This whimsical piece of art is a type of audio-kinetic sculpture. Balls are raised to a high point on the curved blue track. As the balls roll down the track, they turn levers, spin rotors, and bounce off elastic membranes.

As each ball travels along the track, the total energy of the system remains unchanged. The types of energy that are involved—whether associated with the ball’s motion, the ball’s position above the ground, or friction—vary in ways that keep the total energy of the system constant.

In this chapter, you will learn about work and the different types of energy that are relevant to mechanics.

- How many different kinds of energy are used in this sculpture?
- How are work, energy, and power related in the functioning of this sculpture?

**CONCEPT REVIEW**

- Kinematics (Section 2-2)
- Newton’s second law (Section 4-3)
- Force of friction (Section 4-4)
DEFINITION OF WORK

Many of the terms you have encountered so far in this book have meanings in physics that are similar to their meanings in everyday life. In its everyday sense, the term work means to do something that takes physical or mental effort. But in physics, work has a distinctly different meaning. Consider the following situations:

• A student holds a heavy chair at arm's length for several minutes.
• A student carries a bucket of water along a horizontal path while walking at constant velocity.

It might surprise you to know that under the scientific definition of work, there is no work done on the chair or the bucket, even though effort is required in both cases. We will return to these examples later.

A force that causes a displacement of an object does work on the object

Imagine that your car, like the car shown in Figure 5-1, has run out of gas and you have to push it down the road to the gas station. If you push the car with a constant force, the work you do on the car is equal to the magnitude of the force, \( F \), times the magnitude of the displacement of the car. Using the symbol \( d \) instead of \( \Delta x \) for displacement, we can define work as follows:

\[ W = Fd \]

Work is not done on an object unless the object is moved because of the action of a force. The application of a force alone does not constitute work. For this reason, no work is done on the chair when a student holds the chair at arm’s length. Even though the student exerts a force to support the chair, the chair does not move. The student’s tired arms suggest that work is being done, which is indeed true. The quivering muscles in the student’s arms go through many small displacements and do work within the student’s body. However, work is not done on the chair.

Work is done only when components of a force are parallel to a displacement

When the force on an object and the object’s displacement are in different directions, only the component of the force that is in the direction of the object’s displacement does work. Components of the force perpendicular to a displacement do not do work.
For example, imagine pushing a crate along the ground. If the force you exert is horizontal, all of your effort moves the crate. If your force is other than horizontal, only the horizontal component of your applied force causes a displacement and does work. If the angle between the force and the direction of the displacement is \( \theta \), as in Figure 5-2, work can be written as follows:

\[
W = Fd \cos(\theta)
\]

If \( \theta = 0^\circ \), then \( \cos 0^\circ = 1 \) and \( W = Fd \), which is the definition of work given earlier. If \( \theta = 90^\circ \), however, then \( \cos 90^\circ = 0 \) and \( W = 0 \). So, no work is done on a bucket of water being carried by a student walking horizontally. The upward force exerted to support the bucket is perpendicular to the displacement of the bucket, which results in no work done on the bucket.

Finally, if many constant forces are acting on an object, you can find the net work done by first finding the net force.

**Net Work Done by a Constant Net Force**

\[
W_{\text{net}} = F_{\text{net}}d \cos(\theta)
\]

- net work = net force \( \times \) displacement \( \times \) cosine of the angle between them

Work has dimensions of force times length. In the SI system, work has a unit of newtons times meters (N \( \times \) m), or joules (J). The work done in lifting an apple from your waist to the top of your head is about 1 J. Three push-ups require about 1000 J.

**Sample Problem 5A**

**Problem**

How much work is done on a vacuum cleaner pulled 3.0 m by a force of 50.0 N at an angle of 30.0° above the horizontal?

**Solution**

Given: \( F = 50.0 \text{ N} \quad \theta = 30.0^\circ \quad d = 3.0 \text{ m} \)

**Unknown:** \( W = ? \)

Use the equation for net work done by a constant force:

\[
W = Fd \cos(\theta)
\]

Only the horizontal component of the applied force is doing work on the vacuum cleaner.

\[
W = (50.0 \text{ N})(3.0 \text{ m})(\cos 30.0^\circ)
\]

\[
W = 130 \text{ J}
\]

**Did you know?**

The joule is named for the British physicist James Prescott Joule (1818–1889). Joule made major contributions to the understanding of energy, heat, and electricity.
The sign of work is important

Work is a scalar quantity and can be positive or negative, as shown in Figure 5-3. Work is positive when the component of force is in the same direction as the displacement. For example, when you lift a box, the work done by the force you exert on the box is positive because that force is upward, in the same
direction as the displacement. Work is negative when the force is in the direction opposite the displacement. For example, the force of kinetic friction between a sliding box and the floor is opposite to the displacement of the box, so the work done by the force on the box is negative. If you are very careful in applying the equation for work, your answer will have the correct sign: \( \cos \theta \) is negative for angles greater than 90° but less than 270°.

If the work done on an object results only in a change in the object’s speed, the sign of the net work on the object tells you whether the object’s speed is increasing or decreasing. If the net work is positive, the object speeds up and the net force does work on the object. If the net work is negative, the object slows down and work is done by the object on another object.

**Section Review**

1. For each of the following statements, identify whether the everyday or the scientific meaning of work is intended.
   a. Jack had to work against time as the deadline neared.
   b. Jill had to work on her homework before she went to bed.
   c. Jack did work carrying the pail of water up the hill.

2. If a neighbor pushes a lawnmower four times as far as you do but exerts only half the force, which one of you does more work and by how much?

3. For each of the following cases, indicate whether the work done on the second object in each example will have a positive or a negative value.
   a. The road exerts a friction force on a speeding car skidding to a stop.
   b. A rope exerts a force on a bucket as the bucket is raised up a well.
   c. Air exerts a force on a parachute as the parachutist slowly falls to Earth.

4. Determine whether work is being done in each of the following examples:
   a. a train engine pulling a loaded boxcar initially at rest
   b. a tug of war that is evenly matched
   c. a crane lifting a car

5. A worker pushes a \( 1.50 \times 10^3 \) N crate with a horizontal force of 345 N a distance of 24.0 m. Assume the coefficient of kinetic friction between the crate and the floor is 0.220.
   a. How much work is done by the worker on the crate?
   b. How much work is done by the floor on the crate?
   c. What is the net work done on the crate?

6. **Physics in Action**  
   A 0.075 kg ball in a kinetic sculpture is raised 1.32 m above the ground by a motorized vertical conveyor belt. A constant frictional force of 0.350 N acts in the direction opposite the conveyor belt’s motion. What is the net work done on the ball?
KINETIC ENERGY

Kinetic energy is energy associated with an object in motion. Figure 5-4 shows a cart of mass $m$ moving to the right on a frictionless air track under the action of a constant net force, $F$. Because the force is constant, we know from Newton’s second law that the particle moves with a constant acceleration, $a$. While the force is applied, the cart accelerates from an initial velocity $v_i$ to a final velocity $v_f$. If the particle is displaced a distance of $\Delta x$, the work done by $F$ during this displacement is

$$W_{net} = F\Delta x = (ma)\Delta x$$

However, in Chapter 2 we found that the following relationship holds when an object undergoes constant acceleration:

$$v_f^2 = v_i^2 + 2a\Delta x$$
$$a\Delta x = \frac{v_f^2 - v_i^2}{2}$$

Substituting this result into the equation $W_{net} = (ma)\Delta x$ gives

$$W_{net} = m\left(\frac{v_f^2 - v_i^2}{2}\right)$$
$$W_{net} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2$$

Kinetic energy depends on speed and mass

The quantity $\frac{1}{2}mv^2$ has a special name in physics: kinetic energy. The kinetic energy of an object with mass $m$ and speed $v$, when treated as a particle, is given by the expression shown on the next page.
Kinetic energy is a scalar quantity, and the SI unit for kinetic energy (and all other forms of energy) is the joule. Recall that a joule is also used as the basic unit for work.

Kinetic energy depends on both an object’s speed and its mass. If a bowling ball and a volleyball are traveling at the same speed, which do you think has more kinetic energy? You may think that because they are moving with identical speeds they have exactly the same kinetic energy. However, the bowling ball has more kinetic energy than the volleyball traveling at the same speed because the bowling ball has more mass than the volleyball.
The equation \( W_{\text{net}} = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 \) derived at the beginning of this section says that the net work done by a net force acting on an object is equal to the change in the kinetic energy of the object. This important relationship, known as the work–kinetic energy theorem, is often written as follows:

**WORK–KINETIC ENERGY THEOREM**

\[ W_{\text{net}} = \Delta KE \]

net work = change in kinetic energy

It is important to note that when we use this theorem, we must include all the forces that do work on the object in calculating the net work done. From this theorem, we see that the speed of the object increases if the net work done on it is positive, because the final kinetic energy is greater than the initial kinetic energy. The object’s speed decreases if the net work is negative, because the final kinetic energy is less than the initial kinetic energy.

The work–kinetic energy theorem allows us to think of kinetic energy as the work an object can do as it comes to rest, or the amount of energy stored in the object. For example, the moving hammer on the verge of striking a nail in Figure 5-5 has kinetic energy and can therefore do work on the nail. Part of this energy is used to drive the nail into the wall, and part goes into warming the hammer and nail upon impact.

### Practice 5B

**Kinetic energy**

1. Calculate the speed of an 8.0 \( \times \) 10^4 kg airliner with a kinetic energy of 1.1 \( \times \) 10^9 J.

2. What is the speed of a 0.145 kg baseball if its kinetic energy is 109 J?

3. Two bullets have masses of 3.0 g and 6.0 g, respectively. Both are fired with a speed of 40.0 m/s. Which bullet has more kinetic energy? What is the ratio of their kinetic energies?

4. Two 3.0 g bullets are fired with speeds of 40.0 m/s and 80.0 m/s, respectively. What are their kinetic energies? Which bullet has more kinetic energy? What is the ratio of their kinetic energies?

5. A car has a kinetic energy of 4.32 \( \times \) 10^5 J when traveling at a speed of 23 m/s. What is its mass?
SAMPLE PROBLEM 5C

Work–kinetic energy theorem

PROBLEM

On a frozen pond, a person kicks a 10.0 kg sled, giving it an initial speed of 2.2 m/s. How far does the sled move if the coefficient of kinetic friction between the sled and the ice is 0.10?

SOLUTION

1. DEFINE

Given: \( m = 10.0 \text{ kg} \quad v_i = 2.2 \text{ m/s} \quad v_f = 0 \text{ m/s} \quad \mu_k = 0.10 \)

Unknown: \( d = ? \)

Diagram:

![Diagram of sled and forces](image)

2. PLAN

Choose an equation(s) or situation: This problem can be solved using the definition of work and the work–kinetic energy theorem.

\[
W_{net} = F_{net}d \cos \theta
\]

\[
W_{net} = \Delta KE
\]

The initial kinetic energy is given to the sled by the person.

\[
KE_i = \frac{1}{2}mv_i^2
\]

Because the sled comes to rest, the final kinetic energy is zero.

\[
KE_f = 0
\]

\[
\Delta KE = KE_f - KE_i = -\frac{1}{2}mv_i^2
\]

The net work done on the sled is provided by the force of kinetic friction.

\[
W_{net} = F_{net}d \cos \theta = \mu_k mgd \cos \theta
\]

The force of kinetic friction is in the direction opposite \( d \).

\[
\theta = 180^\circ
\]

3. CALCULATE

Substitute values into the equations:

\[
W_{net} = (0.10)(10.0 \text{ kg})(9.81 \text{ m/s}^2) \ d \ (\cos 180^\circ)
\]

\[
W_{net} = (-9.8 \text{ N})d
\]

\[
\Delta KE = -KE_i = -(\frac{1}{2})(10.0 \text{ kg})(2.2 \text{ m/s})^2 = -24 \text{ J}
\]

Use the work–kinetic energy theorem to solve for \( d \).

\[
W_{net} = \Delta KE
\]

\[
(-9.8 \text{ N})d = -24 \text{ J}
\]

\[
d = 2.4 \text{ m}
\]

CALCULATOR SOLUTION

Your calculator should give an answer of 2.44898, but because the answer is limited to two significant figures, this number should be rounded to 2.4.
Note that because the direction of the force of kinetic friction is opposite the displacement, the net work done is negative. Also, according to Newton’s second law, the acceleration of the sled is about \(-1 \text{ m/s}^2\) and the time it takes the sled to stop is about 2 s. Thus, the distance the sled traveled in the given amount of time should be less than the distance it would have traveled in the absence of friction.

\[
2.4 \text{ m} < (2.2 \text{ m/s})(2 \text{ s}) = 4.4 \text{ m}
\]

**PRACTICE 5C**

**Work–kinetic energy theorem**

1. A student wearing frictionless in-line skates on a horizontal surface is pushed by a friend with a constant force of 45 N. How far must the student be pushed, starting from rest, so that her final kinetic energy is 352 J?

2. A \(2.0 \times 10^3\) kg car accelerates from rest under the actions of two forces. One is a forward force of 1140 N provided by traction between the wheels and the road. The other is a 950 N resistive force due to various frictional forces. Use the work–kinetic energy theorem to determine how far the car must travel for its speed to reach 2.0 m/s.

3. A \(2.1 \times 10^3\) kg car starts from rest at the top of a driveway that is sloped at an angle of 20.0° with the horizontal. An average friction force of \(4.0 \times 10^3\) N impedes the car’s motion so that the car’s speed at the bottom of the driveway is 3.8 m/s. What is the length of the driveway?

4. A 75 kg bobsled is pushed along a horizontal surface by two athletes. After the bobsled is pushed a distance of 4.5 m starting from rest, its speed is 6.0 m/s. Find the magnitude of the net force on the bobsled.

5. A 10.0 kg crate is pulled up a rough incline with an initial speed of 1.5 m/s. The pulling force is 100.0 N parallel to the incline, which makes an angle of 15.0° with the horizontal. Assuming the coefficient of kinetic friction is 0.40 and the crate is pulled a distance of 7.5 m, find the following:
   - **a.** the work done by the Earth’s gravity on the crate
   - **b.** the work done by the force of friction on the crate
   - **c.** the work done by the puller on the crate
   - **d.** the change in kinetic energy of the crate
   - **e.** the speed of the crate after it is pulled 7.5 m
**POTENTIAL ENERGY**

Consider the balanced boulder shown in Figure 5-6. While the boulder remains balanced, it has no kinetic energy. If it becomes unbalanced, it will fall vertically to the desert floor and will gain kinetic energy as it falls. A similar example is an arrow ready to be released on a bent bow. Once the arrow is in flight, it will have kinetic energy.

**Potential energy is stored energy**

As we have seen, an object in motion has kinetic energy. But a system can have other forms of energy. The examples above describe a form of energy that is due to the position of an object in relation to other objects or to a reference point. **Potential energy** is present in an object that has the potential to move because of its position relative to some other location. Unlike kinetic energy, potential energy depends not only on the properties of an object but also on the object’s interaction with its environment.

**Gravitational potential energy depends on height from a zero level**

In Chapter 3 we saw how gravitational force influences the motion of a projectile. If an object is thrown up in the air, the force of gravity will cause the object to eventually fall back down, provided the object was not thrown too hard. Similarly, the force of gravity will cause the unbalanced boulder in the previous example to fall. The energy associated with an object due to the object’s position relative to a gravitational source is called **gravitational potential energy**.

Imagine an egg falling off a table. As it falls, it gains kinetic energy. But where does the egg’s kinetic energy come from? It comes from the gravitational potential energy that is associated with the egg’s initial position on the table relative to the floor. Gravitational potential energy can be determined using the following equation:

\[
PE_g = mgh
\]

**GRAVITATIONAL POTENTIAL ENERGY**

Gravitational potential energy = mass \( \times \) free-fall acceleration \( \times \) height

The SI unit for gravitational potential energy, like for kinetic energy, is the joule. Note that the definition for gravitational potential energy in this chapter is valid only when the free-fall acceleration is constant over the entire height, such as at any point near the Earth’s surface. Furthermore, gravitational potential energy depends on both the height and the free-fall acceleration, neither of which is a property of an object.

**Did you know?**

Another commonly used unit for energy besides the joule is the kilowatt-hour (kW-h). It is equal to \(3.6 \times 10^6\) J. Electrical energy is often measured in kilowatt-hours.
Suppose you drop a volleyball from a second-floor roof and it lands on the first-floor roof of an adjacent building (see Figure 5-7). If the height is measured from the ground, the gravitational potential energy is not zero because the ball is still above the ground. But if the height is measured from the first-floor roof, the potential energy is zero when the ball lands on the roof.

Gravitational potential energy is a result of an object’s position, so it must be measured relative to some zero level. The zero level is the vertical coordinate at which gravitational potential energy is defined to be zero. This zero level is arbitrary, but it is chosen to make a specific problem easier to solve. In many cases, the statement of the problem suggests what to use as a zero level.

**Elastic potential energy depends on distance compressed or stretched**

Imagine you are playing with a spring on a tabletop. You push a block into the spring, compressing the spring, and then release the block. The block slides across the tabletop. The kinetic energy of the block came from the stored energy in the stretched or compressed spring. This potential energy is called elastic potential energy. Elastic potential energy is stored in any compressed or stretched object, such as a spring or the stretched strings of a tennis racket or guitar.

The length of a spring when no external forces are acting on it is called the relaxed length of the spring. When an external force compresses or stretches the spring, elastic potential energy is stored in the spring. The amount of energy depends on the distance the spring is compressed or stretched from its relaxed length, as shown in Figure 5-8. Elastic potential energy can be determined using the following equation:

\[
PE_{\text{elastic}} = \frac{1}{2} kx^2
\]

The symbol \( k \) is called the spring constant, or force constant. For a flexible spring, the spring constant is small, whereas for a stiff spring, the spring constant is large. Spring constants have units of newtons divided by meters (N/m).
Potential energy

**PROBLEM**
A 70.0 kg stuntman is attached to a bungee cord with an unstretched length of 15.0 m. He jumps off a bridge spanning a river from a height of 50.0 m. When he finally stops, the cord has a stretched length of 44.0 m. Treat the stuntman as a point mass, and disregard the weight of the bungee cord. Assuming the spring constant of the bungee cord is 71.8 N/m, what is the total potential energy relative to the water when the man stops falling?

**SOLUTION**

1. **DEFINE**

   - Given: $m = 70.0 \text{ kg}$, $k = 71.8 \text{ N/m}$, $g = 9.81 \text{ m/s}^2$
   - $h = 50.0 \text{ m} - 44.0 \text{ m} = 6.0 \text{ m}$
   - $x = 44.0 \text{ m} - 15.0 \text{ m} = 29.0 \text{ m}$
   - $PE = 0 \text{ J}$ at river level

   - **Unknown:** $PE_{tot} = ?$

2. **PLAN**

   - **Diagram:**
     - 50.0 m
     - Relaxed length = 15.0 m
     - Stretched length = 44.0 m

3. **CALCULATE**

   - **Choose an equation(s) or situation:** The zero level for gravitational potential energy is chosen to be at the surface of the water. The total potential energy is the sum of the gravitational and elastic potential energy.
     - $PE_{tot} = PE_g + PE_{elastic}$
     - $PE_g = mgh$
     - $PE_{elastic} = \frac{1}{2}kx^2$

   - **Substitute values into the equations:**
     - $PE_g = (70.0 \text{ kg})(9.81 \text{ m/s}^2)(6.0 \text{ m}) = 4.1 \times 10^3 \text{ J}$
     - $PE_{elastic} = \frac{1}{2}(71.8 \text{ N/m})(29.0 \text{ m})^2 = 3.02 \times 10^4 \text{ J}$
     - $PE_{tot} = 4.1 \times 10^3 \text{ J} + 3.02 \times 10^4 \text{ J}$
     - $PE_{tot} = 3.43 \times 10^4 \text{ J}$

4. **EVALUATE**

   - One way to evaluate the answer is to make an order-of-magnitude estimate. The gravitational potential energy is on the order of $10^2 \text{ kg} \times 10 \text{ m/s}^2 \times 10 \text{ m} = 10^4 \text{ J}$. The elastic potential energy is on the order of $1 \times 10^2 \text{ N/m} \times 10^2 \text{ m}^2 = 10^4 \text{ J}$. Thus, the total potential energy should be on the order of $2 \times 10^4 \text{ J}$. This number is close to the actual answer.
**PRACTICE 5D**

**Potential energy**

1. A spring with a force constant of 5.2 N/m has a relaxed length of 2.45 m. When a mass is attached to the end of the spring and allowed to come to rest, the vertical length of the spring is 3.57 m. Calculate the elastic potential energy stored in the spring.

2. The staples inside a stapler are kept in place by a spring with a relaxed length of 0.115 m. If the spring constant is 51.0 N/m, how much elastic potential energy is stored in the spring when its length is 0.150 m?

3. A 40.0 kg child is in a swing that is attached to ropes 2.00 m long. Find the gravitational potential energy associated with the child relative to the child’s lowest position under the following conditions:
   a. when the ropes are horizontal
   b. when the ropes make a 30.0° angle with the vertical
   c. at the bottom of the circular arc

---

**Section Review**

1. What forms of energy are involved in the following situations?
   a. a bicycle coasting along a level road
   b. heating water
   c. throwing a football
   d. winding the mainspring of a clock

2. How do the forms of energy in item 1 differ from one another? Be sure to discuss mechanical versus nonmechanical energy, kinetic versus potential energy, and gravitational versus elastic potential energy.

3. A pinball bangs against a bumper, giving the ball a speed of 42 cm/s. If the ball has a mass of 50.0 g, what is the ball’s kinetic energy in joules?

4. A student slides a 0.75 kg textbook across a table, and it comes to rest after traveling 1.2 m. Given that the coefficient of kinetic friction between the book and the table is 0.34, use the work–kinetic energy theorem to find the book’s initial speed.

5. A spoon is raised 21.0 cm above a table. If the spoon and its contents have a mass of 30.0 g, what is the gravitational potential energy associated with the spoon at that height relative to the surface of the table?
Conservation of energy

CONSERVED QUANTITIES

When we say that something is conserved, we mean that it remains constant. If we have a certain amount of a conserved quantity at some instant of time, we will have the same amount of that quantity at a later time. This does not mean that the quantity cannot change form during that time, but if we consider all the forms that the quantity can take, we will find that we always have the same amount.

For example, the amount of money you now have is not a conserved quantity because it is likely to change over time. For the moment, however, let us assume that you do not spend the money you have, so your money is conserved. This means that if you have a dollar in your pocket, you will always have that same amount, although it may change form. One day it may be in the form of a bill. The next day you may have a hundred pennies, and the next day you may have an assortment of dimes and nickels. But when you total the change, you always have the equivalent of a dollar. It would be nice if money were like this, but of course it isn't. Because money is often acquired and spent, it is not a conserved quantity.

An example of a conserved quantity that you are already familiar with is mass. For instance, imagine that a light bulb is dropped on the floor and shatters into many pieces, as shown in Figure 5-9. No matter how the bulb shatters, the total mass of all of the pieces together is the same as the mass of the intact light bulb because mass is conserved.

MECHANICAL ENERGY

We have seen examples of objects that have either kinetic or potential energy. The description of the motion of many objects, however, often involves a combination of kinetic and potential energy as well as different forms of potential energy. Situations involving a combination of these different forms of energy can often be analyzed simply. For example, consider the motion of the different parts of a pendulum clock. The pendulum swings back and forth. At the highest point of its swing, there is only gravitational potential energy associated with its position. At other points in its swing, the pendulum is in motion, so it has kinetic energy as well. Elastic potential energy is also present in

Figure 5-9
The mass of the light bulb, whether whole or in pieces, is constant and thus conserved.
the many springs that are part of the inner workings of the clock. The motion of the pendulum in a clock is shown in Figure 5-10.

Analyzing situations involving kinetic, gravitational potential, and elastic potential energy is relatively simple. Unfortunately, analyzing situations involving other forms of energy—such as chemical potential energy—is not as easy.

We can ignore these other forms of energy if their influence is negligible or if they are not relevant to the situation being analyzed. In most situations that we are concerned with, these forms of energy are not involved in the motion of objects. In ignoring these other forms of energy, we will find it useful to define a quantity called **mechanical energy**. The mechanical energy is the sum of kinetic energy and all forms of potential energy associated with an object or group of objects.

\[ ME = KE + \Sigma PE \]

All energy, such as nuclear, chemical, internal, and electrical, that is not mechanical energy is classified as **nonmechanical energy**. Do not be confused by the term mechanical energy. It is not a unique form of energy. It is merely a way of classifying mechanical energy. It is not a unique form of energy. It is merely a way of classifying energy, as shown in Figure 5-11. As you learn about new forms of energy in this book, you will be able to add them to this chart.

**Mechanical energy is often conserved**

Imagine a 75 g egg located on a countertop 1.0 m above the ground. The egg is knocked off the edge and falls to the ground. Because the acceleration of the egg is constant as it falls, you can use the kinematic formulas from Chapter 2 to determine the speed of the egg and the distance the egg has fallen at any subsequent time. The distance fallen can then be subtracted from the initial height to find the height of the egg above the ground at any subsequent time. For example, after 0.10 s, the egg has a speed of 0.98 m/s and has fallen a distance of 0.05 m, corresponding to a height above the ground of 0.95 m. Once the egg’s speed and its height above the ground are known as a function of time, you can use what you have learned in this chapter to calculate both the kinetic energy of the egg and the gravitational potential energy associated with the position of the egg at any subsequent time. Adding the kinetic and potential energy gives the total mechanical energy at each position.
In the absence of friction, the total mechanical energy remains the same. This principle is called conservation of mechanical energy. Although the amount of mechanical energy is constant, mechanical energy itself can change form. For instance, consider the forms of energy for the falling egg, as shown in Table 5-1. As the egg falls, the potential energy is continuously converted into kinetic energy. If the egg were thrown up in the air, kinetic energy would be converted into gravitational potential energy. In either case, mechanical energy is conserved. The conservation of mechanical energy can be written symbolically as follows:

**CONSERVATION OF MECHANICAL ENERGY**

\[ ME_i = ME_f \]

*initial mechanical energy = final mechanical energy*

*(in the absence of friction)*

The mathematical expression for the conservation of mechanical energy depends on the forms of potential energy in a given problem. For instance, if the only force acting on an object is the force of gravity, as in the egg example, the conservation law can be written as follows:

\[ \frac{1}{2}mv_i^2 + mgh_i = \frac{1}{2}mv_f^2 + mgh_f \]

If other forces (except friction) are present, simply add the appropriate potential energy terms associated with each force. For instance, if the egg happened to compress or stretch a spring as it fell, the conservation law would also include an elastic potential energy term on each side of the equation.

In situations in which frictional forces are present, the principle of mechanical energy conservation no longer holds because kinetic energy is not simply converted to a form of potential energy. This special situation will be discussed more thoroughly on page 186.
SAMPLE PROBLEM 5E

Conservation of mechanical energy

PROBLEM
Starting from rest, a child zooms down a frictionless slide from an initial height of 3.00 m. What is her speed at the bottom of the slide? Assume she has a mass of 25.0 kg.

SOLUTION

1. DEFINE

Given:

\[ h = h_i = 3.00 \text{ m} \quad m = 25.0 \text{ kg} \quad v_i = 0.0 \text{ m/s} \]

\[ h_f = 0 \text{ m} \]

Unknown:

\[ v_f = ? \]

2. PLAN

Choose an equation(s) or situation: The slide is frictionless, so mechanical energy is conserved. Kinetic energy and gravitational potential energy are the only forms of energy present.

\[
KE = \frac{1}{2}mv^2 \\
PE = mgh
\]

The zero level chosen for gravitational potential energy is the bottom of the slide. Because the child ends at the zero level, the final gravitational potential energy is zero.

\[ PE_{g,f} = 0 \]

The initial gravitational potential energy at the top of the slide is

\[ PE_{g,i} = mgh_i = mgh \]

Because the child starts at rest, the initial kinetic energy at the top is zero.

\[ KE_i = 0 \]

Therefore, the final kinetic energy is as follows:

\[ KE_f = \frac{1}{2}mv^2_f \]

3. CALCULATE

Substitute values into the equations:

\[ PE_{g,i} = (25.0 \text{ kg})(9.81 \text{ m/s}^2)(3.00 \text{ m}) = 736 \text{ J} \]

\[ KE_f = \left(\frac{1}{2}\right)(25.0 \text{ kg})v^2_f \]

Now use the calculated quantities to evaluate the final velocity.

\[ ME_i = ME_f \]

\[ PE_i + KE_i = PE_f + KE_f \]

\[ 736 \text{ J} + 0 \text{ J} = 0 \text{ J} + (0.500)(25.0 \text{ kg})v^2_f \]

\[ v_f = 7.67 \text{ m/s} \]

CALCULATOR SOLUTION

Your calculator should give an answer of 7.67333, but because the answer is limited to three significant figures, it should be rounded to 7.67.
The expression for the square of the final speed can be written as follows:

\[ v_f^2 = \frac{2mgh}{mr} = 2gh \]

Notice that the masses cancel, so the final speed does not depend on the mass of the child. This result makes sense because the acceleration of an object due to gravity does not depend on the mass of the object.

**PRACTICE 5E**

**Conservation of mechanical energy**

1. A bird is flying with a speed of 18.0 m/s over water when it accidentally drops a 2.00 kg fish. If the altitude of the bird is 5.40 m and friction is disregarded, what is the speed of the fish when it hits the water?

2. A 755 N diver drops from a board 10.0 m above the water’s surface. Find the diver’s speed 5.00 m above the water’s surface. Then find the diver’s speed just before striking the water.

3. If the diver in item 2 leaves the board with an initial upward speed of 2.00 m/s, find the diver’s speed when striking the water.

4. An Olympic runner leaps over a hurdle. If the runner’s initial vertical speed is 2.2 m/s, how much will the runner’s center of mass be raised during the jump?

5. A pendulum bob is released from some initial height such that the speed of the bob at the bottom of the swing is 1.9 m/s. What is the initial height of the bob?

**Energy conservation occurs even when acceleration varies**

If the slope of the slide in Sample Problem 5E was constant, the acceleration along the slide would also be constant and the kinematic formulas from Chapter 2 could have been used to solve the problem. However, you do not know the shape of the slide. Thus, the acceleration may not be constant, and the kinematic formulas could not be used.

But now we can apply a new method to solve such a problem. Because the slide is frictionless, mechanical energy is conserved. We simply equate the initial mechanical energy to the final mechanical energy and ignore all the details in the middle. The shape of the slide is not a contributing factor to the system’s mechanical energy as long as friction can be ignored.
Mechanical energy is not conserved in the presence of friction

If you have ever used a sanding block to sand a rough surface, such as in Figure 5-12, you may have noticed that you had to keep applying a force to keep the block moving. The reason is that kinetic friction between the moving block and the surface causes the kinetic energy of the block to be converted into a nonmechanical form of energy. As you continue to exert a force on the block, you are replacing the kinetic energy that is lost because of kinetic friction. The observable result of this energy dissipation is that the sanding block and the tabletop become warmer.

In the presence of kinetic friction, nonmechanical energy is no longer negligible and mechanical energy is no longer conserved. This does not mean that energy in general is not conserved—total energy is always conserved. However, the mechanical energy is converted into forms of energy that are much more difficult to account for, and the mechanical energy is therefore considered to be “lost.”

Section Review

1. If the spring of a jack-in-the-box is compressed a distance of 8.00 cm from its relaxed length and then released, what is the speed of the toy head when the spring returns to its natural length? Assume the mass of the toy head is 50.0 g, the spring constant is 80.0 N/m, and the toy head moves only in the vertical direction. Also disregard the mass of the spring. (Hint: Remember that there are two forms of potential energy in the problem.)

2. You are designing a roller coaster in which a car will be pulled to the top of a hill of height $h$ and then, starting from a momentary rest, will be released to roll freely down the hill and toward the peak of the next hill, which is 1.1 times as high. Will your design be successful? Explain your answer.

3. Is conservation of mechanical energy likely to hold in these situations?
   a. a hockey puck sliding on a frictionless surface of ice
   b. a toy car rolling on a carpeted floor
   c. a baseball being thrown into the air

4. Physics in Action What parts of the kinetic sculpture on pp. 166 and 167 involve the conversion of one form of energy to another? Is mechanical energy conserved in these processes?
5-4 Power

RATE OF ENERGY TRANSFER

The rate at which work is done is called power. More generally, power is the rate of energy transfer by any method. Like the concepts of energy and work, power has a specific meaning in science that differs from its everyday meaning.

Imagine you are producing a play and you need to raise and lower the curtain between scenes in a specific amount of time. You decide to use a motor that will pull on a rope connected to the top of the curtain rod. Your assistant finds three motors but doesn’t know which one to use. One way to decide is to consider the power output of each motor.

If the work done on an object is \( W \) in a time interval \( \Delta t \), then the power delivered to the object over this time interval is written as follows:

\[
P = \frac{W}{\Delta t}
\]

power = work ÷ time interval

It is sometimes useful to rewrite this equation in an alternative form by substituting the definition of work into the definition of power.

\[
W = Fd
\]

\[
P = \frac{W}{\Delta t} = \frac{Fd}{\Delta t}
\]

The distance moved per unit time is just the speed of the object.

Conceptual Challenge

1. **Mountain roads**  Many mountain roads are built so that they zigzag up the mountain rather than go straight up toward the peak. Discuss the advantages of such a design from the viewpoint of energy conservation and power.

2. **Light bulbs**  A light bulb is described as having 60 watts. What’s wrong with this statement?
CONCEPT PREVIEW

Machines with different power ratings do the same work in different time intervals

In Sample Problem 5F, the three motors would lift the curtain at different rates because the power output for each motor is different. So each motor would do work on the curtain at different rates and would thus transfer energy to the curtain at different rates.

In a given amount of time, each motor would do different amounts of work on the curtain. The 5.5 kW motor would do the most amount of work in a given time, and the 1.0 kW motor would do the least amount of work in the same time. Yet all three motors would perform the same total amount of work in lifting the curtain. The important difference is that the more powerful motor could do the work in a shorter time interval.

SAMPLE PROBLEM 5F

Power

A 193 kg curtain needs to be raised 7.5 m, at constant speed, in as close to 5.0 s as possible. The power ratings for three motors are listed as 1.0 kW, 3.5 kW, and 5.5 kW. Which motor is best for the job?

Given: \( m = 193 \text{ kg} \), \( \Delta t = 5.0 \text{ s} \), \( d = 7.5 \text{ m} \)

Unknown: \( P = ? \)

Use the power equation from page 187.

\[
P = \frac{W}{\Delta t} = \frac{F \Delta d}{\Delta t} = \frac{mgd}{\Delta t} \]

\[
= \frac{(193 \text{ kg})(9.81 \text{ m/s}^2)(7.5 \text{ m})}{5.0 \text{ s}}
\]
Power

1. A $1.0 \times 10^3$ kg elevator carries a maximum load of 800.0 kg. A constant frictional force of $4.0 \times 10^3$ N retards the elevator's motion upward. What minimum power, in kilowatts, must the motor deliver to lift the fully loaded elevator at a constant speed of 3.00 m/s?

2. A car with a mass of $1.50 \times 10^3$ kg starts from rest and accelerates to a speed of 18.0 m/s in 12.0 s. Assume that the force of resistance remains constant at 400.0 N during this time. What is the average power developed by the car's engine?

3. A rain cloud contains $2.66 \times 10^7$ kg of water vapor. How long would it take for a 2.00 kW pump to raise the same amount of water to the cloud's altitude, 2.00 km?

4. How long does it take a 19 kW steam engine to do $6.8 \times 10^7$ J of work?

5. A $1.50 \times 10^3$ kg car accelerates uniformly from rest to 10.0 m/s in 3.00 s.
   a. What is the work done on the car in this time interval?
   b. What is the power delivered by the engine in this time interval?

Section Review

1. How are energy, time, and power related?

2. A 50.0 kg student climbs 5.00 m up a rope at a constant speed. If the student's power output is 200.0 W, how long does it take the student to climb the rope? How much work does the student do?

3. A motor-driven winch pulls the student in item 2 5.00 m up the rope at a constant speed of 1.25 m/s. How much power does the motor use in raising the student? How much work does the motor do on the student?
Einstein’s $E_R = mc^2$ is one of the most famous equations of the twentieth century. This equation was a surprise to Einstein, who discovered it through his work with relative velocity and kinetic energy.

**Relativistic kinetic energy**

In the “Relativistic addition of velocities” feature in Chapter 3, you learned how Einstein’s special theory of relativity modifies the classical addition of velocities. The classical equation for kinetic energy ($KE = \frac{1}{2}mv^2$) must also be modified for relativity. In 1905, Einstein derived a new equation for kinetic energy based on the principles of special relativity:

$$KE = mc^2 \sqrt{1 - \left(\frac{v^2}{c^2}\right)}$$

In this equation, $m$ is the mass of the object, $v$ is the velocity of the object, and $c$ is the speed of light. (Some texts distinguish between a rest mass, $m_0$, and a relativistic mass, $m$; in this book, relativistic mass is not used, and $m$ always refers to rest mass.) Although it isn’t immediately obvious, this equation reduces to the classical equation $KE = \frac{1}{2}mv^2$ for speeds that are small relative to the speed of light, as shown in Figure 5-14.

Einstein’s relativistic expression for kinetic energy has been confirmed by experiments in which electrons are accelerated to extremely high speeds in particle accelerators. In all cases, the experimental data correspond to Einstein’s equation rather than to the classical equation. Nonetheless, the difference between the two theories at low speeds (relative to $c$) is so minimal that the classical equation can be used in all such cases when the speed is much less than $c$.

**Figure 5-14**

This graph of kinetic energy versus velocity for both the classical and relativistic equations shows that the two theories are in agreement when $v$ is much less than $c$. Note that $v$ is always less than $c$ in the relativistic case.
Rest energy

The second term of Einstein’s equation for kinetic energy, \(-mc^2\), is required so that \(KE = 0\) when \(v = 0\). Note that this term is independent of velocity. This suggests that the total energy of an object equals its kinetic energy plus some additional form of energy equal to \(mc^2\). The mathematical expression of this additional energy is the familiar Einstein equation:

\[ E_R = mc^2 \]

This equation shows that an object has a certain amount of energy \((E_R)\), known as rest energy, simply by virtue of its mass. The rest energy of a body is equal to its mass, \(m\), multiplied by the speed of light squared, \(c^2\). Thus, the mass of a body is a measure of its rest energy. This equation is significant because rest energy is an aspect of special relativity that was not predicted by classical physics.

Experimental verification

The magnitude of the conversion factor between mass and rest energy \((c^2 = 9 \times 10^{16} \text{ m}^2/\text{s}^2)\) is so great that even a very small mass has a huge amount of rest energy. Nuclear reactions utilize this relationship by converting mass (rest energy) into other forms of energy. In nuclear fission, which is the energy source of nuclear power plants, the nucleus of an atom is split into two or more nuclei. Taken together, the mass of these nuclei is slightly less than the mass of the original nucleus, and a very large amount of energy is released. In typical nuclear reactions, about one-thousandth of the initial mass is converted from rest energy into other forms of energy. This change in mass, although very small, can be detected experimentally.

Another type of nuclear reaction that converts mass into energy is fusion, which is the source of energy for our sun and other stars. About 4.5 million tons of the sun’s mass is converted into other forms of energy every second. Fortunately, the sun has enough mass to last approximately 5 billion more years.

Most of the energy changes encountered in your typical experiences are much smaller than the energy changes that occur in nuclear reactions. As a result, the change in mass is even less than that observed in nuclear reactions. Such changes are far too small to be detected experimentally. Thus, for typical cases, the classical equation still holds, and mass and energy can be thought of as separate.

Before Einstein’s theory of relativity, conservation of energy and conservation of mass were regarded as two separate laws. The equivalence between mass and energy reveals that in fact these two laws are one. In the words of Einstein, “Prerelativity physics contains two conservation laws of fundamental importance. . . . Through relativity theory, they melt together into one principle.”

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KEY IDEAS

Section 5-1 Work
• Work is done on an object only when a net force acts on the object to displace it in the direction of a component of the net force.
• The amount of work done on an object is given by the following equation, where \( \theta \) is the angle between the applied force, \( F \), and the displacement of the object, \( d \):

\[
W = Fd \cos \theta
\]

Section 5-2 Energy
• Objects in motion have kinetic energy because of their mass and speed.
• The net work done on or by an object is equal to the change in the kinetic energy of the object.
• Potential energy is energy associated with an object’s position. Two forms of potential energy discussed in this chapter are gravitational potential energy and elastic potential energy.

Section 5-3 Conservation of energy
• Energy can change form but can never be created or destroyed.
• Mechanical energy is the total kinetic and potential energy present in a given situation.
• In the absence of friction, mechanical energy is conserved, so the amount of mechanical energy remains constant.

Section 5-4 Power
• Power is the rate at which work is done or the rate of energy transfer.
• Machines with different power ratings do the same amount of work in different time intervals.

KEY TERMS
elastic potential energy (p. 178)
gravitational potential energy (p. 177)
kinetic energy (p. 172)
mechanical energy (p. 182)
potential energy (p. 177)
power (p. 187)
spring constant (p. 178)
work (p. 168)
work–kinetic energy theorem (p. 174)

CHAPTER 5
Summary

Variable symbols

<table>
<thead>
<tr>
<th>Quantities</th>
<th>Units</th>
<th>Conversions</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W ) work</td>
<td>J</td>
<td>( = N \cdot m )</td>
</tr>
<tr>
<td>( KE ) kinetic energy</td>
<td>J</td>
<td>( = \text{kg} \cdot \text{m}^2/\text{s}^2 )</td>
</tr>
<tr>
<td>( PE_g ) gravitational potential energy</td>
<td>J</td>
<td>( = \text{kg} \cdot \text{m}^2/\text{s}^2 )</td>
</tr>
<tr>
<td>( PE_{elastic} ) elastic potential energy</td>
<td>J</td>
<td>( = \text{kg} \cdot \text{m}^2/\text{s}^2 )</td>
</tr>
<tr>
<td>( P ) power</td>
<td>W</td>
<td>( = J/\text{s} )</td>
</tr>
</tbody>
</table>
WORK

Review questions

1. Can the speed of an object change if the net work done on it is zero?

2. Discuss whether any work is being done by each of the following agents and, if so, whether the work is positive or negative.
   a. a chicken scratching the ground
   b. a person studying
   c. a crane lifting a bucket of concrete
   d. the force of gravity on the bucket in (c)

3. Furniture movers wish to load a truck using a ramp from the ground to the rear of the truck. One of the movers claims that less work would be required if the ramp’s length were increased, reducing its angle with the horizontal. Is this claim valid? Explain.

Conceptual questions

4. A pendulum swings back and forth, as shown in Figure 5-17. Does the tension force in the string do work on the pendulum bob? Does the force of gravity do work on the bob? Explain your answers.

5. The drivers of two identical cars heading toward each other apply the brakes at the same instant. The skid marks of one of the cars are twice as long as the skid marks of the other vehicle. Assuming that the brakes of both cars apply the same force, what conclusions can you draw about the motion of the cars?

6. When a punter kicks a football, is he doing work on the ball while his toe is in contact with it? Is he doing work on the ball after the ball loses contact with his toe? Are any forces doing work on the ball while the ball is in flight?

Practice problems

7. A person lifts a 4.5 kg cement block a vertical distance of 1.2 m and then carries the block horizontally a distance of 7.3 m. Determine the work done by the person and by the force of gravity in this process. (See Sample Problem 5A.)

8. A plane designed for vertical takeoff has a mass of $8.0 \times 10^3$ kg. Find the net work done by all forces on the plane as it accelerates upward at $1.0 \text{ m/s}^2$ through a distance of 30.0 m after starting from rest. (See Sample Problem 5A.)

9. A catcher “gives” with a baseball when catching it. If the baseball exerts a force of 475 N on the glove such that the glove is displaced 10.0 cm, how much work is done by the ball? (See Sample Problem 5A.)

10. A flight attendant pulls her 70.0 N flight bag a distance of 253 m along a level airport floor at a constant velocity. The force she exerts is 40.0 N at an angle of $52.0^\circ$ above the horizontal. Find the following:
   a. the work she does on the flight bag
   b. the work done by the force of friction on the flight bag
   c. the coefficient of kinetic friction between the flight bag and the floor
   (See Sample Problem 5A.)

ENERGY

Review questions

11. A person drops a ball from the top of a building while another person on the ground observes the ball’s motion. Will these two people always agree on the following?
   a. the ball’s potential energy
   b. the ball’s change in potential energy
   c. the ball’s kinetic energy
12. Can the kinetic energy of an object be negative? Explain your answer.

13. Can the gravitational potential energy of an object be negative? Explain your answer.

14. Two identical objects move with speeds of 5.0 m/s and 25.0 m/s. What is the ratio of their kinetic energies?

Conceptual questions

15. A satellite is in a circular orbit above Earth’s surface. Why is the work done on the satellite by the gravitational force zero? What does the work–kinetic energy theorem predict about the satellite’s speed?

16. A car traveling at 50.0 km/h skids a distance of 35 m after its brakes lock. Estimate how far it will skid if its brakes lock when its initial speed is 100.0 km/h. What happens to the car’s kinetic energy as it comes to rest?

17. Explain why more energy is needed to walk down stairs than to walk horizontally at the same speed.

18. How can the work–kinetic energy theorem explain why the force of sliding friction reduces the kinetic energy of a particle?

Practice problems

19. What is the kinetic energy of an automobile with a mass of 1250 kg traveling at a speed of 11 m/s? (See Sample Problem 5B.)

20. What speed would a fly with a mass of 0.55 g need in order to have the same kinetic energy as the automobile in item 19? (See Sample Problem 5B.)

21. A 50.0 kg diver steps off a diving board and drops straight down into the water. The water provides an average net force of resistance of 1500 N to the diver’s fall. If the diver comes to rest 5.0 m below the water’s surface, what is the total distance between the diving board and the diver’s stopping point underwater? (See Sample Problem 5C.)

22. In a circus performance, a monkey on a sled is given an initial speed of 4.0 m/s up a 25° incline. The combined mass of the monkey and the sled is 20.0 kg, and the coefficient of kinetic friction between the sled and the incline is 0.20. How far up the incline does the sled move? (See Sample Problem 5C.)

23. A 55 kg skier is at the top of a slope, as in Figure 5-18. At the initial point A, the skier is 10.0 m vertically above the final point B.
   a. Set the zero level for gravitational potential energy at B, and find the gravitational potential energy associated with the skier at A and at B. Then find the difference in potential energy between these two points.
   b. Repeat this problem with the zero level at point A.
   c. Repeat this problem with the zero level midway down the slope, at a height of 5.0 m. (See Sample Problem 5D.)

24. A 2.00 kg ball is attached to a ceiling by a 1.00 m long string. The height of the room is 3.00 m. What is the gravitational potential energy associated with the ball relative to each of the following?
   a. the ceiling
   b. the floor
   c. a point at the same elevation as the ball (See Sample Problem 5D.)

25. A spring has a force constant of 500.0 N/m. Show that the potential energy stored in the spring is as follows:
   a. 0.400 J when the spring is stretched 4.00 cm from equilibrium
   b. 0.225 J when the spring is compressed 3.00 cm from equilibrium
   c. zero when the spring is unstretched (See Sample Problem 5D.)
CONSERVATION OF MECHANICAL ENERGY

Review questions

26. Each of the following objects possesses energy. Which forms of energy are mechanical, which are nonmechanical, and which are a combination?
   a. glowing embers in a campfire
   b. a strong wind
   c. a swinging pendulum
   d. a person sitting on a mattress
   e. a rocket being launched into space

27. Discuss the energy transformations that occur during the pole-vault event shown in Figure 5-19. Disregard rotational motion and air resistance.

28. A bowling ball is suspended from the center of the ceiling of a lecture hall by a strong cord. The ball is drawn up to the tip of a lecturer’s nose at the front of the room and then released. If the lecturer remains stationary, explain why the lecturer is not struck by the ball on its return swing. Would this person be safe if the ball were given a slight push from its starting position at the person’s nose?

Conceptual questions

29. Discuss the work done and change in mechanical energy as an athlete does the following:
   a. lifts a weight
   b. holds the weight up in a fixed position
   c. lowers the weight slowly

30. A ball is thrown straight up. At what position is its kinetic energy at its maximum? At what position is gravitational potential energy at its maximum?

31. Advertisements for a toy ball once stated that it would rebound to a height greater than the height from which it was dropped. Is this possible?

32. A weight is connected to a spring that is suspended vertically from the ceiling. If the weight is displaced downward from its equilibrium position and released, it will oscillate up and down. How many forms of potential energy are involved? If air resistance and friction are disregarded, will the total mechanical energy be conserved? Explain.

Practice problems

33. A child and sled with a combined mass of 50.0 kg slide down a frictionless hill that is 7.34 m high. If the sled starts from rest, what is its speed at the bottom of the hill? (See Sample Problem 5E.)

34. Tarzan swings on a 30.0 m long vine initially inclined at an angle of 37.0° with the vertical. What is his speed at the bottom of the swing if he does the following?
   a. starts from rest
   b. pushes off with a speed of 4.00 m/s (See Sample Problem 5E.)

POWER

Practice problems

35. If an automobile engine delivers 50.0 hp of power, how much time will it take for the engine to do $6.40 \times 10^5$ J of work? (Hint: Note that one horsepower, 1 hp, is equal to 746 watts.) (See Sample Problem 5F.)

36. Water flows over a section of Niagara Falls at the rate of $1.2 \times 10^6$ kg/s and falls 50.0 m. How much power is generated by the falling water? (See Sample Problem 5F)
MIXED REVIEW

37. A 215 g particle is released from rest at point A inside a smooth hemispherical bowl of radius 30.0 cm, as shown in Figure 5-20. Calculate the following:
   a. the gravitational potential energy at A relative to B
   b. the particle’s kinetic energy at B
   c. the particle’s speed at B
   d. the potential energy and kinetic energy at C

38. A person doing a chin-up weighs 700.0 N, disregarding the weight of the arms. During the first 25.0 cm of the lift, each arm exerts an upward force of 355 N on the torso. If the upward movement starts from rest, what is the person’s speed at this point?

39. A 50.0 kg pole vaulter running at 10.0 m/s vaults over the bar. If the vaulter’s horizontal component of velocity over the bar is 1.0 m/s and air resistance is disregarded, how high was the jump?

40. An 80.0 N box of clothes is pulled 20.0 m up a 30.0° ramp by a force of 115 N that points along the ramp. If the coefficient of kinetic friction between the box and ramp is 0.22, calculate the change in the box’s kinetic energy.

41. A 98.0 N grocery cart is pushed 12.0 m along an aisle by a shopper who exerts a constant horizontal force of 40.0 N. If all frictional forces are neglected and the cart starts from rest, what is the grocery cart’s final speed?

42. Tarzan and Jane, whose total mass is 130.0 kg, start their swing on a 5.0 m long vine when the vine is at an angle of 30.0° with the horizontal. At the bottom of the arc, Jane, whose mass is 50.0 kg, releases the vine. What is the maximum height at which Tarzan can land on a branch after his swing continues? (Hint: Treat Tarzan’s and Jane’s energies as separate quantities.)

43. A 0.250 kg block on a vertical spring with a spring constant of \(5.00 \times 10^3\) N/m is pushed downward, compressing the spring 0.100 m. When released, the block leaves the spring and travels upward vertically. How high does it rise above the point of release?

44. Three identical balls, all with the same initial speed, are thrown by a juggling clown on a tightrope. The first ball is thrown horizontally, the second is thrown at some angle above the horizontal, and the third is thrown at some angle below the horizontal. Disregarding air resistance, describe the motions of the three balls, and compare the speeds of the balls as they reach the ground.

45. A 0.60 kg rubber ball has a speed of 2.0 m/s at point A and kinetic energy of 7.5 J at point B. Determine the following:
   a. the ball’s kinetic energy at A
   b. the ball’s speed at B
   c. the total work done on the ball as it moves from A to B

46. Starting from rest, a 5.0 kg block slides 2.5 m down a rough 30.0° incline in 2.0 s. Determine the following:
   a. the work done by the force of gravity
   b. the mechanical energy lost due to friction
   c. the work done by the normal force between the block and the incline

47. A 70.0 kg base runner begins his slide into second base while moving at a speed of 4.0 m/s. The coefficient of friction between his clothes and Earth is 0.70. He slides so that his speed is zero just as he reaches the base.
   a. How much mechanical energy is lost due to friction acting on the runner?
   b. How far does he slide?

48. A horizontal force of 150 N is used to push a 40.0 kg packing crate a distance of 6.00 m on a rough horizontal surface. If the crate moves with constant velocity, calculate the following:
   a. the work done by the force
   b. the coefficient of kinetic friction

49. A 5.00 g bullet moving at 600.0 m/s penetrates a tree trunk to a depth of 4.00 cm.
   a. Use work and energy considerations to find the magnitude of the force that stops the bullet.
   b. Assuming that the frictional force is constant, determine how much time elapses between the moment the bullet enters the tree and the moment the bullet stops moving.
50. A skier of mass 70.0 kg is pulled up a slope by a motor-driven cable. How much work is required to pull the skier 60.0 m up a 35° slope (assumed to be frictionless) at a constant speed of 2.0 m/s?

51. A $2.50 \times 10^3$ kg car requires 5.0 kJ of work to move from rest to some final speed. During this time, the car moves 25.0 m. Neglecting friction between the car and the road, find the following:
   a. the final speed
   b. the horizontal force exerted on the car

52. An acrobat on skis starts from rest 50.0 m above the ground on a frictionless track and flies off the track at a 45.0° angle above the horizontal and at a height of 10.0 m. Disregard air resistance.
   a. What is the skier’s speed when leaving the track?
   b. What is the maximum height attained?

53. Figure 5-21 is a graph of the gravitational potential energy and kinetic energy of a 75 g yo-yo as it moves up and down on its string. Use the graph to answer the following questions:
   a. By what amount does the mechanical energy of the yo-yo change after 6.0 s?
   b. What is the speed of the yo-yo after 4.5 s?
   c. What is the maximum height of the yo-yo?

54. A skier starts from rest at the top of a hill that is inclined at 10.5° with the horizontal. The hillside is 200.0 m long, and the coefficient of friction between the snow and the skis is 0.075. At the bottom of the hill, the snow is level and the coefficient of friction is unchanged. How far does the skier move along the horizontal portion of the snow before coming to rest?

55. Starting from rest, a 10.0 kg suitcase slides 3.00 m down a frictionless ramp inclined at 30.0° from the floor. The suitcase then slides an additional 5.00 m along the floor before coming to a stop. Determine the following:
   a. the speed of the suitcase at the bottom of the ramp
   b. the coefficient of kinetic friction between the suitcase and the floor
   c. the change in mechanical energy due to friction

56. An egg is dropped from a third-floor window and lands on a foam-rubber pad without breaking. If a 56.0 g egg falls 12.0 m from rest and the 5.00 cm thick foam pad stops it in 6.25 ms, by how much is the pad compressed? Assume constant upward acceleration as the egg compresses the foam-rubber pad. (Hint: Assume that the potential energy that the egg gains while the pad is being compressed is negligible.)

57. A 75 kg man jumps from a window 1.0 m above a sidewalk.
   a. What is his speed just before his feet strike the pavement?
   b. If the man jumps with his knees and ankles locked, the only cushion for his fall is approximately 0.50 cm in the pads of his feet. Calculate the magnitude of the average force exerted on him by the ground in this situation.

58. A projectile of mass 5.0 kg is shot horizontally with an initial speed of 17 m/s from a height of 25.0 m above a flat desert surface. For the instant before the projectile hits the surface, calculate each of the following quantities:
   a. the work done on the projectile by gravity
   b. the change in kinetic energy since the projectile was fired
   c. the final kinetic energy of the projectile

59. A light horizontal spring has a spring constant of 105 N/m. A 2.00 kg block is pressed against one end of the spring, compressing the spring 0.100 m. After the block is released, the block moves 0.250 m to the right before coming to rest. What is the coefficient of kinetic friction between the horizontal surface and the block?
60. A 5.0 kg block is pushed 3.0 m at a constant velocity up a vertical wall by a constant force applied at an angle of 30.0° with the horizontal, as shown in Figure 5-22. If the coefficient of kinetic friction between the block and the wall is 0.30, determine the following:

a. the work done by the force on the block
b. the work done by gravity on the block
c. the magnitude of the normal force between the block and the wall

61. A 25 kg child on a 2.0 m long swing is released from rest when the swing supports make an angle of 30.0° with the vertical.

a. What is the maximum potential energy associated with the child?
b. Disregarding friction, find the child’s speed at the lowest position.
c. What is the child’s total mechanical energy?
d. If the speed of the child at the lowest position is 2.00 m/s, what is the change in mechanical energy due to friction?

First, be certain the calculator is in degree mode by pressing \( \text{MODE} \ \uparrow \ \downarrow \ \leftarrow \ \rightarrow \ \text{ENTER} \).

Execute “Chap5” on the PRGM menu and press \( \text{ENTER} \) to begin the program. Enter the value for the net force applied (shown below) and press \( \text{ENTER} \). Then enter the value for the angle at which the force is applied and press \( \text{ENTER} \).

The calculator will provide the table of the work done in joules for various displacements in meters. Press \( \uparrow \) to scroll down through the table to find the displacement value you are looking for.

For each of the following situations, determine how much work is done on a sled by a person pulling on the sled on level ground.

b. a constant force of 225 N at an angle of 35° for a distance of 15 m
c. the same force at the same angle for a distance of 22 m
d. a constant force of 215 N at an angle of 25° for a distance of 15 m
e. the same force at the same angle for a distance of 22 m
f. If the forces in b and d were applied over the same time interval, in which case would the sled have more kinetic energy?

Press \( \text{ENTER} \) to stop viewing the table. Press \( \text{ENTER} \) again to enter a new value or \( \text{CLEAR} \) to end the program.

**Graphing calculators**

Refer to Appendix B for instructions on downloading programs for your calculator. The program “Chap5” builds a table of work done for various displacements.

Work done, as you learned earlier in this chapter, is described by the following equation:

\[ W_{\text{net}} = F_{\text{net}}d(\cos \theta) \]

The program “Chap5” stored on your graphing calculator makes use of the equation for work done. Once the “Chap5” program is executed, your calculator will ask for \( F \), the net force acting on the object, and \( \theta \), the angle at which the force acts. The graphing calculator will use the following equation to create the table of work done (\( Y_1 \)) for various displacements (\( X \)). Note that the relationships in this equation are the same as those in the work equation shown above.

\[ Y_1 = FX\cos(\theta) \]

a. An elephant applies a force of 2055 N against the front of a clown car. If the car pushes toward the elephant with a 3010 N force, what is the value of \( F \) in the equation above?
62. A ball of mass 522 g starts at rest and slides down a frictionless track, as shown in Figure 5-23. It leaves the track horizontally, striking the ground.

a. At what height above the ground does the ball start to move?

b. What is the speed of the ball when it leaves the track?

c. What is the speed of the ball when it hits the ground?

Alternative Assessment

Performance assessment

1. Design experiments for measuring your power output when doing push-ups, running up a flight of stairs, pushing a car, loading boxes onto a truck, throwing a baseball, or performing other energy-transferring activities. What data do you need to measure or calculate? Form groups to present and discuss your plans. If your teacher approves your plans, perform the experiments.

2. Investigate the amount of kinetic energy involved when your car’s speed is 60 km/h, 50 km/h, 40 km/h, 30 km/h, 20 km/h, and 10 km/h. (Hint: Find your car’s mass in the owner’s manual.) How much work does the brake system have to do to stop the car at each speed?

If the owner’s manual includes a table of braking distances at different speeds, determine the force the braking system must exert. Organize your findings in charts and graphs to study the questions and present your conclusions.

3. Investigate the energy transformations of your body as you swing on a swingset. Working with a partner, measure the height of the swing at the high and low points of your motion. What points involve a maximum gravitational potential energy? What points involve a maximum kinetic energy? For three other points in the path of the swing, calculate the gravitational potential energy, the kinetic energy, and the velocity. Organize your findings in bar graphs.

Portfolio projects

4. In order to save fuel, an airline executive recommended the following changes in the airlines’ largest jet flights:

a. restrict the weight of personal luggage

b. remove pillows, blankets, and magazines from the cabin

c. lower flight altitudes by 5 percent

d. reduce flying speeds by 5 percent

Research the information necessary to calculate the approximate kinetic and potential energy of a large passenger aircraft. Which of the measures described above would result in significant savings? What might be their other consequences? Summarize your conclusions in a presentation or report.

5. Make a chart of the kinetic energies your body can have. Measure your mass and speed when walking, running, sprinting, riding a bicycle, and driving a car. Make a poster graphically comparing these findings.

6. You are trying to find a way to bring electricity to a remote village in order to run a water-purifying device. A donor is willing to provide battery chargers that connect to bicycles. Assuming the water-purification device requires 18.6 kW•h daily, how many bicycles would a village need if a person can average 100 W while riding a bicycle? Is this a useful way to help the village? Evaluate your findings for strengths and weaknesses. Summarize your comments and suggestions in a letter to the donor.
**OBJECTIVES**
- Determine the spring constant of a spring.
- Calculate elastic potential energy.
- Calculate gravitational potential energy.
- Determine whether mechanical energy is conserved in an oscillating spring.

**MATERIALS LIST**
- ✔ meterstick
- ✔ set of masses
- ✔ support stand and clamp

**PROCEDURE**

**CBL AND SENSORS**
- ✔ C-clamp
- ✔ CBL
- ✔ CBL motion detector
- ✔ force sensor with CBL-DIN adapter
- ✔ graphing calculator with link cable
- ✔ lattice rod and right angle clamp
- ✔ spring
- ✔ tape
- ✔ wire letter basket

**HOOKE’S LAW APPARATUS**
- ✔ Hooke’s law apparatus
- ✔ rubber bands

**SAFETY**
- Tie back long hair, secure loose clothing, and remove loose jewelry to prevent their getting caught in moving or rotating parts.
- Attach masses securely. Perform this experiment in a clear area. Swinging or dropped masses can cause serious injury.

**CONSERVATION OF MECHANICAL ENERGY**
A mass on a spring will oscillate vertically when it is lifted to the length of the relaxed spring and released. The gravitational potential energy increases from a minimum at the lowest point to a maximum at the highest point. The elastic potential energy in the spring increases from a minimum at the highest point, where the spring is relaxed, to a maximum at the lowest point, where the spring is stretched. Because the mass is temporarily at rest, the kinetic energy of the mass is zero at the highest and lowest points. Thus, the total mechanical energy at those points is the sum of the elastic potential energy and the gravitational potential energy.

**PREPARATION**

1. Determine whether you will be using the CBL and sensors or the Hooke’s law apparatus to perform this experiment. Read the entire lab procedure for the appropriate method. Plan the steps you will take.

2. Prepare a data table in your lab notebook with four columns and seven rows. In the first row, label the first through fourth columns *Trial*, *Mass (kg)*, *Stretched spring (m)*, and *Force (N)*. In the first column, label the second through seventh rows 1, 2, 3, 4, 5, and 6. Above or below the data table, make a space to enter the value for *Initial spring (m)*.

3. Prepare a second data table in your lab notebook with three columns and seven rows. In the first row, label the first through third columns *Trial*, *Highest point (m)*, and *Lowest point (m)*. In the first column, label the second through seventh rows 1, 2, 3, 4, 5, and 6. Above or below the data table, make a space to enter the value for *Initial distance (m)*.

Hooke’s law apparatus procedure begins on page 203.
PROCEDURE

CBL AND SENSORS

Spring constant

4. Set up the CBL, graphing calculator, force sensor, and motion detector as shown in Figure 5-24.

5. Connect the CBL unit to the calculator with the unit-to-unit link cable using the ports located on each unit. Connect the force sensor to the CH1 port on the CBL unit, and connect the motion detector to the SONIC port.

6. Place the ring stand near the edge of the lab table. Use the C-clamp to clamp the base of the ring stand securely to the table. Position the clamp so that it protrudes as little as possible from the edge of the table. Attach the force sensor to the ring stand with the lattice rod and clamp.

7. Hook one end of the spring securely onto the force sensor. Attach the mass hanger securely to the spring. Tape the motion detector onto a lab stool directly below the force sensor so that the motion detector faces up. The motion detector should be more than 0.5 m away from the mass hanger on the bottom of the spring. Place the wire letter basket upside down over the motion detector to protect the sensor in case the masses fall.

8. Measure the distance from the floor to the top of the motion detector. Record this as Initial distance \((m)\) in your data table. This distance must remain constant throughout the lab.

9. Turn on the CBL and the graphing calculator. Start the program PHYSICS on the graphing calculator.

   a. Select option \(\textit{SET UP PROBES}\) from the MAIN MENU. Enter 2 for the number of probes. Select the motion detector, and then select the force sensor from the list. Your teacher will tell you what kind of force sensor you are using. Enter 1 for the channel number. Select \(\textit{USE STORED}\) from the CALIBRATION menu.

   b. Select the \(\textit{COLLECT DATA}\) option from the MAIN MENU. Select the \(\textit{TIME GRAPH}\) option from the DATA COLLECTION menu. Enter 0.02 for the time between samples. Enter 99 for the number of samples. Check the values you entered, and press ENTER. Press ENTER to continue. If you made a mistake entering the time values, select \(\textit{MODIFY SETUP}\), reenter the values, and continue.

Figure 5-24

Step 6: Attach the force sensor securely to the ring stand. Tape the force sensor lead to the stand to keep it out of the way while you work.

Step 7: Make sure the motion detector is directly below the hanging mass. Make sure the force sensor is far enough over the edge of the table so that the motion detector will read the position of the mass without interference from the tabletop.

Step 9: In this part of the lab, you will collect data to find the spring constant of the spring.

Step 14: In this part of the lab, you will oscillate a mass on the spring to find out whether mechanical energy is conserved.
10. Press ENTER on the graphing calculator to begin collecting data. The motion detector will begin to click as it collects data. When the motion detector stops clicking and the CBL shows DONE, press ENTER on the graphing calculator.

11. Select the SONIC option from the SELECT CHANNELS menu. Select DISTANCE to plot a graph of the distance in meters against the time in seconds. Press TRACE on the graphing calculator, and use the arrow keys to trace the graph. The distance (y) values should be fairly constant. Record this value as Initial spring (m) in your data table. Press ENTER on the graphing calculator. Select RETURN from the SELECT CHANNEL menu. Select RETURN again. Select YES from the REPEAT? menu.

12. Add enough mass to stretch the spring to about 1.25 times its original length. Record the mass in the first data table. Press ENTER on the graphing calculator. The motion detector will begin to click as it collects data. When the motion detector stops clicking and the CBL shows DONE, press ENTER on the graphing calculator.

   a. Select the ANALOG option from the SELECT CHANNELS menu to graph the force in newtons for each second. Use the arrow keys to trace the graph. The force (y) values should be fairly constant. Record this value in the first data table. Sketch the graph in your lab notebook. Press ENTER on the graphing calculator.

   b. Select the SONIC option from the SELECT CHANNELS menu. Select DISTANCE to plot a graph of the distance in meters against the time in seconds. Use the arrow keys to trace the graph. The distance (y) values should be fairly constant. Record this value in your data table. Sketch the graph in your lab notebook. Press ENTER on the graphing calculator.

13. Perform several trials with increasing masses. Record the mass, force, and distance measurements in the first data table for each trial.

Conservation of mechanical energy

14. Starting with a small mass and gradually increasing the mass in small increments, place masses on the mass hanger until you find a mass that will stretch the spring to about twice its original length. Record the mass in the second data table. Leave the mass in place on the hanger so that the spring remains stretched.

15. Raise the mass hanger until the mass hanger is at the zero position, the position where you measured the Initial spring measurement.

16. Press ENTER on the graphing calculator and simultaneously release the hanger gently to let the hanger drop. The motion detector will begin to click as it collects data. It is best to release the hanger from above and pull your hand out quickly to the side. If your hand passes between the hanger and the motion detector, it will seriously affect your measurements.

17. When the motion detector stops clicking and the CBL shows DONE, press ENTER on the graphing calculator so that the calculator will receive the lists of data collected by the CBL.

18. Select SONIC from the SELECT CHANNELS menu. Select DISTANCE to plot a graph of the distance in meters against the time in seconds. Press TRACE on the graphing calculator, and use the arrow keys to trace the graph. The graph should move between high points and low points to reflect the oscillation of the mass on the spring. Record the distance (y) values of the Highest point and Lowest point in your data table. Sketch the graph in your lab notebook. Press ENTER on the graphing calculator.

19. Select RETURN from the SELECT CHANNEL menu. Select RETURN again. Select YES from the REPEAT? menu to continue to perform more trials.

20. Perform several more trials, using a different mass for each trial. Record all data in your data table.

21. Clean up your work area. Put equipment away safely so that it is ready to be used again.

Analysis and Interpretation begins on page 204.
**PROCEDURE**

**HOKE’S LAW APPARATUS**

**Spring constant**

4. Set up the Hooke’s law apparatus as shown in Figure 5-25.

5. Place a rubber band around the scale at the initial resting position of the pointer, or adjust the scale or pan to read 0.0 cm. Record this position of the pointer as Initial spring (m). If you have set the scale at 0.0 cm, record 0.00 m as the initial spring position.

6. Measure the distance from the floor to the rubber band on the scale. Record this measurement in the second data table under Initial distance (m). This distance must remain constant throughout the lab.

7. Find a mass that will stretch the spring so that the pointer moves approximately one-quarter of the way down the scale.

8. Record the value of the mass. Also record the position of the pointer under Stretched spring in the data table.

9. Perform several trials with increasing masses until the spring stretches to the bottom of the scale. Record the mass and the position of the pointer for each trial.

**Conservation of mechanical energy**

10. Find a mass that will stretch the spring to about twice its original length. Record the mass in the second data table. Leave the mass in place on the pan.

11. Raise the pan until the pointer is at the zero position, the position where you measured the Initial spring measurement.

12. Gently release the pan to let the pan drop. Watch closely to identify the high and low points of the oscillation.

13. Use a rubber band to mark the lowest position to which the pan falls, as indicated by the pointer. This point is the lowest point of the oscillation. Record the values as Highest point and Lowest point in your data table.

14. Perform several more trials, using a different mass for each trial. Record all data in your data table.

15. Clean up your work area. Put equipment away safely so that it is ready to be used again.

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**Figure 5-25**

**Step 5**: If the scale is adjusted to read 0.0 cm, record 0.0 as the initial spring length in your data table.

**Step 7**: In this part of the lab, you will collect data to find the spring constant of the spring.

**Step 10**: In this part of the lab, you will oscillate a mass on the spring to find out whether mechanical energy is conserved.
ANALYSIS AND INTERPRETATION

Calculations and data analysis

1. Organizing data  Use your data from the first data table to calculate the elongation of the spring.

   a. CBL and sensors  Use the equation \( \text{elongation} = \text{initial spring} - \text{stretched spring} \).

   b. Hooke’s law apparatus  Use the equation \( \text{elongation} = \text{stretched spring} - \text{initial spring} \).

   c. Hooke’s law apparatus  Convert the masses used to measure the spring constant to their force equivalents.

2. Evaluating data  For each trial, calculate the spring constant using the equation \( \frac{\text{force}}{\text{elongation}} \). Take the average of all trials, and use this value as the spring constant.

3. Analyzing results  How would using a stiffer spring affect the value for the spring constant? How would this change affect the values for the elastic and gravitational potential energies?

4. Organizing data  Using your data from the second data table, calculate the elongation of the spring at the highest point of each trial.

   a. CBL and sensors  Use the equation \( \text{elongation} = \text{initial spring} - \text{highest point} \).

   b. Hooke’s law apparatus  Use the equation \( \text{elongation} = \text{highest point} - \text{initial spring} \).

5. Organizing data  Calculate the elongation of the spring at the lowest point of each trial.

   a. CBL and sensors  Use the equation \( \text{elongation} = \text{initial spring} - \text{lowest point} \).

   b. Hooke’s law apparatus  Use the equation \( \text{elongation} = \text{lowest point} - \text{initial spring} \).

6. Analyzing information  For each trial, calculate the elastic potential energy, \( PE_{\text{elastic}} = \frac{1}{2}kx^2 \), at the highest point of the oscillation.

7. Analyzing information  For each trial, calculate the elastic potential energy at the lowest point of the oscillation.

8. Analyzing results  Based on your calculations in items 6 and 7, where is the elastic potential energy greatest? Where is it the least? Explain these results in terms of the energy stored in the spring.
9. **Organizing data**  Calculate the height of the mass at the highest point of each trial.

   a. **CBL and sensors**  Use the equation \( \text{highest} = \text{initial distance} + \text{highest point} \).

   b. **Hooke’s law apparatus**  Use the equation \( \text{highest} = \text{initial distance} - \text{elongation} \).

10. **Organizing data**  Calculate the height of the mass at the lowest point of each trial.

   a. **CBL and sensors**  Use the equation \( \text{lowest} = \text{initial distance} + \text{lowest point} \).

   b. **Hooke’s law apparatus**  Use the equation \( \text{lowest} = \text{initial distance} - \text{elongation} \).

11. **Applying ideas**  For each trial, calculate the gravitational potential energy, \( \text{PE}_g = mgh \), at the highest point of the oscillation.

12. **Applying ideas**  For each trial, calculate the gravitational potential energy at the lowest point of the oscillation.

13. **Analyzing results**  According to your calculations in items 11 and 12, where is the gravitational potential energy the greatest? Where is it the least? Explain these results in terms of gravity and the height of the mass and the spring.

14. **Evaluating data**  Find the total potential energy at the top of the oscillation and at the bottom of the oscillation.

**Conclusions**

15. **Drawing conclusions**  Based on your data, is mechanical energy conserved in the oscillating mass on the spring? Explain how your data support your answers.

**Extensions**

16. **Extending ideas**  Use your data to find the midpoint of the oscillation for each trial. Calculate the gravitational potential energy and the elastic potential energy at the midpoint. Use the principle of the conservation of mechanical energy to find the kinetic energy and the speed of the mass at the midpoint.