exergonic reaction**, and its products contain less energy than the reactants:

Exergonic reaction



Conversely, an **endergonic reaction** requires an input of energy from some outside source. The products of an endergonic reaction contain more energy than the reactants:

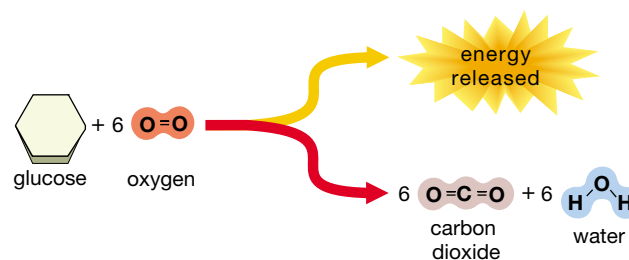
Endergonic reaction



Let’s look at two processes that illustrate these types of reactions: burning sugar and photosynthesis.

Exergonic Reactions Release Energy

When sugar is burned by a flame, it reacts with oxygen (O_2) to produce carbon dioxide (CO_2) and water (H_2O) and energy, as described by this equation:

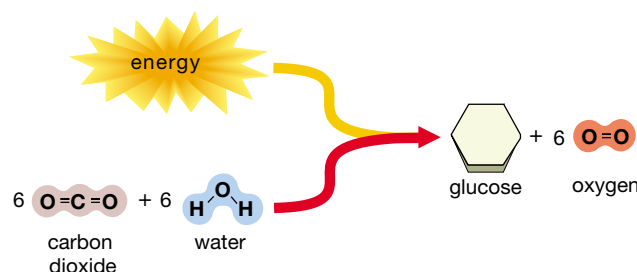


The combustion of sugar is an exergonic reaction, in which the reactants contain more energy than the products. That is, the molecules of sugar and oxygen contain much more energy than the molecules of carbon dioxide and water that are produced when the sugar breaks down. The extra energy is released as heat.

Once started, exergonic reactions proceed without an input of energy. Once ignited, a spoonful of sugar continues to burn spontaneously until all sugar molecules are consumed. It’s as if exergonic reactions run “downhill,” from high energy to low energy, just as a rock pushed from atop a hill rolls to the bottom.

Endergonic Reactions Require an Input of Energy

Unlike the energy-releasing reaction that takes place when sugar burns, many reactions in living things create products that contain *more* energy than the reactants. For example, the sugar produced by photosynthesis contains far more energy than the carbon dioxide and water from which it is formed:



Similarly, a protein molecule contains more energy than the individual amino acids that were joined together to build it.

Completing reactions that form complex biological molecules requires an overall input of energy. The energy for photosynthesis, for example, comes from sunlight. We can view endergonic reactions such as photosynthesis as “uphill” reactions, going from low energy to high energy, like pushing a rock to the top of a hill.

All Reactions Require an Initial Input of Energy

All chemical reactions, even exergonic ones that release energy overall, require an initial input of energy to get started. For example, even though burning sugar releases energy, a spoonful of sugar can’t burst into flames by itself; the fire doesn’t begin until some energy is added.