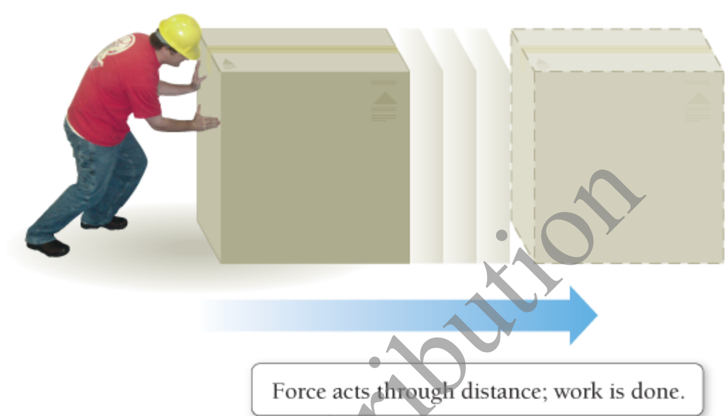
Pearson

E.6: Energy and Its Units

The two fundamental components of our universe are matter, which we will discuss in Chapter 1, and energy, which we introduce briefly here. We first introduce the basic nature of energy, then we define its units, and lastly we discuss how we quantify changes in energy.

The Nature of Energy

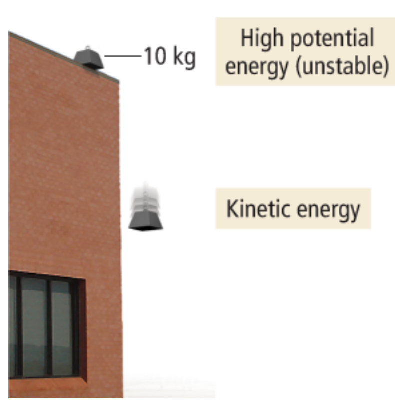
The basic definition of **energy** is *the capacity to do work*. **Work** is defined as the action of a force through a distance. For instance, when you push a box across the floor or pedal your bicycle down the street, you do work.

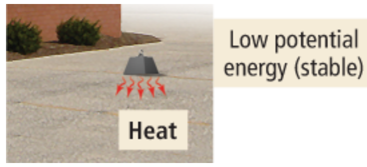


The *total energy* of an object is a sum of its **kinetic energy**, the energy associated with its motion, and its **potential energy**, the energy associated with its position or composition. For example, a weight held several meters above the ground has potential energy due to its position within Earth's gravitational field (Figure E.6). If you drop the weight, it accelerates, and its potential energy is converted to kinetic energy. When the weight hits the ground, its kinetic energy is converted primarily to **thermal energy**, the energy associated with the temperature of an object. Thermal energy is actually a type of kinetic energy because it arises from the motion of the individual atoms or molecules that make up an object. When the weight hits the ground, its kinetic energy is essentially transferred to the atoms and molecules that compose the ground, raising the temperature of the ground ever so slightly.

Figure E.6 Energy Changes

Gravitational potential energy is converted into kinetic energy when the weight is released. The kinetic energy is converted mostly to thermal energy when the weight strikes the ground.





The first principle to note about the way energy changes as the weight falls to the ground is that *energy is neither created nor destroyed*. The potential energy of the weight becomes kinetic energy as the weight accelerates toward the ground. The kinetic energy then becomes thermal energy when the weight hits the ground. The total amount of thermal energy that is released through the process is exactly equal to the initial potential energy of the weight. The idea that energy is neither created nor destroyed is known as the **law of conservation of energy**. Although energy can change from one type into another and it can flow from one object to another, the *total quantity* of energy does not change—it remains constant.

> In Chapter 20 we will discuss how energy conservation is actually part of a more general law that allows for the interconvertibility of mass and energy.

The second principle to note about the raised weight and its fall is *the tendency of systems with high potential energy to change in a way that lowers their potential energy.* For this reason, objects or systems with high potential energy tend to be *unstable*. The weight lifted several meters from the ground is unstable because it contains a significant amount of potential energy. Unless restrained, the weight will naturally fall, lowering its potential energy. We can harness some of the raised weight's potential energy to do work. For example, we can attach the weight to a rope that turns a paddle wheel or spins a drill as the weight falls. After the weight falls to the ground, it contains less potential energy—it has become more *stable*.

Some chemical substances are like a raised weight. For example, the molecules that compose gasoline have a relatively high potential energy—energy is concentrated in them just as energy is concentrated in a raised weight. The molecules in the gasoline tend to undergo chemical changes (specifically combustion) that lower their potential energy. As the energy of the molecules in gasoline is released, some of it can be harnessed to do work, such as moving a car forward (Figure E.7). The molecules that result from the chemical change have less potential energy than the original molecules in gasoline and are more stable.

Figure E.7 Using Chemical Energy to Do Work

Gasoline molecules have high potential energy. When they are burned, they form molecules with lower potential energy. The difference in potential energy can be harnessed to move the car.

Chemical potential energy, such as the energy contained in the molecules that compose gasoline, arises primarily from electrostatic forces (see Section 1.6) between the electrically charged particles (protons and electrons) that compose atoms and molecules. Recall that molecules contain specific, usually complex, arrangements of protons and electrons. Some of these arrangements—such as the one within the molecules that compose gasoline—have a much higher potential energy than others. When gasoline undergoes combustion, the arrangement of these particles changes, creating molecules with lower potential energy and transferring energy (mostly in the form of heat) to the surroundings. In other words, the structure of a molecule—the way its protons and electrons are arranged—determines the potential energy of the molecule, which in turn determines its properties.

properties.

Energy Units

We can deduce the units of energy from the definition of kinetic energy. An object of mass m, moving at velocity v, has a kinetic energy (KE) given by:

$$\mathrm{KE} = \frac{1}{2}\underset{\text{kg}}{m}\underset{\text{m/s}}{v}^2$$

The SI unit of mass is the kg, and the unit of velocity is m/s. The SI unit of energy is $\mathrm{kg \cdot m^2/s^2}$, defined as the **joule (J)**, named after the English scientist James Joule (1818–1889).

$$1\ \mathrm{kg}\frac{\mathrm{m}^2}{\mathrm{s}^2} = 1\ \mathrm{J}$$

One joule is a relatively small amount of energy—for example, a 100-watt light bulb uses 3.6×10^5 J in 1 hour. Therefore, we often use the kilojoule (kJ) in our energy discussions and calculations (1 kJ = 1000 J). A second common unit of energy is the **calorie (cal)**, originally defined as the amount of energy required to raise the temperature of 1 g of water by 1 °C. The current definition is 1 cal = 4.184 J (exact); a calorie is a larger unit than a joule. A related energy unit is the nutritional, or uppercase "C" **Calorie (Cal)**, equivalent to 1000 lowercase "c" calories. The Calorie is the same as a kilocalorie (kcal): 1 Cal = 1 kcal = 1000 cal. Electricity bills typically are based on another, even larger, energy unit, the **kilowatt-hour (kWh)**: 1 kWh = 3.60×10^6 J. Electricity costs \$0.08–\$0.15 per kWh. Table E.5 lists various energy units and their conversion factors. Table E.6 shows the amount of energy required for various processes.

Table E.5 Energy Conversion Factors*

1 calorie (Cal)	= 4.184 joules (J)
1 Calorie (Cal) or kilocalorie (kcal)	= 1000 cal = 4184 J
1 kilowatt-hour (kWh)	= 3.60×10^6 J

*All conversion factors in this table are exact.

Table E.6 Energy Uses in Various Units

Unit	Amount Required to Raise Temperature of 1 g of Water by 1 °C	Amount Required to Light 100-W Bulb for 1 Hour	Amount Used by Human Body in Running 1 Mile (Approximate)	Amount Used by Average U.S. Citizen in 1 Day
joule (J)	4.18	3.60×10^5	4.2×10^5	9.0×10^8
calorie (cal)	1.00	8.60×10^4	1.0×10^5	2.2×10^8
Calorie (Cal)	0.00100	86.0	100	2.2×10^5
kilowatt-hour (kWh)	1.16×10^{-6}	0.100	0.12	2.5×10^2

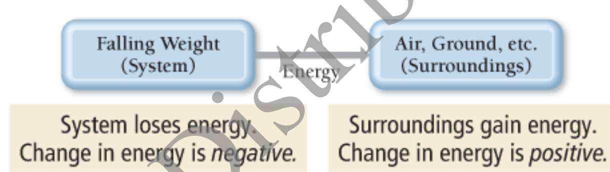
The "calorie" referred to on all nutritional labels (regardless of the capitalization) is always the capital *C* Calorie.

A watt (W) is 1 J/s, so a 100-W light bulb uses 100 J every second or 3.6×10^5 J every hour.

Quantifying Changes in Energy

Recall that energy is conserved in any process—it is neither created nor destroyed. However, energy can be transferred from one object or system to another. For example, when a raised weight is dropped, its potential energy is transferred to its surroundings as heat, or when gasoline is burned in an automobile engine, its potential energy is transferred to the kinetic energy associated with the motion of the car.

In this book, we always view the transfer of energy from the point of view of the *system* under observation. For example, if we drop a weight, we can define the weight as the system. As the weight drops, it loses energy to the *surroundings*. The *surroundings* include anything with which the system interacts. Notice that, for the falling weight, the system *loses* energy and the surroundings *gain* energy.



We can think of the energy of the system in the same way that we think of the balance in a checking account. The loss of energy from the system carries a negative sign, just like a withdrawal from a checking account carries a negative sign. Conversely, a gain in energy by the system carries a positive sign, just like a deposit in a checking account carries a positive sign.

Chemical processes almost always involve energy changes. For example, as we saw previously, when we burn gasoline, energy is given off. If we define the gasoline as the system, then the system loses energy (the change in energy is negative). Processes in which the system loses thermal energy are **exothermic**, and the change in energy is negative. In contrast, processes in which the system gains thermal energy are **endothermic**, and the change in energy is positive. For example, the chemical cold packs often used to ice athletic injuries contain substances within them that undergo an endothermic reaction when mixed. If we define the chemicals in the cold pack as the system, then the energy absorbed *by the system* cools down the muscle (which is acting as part of the surroundings) and helps prevent swelling.

Summarizing Energy and Its Units:

- Energy is the capacity to do work and is commonly measured in joules (J).
- Energy is conserved in any process but can be transferred between a system and its surroundings.
- An exothermic process involves the transfer of energy *from* the system *to* the surroundings and carries a negative sign (like a withdrawal from a checking account).
- An endothermic process involves the transfer of energy *to* the system *from* the surroundings and carries a positive sign (like a deposit into a checking account).

Conceptual Connection E.3 **Energy Changes**

Interactive