

9.2 Mechanical Energy and Conservation of Energy

Section Learning Objectives

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

- Explain the law of conservation of energy in terms of kinetic and potential energy
- Perform calculations related to kinetic and potential energy. Apply the law of conservation of energy

Teacher Support

Teacher Support The learning objectives in this section will help your students master the following standards:

- (6) Science concepts. The student knows that changes occur within a physical system and applies the laws of conservation of energy and momentum. The student is expected to:
 - (B) investigate examples of kinetic and potential energy and their transformations;
 - (D) demonstrate and apply the laws of conservation of energy and conservation of momentum in one dimension.

In addition, the High School Physics Laboratory Manual addresses content in this section in the lab titled: Work and Energy, as well as the following standards:

- (6) Science concepts. The student knows that changes occur within a physical system and applies the laws of conservation of energy and momentum. The student is expected to:
 - (B) investigate examples of kinetic and potential energy and their transformations;
 - (D) demonstrate and apply the laws of conservation of energy and conservation of momentum in one dimension.

Section Key Terms

Teacher Support

Teacher Support [BL][OL] Begin by distinguishing mechanical energy from other forms of energy. Explain how the general definition of energy as the ability to do work makes perfect sense in terms of either form of mechanical energy. Discuss the law of conservation of energy and dispel any misconceptions related

to this law, such is the idea that moving objects just slow down naturally. Identify heat generated by friction as the usual explanation for apparent violations of the law.

[AL] Start a discussion about how other useful forms of energy also end up as wasted heat, such as light, sound, and electricity. Try to get students to understand heat and temperature at a molecular level. Explain that energy lost to friction is really transforming kinetic energy at the macroscopic level to kinetic energy at the atomic level.

Mechanical Energy and Conservation of Energy

We saw earlier that mechanical energy can be either potential or kinetic. In this section we will see how energy is transformed from one of these forms to the other. We will also see that, in a closed system, the sum of these forms of energy remains constant.

Quite a bit of potential energy is gained by a roller coaster car and its passengers when they are raised to the top of the first hill. Remember that the *potential* part of the term means that energy has been stored and can be used at another time. You will see that this stored energy can either be used to do work or can be transformed into kinetic energy. For example, when an object that has gravitational potential energy falls, its energy is converted to kinetic energy. Remember that both work and energy are expressed in joules.

Refer back to Figure 9.3. The amount of work required to raise the TV from point A to point B is equal to the amount of gravitational potential energy the TV gains from its height above the ground. This is generally true for any object raised above the ground. If all the work done on an object is used to raise the object above the ground, the amount work equals the object's gain in gravitational potential energy. However, note that because of the work done by friction, these energy-work transformations are never perfect. Friction causes the loss of some useful energy. In the discussions to follow, we will use the approximation that transformations are frictionless.

Now, let's look at the roller coaster in Figure 9.7. Work was done on the roller coaster to get it to the top of the first rise; at this point, the roller coaster has gravitational potential energy. It is moving slowly, so it also has a small amount of kinetic energy. As the car descends the first slope, its *PE* is converted to *KE*. At the low point much of the original *PE* has been transformed to *KE*, and speed is at a maximum. As the car moves up the next slope, some of the *KE* is transformed back into *PE* and the car slows down.

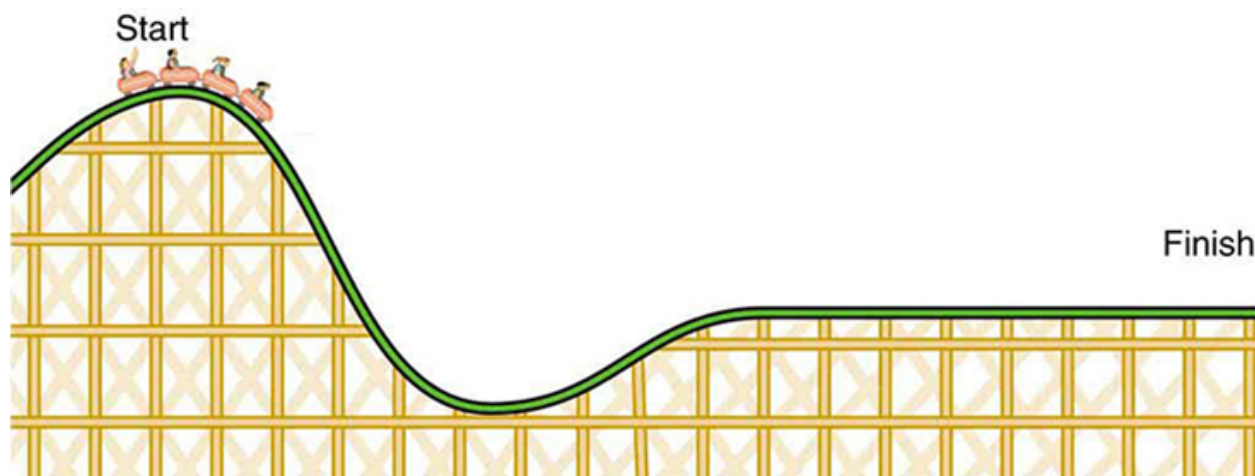


Figure 9.7 During this roller coaster ride, there are conversions between potential and kinetic energy.

Teacher Support

Teacher Support [OL][AL] Ask if definitions of energy make sense to the class, and try to bring out any expressions of confusions or misconceptions. Help them make the logical leap that, if energy is the ability to do work, it makes sense that it is expressed by the same unit of measurement. Ask students to name all the forms of energy they can. Ask if this helps them get a feel for the nature of energy. Ask if they have a problem seeing how some forms of energy, such as sunlight, can do work.

[BL][OL] You may want to introduce the concept of a reference point as the starting point of motion. Relate this to the origin of a coordinate grid.

[BL] Make it clear that energy is a different property with different units than either force or power.

[OL] Help students understand that the speed with which the TV is delivered is not part of the calculation of PE . It is assumed that the speed is constant. Any KE due to increases in delivery speed will be lost when motion stops.

[BL] Be sure there is a clear understanding of the distinction between kinetic and potential energy and between velocity and acceleration. Explain that the word *potential* means that the energy is available but it does not mean that it *has* to be used or *will* be used.

Virtual Physics

Energy Skate Park Basics This simulation shows how kinetic and potential energy are related, in a scenario similar to the roller coaster. Observe the changes in KE and PE by clicking on the bar graph boxes. Also try the three differently shaped skate parks. Drag the skater to the track to start the animation.

Click to view content

This simulation (<http://phet.colorado.edu/en/simulation/energy-skate-park-basics>) shows how kinetic and potential energy are related, in a scenario similar to the roller coaster. Observe the changes in KE and PE by clicking on the bar graph boxes. Also try the three differently shaped skate parks. Drag the skater to the track to start the animation. The bar graphs show how KE and PE are transformed back and forth. Which statement best explains what happens to the mechanical energy of the system as speed is increasing?

- a. The mechanical energy of the system increases, provided there is no loss of energy due to friction. The energy would transform to kinetic energy when the speed is increasing.
- b. The mechanical energy of the system remains constant provided there is no loss of energy due to friction. The energy would transform to kinetic energy when the speed is increasing.
- c. The mechanical energy of the system increases provided there is no loss of energy due to friction. The energy would transform to potential energy when the speed is increasing.
- d. The mechanical energy of the system remains constant provided there is no loss of energy due to friction. The energy would transform to potential energy when the speed is increasing.

Teacher Support

Teacher Support This animation shows the transformations between KE and PE and how speed varies in the process. Later we can refer back to the animation to see how friction converts some of the mechanical energy into heat and how total energy is conserved.

On an actual roller coaster, there are many ups and downs, and each of these is accompanied by transitions between kinetic and potential energy. Assume that no energy is lost to friction. At any point in the ride, the total mechanical energy is the same, and it is equal to the energy the car had at the top of the first rise. This is a result of the law of conservation of energy, which says that, in a closed system, total energy is conserved—that is, it is constant. Using subscripts 1 and 2 to represent initial and final energy, this law is expressed as

$$KE_1 + PE_1 = KE_2 + PE_2.$$

Either side equals the total mechanical energy. The phrase *in a closed system*

means we are assuming no energy is lost to the surroundings due to friction and air resistance. If we are making calculations on dense falling objects, this is a good assumption. For the roller coaster, this assumption introduces some inaccuracy to the calculation.

Calculations involving Mechanical Energy and Conservation of Energy

Tips For Success

When calculating work or energy, use units of meters for distance, newtons for force, kilograms for mass, and seconds for time. This will assure that the result is expressed in joules.

Teacher Support

Teacher Support [BL][OL] Impress upon the students the significant amount of work required to get a roller coaster car to the top of the first, highest point. Compare it to the amount of work it would take to walk to the top of the roller coaster. Ask students why they may feel tired if they had to walk or climb to the top of the roller coaster (they have to use energy to exert the force required to move their bodies upwards against the force of gravity). Check if students can correctly predict that the ratio of the mass of the car to a person's mass would be the ratio of work done and energy gained (for example, if the car's mass was 10 times a person's mass, the amount of work needed to move the car to the top of the hill would be 10 times the work needed to walk up the hill).

Watch Physics

Conservation of Energy This video discusses conversion of PE to KE and conservation of energy. The scenario is very similar to the roller coaster and the skate park. It is also a good explanation of the energy changes studied in the snap lab.

[Click to view content](#)

Teacher Support

Teacher Support Before showing the video, review all the equations involving kinetic and potential energy and conservation of energy. Also be sure the students have a qualitative understanding of the energy transformation taking place. Refer back to the snap lab and the simulation lab.

Watch Physics: Conservation of Energy. This video introduces the law of conservation of energy and explains how potential energy is converted to kinetic

energy.

[Click to view content](#)

Did you expect the speed at the bottom of the slope to be the same as when the object fell straight down? Which statement best explains why this is not exactly the case in real-life situations?

- a. The speed was the same in the scenario in the animation because the object was sliding on the ice, where there is large amount of friction. In real life, much of the mechanical energy is lost as heat caused by friction.
- b. The speed was the same in the scenario in the animation because the object was sliding on the ice, where there is small amount of friction. In real life, much of the mechanical energy is lost as heat caused by friction.
- c. The speed was the same in the scenario in the animation because the object was sliding on the ice, where there is large amount of friction. In real life, no mechanical energy is lost due to conservation of the mechanical energy.
- d. The speed was the same in the scenario in the animation because the object was sliding on the ice, where there is small amount of friction. In real life, no mechanical energy is lost due to conservation of the mechanical energy.

Worked Example

Applying the Law of Conservation of Energy A 10 kg rock falls from a 20 m cliff. What is the kinetic and potential energy when the rock has fallen 10 m?

Strategy

Choose the equation.

$$KE_1 + PE_1 = KE_2 + PE_2$$

9.4

$$KE = \frac{1}{2}mv^2; \quad PE = mgh$$

9.5

$$\frac{1}{2}mv_1^2 + mgh_1 = \frac{1}{2}mv_2^2 + mgh_2$$

9.6

List the knowns.

$$m = 10 \text{ kg}, \quad v_1 = 0, \quad g = 9.80$$

$$\frac{\text{m}}{\text{s}^2},$$

9.7

$$h_1 = 20 \text{ m}, h_2 = 10 \text{ m}$$

Identify the unknowns.

$$KE_2 \text{ and } PE_2$$

Substitute the known values into the equation and solve for the unknown variables.

Solution

$$PE_2 = mgh_2 = 10(9.80)10 = 980 \text{ J}$$

9.8

$$KE_2 = PE_2 - (KE_1 + PE_1) = 980 - \{[0 - [10(9.80)20]]\} = 980 \text{ J}$$

9.9

Discussion

Alternatively, conservation of energy equation could be solved for \mathbf{v}_2 and KE_2 could be calculated. Note that m could also be eliminated.

Tips For Success

Note that we can solve many problems involving conversion between KE and PE without knowing the mass of the object in question. This is because kinetic and potential energy are both proportional to the mass of the object. In a situation where $KE = PE$, we know that $mgh = (1/2)m\mathbf{v}^2$.

Dividing both sides by m and rearranging, we have the relationship

$$2gh = \mathbf{v}^2.$$

Teacher Support

Teacher Support Kinetic and potential energy are both proportional to the mass of the object. In a situation where $KE = PE$, we know that $mgh = (1/2)m\mathbf{v}^2$. Dividing both sides by m and rearranging, we get the relationship $2gh = \mathbf{v}^2$.

Practice Problems

5.

A child slides down a playground slide. If the slide is 3 m high and the child weighs 300 N, how much potential energy does the child have at the top of the slide? (Round g to

$$10 \text{ m/s}^2.$$

)

- a. 0 J
- b. 100 J
- c. 300 J
- d. 900 J

6.

A 0.2 kg apple on an apple tree has a potential energy of 10 J. It falls to the ground, converting all of its PE to kinetic energy. What is the velocity of the apple just before it hits the ground?

- a. 0 m/s
- b. 2 m/s
- c. 10 m/s
- d. 50 m/s

Snap Lab

Converting Potential Energy to Kinetic Energy In this activity, you will calculate the potential energy of an object and predict the object's speed when all that potential energy has been converted to kinetic energy. You will then check your prediction.

You will be dropping objects from a height. Be sure to stay a safe distance from the edge. Don't lean over the railing too far. Make sure that you do not drop objects into an area where people or vehicles pass by. Make sure that dropping objects will not cause damage.

You will need the following:

Materials for each pair of students:

- Four marbles (or similar small, dense objects)
- Stopwatch

Materials for class:

- Metric measuring tape long enough to measure the chosen height
- A scale

Instructions

Procedure

1. Work with a partner. Find and record the mass of four small, dense objects per group.
2. Choose a location where the objects can be safely dropped from a height of at least 15 meters. A bridge over water with a safe pedestrian walkway will work well.
3. Measure the distance the object will fall.
4. Calculate the potential energy of the object before you drop it using $PE = mgh = (9.80)mh$.

5. Predict the kinetic energy and velocity of the object when it lands using $PE = KE$ and so, $mgh = \frac{mv^2}{2}$; $\mathbf{v} = \sqrt{2(9.80)h} = 4.43\sqrt{h}$.
6. One partner drops the object while the other measures the time it takes to fall.
7. Take turns being the dropper and the timer until you have made four measurements.
8. Average your drop multiplied by and calculate the velocity of the object when it landed using $\mathbf{v} = \mathbf{a}t = \mathbf{g}t = (9.80)t$.
9. Compare your results to your prediction.

Teacher Support

Teacher Support Before students begin the lab, find the nearest location where objects can be dropped safely from a height of at least 15 m.

As students work through the lab, encourage lab partners to discuss their observations. Encourage them to discuss differences in results between partners. Ask if there is any confusion about the equations they are using and whether they seem valid based on what they have already learned about mechanical energy. Ask them to discuss the effect of air resistance and how density is related to that effect.

7.

Galileo's experiments proved that, contrary to popular belief, heavy objects do not fall faster than light objects. How do the equations you used support this fact?

- a. Heavy objects do not fall faster than the light objects because while conserving the mechanical energy of the system, the mass term gets cancelled and the velocity is independent of the mass. In real life, the variation in the velocity of the different objects is observed because of the non-zero air resistance.
- b. Heavy objects do not fall faster than the light objects because while conserving the mechanical energy of the system, the mass term does not get cancelled and the velocity is dependent on the mass. In real life, the variation in the velocity of the different objects is observed because of the non-zero air resistance.
- c. Heavy objects do not fall faster than the light objects because while conserving the mechanical energy the system, the mass term gets cancelled and the velocity is independent of the mass. In real life, the variation in the velocity of the different objects is observed because of zero air resistance.
- d. Heavy objects do not fall faster than the light objects because while conserving the mechanical energy of the system, the mass term does not get cancelled and the velocity is dependent on the mass. In real life, the variation in the velocity of the different objects is observed because of zero air resistance.

Check Your Understanding

8.

Describe the transformation between forms of mechanical energy that is happening to a falling skydiver before her parachute opens.

- a. Kinetic energy is being transformed into potential energy.
- b. Potential energy is being transformed into kinetic energy.
- c. Work is being transformed into kinetic energy.
- d. Kinetic energy is being transformed into work.

9.

True or false—If a rock is thrown into the air, the increase in the height would increase the rock's kinetic energy, and then the increase in the velocity as it falls to the ground would increase its potential energy.

- a. True
- b. False

10.

Identify equivalent terms for *stored energy* and *energy of motion*.

- a. Stored energy is potential energy, and energy of motion is kinetic energy.
- b. Energy of motion is potential energy, and stored energy is kinetic energy.
- c. Stored energy is the potential as well as the kinetic energy of the system.
- d. Energy of motion is the potential as well as the kinetic energy of the system.

Teacher Support

Teacher Support Use the Check Your Understanding questions to assess students' achievement of the section's learning objectives. If students are struggling with a specific objective, the Check Your Understanding will help identify which one and direct students to the relevant content.