

## 3.5: Conservation of Energy

### Learning Objectives

By the end of this section, you will be able to:

- Explain the law of the conservation of energy.
- Describe some of the many forms of energy.
- Define efficiency of an energy conversion process as the fraction left as useful energy or work, rather than being transformed, for example, into thermal energy.

Energy, as we have noted, is conserved, making it one of the most important physical quantities in nature. The law of conservation of energy can be stated as follows:

We have explored some forms of energy and some ways it can be transferred from one system to another. This exploration led to the definition of two major types of energy—mechanical energy ( $KE + PE$ ) and energy transferred via work done by **nonconservative forces** ( $W_{nc}$ ). But energy takes *many* other forms, manifesting itself in *many* different ways, and we need to be able to deal with all of these before we can write an equation for the above general statement of the conservation of energy.

### Other Forms of Energy than Mechanical Energy

At this point, we deal with all other forms of energy by lumping them into a single group called other energy ( $OE$ ). Then we can state the conservation of energy in equation form as

$$KE_i + PE_i + W_{nc} + OE_i = KE_f + PE_f + OE_f. \quad (3.5.1)$$

All types of energy and work can be included in this very general statement of conservation of energy. Kinetic energy is  $KE$ , work done by a conservative force is represented by  $PE$ , work done by nonconservative forces is  $W_{nc}$  and all other energies are included as  $OE$ . This equation applies to all previous examples; in those situations  $OE$  was constant, and so it subtracted out and was not directly considered.

### Usefulness of the Energy Conservation Principle

The fact that energy is conserved and has many forms makes it very important. You will find that energy is discussed in many contexts, because it is involved in all processes. It will also become apparent that many situations are best understood in terms of energy and that problems are often most easily conceptualized and solved by considering energy.

When does  $OE$  play a role? One example occurs when a person eats. Food is oxidized with the release of carbon dioxide, water, and energy. Some of this chemical energy is converted to kinetic energy when the person moves, to potential energy when the person changes altitude, and to thermal energy (another form of  $OE$ ).

### Some of the Many Forms of Energy

What are some other forms of energy? You can probably name a number of forms of energy not yet discussed. Many of these will be covered in later chapters, but let us detail a few here. **Electrical energy** is a common form that is converted to many other forms and does work in a wide range of practical situations. Fuels, such as gasoline and food, carry **chemical energy** that can be transferred to a system through oxidation. Chemical fuel can also produce electrical energy, such as in batteries. Batteries can in turn produce light, which is a very pure form of energy. Most energy sources on Earth are in fact stored energy from the energy we receive from the Sun. We sometimes refer to this as **radiant energy**, or electromagnetic radiation, which includes visible light, infrared, and ultraviolet radiation. **Nuclear energy** comes from processes that convert measurable amounts of mass into energy. Nuclear energy is transformed into the energy of sunlight, into electrical energy in power plants, and into the energy of the heat transfer and blast in weapons. Atoms and molecules inside all objects are in random motion. This internal mechanical energy from the random motions is called **thermal energy**, because it is related to the temperature of the object. These and all other forms of energy can be converted into one another and can do work.

Table gives the amount of energy stored, used, or released from various objects and in various phenomena. The range of energies and the variety of types and situations is impressive.

### Problem-Solving Strategies for Energy

You will find the following problem-solving strategies useful whenever you deal with energy. The strategies help in organizing and reinforcing energy concepts. In fact, they are used in the examples presented in this chapter. The familiar general problem-solving strategies presented earlier—involving identifying physical principles, knowns, and unknowns, checking units, and so on—continue to be relevant here.

**Step 1.** Determine the system of interest and identify what information is given and what quantity is to be calculated. A sketch will help.

**Step 2.** Examine all the forces involved and determine whether you know or are given the potential energy from the work done by the forces. Then use step 3 or step 4.

**Step 3.** If you know the potential energies for the forces that enter into the problem, then forces are all conservative, and you can apply conservation of mechanical energy simply in terms of potential and kinetic energy. The equation expressing conservation of energy is

$$KE_i + PE_i = KE_f + PE_f. \quad (3.5.2)$$

**Step 4.** If you know the potential energy for only some of the forces, possibly because some of them are nonconservative and do not have a potential energy, or if there are other energies that are not easily treated in terms of force and work, then the conservation of energy law in its most general form must be used.

$$KE_i + PE_i + W_{nc} + OE_i = KE_f + PE_f + OE_f. \quad (3.5.3)$$

In most problems, one or more of the terms is zero, simplifying its solution. Do not calculate  $W_c$ , the work done by conservative forces; it is already incorporated in the  $PE$  terms.

**Step 5.** You have already identified the types of work and energy involved (in step 2). Before solving for the unknown, *eliminate terms wherever possible* to simplify the algebra. For example, choose  $h = 0$  at either the initial or final point, so that  $PE_g$  is zero there. Then solve for the unknown in the customary manner.

**Step 6.** *Check the answer to see if it is reasonable.* Once you have solved a problem, reexamine the forms of work and energy to see if you have set up the conservation of energy equation correctly. For example, work done against friction should be negative, potential energy at the bottom of a hill should be less than that at the top, and so on. Also check to see that the numerical value obtained is reasonable. For example, the final speed of a skateboarder who coasts down a 3-m-high ramp could reasonably be 20 km/h, but *not* 80 km/h.

### Transformation of Energy

The transformation of energy from one form into others is happening all the time. The chemical energy in food is converted into thermal energy through metabolism; light energy is converted into chemical energy through photosynthesis. In a larger example, the chemical energy contained in coal is converted into thermal energy as it burns to turn water into steam in a boiler. This thermal energy in the steam in turn is converted to mechanical energy as it spins a turbine, which is connected to a generator to produce electrical energy. (In all of these examples, not all of the initial energy is converted into the forms mentioned. This important point is discussed later in this section.)

Another example of energy conversion occurs in a solar cell. Sunlight impinging on a solar cell (Figure 7.7.1) produces electricity, which in turn can be used to run an electric motor. Energy is converted from the primary source of solar energy into electrical energy and then into mechanical energy.



Figure 3.5.1: Solar energy is converted into electrical energy by solar cells, which is used to run a motor in this solar-power aircraft. (credit: NASA)

Object/phenomenon	Energy in joules
Big Bang	$10^{68}$
Energy released in a supernova	$10^{44}$
Fusion of all the hydrogen in Earth's oceans	$10^{34}$
Annual world energy use	$4 \times 10^{20}$
Large fusion bomb (9 megaton)	$3.8 \times 10^{16}$
1 kg hydrogen (fusion to helium)	$6.4 \times 10^{14}$
1 kg uranium (nuclear fission)	$8.0 \times 10^{13}$
Hiroshima-size fission bomb (10 kiloton)	$4.2 \times 10^{13}$
90,000-ton aircraft carrier at 30 knots	$1.1 \times 10^{10}$
1 barrel crude oil	$5.9 \times 10^9$
1 ton TNT	$4.2 \times 10^9$
1 gallon of gasoline	$1.2 \times 10^8$
Daily home electricity use (developed countries)	$7n \times 10^7$
Daily adult food intake (recommended)	$1.2 \times 10^7$
1000-kg car at 90 km/h	$3.1 \times 10^5$
1 g fat (9.3 kcal)	$3.9 \times 10^4$
ATP hydrolysis reaction	$3.2 \times 10^4$
1 g carbohydrate (4.1 kcal)	$1.7 \times 10^4$
1 g protein (4.1 kcal)	$1.7 \times 10^4$
Tennis ball at 100 km/h	22
Mosquito g at 0.5 m/s)	$1.3 \times 10^{-6}$
Single electron in a TV tube beam	$4.0 \times 10^{-15}$
Energy to break one DNA strand	$4.0 \times 10^{-19}$

## Efficiency

Even though energy is conserved in an energy conversion process, the output of *useful energy* or work will be less than the energy input. The efficiency  $E_{ff}$  of an energy conversion process is defined as

$$Efficiency (E_{ff}) = \frac{\text{useful energy or work output}}{\text{total energy input}} = \frac{W_{out}}{E_{in}}. \quad (3.5.4)$$

Table lists some efficiencies of mechanical devices and human activities. In a coal-fired power plant, for example, about 40% of the chemical energy in the coal becomes useful electrical energy. The other 60% transforms into other (perhaps less useful) energy forms, such as thermal energy, which is then released to the environment through combustion gases and cooling towers.

Activity/device	Efficiency (%)
Cycling and climbing	20
Swimming, surface	2
Swimming, submerged	4
Shoveling	3
Weightlifting	9
Steam engine	17
Gasoline engine	30
Diesel engine	35
Nuclear power plant	35
Coal power plant	42
Electric motor	98
Compact fluorescent light	20
Gas heater (residential)	90
Solar cell	10

### Efficiency of the Human Body and Mechanical Devices

#### PhET Explorations: Masses and Springs

A realistic mass and spring laboratory. Hang masses from springs and adjust the spring stiffness and damping. You can even slow time. Transport the lab to different planets. A chart shows the kinetic, potential, and thermal energies for each spring.



PhET Interactive Simulation

Figure 3.5.2: Masses and Springs

## Summary

- The law of conservation of energy states that the total energy is constant in any process. Energy may change in form or be transferred from one system to another, but the total remains the same.
- When all forms of energy are considered, conservation of energy is written in equation form as

$$KE_i + PE_i + W_{nc} + OE_i = KE_f + PE_f + OE_f, \quad (3.5.5)$$

where  $OE$  is all **other forms of energy** besides mechanical energy.

- Commonly encountered forms of energy include electric energy, chemical energy, radiant energy, nuclear energy, and thermal energy.

- Energy is often utilized to do work, but it is not possible to convert all the energy of a system to work.

The efficiency  $E_{ff}$  of a machine or human is defined to be  $E_{ff} = \frac{W_{out}}{E_{in}}$ , where  $W_{out}$  is useful work output and  $E_{in}$  is the energy consumed.

## Glossary

### law of conservation of energy

the general law that total energy is constant in any process; energy may change in form or be transferred from one system to another, but the total remains the same

### electrical energy

the energy carried by a flow of charge

### chemical energy

the energy in a substance stored in the bonds between atoms and molecules that can be released in a chemical reaction

### radiant energy

the energy carried by electromagnetic waves

### nuclear energy

energy released by changes within atomic nuclei, such as the fusion of two light nuclei or the fission of a heavy nucleus

### thermal energy

the energy within an object due to the random motion of its atoms and molecules that accounts for the object's temperature

### efficiency

a measure of the effectiveness of the input of energy to do work; useful energy or work divided by the total input of energy

## Contributors and Attributions

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