CONCEPT 1

Matter and energy interact in physical and chemical changes.

Activity

Changes and Energy

Your teacher will provide you and a partner with a piece of ice. What happens to the ice as it sits at room temperature? How is energy involved in this process? What happens if the ice is in your hand? Is the amount of energy in your hand increasing or decreasing? Support your answers with evidence from the activity.

Matter and energy are continually interacting in the world around us. Cooking food is just one common example. To boil the water and make the toast in **Figure 2.16**, energy is needed. The temperature of the water increases as energy is transferred from the stove burner, and the changes to the bread rely on the addition of energy from a toaster.

Figure 2.16 Many common events at home require an input of energy.

$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$

propane + oxygen →
carbon dioxide + water

Figure 2.17 A lighter provides energy to start the reaction between oxygen and propane. **Predicting: If energy input was not needed to light this torch, what would happen when propane was released from the tank?**

Getting Things Started

For any chemical change to occur, the reactants must collide with enough energy to begin to break the bonds in the reactants. This minimum amount of energy needed for a reaction to occur is called the *activation energy*. It is often useful to think of the activation energy as a barrier or "hill" that needs to be overcome for a reaction to happen.

Many chemical reactions require an initial input of energy—the reactants will not react by simply mixing them together. For example, lighting a propane torch requires a spark or lighter (**Figure 2.17**). This is the energy input needed for the chemical reaction between oxygen (in the air) and the propane gas. The lighter provides a few molecules of oxygen and propane with enough energy to overcome the energy barrier. In the case of this reaction, a large amount of energy is released—that's what the flame and heat to weld material are. Once the propane is ignited, it will continue to burn because the energy released during the reaction provides the energy for other molecules to overcome the energy barrier to react.

CONCEPT 2

Energy is transferred between chemical reactions and the surroundings.

Activity

Where Did the Energy Go?

1. Read the procedure and make a table to record your observations.
2. Place 5 mL of vinegar into a large test tube that is in a test tube rack. Using a thermometer, record the temperature of the vinegar. Leave the thermometer in the test tube.
3. Add a small scoop (about 0.5 g) of baking soda to the test tube. Record the temperature every 5 seconds, until it no longer changes. Record any other observations. Draw a temperature versus time graph of your data. What is the overall temperature change? How would you describe the reaction in terms of energy changes? Was more energy involved in breaking bonds in this reaction or in forming bonds?

All chemical reactions are accompanied by changes in energy. These energy changes are crucial to life on Earth. For example, through photosynthesis green plants absorb energy from sunlight and store it in the chemical bonds of the sugar molecules they produce. Animals that eat the plants use the stored energy through the process of cellular respiration to fuel things such as growth and movement (**Figure 2.18**).

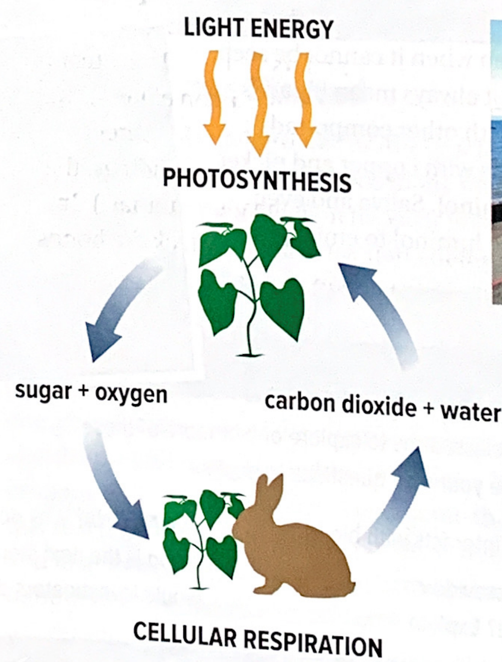

Figure 2.18 Energy stored in the chemical bonds of molecules used to fuel our bodies is released through the chemical reactions of cellular respiration.

Plants, animals, and other organisms use the sugar and oxygen produced by photosynthesis as part of cellular respiration.

Plants and other organisms use the carbon dioxide and water produced by cellular respiration as part of photosynthesis.

The System and the Surroundings

Chemists think of energy changes in chemical reactions in terms of energy transfers between the *system* and the *surroundings*. The system is the materials involved in the chemical reaction and everything else in the universe is the surroundings. The *law of conservation of energy* states that the total energy of the universe is constant—energy cannot be created or destroyed. In terms of a chemical reaction, it means energy that leaves the system must enter the surroundings, and energy that enters the system must come from the surroundings (**Figure 2.19**).

Figure 2.19 The chemical reaction occurring in the flask is the system. The flask, the student, and the laboratory are part of the surroundings.

Exothermic and Endothermic Reactions

Recall that energy must be absorbed to break bonds and energy is released when bonds form. By comparing the total energy used when bonds in the reactants are broken with the total energy released when bonds in the products are formed, you can determine whether there is an overall release of energy or absorption of energy in a chemical reaction.

When, overall, more energy is released into the surroundings than absorbed by the system, the reaction is called an **exothermic reaction**. (The prefix *exo* means "external" and *thermic* refers to heat.) In exothermic reactions, there is more energy released from the formation of bonds than energy required to break the bonds. When there is an overall greater amount of energy absorbed by the system than released to the surroundings, the reaction is called an **endothermic reaction** (*endo* means "internal"). In endothermic reactions, there is more energy required to break the bonds than energy released from the formation of bonds (**Figure 2.20**).

exothermic reaction a chemical reaction in which there is net release of energy to the surroundings

endothermic reaction a chemical reaction in which there is net absorption of energy from the surroundings

Figure 2.20 When the energy_2 term is greater than the energy_1 term, the overall process is exothermic. When energy_1 is greater than energy_2, the overall process is endothermic.

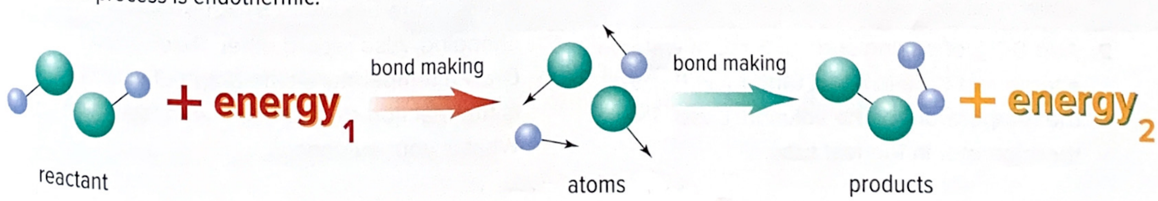

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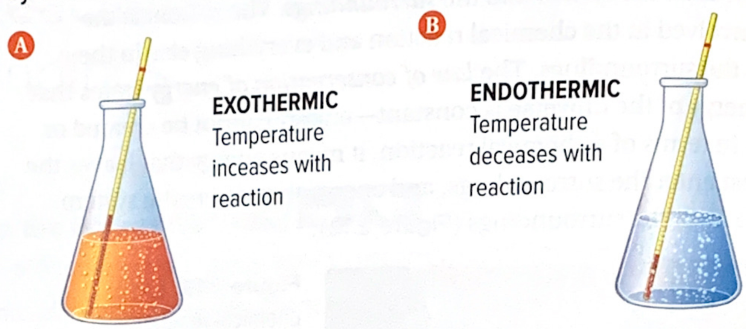
Figure 2.21 Comparing the temperature of reactions occuring in solution.
Analyzing: How do the relative amounts of energy absorbed and released by the reactions compare?



Measuring Energy Changes

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Energy changes in a reaction can be monitored by measuring change in temperature. For example, many chemical reactions occur in a solvent such as water. In **Figure 2.21A**, the temperature of the solution increases as energy released from the reaction (system) is transferred to the surroundings. In **Figure 2.21B**, the temperature of the solution decreases as energy is absorbed by the reaction from the surroundings. Sometimes, though, as in **Figure 2.22**, you don't need a thermometer to tell if a reaction is exothermic or endothermic.

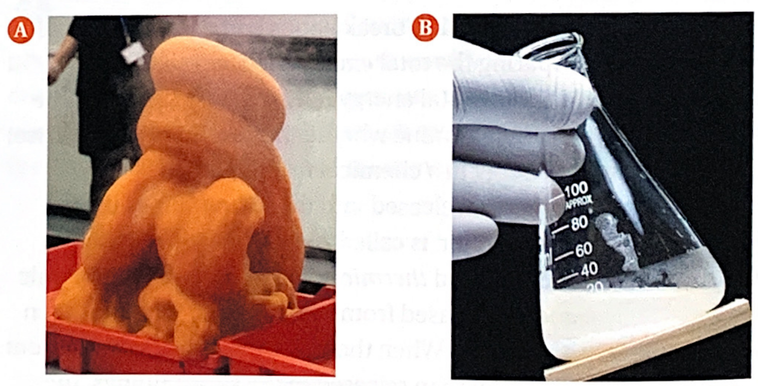

Figure 2.22 Steamy foam in A results from a reaction of yeast, dish soap, and hydrogen peroxide. In B, the reaction of ammonium thiocyanate and barium hydroxide freezes the flask to the wooden base.
Analyzing: Which reaction is absorbing energy?

Activity

Warming Up

The reaction you will perform is $2NaHCO_3 + CaCl_2 \rightarrow CaCO_3 + CO_2 + 2NaCl + H_2O$

1. Read the procedure and make an appropriate table to record your observations.
2. Add 0.3 g of baking soda to 5 mL of water in a large test tube in a test tube rack. Record the temperature of the solution. Leave the thermometer in the test tube.
3. Add 0.5 g of $CaCl_2$ to the test tube. Record the temperature every 5 s until it stops changing. Also record other observations. Draw a temperature-time graph of your data. Is the reaction exothermic or endothermic? What is your evidence?

Representing Energy Changes

Consider the reaction below. For every molecule of nitrogen that reacts with a molecule of oxygen, two molecules of nitrogen monoxide are produced.

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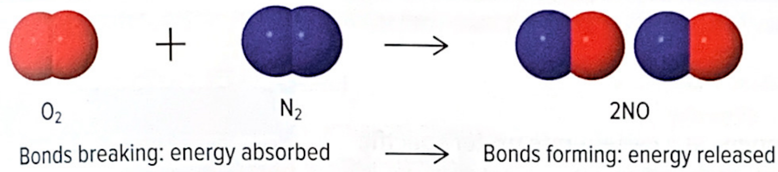
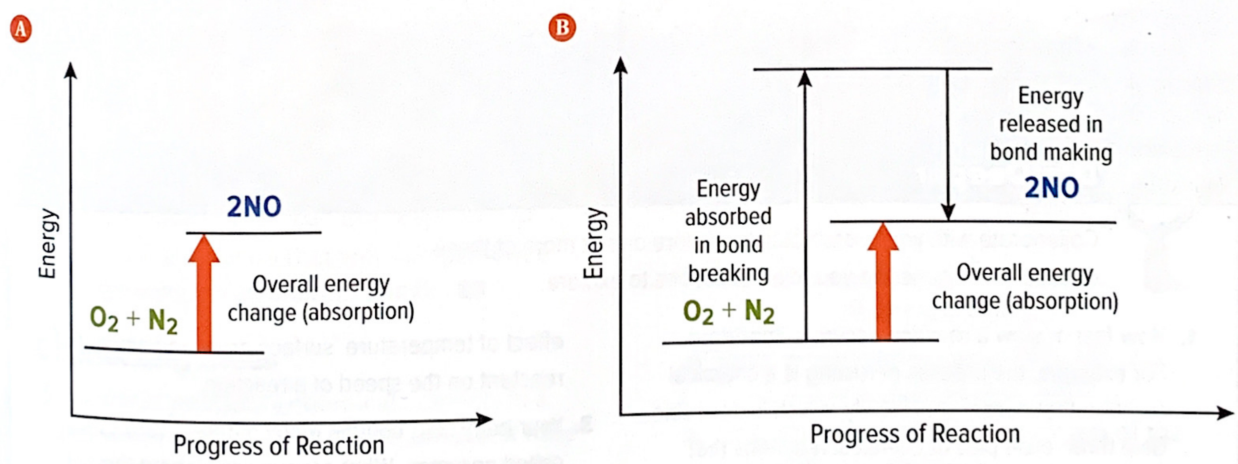


In this reaction, nitrogen-nitrogen bonds and oxygen-oxygen bonds are broken. The breaking of these bonds in each case absorbs energy. Nitrogen-oxygen bonds form, and the formation of these bonds releases energy. The total energy absorbed to break each nitrogen-nitrogen bond and oxygen-oxygen bond is more than the total energy released when nitrogen-oxygen bonds form. Therefore, there is an overall absorption of energy, and the reaction is endothermic.

Figure 2.23 shows how energy changes of a reaction can be represented. These are called energy-level diagrams, and they show the relative energy levels of the reactants and products in a reaction. For endothermic reactions, there is more energy required to break bonds than energy that is released when new bonds form. Therefore, there is an overall absorption of energy. This means that the energy of the products is greater than the energy of the reactants. For exothermic reactions, there is an overall release of energy, and the products are at a lower energy than the reactants.

Figure 2.23 (A) This diagram shows the overall absorption of energy. Notice that the products have more energy than the reactants. (B) This diagram shows how the overall energy change is the net result of energy absorbed to break bonds and energy released in the forming of bonds.



Before you leave this page . . .

1. What is an endothermic reaction?
2. Describe the relative energies of reactants and products in an endothermic reaction.
3. If there is a decrease in energy of the system, what happens to the energy of the surroundings?