

## Chapter 2: Forms of Energy

### Goals of Period 2

Section 2.1: To describe the forms of energy

Section 2.2: To illustrate conversions from one form of energy to another

Section 2.3: To define the efficiency of energy conversion processes

Section 2.4: To describe energy storage

Period 1 introduced energy in society and discussed some of the mathematical tools used in the World of Energy courses. Now we broaden our exploration of the World of Energy by describing various forms of energy, energy conversions from one form into another, and the efficiency of these conversions.

The universe is made of matter and energy. While most of us have an intuitive sense of what matter is, the concept of energy is more difficult to grasp. Energy is most apparent when it is changing from one form into another. Period 2 class activities illustrate many types of these energy conversions.

Energy is important because it provides the ability to do work. Work is done when one or more forces move an object over a distance. The objects being moved can be very small, such as molecules, atoms, electrons, or protons, or they can be much larger objects. When forces act on objects and do work, energy is converted from one form to another. In later periods we will learn how forces act on objects to do work. All forces can be related to one or more of the four fundamental forces of nature.

As energy is converted from one form into another, the Law of Conservation of Energy requires that no energy can be lost. The total amount of energy put into a conversion process must equal the total amount of energy out. However, during each energy conversion some energy is converted into a form other than the form you desire. Energy converted into an undesirable form is called wasted energy. Many energy conversion processes require multiple steps, such as the steps involved when coal is converted into electrical energy. Each step in the process converts some energy into a form other than that needed for the next step. Because of this wasted energy, the amount of electrical energy obtained is less than the amount of energy in the coal burned to produce the electricity. The energy wasted at each step makes the overall process less efficient than the efficiency of any step.

### 2.1 Forms of Energy

Although there are many ways to classify energy, we will discuss eleven forms of energy. The first three forms of energy are related to the energy of motion associated with moving objects, atoms, and molecules.

**Mechanical Energy of Motion:** Moving objects exhibit mechanical energy of motion, also called kinetic energy. A ball thrown through the air or a car travelling down a road has mechanical energy of motion.

**Thermal Energy:** Energy of motion occurs within an object as its atoms and molecules vibrate randomly. Thermal energy is the unorganized energy of motion of vibrating objects too small to see. The faster the atoms and molecules in a substance vibrate, the more thermal energy the substance has and the higher its temperature.

**Sound Energy:** When atoms and molecules vibrate in an organized manner, their vibrations may travel as a wave. Sound is the transmission of vibrations through a solid, liquid, or gas by vibrating atoms or molecules. When sound waves reach our eardrums, the energy in the sound waves causes our eardrums to vibrate. Our brains interpret the vibrations as sounds.

Matter contains positive and negative charges. Forms of energy that result from the forces between these charges are called electromagnetic energy. We can distinguish three forms of electromagnetic energy.

**Electrical Energy:** Electrical energy results from the forces between charged particles. These electrical forces exist between charged particles at rest and in motion.

**Magnetic Energy:** Charges moving within some types of materials produce magnetic forces. These magnetic forces are in addition to the electrical forces between moving charges. Magnetic materials are called magnets and attract or repel one another due to their magnetic forces. A coil of wire with charges moving through it acts like a magnet and is called an electromagnet. As we will see in Periods 15 and 16, electrical and magnetic energy are closely related.

**Radiant Energy:** While vibrations of matter produce thermal and sound energy, radiant energy results from vibrations of charges. Radiant energy is another name for waves of electromagnetic energy. For example, the sun's energy is transported to Earth as waves of radiant energy. Radio waves, microwaves, infrared radiation, light waves, X-rays and cosmic rays are all waves of radiant energy.

Stored energy, which can be used to do work, is called potential energy. We consider five types of potential energy.

**Gravitational Potential Energy:** When a rock is raised above the Earth and released, the gravitational attraction between the rock and the Earth causes the rock to fall to the ground. A raised object has gravitational potential energy.

**Strain Potential Energy:** If we stretch or compress a spring and release it, the spring moves back toward its original length. The stretched or compressed spring has strain potential energy because it has the potential to move.

**Chemical Potential Energy:** Chemical potential energy exists because atoms and molecules can take in or give off energy when their chemical bonds are formed or broken.

**Electrical Potential Energy:** Electrical potential energy is stored when positive and negative electric charges are separated. The amount of stored energy depends on the number of separated charges and the distance they are separated.

**Nuclear Energy:** In nuclear reactions, energy is given off or taken in by atomic nuclei. Energy is available from the nuclei of atoms that are radioactive and undergo nuclear changes. We will discuss nuclear energy in detail in Physics 104.

## 2.2 Energy Conversions

Often the form of energy most readily available is not the most useful form. Coal can be burned to provide heat, but converting the chemical energy stored in coal into electrical energy requires a series of intermediate steps. In each step of the conversion process, some energy is wasted. The following examples of energy conversions preview some of the activities and demonstrations you will see in class.

### **Electrical Energy $\Rightarrow$ Mechanical Energy of Motion**

The model electric train illustrates the conversion of electrical energy into mechanical energy of motion. Electrical energy, which operates the train, is generated at a power plant. The electric motor in the train's engine transforms that electrical energy into mechanical energy of motion. Since electrical energy is delivered to the train at a nearly constant rate, the train slows down as it climbs an incline because energy is required to lift the train up as well as to move it forward. As the train climbs the incline, some of its mechanical energy of motion is converted into gravitational potential energy.

### **Mechanical Energy of Motion $\Rightarrow$ Electrical Energy**

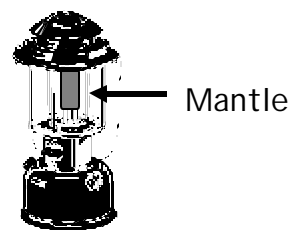
Although we cannot easily store large amounts of electrical energy, electricity can be continuously transferred to us from a generating plant. In class, you will use hand-cranked generators to convert the mechanical energy of motion of your arm into electrical energy. In future periods we will learn more about the power plant generators that provide electricity for our homes and businesses.

A spark generator converts mechanical energy of motion into the electrical energy of a spark. When the spark generator's spring is compressed, mechanical energy is stored as potential strain energy. When the stored strain energy is released,

the spring exerts force on the surfaces of a certain type of crystal, which then becomes electrically charged. If enough charge accumulates on the surfaces, a spark will jump between oppositely charged parts of the crystal.

### **Thermal Energy $\Rightarrow$ Radiant Energy**

Campers sometimes use gas lanterns as a light source. The lantern's gas flame has a high temperature but gives off very little visible light. To convert its thermal energy into visible radiant energy, the lantern has a "mantle" of knitted fabric soaked with heavy metal oxides. The mantle glows brightly when heated in the gas flame, but does not burn. In class we use a Bunsen burner flame rather than the usual lantern propane or butane flame to illustrate this energy conversion.



### **Electrical Energy $\Rightarrow$ Thermal Energy**

The conversion of electrical energy into thermal energy is the most common energy conversion in our household appliances. Many appliances, such as toasters, hair dryers, and electric heaters, convert electrical energy into useful thermal energy. Appliances designed for purposes other than providing heat waste energy by converting some of their electrical energy into undesirable thermal energy, giving the warmth you feel when you touch an operating television or computer.

### **Thermal Energy $\Rightarrow$ Mechanical Energy of Motion**

Appliances, such as toasters and hair dryers, contain thermostats to regulate their temperature. Some thermostats illustrate the conversion of thermal energy into mechanical energy of motion. In class you will see a demonstration of how thermostats with bimetallic strips work. A bimetallic strip consists of two layers of different metals, which react differently when they are heated. The metal in one layer of the strip expands more when heated than does the metal in the other layer, causing the strip to bend. When a bimetallic strip is heated to a critical temperature, the strip bends until it opens a switch, which interrupts the flow of electric current and turns off the appliance.

### **Electrical Energy $\Rightarrow$ Radiant Energy**

In class you will see an electroluminescent nightlight, which converts electrical energy to visible light, a form of radiant energy. The nightlight is dim because it operates with a very small amount of energy – only 0.02 watts of electrical energy compared to 100 watts for an average light bulb.

### **Radiant Energy $\Rightarrow$ Electrical Energy**

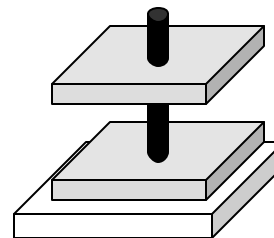
Solar cells convert radiant energy from the sun into electrical energy. In class, we will use solar cells to light a flashlight bulb, run a toy car, and operate a small motor.

### **Mechanical Energy of Motion** $\Rightarrow$ **Thermal Energy**

Mechanical energy of motion is converted into thermal energy when surfaces rub together, producing friction between the objects. We will illustrate thermal energy from friction by using an electric drill to rotate a metal tube filled with water. Two blocks of wood squeezed against the tube produce the friction. When we pour a small amount of water into the metal tube and cork it with a rubber stopper, the mechanical energy of motion converted into heat by friction turns the water into steam. The steam blows the cork out of the tube, thus converting thermal energy back into mechanical energy of motion of the stopper.

### **Magnetic Energy** $\Rightarrow$ **Gravitational Energy**

If two magnets are placed on top of one another with their like poles facing, the magnets repel each other. We can feel this force when we do work to push the top, floating magnet closer to the bottom magnet. When we release the floating magnet, some magnetic energy is converted into mechanical energy of motion and gravitational potential energy as the magnet moves upward and floats.



The repulsive force between two magnets causes one to float above the other.

### **Chemical Potential Energy** $\Rightarrow$ **Electrical Energy**

Perhaps the most common energy storage device is the battery. Batteries store chemical potential energy, which is converted into electrical energy when the battery operates.

### **Chemical Potential Energy** $\Rightarrow$ **Thermal Energy**

When substances burn, their stored chemical energy is converted into thermal energy and into visible and invisible radiant energy. Burning natural gas, coal, and petroleum products is one of our most economically important energy conversion processes. We will explore the economic and environmental consequences of this energy conversion.

### **Chemical Potential Energy** $\Rightarrow$ **Radiant Energy**

Unlike light bulbs, which give off invisible infrared radiation as well as visible light, some chemical reactions produce visible light without giving off discernable amounts of infrared radiation. Such chemiluminescent reactions occur when a firefly gives off light. In class, we will see demonstrations of the conversion of chemical energy into visible light.

### **Radiant Energy** $\Rightarrow$ **Chemical Potential Energy**

Plants convert radiant energy from the sun into stored chemical energy through the process of photosynthesis. Nuclear energy produced in the Sun's core radiates away from the Sun in all directions. Some of this radiant energy strikes the Earth and is absorbed by plants. Plant cells use radiant energy to produce chemical energy in the form of carbohydrates. When we consume plants, our bodies convert their stored chemical energy into energy stored in our bodies.

### Concept Check 2.1

a) What is the primary energy conversion that occurs when a battery discharges?

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b) What series of energy conversions takes place when you ride a bicycle up a hill?

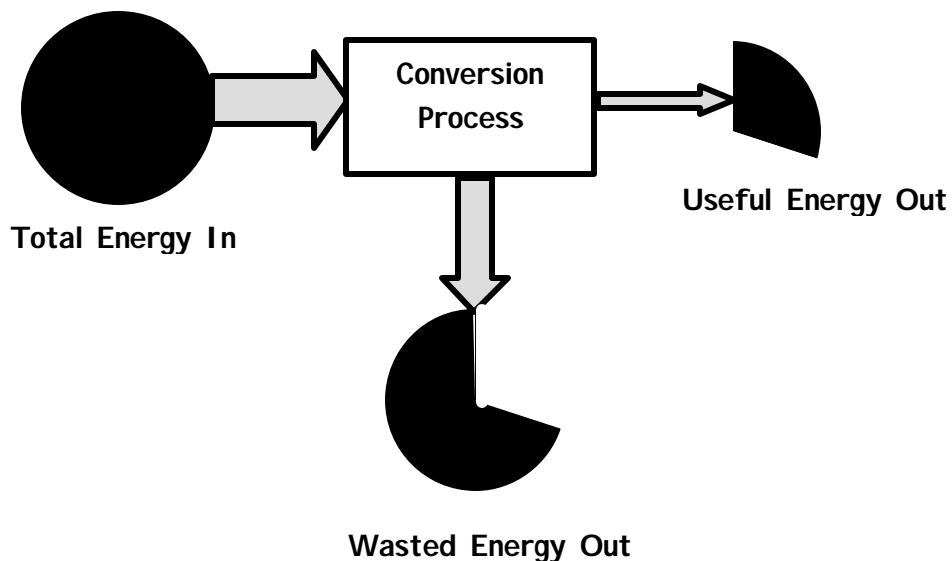
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### 2.3 Efficiency of Energy Conversions

In all energy conversions, some energy is wasted. However, some energy conversion processes require a large amount of energy in to obtain a small amount of energy out. Such conversion processes are inefficient. Reducing energy costs requires efficient energy conversions, which waste the least energy. For example, an incandescent light bulb converts electrical energy into radiant energy in the forms of visible light and infrared radiation. While the visible light is useful, the infrared radiation is wasted. The wasted infrared radiation can be felt as heat when you hold your hand near the bulb. Part of this infrared radiation goes into increasing the thermal energy of the light bulb glass, which is very hot if touched. Fluorescent lights are more efficient than incandescent bulbs because they produce the same amount of visible light but much less infrared radiation.

Fig. 2.1 Efficiency of an Energy Conversion



$$\text{Total Energy In} = \text{Useful Energy Out} + \text{Wasted Energy Out}$$

The efficiency of an energy conversion process equals the ratio of the amount of energy of the desired type produced per total amount of energy put into the conversion process.

$$\text{Efficiency} = \frac{\text{Useful Energy Out}}{\text{Total Energy In}} \quad \text{(Equation 2.1)}$$

Since every energy conversion process wastes some energy, the efficiency ratio for any energy conversion process is less than one – the useful energy out is always less than the total energy put in. Example 2.1 illustrates the calculation of energy efficiency using joules of energy, the usual unit of energy measurement.

**(Example 2.1)**

What is the efficiency of an energy conversion that requires 600 joules of energy to produce 150 joules of useful energy?

$$\text{Efficiency} = \frac{\text{Useful Energy Out}}{\text{Total Energy In}} = \frac{150 \text{ joules}}{600 \text{ joules}} = 0.25 = 25 \%$$

When a series of energy conversions are required to produce the desired form of energy, energy is wasted in each step of the process. The overall efficiency of a series of energy conversion processes can be quite low. The overall efficiency is the product of the efficiencies of each step in the process.

$$\text{Overall Efficiency} = (\text{Efficiency of step 1}) \times (\text{Efficiency of step 2}) \times (\text{Efficiency of step 3}) \times \dots$$

or

$$\text{Overall Efficiency} = \text{Efficiency}_1 \times \text{Efficiency}_2 \times \text{Efficiency}_3 \times \dots$$

**(Example 2.2)**

A series of energy conversions take place when a hand-cranked generator is used to light a small bulb. Suppose that the efficiency the motion of the hand turning the generator crank is 40%. Assume that the efficiency of the generator converting mechanical energy of motion into electrical energy is 50%. Let efficiency of the light bulb converting electrical energy into visible light be 20%. What is the overall efficiency of this series of energy conversions? If the total energy put into turning the generator crank is 1,000 joules, how much useful energy is obtained as visible light from the bulb?

$$\text{Overall Efficiency} = \text{Efficiency}_{\text{hand}} \times \text{Efficiency}_{\text{generator}} \times \text{Efficiency}_{\text{bulb}} =$$

$$0.40 \times 0.50 \times 0.20 = 0.04 = 4\%$$

$$1,000 \text{ joules} \times 0.04 = 40 \text{ joules of useful energy}$$

**Concept Check 2.2**

a) What is the efficiency of an energy conversion process that requires 1,500 joules of energy in to produce 500 joules of useful energy?

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b) How many joules of energy are wasted in this process?

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c) A series of energy conversions have efficiencies of 25%, 60%, and 50%. What is the overall efficiency of this series of conversions?

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**2.4 Energy Storage**

Energy can be stored in many forms. Chemical potential energy is stored in fuels such as coal, wood, and food, or in the chemicals in batteries and fuel cells. Phosphorescent materials store some of the energy they absorb from visible light. After a time delay, they convert this energy back into visible light. Often energy storage involves energy conversions. Winding a music box stores the mechanical energy of motion of our arm's motion as strain potential energy in the music box spring. Gravitational potential energy is stored by raising an object to a higher level.

Unfortunately, electrical energy cannot easily be stored in large amounts. For this reason, generating plants must produce and transmit electrical energy as consumers require it. As we will see in Chapter 10, it is possible to store electrical potential energy in devices called capacitors. For example, cameras use capacitors to store electrical potential energy and then release the energy quickly to produce a flash. But capacitors are not practical for storing large amounts of electrical energy.

**Concept Check 2.3**

a) When mechanical energy of motion is stored by converting it into gravitational potential energy, how does the amount of gravitational energy stored compare to the amount of mechanical energy of motion used to store it? \_\_\_\_\_

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## Period 2 Summary

**2.1:** Energy provides the ability to do work. Work is done when forces act on an object to move it over a distance.

Energy takes many different forms. Eleven forms of energy are defined on pages 21-23.

**2.2:** Energy is often converted from its most available form, such as chemical potential energy, into a more useful form, such as electrical energy.

Converting energy into the desired form may require a series of conversions.

In each step in the conversion process, some energy is wasted.

**2.3:** Although energy is wasted in conversion processes, it is not lost.

The total amount of energy put into a conversion process must equal the total amount of energy out in all forms.

The efficiency of an energy conversion =  $\frac{\text{Useful Energy Out}}{\text{Total Energy In}}$

The overall efficiency of a series of energy conversions is the product of the efficiencies of each step in the process.

Overall Efficiency = Efficiency<sub>1</sub> x Efficiency<sub>2</sub> x Efficiency<sub>3</sub> x .....

**2.4:** Energy can be stored in various ways such as chemical potential, electrical potential, nuclear, gravitational potential, or strain potential energy. Although capacitors can store electrical potential energy, there is no practical way to store large amounts of electrical energy.

## Period 2 Exercises

E.1 Which energy conversion is involved in the process of photosynthesis?

- a) nuclear energy to thermal energy
- b) electrical energy to thermal energy
- c) radiant energy to chemical energy
- d) mechanical energy of motion to radiant energy
- e) chemical energy to electrical energy

- E.2 Which of the following devices is gaining gravitational potential energy?
- a) a train climbing a hill
  - b) a train coming down a hill
  - c) a boy riding a bicycle on level ground
  - d) a boat falling over a waterfall
  - e) a capacitor being charged
- E.3 Friction is a process by which energy of some other form is converted into
- a) visible radiant energy.
  - b) nuclear energy.
  - c) thermal energy.
  - d) gravitational potential energy.
  - e) chemical potential energy.
- E.4 Richard raises a block of metal to a height of 6 feet off the floor and releases it. The block falls to the floor and comes to rest. Considering both Richard and the block, the series of energy conversions that occur in this sequence of events are, respectively,
- a) thermal, mechanical, chemical, gravitational, and mechanical.
  - b) chemical, mechanical, gravitational, mechanical, and thermal.
  - c) mechanical, gravitational, chemical, thermal, and radiant.
  - d) gravitational, thermal, chemical, mechanical, and gravitational.
  - e) chemical, radiant, mechanical, gravitational, and thermal.
- E.5 When you wind up a spring, you convert stored chemical energy in your muscles into mechanical energy of motion into
- a) strain potential energy of the spring.
  - b) nuclear energy of the spring.
  - c) gravitational potential energy of the spring.
  - d) chemical potential energy of the spring.
  - e) none of the above is correct.

- E.6 Which statement regarding energy conversion processes is **TRUE** ?
- a) A clever person can design a machine that operates with no wasted energy.
  - b) Because of the thermal energy involved, the conversion of electrical energy into radiant energy produces more radiant energy than electrical energy used in the conversion process
  - c) The efficiency of energy conversion processes is less than one.
  - d) The efficiency of an energy conversion process equals the useful energy out divided by the wasted energy.
  - e) None of the above statements is true.
- E.7 An energy conversion process requires two steps. In the first step, 1,000 joules of energy are required to produce 750 joules of useful energy out. In the second step, 1,000 joules of energy are required to produce 250 joules of useful energy out. What is the overall efficiency of the conversion process?
- a) 5%
  - b) 19%
  - c) 30%
  - d) 50%
  - e) 100%

### Period 2 Review Questions

- R.1 Describe the energy conversions that occur when you ride the exercise bicycle and light the bulbs connected to it. Which conversion provides the useful energy you want?
- R.2 Give examples of storing different forms of energy.
- R.3 How does the total amount of energy put into a conversion process compare to the total amount of energy out of that process? How does the total amount of energy put into the process compare to the useful energy out?
- R.4 Describe the efficiency of an energy conversion process in words and with an equation.
- R.5 If energy is conserved, how can we say that energy is wasted in energy conversion processes?

