5.3 Types of Energy and the Law of Conservation of Energy

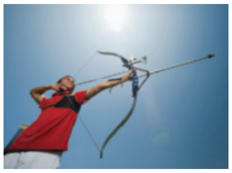
You use mechanical energy (a combination of kinetic energy and gravitational potential energy) to do mechanical work every day. Is mechanical energy the only type of energy? In fact, there are many types of energy in the universe, all of which involve kinetic energy, potential energy, or both. Different types of energy have different names. **Table 1** describes some different types of energy.

Table 1 Types of Energy

Type of energy	Form (kinetic, potential, or both)	Description	Application/Example
mechanical energy	potential and kinetic	energy possessed by objects that are primarily affected by the force of gravity and frictional forces	
gravitational energy	potential	energy possessed by objects that are affected by the force of gravity; applies to all objects on Earth (and the universe)	
radiant energy (also known as light, light energy, or electromagnetic radiation)	potential and kinetic	energy possessed by oscillating electric and magnetic fields	
electrical energy (static electricity)	potential	energy possessed by accumulated static charges	
electrical energy (current electricity)	potential and kinetic	energy possessed by flowing charges (you will learn more about this in Chapter 11)	
thermal energy (sometimes incorrectly called heat energy)	potential and kinetic	energy possessed by randomly moving atoms and molecules (you will learn more about this in Chapter 6)	
sound energy	potential and kinetic	energy possessed by large groups of oscillating atoms and molecules	

thermal energy the total quantity of kinetic and potential energy possessed by the atoms or molecules of a substance

Table 1 (continued)

nuclear energy (also known as atomic energy)	potential	energy possessed by protons and neutrons in atomic nuclei (you will learn more about this in Chapter 7)	
elastic energy (also known as spring energy)	potential	energy possessed by materials that are stretched, compressed, or twisted and tend to return to their original shape	
chemical energy (also known as bond energy, fuel energy, food energy, molecular energy, and internal energy)	potential	energy associated with bonds in molecules	

nuclear energy potential energy of protons and neutrons in atomic nuclei

Energy Transformations

The conversion of energy is called an **energy transformation**: the change of one form or type of energy into another. For example, photosynthesis is a process involving energy transformations in a plant. In photosynthesis, plants transform radiant energy into the chemical energy stored in food molecules (food energy) such as glucose (a sugar) and starch. In the process, some of the radiant energy is also transformed into thermal energy. Animals, including humans, eat plants and transform the chemical energy in the plants into chemical energy in their muscles. Muscles then transform this chemical energy into the kinetic energy of moving limbs, which do work on objects in the environment.

energy transformation the change of one type of energy into another

Technological systems also transform energy from one form into another. For example, an electric light bulb transforms electrical energy into radiant energy (light) and thermal energy (**Figure 1**). The internal combustion engine transforms the chemical energy in fuels such as gasoline and diesel into the kinetic energy of moving cars, motorcycles, trains, buses, and boats (**Figure 2**). In all of these processes, a lot of thermal energy is also produced and emitted into the environment.

Figure 1 A light bulb transforms electrical energy into radiant energy and thermal energy.

The Law of Conservation of Energy

People often wonder how much energy there is in the universe and whether we will eventually run out of energy. Scientists have studied energy and energy transformations and have arrived at some important generalizations. For example, they noticed that when one form of energy is transformed into another form (or forms) of energy, the quantity of one form is reduced by the same amount that the quantity of the other form (or forms) is increased. This suggests that, in an energy transformation, the total amount of energy does not change but remains constant. For example, a light bulb may transform 100 J of electrical energy into 5 J of radiant energy and 95 J of thermal energy. The total amount of energy has not changed:

$$100\text{ J of electrical energy} = 95\text{ J of thermal energy} + 5\text{ J of radiant energy}$$

$$100\text{ J of energy} = 100\text{ J of energy}$$

Figure 2 A gasoline engine transforms the chemical energy in gasoline into kinetic energy, thermal energy, and sound energy.

law of conservation of energy energy is neither created nor destroyed; when energy is transformed from one form into another, no energy is lost

This generalization, known as the **law of conservation of energy**, is stated as follows:

Law of Conservation of Energy

The total amount of energy in the universe is conserved. There is a certain total amount of energy in the universe, and this total never changes. New energy cannot be created out of nothing, and existing energy cannot disappear; the energy that exists can only be changed from one form into another. When an energy transformation occurs, no energy is lost.

Quantifying Energy Transformations

Evidence of the law of conservation of energy is all around us, but to notice it, you need to take measurements and perform simple calculations. Let us see how the law is demonstrated when a 65.0 kg diver performs a handstand dive from a 10.0 m high diving platform into the water below.

Let us analyze the dive in terms of the diver's potential energy, E_g, kinetic energy, E_k, and total mechanical energy, E_m, which is the sum of E_g and E_k. We will calculate these values for three phases of the dive occurring at three distinct moments in time: the phase before the diver leaves the platform, the phase when the diver has travelled half the distance to the water's surface, and the phase when the diver's fingers reach the water's surface. We will assume that the water's surface is the reference level, where $E_g = 0$ J.

Phase 1: Before the Dive

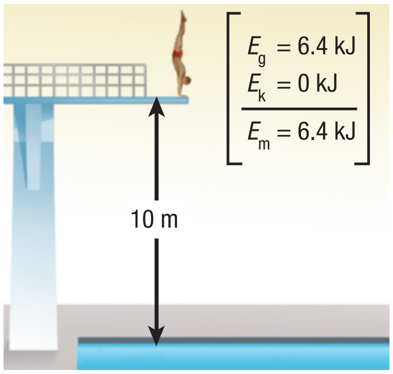


Figure 3 Phase 1: before the dive

The diver begins the dive in a handstand position on the platform of the diving tower (**Figure 3**). Since he is motionless, the diver's kinetic energy is equal to zero ($E_k = 0$ kJ), and his gravitational potential energy is calculated as follows:

$$E_g = mgh$$

$$= (65\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(10.0\ \text{m})$$

$$E_g = 6.4 \times 10^3\ \text{J or } 6.4\ \text{kJ (two extra digits carried)}$$

At this point in the dive, the diver's kinetic energy is equal to 0 J and his potential energy is equal to 6.4 kJ. The diver's total mechanical energy is equal to 6.4 kJ, the sum of his gravitational potential energy and his kinetic energy:

$$E_m = E_g + E_k$$

$$= 6.4\ \text{kJ} + 0\ \text{kJ}$$

$$E_m = 6.4\ \text{kJ}$$

Phase 2: At the Halfway Point

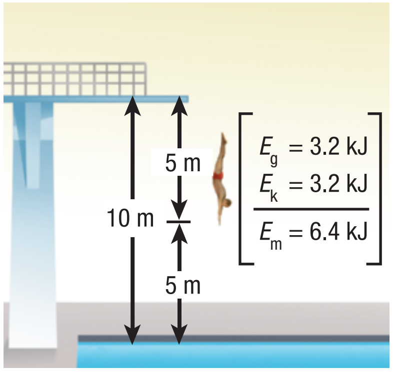


Figure 4 Phase 2: at the halfway point

When the diver leaves the platform, he will accelerate toward the water at 9.8 m/s^2 (assuming negligible friction with the air). At the halfway point, the diver is 5.0 m above the water's surface (**Figure 4**). At this point in the dive, the diver's gravitational potential energy may be calculated as follows:

$$E_g = mgh$$

$$= (65\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(5.0\ \text{m})$$

$$E_g = 3.2 \times 10^3\ \text{J or } 3.2\ \text{kJ}$$

At the halfway point, the diver's kinetic energy may be calculated using the equation $E_k = \frac{mv^2}{2}$. This equation requires us to determine the diver's speed, v, at the halfway point in the dive.

Since the diver accelerates as he descends, we may use the equation $v_f^2 = v_i^2 + 2a\Delta d$ for this purpose. Since v_f in the equation $v_f^2 = v_i^2 + 2a\Delta d$ and v in the equation $E_k = \frac{mv^2}{2}$ both represent the diver's speed at this point in the dive, we will use the symbol v (not v_f) to represent the diver's speed. Thus,

$$v^2 = v_i^2 + 2a\Delta d$$

$$v = \sqrt{v_i^2 + 2a\Delta d}$$

$$= \sqrt{2a\Delta d} \text{ since } v_i = 0 \text{ m/s}$$

$$= \sqrt{2(9.8 \text{ m/s}^2)(5.0 \text{ m})}$$

$$v = 9.899 \text{ m/s (two extra digits carried)}$$

Substituting $v = 9.899$ m/s into the equation $E_k = \frac{mv^2}{2}$ gives

$$E_k = \frac{mv^2}{2}$$

$$= \frac{(65 \text{ kg})(9.899 \text{ m/s})^2}{2}$$

$$E_k = 3.2 \times 10^3 \text{ J or } 3.2 \text{ kJ}$$

At the halfway point, the diver's total mechanical energy is

$$E_g = E_g + E_k$$

$$= 3.2 \text{ kJ} + 3.2 \text{ kJ}$$

$$E_m = 6.4 \text{ kJ}$$

The total mechanical energy is the same at this point in the dive as it was before the dive.

Phase 3: At the Water's Surface

When the diver reaches the surface of the water, his height above the water is 0 m (**Figure 5**). Thus, $E_g = 0$ J since $E_g = mgh$ and $h = 0$ m. By this point, the diver has been accelerating for the full distance between the platform and the water. His kinetic energy is calculated as in Phase 2:

$$v_f = \sqrt{v_i^2 + 2a\Delta d}$$

$$= \sqrt{2a\Delta d}, \text{ since } v_i = 0 \text{ m/s}$$

$$= \sqrt{2(9.8 \text{ m/s}^2)(10.0 \text{ m})}$$

$$v_f = 14 \text{ m/s}$$

$$E_k = \frac{mv^2}{2}$$

$$= \frac{(65 \text{ kg})(14 \text{ m/s})^2}{2}$$

$$E_k = 6.4 \text{ kJ}$$

At the water's surface, the diver's total mechanical energy is

$$E_m = E_g + E_k$$

$$= 0 \text{ kJ} + 6.4 \text{ kJ}$$

$$E_m = 6.4 \text{ kJ}$$

The total mechanical energy is the same at this point in the dive as it was just before the dive and at the halfway point. You can assume that the diver possesses the same total mechanical energy throughout the dive. You can check this assumption by performing similar calculations at different phases of the dive.

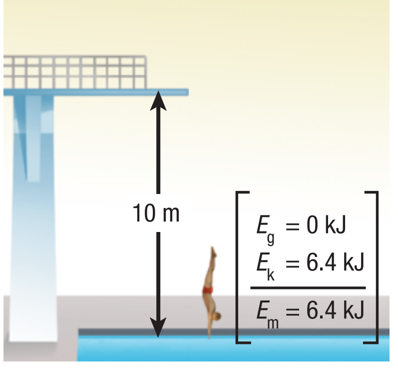


Figure 5 Phase 3: at the water's surface

The example of the diver illustrates the law of conservation of energy by showing that while the diver's gravitational potential energy was transformed into kinetic energy throughout the dive, his total mechanical energy did not change—it was conserved. The law of conservation of energy is an important fundamental law of nature that can help us solve many problems in everyday life.

Tutorial 1 Applying the Law of Conservation of Energy

The law of conservation of energy may be used to solve problems involving energy transformations. In the following Sample Problem, we will analyze the energy transformations that occur when an object (a camera in this case) falls to the ground.

Sample Problem 1

A 1.1 kg camera slips out of a photographer's hands while he is taking a photograph. The camera falls 1.4 m to the ground below.

(a) What is the camera's gravitational potential energy relative to the ground when it is in the photographer's hands?

(b) Using the law of conservation of energy, determine the camera's kinetic energy at the instant it hits the ground.

(c) Use the camera's kinetic energy to determine its speed at the instant it hits the ground.

Solution

(a) **Given:** $m = 1.1$ kg; $h = 1.4$ m

Required: E_g, gravitational potential energy

Analysis: $E_g = mgh$

Solution:
$$\begin{aligned} E_g &= mgh \\ &= (1.1\ \cancel{\text{kg}})\left(9.8\ \frac{\text{N}}{\cancel{\text{kg}}}\right)(1.4\ \text{m}) \\ &= 15\ \text{N}\cdot\text{m} \\ E_g &= 15\ \text{J} \end{aligned}$$

Statement: The camera has 15 J of gravitational potential energy relative to the ground when it is in the photographer's hands.

(b) We know that the camera has 0 J of kinetic energy when it is in the photographer's hands since it is not moving at that time. Using the mechanical energy equation, $E_m = E_g + E_k$, we may show that the camera has 15 J of total mechanical energy, E_m, at this time since

$$\begin{aligned} E_m &= E_g + E_k \\ &= 15\ \text{J} + 0\ \text{J} \\ E_m &= 15\ \text{J} \end{aligned}$$

According to the law of conservation of energy, the camera will have the same total mechanical energy for its entire fall. However, as the camera falls, its gravitational potential energy is transformed into kinetic energy. The camera will continuously lose gravitational potential energy as it gains kinetic energy. At the instant it hits the ground, the camera will have only kinetic energy since it is now at the reference level ($h = 0$) and its gravitational potential energy is zero. We may use the mechanical energy equation, $E_m = E_g + E_k$, to calculate the camera's kinetic energy at the instant it hits the ground:

$$\begin{aligned} E_m &= E_g + E_k \\ E_k &= E_m - E_g \\ &= 15\ \text{J} - 0\ \text{J} \\ E_k &= 15\ \text{J} \end{aligned}$$

The camera has 15 J of kinetic energy when it hits the ground.

(c) Since we know the camera's mass, m, and the kinetic energy, E_k, it has when it hits the ground, we may use the kinetic energy equation, $E_k = \frac{mv^2}{2}$, to determine the camera's speed, v, when it hits the ground.

Given: $E_k = 15$ J; $m = 1.1$ kg

Required: v, speed

Analysis: $E_k = \frac{mv^2}{2}$

Solution:
$$\begin{aligned} E_k &= \frac{mv^2}{2} \\ v &= \sqrt{\frac{2E_k}{m}} \\ &= \sqrt{\frac{2(15\ \text{J})}{1.1\ \text{kg}}} \\ v &= 5.2\ \text{m/s} \end{aligned}$$

Statement: The camera has a speed of 5.2 m/s when it hits the ground.

The camera's speed may also be calculated using the kinematic equations used earlier in this section. Try this approach to check the calculation performed here.

Practice

1. A 0.20 kg ball is thrown straight up from the edge of a 30.0 m tall building at a velocity of 22.0 m/s. The ball moves up to the maximum height and then falls to the ground at the base of the building. Use the law of conservation of energy to answer the following questions, assuming that the reference level for gravitational potential energy is ground level. T/I
   (a) What is the total energy of the ball at the start when it had a velocity of 22.0 m/s? [ans: 110 J]
   (b) What is the velocity of the ball at the maximum height? What is the maximum height of the ball? [ans: 0 m/s [up], 55 m]
   (c) What is the velocity of the ball when it hits the ground? [ans: 33 m/s [down]]

5.3 Summary

- Energy exists in many forms.
- In an energy transformation, energy changes from one form into another.
- The law of conservation of energy states that when energy is changed from one form into another, no energy is lost.
- When using the law of conservation of energy to solve problems, you may find the total mechanical energy, E_m, at one point in the motion of the object and then equate it to the total mechanical energy at another point. The total mechanical energy is $E_m = E_g + E_k$.

5.3 Questions

1. Describe the energy transformations occurring in each of the following situations: K/U
   (a) A ball falls from the top of a building.
   (b) An archer pulls a bow back and releases the arrow.
   (c) A firework explodes.
   (d) An incandescent light bulb comes on.
   (e) A gasoline lawnmower cuts the lawn.
2. A golf ball of mass 45.9 g is launched from a height of 8.0 m above the level of the green at a speed of 20.0 m/s. At the maximum height above the green, the ball is moving at 12 m/s. Assume there is no air resistance acting on the ball. Calculate the following for the golf ball: T/I
   (a) the total mechanical energy at the start (assume the level of the green to be the reference level)
   (b) the maximum height of the ball above the green
   (c) the speed of the ball when it strikes the green
3. Many roller coasters have loops where carts roll on a track that curves sharply up into the air. At the top, the people are upside down (and usually screaming). For safety reasons, many of these roller coasters must have a minimum speed at the top of the loop. In the roller coaster shown in **Figure 6**, the cart must have a minimum speed of 10.0 m/s at the top of the loop to make it around safely. Assuming that the roller coaster starts from rest at the top of the first hill and there is no friction on the roller coaster, what is the minimum height of the first hill? T/I

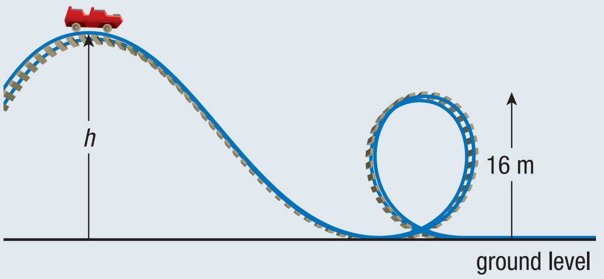


Figure 6

4. A net force acts on an object initially at rest, giving it an acceleration, a, while moving it a distance, Δd, forward across a horizontal surface. T/I C
   (a) Use kinematics equations to show that $v^2 = 2a\Delta d$.
   (b) The final total mechanical energy is $E_k = \frac{mv^2}{2}$.
   Substitute the equation for the final velocity into the equation for the final kinetic energy and simplify. What does this new equation prove?