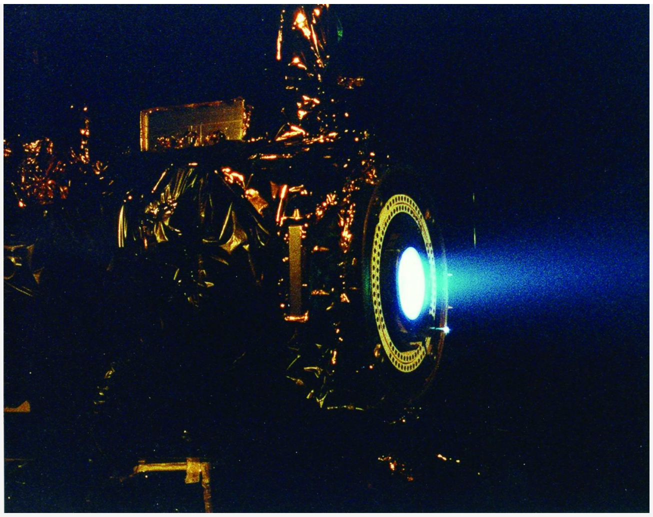
Chapter 7

Energy and Chemistry

Opening Essay

It takes energy to launch a spaceship into space. If it takes 1 energy unit to warm 0.25 g of water by 1°C, then it takes over 15,100 energy units to put that 0.25 g of water into earth orbit. The most powerful engines designed to lift rockets into space were part of the Saturn V rocket, that was built by the National Aeronautics and Space Administration (NASA). The rocket had three stages, with the first stage having the capability of launching about 3.5 million kg of mass. About 2.3 million kg was the actual fuel for the first stage; rockets in space have the unpleasant task of having to take their own chemicals with them to provide thrust.

Having to carry its own fuel puts a lot of mass burden on an engine in space. This is why NASA is developing other types of engines to minimize fuel mass. An ion thruster uses xenon atoms that have had at least one electron removed from their atoms. The resulting ions can be accelerated by electric fields, causing a thrust. Because xenon atoms are very large for atoms, the thrusting efficiency is high even though the actual thrust is low. Because of this, ion engines are useful only in space.



Ion drives have low thrust but high efficiency. They have already been used on several space missions, including NASA's Deep Space 1spacecraft and Japan'sHayabusa asteroid sampling probe.

Source: Photo courtesy of NASA,http://commons.wikimedia.org/wiki/File:Ion_Engine_Test_Firing_-_GPN-2000-000482.jpg.

Energy is a very important quantity in science and the world around us. Although most of our energy ultimately comes from the sun, much of the energy we use on a daily basis is rooted in chemical reactions. The gasoline in your car, the electricity in your house, the food in your diet—all provide substances for chemical reactions to provide energy (gasoline, food) or are produced from chemical reactions (electricity, about 50% of which is generated by burning coal). As such, it is only natural that the study of chemistry involves energy.

7.1 Energy

LEARNING OBJECTIVES

1. Define *energy*.
2. Know the units of energy.
3. Understand the law of conservation of energy.

Energy is the ability to do work. Think about it: when you have a lot of energy, you can do a lot of work; but if you're low on energy, you don't want to do much work. Work (w) itself is defined as a force (F) operating over a distance (Δx):

$$w = F \times \Delta x$$

In SI, force has units of newtons (N), while distance has units of meters. Therefore, work has units of N·m. This compound unit is redefined as a **joule** (J):

$$1 \text{ joule} = 1 \text{ newton·meter} \quad 1 \text{ J} = 1 \text{ N·m}$$

Because energy is the ability to do work, energy is also measured in joules. This is the primary unit of energy we will use here.

How much is 1 J? It is enough to warm up about one-fourth of a gram of water by 1°C. It takes about 12,000 J to warm a cup of coffee from room temperature to 50°C. So a joule is not a lot of energy. It will not be uncommon to measure energies in thousands of joules, so the kilojoule (kJ) is a common unit of energy, with 1 kJ equal to 1,000 J.

An older—but still common—unit of energy is the *calorie*. The calorie (cal) was originally defined in terms of warming up a given quantity of water. The modern definition of calorie equates it to joules:

$$1 \text{ cal} = 4.184 \text{ J}$$

One area where the calorie is used is in nutrition. Energy contents of foods are often expressed in calories. However, the calorie unit used for foods is actually the kilocalorie (kcal). Most foods indicate this by spelling the word with a capital C—Calorie. Figure 7.1 "Calories on Food Labels" shows one example. So be careful counting calories when you eat!

EXAMPLE 1

The label in Figure 7.1 "Calories on Food Labels" states that the serving has 38 Cal. How many joules is this?

Solution

We recognize that with a capital C, the Calories unit is actually kilocalories. To determine the number of joules, we convert first from kilocalories to calories (using the definition of the *kilo-* prefix) and then from calories to joules (using the relationship between calories and joules). So

$$38\ \cancel{\text{kcal}} \times \frac{1{,}000\ \cancel{\text{cal}}}{1\ \cancel{\text{kcal}}} \times \frac{4.184\ \text{J}}{1\ \cancel{\text{cal}}} = 160{,}000\ \text{J}$$

Test Yourself

A serving of breakfast cereal usually has 110 Cal. How many joules of energy is this?

Answer

460,000 J

In the study of energy, we use the term system to describe the part of the universe under study: a beaker, a flask, or a container whose contents are being observed and measured. An isolated system is a system that does not allow a transfer of energy or matter into or out of the system. A good approximation of an isolated system is a closed, insulated thermos-type bottle. The fact that the thermos-type bottle is closed keeps matter from moving in or out, and the fact that it is insulated keeps energy from moving in or out.

One of the fundamental ideas about the total energy of an isolated system is that is does not increase or decrease. When this happens to a quantity, we say that the quantity is *conserved*. The statement that the total energy of an isolated system does not change is called the **law of conservation of energy**. As a scientific law, this concept occupies the highest level of understanding we have about the natural universe.

KEY TAKEAWAYS

- Energy is the ability to do work and uses the unit joule.
- The law of conservation of energy states that the total energy of an isolated system does not increase or decrease.

EXERCISES

1. Define *energy*. How is work related to energy?
2. Give two units of energy and indicate which one is preferred.
3. Express the quantity of 422 J in calories.
4. Express the quantity of 3.225 kJ in calories.
5. Express the quantity 55.69 cal in joules.
6. Express the quantity 965.33 kcal in joules.
7. How does a Calorie differ from a calorie?
8. Express the quantity 965.33 Cal in joules.
9. What is the law of conservation of energy?

10. What does the word *conserved* mean as applied to the law of conservation of energy?

ANSWERS

1. Energy is the ability to do work. Work is a form of energy.

3. 101 cal

5. 233.0 J

7. A Calorie is actually a kilocalorie, or 1,000 calories.

9. The total energy of an isolated system does not increase or decrease.