# Energy and Energy Transfer
# Content Background Document

## 1. Introduction

Energy is all around us. We use it to heat and cool our homes, cook and cool our food, run appliances and machines, and communicate. Energy is necessary for water to evaporate, for clouds to form and rain to fall, for the wind to blow, for lightning to flash across the sky and the thunder to roll, for earthquakes, and for ocean tides. Energy is also necessary for plants and animals to grow, repair cells and tissues, and reproduce and survive.

You may know quite a bit about energy from everyday experiences. But could you define it? Do you know about how energy is measured and how it moves or is transferred from one place to another? Where does energy come from? Is it created when we turn on a light or fall off a ledge? Is it destroyed when we douse a flame or turn off the radio? Take a moment to think about your own understanding of energy.


**STOP AND THINK**

How would you define *energy*?
What examples of energy are around you at this very moment?

This document will challenge you to broaden and deepen your understanding of energy. It's designed to support and further your content learning about how scientists define, measure, and explain phenomena in the world related to energy. It will help you answer such questions as *Where does the energy in an object come from? How does energy flow from object to object or system to system? If energy is never destroyed, why do we need to conserve it?* The goal is for you to develop a conceptual understanding of these science ideas so you'll be able to more effectively teach elementary students about energy and energy transfer.

The content is written with you, the teacher, in mind. The subject matter is tied to the model lessons you'll be teaching, but the concepts are presented at a higher level to equip you with the tools and background you'll need to guide student learning. After all, teachers should know more than their students about the science ideas they'll be teaching!

## 2. What Is Energy?

If you look up the word *energy* in a dictionary, you'll find many different definitions. Energy can refer to vitality, vigor, or pep. That's the meaning you may have in mind when you buy an energy drink at the grocery story. The energy in the drink can keep you wide awake or make you jittery even if the drink contains no dietary Calories. (Calories are one way scientists measure energy.)

Some days as a teacher, you may find yourself thinking, *My students just have too much energy today!* Or you may think, *I just don't have enough energy to keep up with these children today!* But these aren't scientific references to energy. Scientists have a very specific way of defining this term:

**Energy is the ability to do work.**

To most of us, that definition isn't very helpful. It doesn't exactly match our experience of the energy we sense when we turn on the radio or see the flash of a lightning bolt. One of the things that makes energy so hard to understand is that it isn't a thing; it's a characteristic of an object or a system. We can't hold energy, but we can detect its presence by the way it causes something to happen (or has the potential to cause something to happen). We have ways of measuring energy, but energy isn't something we can place on a scale or in a beaker and measure. We can only measure the changes that energy causes (or has the potential to cause).

Because science ideas about energy are so abstract, it's essential to make them concrete for elementary students by using a definition-by-example approach to developing a concept of energy. Students will be asked to define and describe energy based on what they can detect with their senses—what they can see, hear, and feel—and they'll be asked to reason about the energy they can't see, such as the potential energy in an object at the top of a hill.


**STOP AND THINK**

What are some examples of energy in objects or systems?
How can you detect energy in your everyday life?
What names do you give the different ways energy is experienced in the world?

## 3. Forms of Energy

Energy is evident in the world in a variety of phenomena that we can detect with our senses. Examples include motion, light, sound, electricity, magnetic fields, and thermal energy (which you might call *heat*). Throughout history, scientists thought these forms of energy were unique, even as they acknowledged that one form could change to another form. As scientists explored the relationship between these different forms of energy, they came to understand how, at a microscopic level, there are really only two forms. Energy describes either some kind of *motion* or the *potential* for motion. For example, what is often described as *thermal energy* is actually the motion of molecules that you can feel. A substance whose molecules are moving faster is warmer, but when those same molecules are moving slower, the substance is cooler. Sound is the motion of particles that you can hear. For example, when a student hits a drum, this causes the drum head to vibrate (motion), which causes the air to vibrate (also motion), which causes your eardrum to vibrate (motion again), and your brain interprets that vibration as sound. The scientific term for the energy of motion is *kinetic energy*. So we could say that most of the energy we can detect is, at a fundamental level, kinetic energy.

In contrast, *potential energy* describes motion that *could* happen simply because of the position of one object relative to another object. An object at the top of a hill has potential energy because Earth's gravity is pulling it, and it could move down the hill. Potential energy is the interaction between the object at the top of the hill and the center of Earth. A stretched rubber band has potential energy because if you were to let it go, it could spring back into its relaxed position. In the same way, a battery has potential energy because of the position of particular chemicals (and their positive and negative charges) inside the battery. These chemicals and their charges are able to change to electrical current only when a circuit is complete. Even the food we eat has potential energy because of the position of atoms and electrons relative to one another.

Sometimes, when the position of atoms and electrons changes through a chemical reaction, energy is released, and your body can convert it to thermal energy, motion, and sound. *Potential energy* is the scientific term for energy relative to the orientation, position, or composition of two or more objects. More specifically, *gravitational potential energy* is the term scientists use for the energy of an object that is above the ground (the lowest surface of Earth) and can move because of the force of gravity. Rocks on a cliff, a roller coaster at the top of a hill, or a marble at the top of a ramp are all examples of an object with gravitational potential energy. Gravitational potential energy is the potential energy your students will learn about in this unit. However, to simplify this concept for students, we'll refer to it as *potential energy*. But keep in mind that potential energy in an object can be expressed in many different ways.

The *Next Generation Science Standards* (NGSS Lead States, 2013) emphasizes that it's misleading to differentiate the various forms of energy, such as motion and heat, because it implies that the energy in these forms is somehow different. In reality, all energy is energy; it's just detected in different ways. This idea, however, will be very difficult for elementary students to grasp.

In the 4th-grade RESPeCT lessons, we'll talk about the various ways we can detect energy or gather evidence of energy by describing sound, light, heat, and motion. Or we'll describe the potential energy of an object based on its position (e.g., an object sitting at the top of a hill).

### 4. Energy Can Be Transformed

Where does a roller coaster get the energy to plunge down a hill and move through loops and curves? When a track system carries the cars up an incline, the machinery of the roller coaster is performing work on the cars; in other words, it's *moving* the cars. Since these cars are moving up an incline, they have the *potential* to move back down.

If you've ever ridden a roller coaster, you know it feels as though you come to a complete stop at the top of the highest peak (see figure 1). Then in a matter of seconds, you race down the hill, moving faster and faster. At the top of the highest peak, you're motionless for a split second; in scientific terms, your *kinetic energy* is zero. Then you start moving again and pick up speed. You now have more and more kinetic energy because you're moving faster and faster. Where did this energy come from?

You've just experienced *energy transformation* on a roller coaster. As the machinery carried you up the highest hill, it was performing work on you and the car you were sitting in. As you rose above the ground, you were storing this work as potential energy. The higher you got off the ground, the more gravitational potential energy you had. Once you began your descent down the hill, your potential energy decreased because you were getting closer to the ground. At the same time, your kinetic energy and speed increased. As you raced down the hill, your potential energy transformed into kinetic energy. All the way down the hill, your potential energy was transforming into kinetic energy.

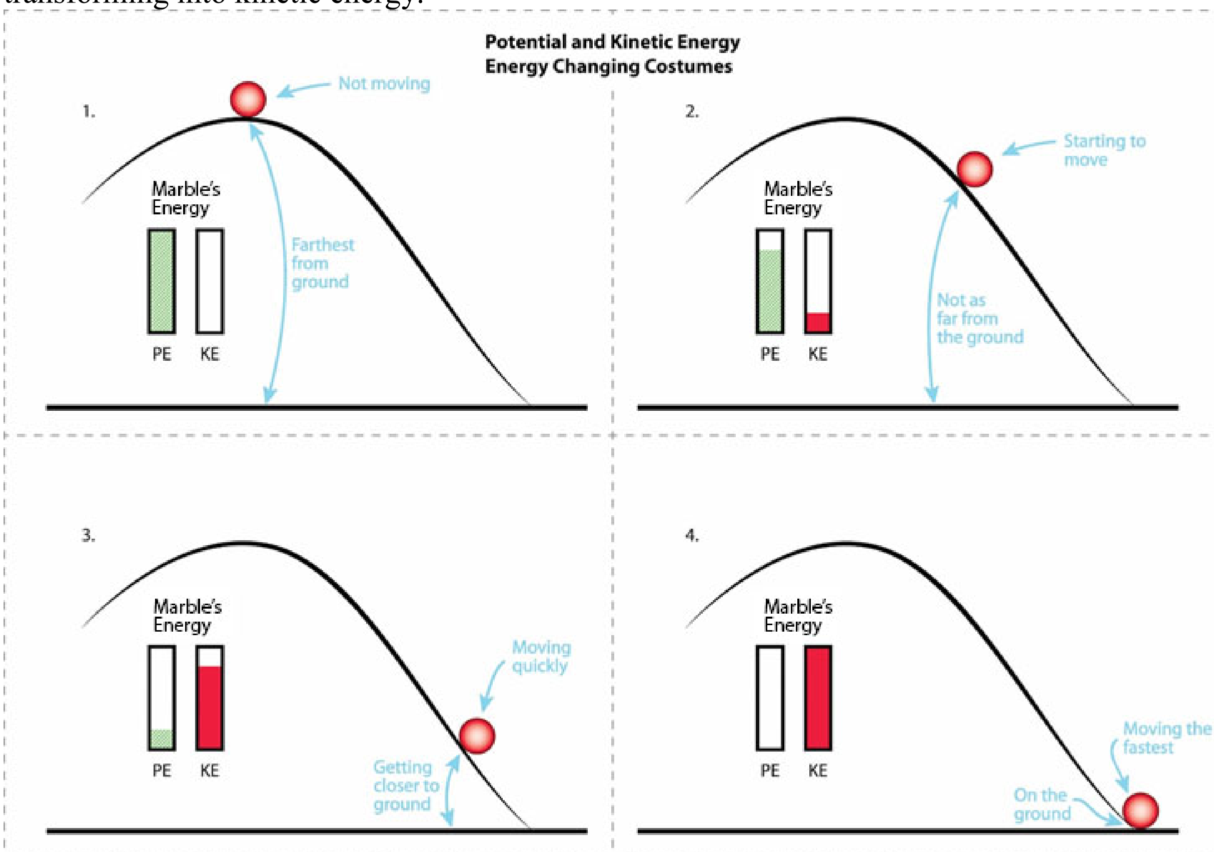



**Figure 1. Energy transformation:** This diagram illustrates how the potential energy of an object transforms into kinetic energy as the object moves down a hill.

You know that the higher the hill, the faster you'll be moving at the bottom of the hill. Once you arrive at the bottom of the hill, you're no longer off the ground, so the potential energy you started with at the top of the hill has been transformed into kinetic energy at the bottom. The more gravitational potential energy an object has (the higher it is off the ground), the faster it will move and the more kinetic energy it will have at the bottom of the hill. In this example, the bottom of the hill is our reference point for the location where the potential energy is zero. At this point, we can't get any lower on the ground. But if we were talking about a marble rolling down a ramp sitting on a table, we would need to be very clear about what we consider to be the lowest point where the potential energy is zero: the bottom of the ramp or the floor below the table. We get to choose the reference point that makes the most sense in any given system.

Does *all* of the potential energy transform to kinetic energy in the roller-coaster example? What do you think? Can you detect any other evidence of the roller coaster's energy besides its motion? You should be able to detect energy in many different ways. For example, you should hear the cars rattle and screech as they move along the tracks. And although it wouldn't be safe to do, if you felt the tracks after a roller coaster had raced over it, they would be very hot!


**STOP AND THINK**

Pick up a glass and set it on a table. Describe the energy of the glass. What happens to that energy when you accidentally knock the glass off the table, and it falls to the ground and breaks?

**5. Energy Can Be Measured**

How do you measure energy? You've heard terms like *decibels*, *volts*, *degrees Celsius* (or *Fahrenheit*), or *speed* that quantify sound, light, thermal energy, or motion. These aren't units of energy, but they all relate to the *amount* of energy in a system. These quantifiers can help you detect greater or lesser amounts of energy in many situations. Each quantifier, in its own way, is related to either some form of motion or some positional measure that indicates there is energy in a system.

You might be familiar with one way of measuring the potential energy stored in chemical bonds using a unit called *calories*. The number of calories tells us how much potential energy is in the food we eat or the gas we put in our cars. A scientist measuring the calories in a substance (like a potato chip or a gallon of gas) would say it's equivalent to the amount of energy necessary to raise 1 milliliter of water 1 degree Celsius. You may have conducted an experiment in your high school or college science class in which you burned a peanut or a potato chip by lighting it on fire under a beaker of water. Measuring the temperature change in the water gave you a rough idea of the amount of energy in the food you burned. This isn't a very efficient way to determine calories, because not all of the energy from the burning food is transferred to the water. Some of it warms the air, and some of it warms the beaker. But this experiment gets across the idea to students that calories can be used to measure the energy stored in food, and it can be linked to another way of measuring energy: determining a change in the temperature of water. As the temperature of the water increases, the average speed of the water particles also increases, and the water has more thermal energy.

Each of these methods is a way of quantifying energy by measuring the change it causes (or has the potential to cause). Fourth-grade students don't need to quantify energy to have some idea of how much is present in an object. Your students can use *qualitative* descriptors rather than scientific quantifiers to measure energy. For example, your students should be able to say that the faster an object is moving, the more energy it has. The brighter the light, the more energy it has. The louder the sound, the more energy it has. The hotter an object, the more energy it has.

However, qualitative descriptions of energy, such as *faster*, *brighter louder*, and *hotter*, can be misleading. In general, if two cups contain the same amount of tea, and one is hotter than the other, you can say that the cup of tea with a higher temperature has more energy than the cup of tea with a lower temperature. But what about a cup of tea at 75 degrees Celsius and a large bathtub filled with water at 75 degrees Celsius? Does the liquid in the cup and the bathtub have the same amount of energy? No! The bathtub holds more energy than the cup of tea at the same temperature because there are so many more liquid molecules in the bathtub. Since each molecule is traveling at the same average speed in both the bathtub and the teacup, the bathtub has more energy. In the same way, a marble that's rolling very fast has more energy than a marble that's rolling at a slower speed. But what about a marble rolling at 1 foot per second and a car driving down the street at 1 foot per second? Do they have the same amount of energy? No. The moving car has more energy than the rolling marble because it has a greater mass. The more mass there is at a certain speed, a certain voltage, or a certain temperature, the more energy there is.

**6. Energy Can't Be Created or Destroyed**

One of the most fundamental concepts regarding energy is that it can't be created or destroyed. This is called the *law of energy conservation*. This concept is also one of the most confusing and doesn't seem to match our experiences with energy in the real world. Let's say you fill your car's gas tank and then drive to work every day for a week. At the end of the week, the gas tank is empty and needs to be refilled. The gas may have been used up, but was the energy? Similarly, let's say you eat a fine and filling meal, and several hours later, you're ready for more. Have you used up that energy? If so, was it destroyed? Even more confusing, when you turn on a flashlight, you can see that the energy in the battery has changed into light, but what happens to that energy when you turn off the flashlight and the room goes dark? Where does the energy go? Does it disappear? When a marble rolls to the bottom of a ramp, it gains speed—and kinetic energy. When it stops rolling at the bottom, where does the energy go?

The best way to understand the idea that energy can't be created or destroyed is to take a much broader view of energy than we normally do. In his book *Dr. Art's Guide to Planet Earth*, Art Sussman describes it this way:

> Our local energy company charges us for the oil or natural gas that we use to heat our home. If we refuse to pay the bill and send a letter to the gas company arguing that the scientific law tells us that we did not use up the energy, what do you think the answer will be?
>
> The energy company might respond to our letter saying:
>
> *Thank you for reminding us about the law of energy conservation. Last month we supplied you with 200,000 units of energy that was contained in coal, oil, and natural gas. That energy has already left our planet as heat. If you can capture it and package it in a convenient form, we will buy it back from you. Otherwise, forget it.*

> When we heat our home, we pay attention only to the fuel and the heat in the house. The law of energy conservation follows the heat after it leaves the house, watches it escape through the atmosphere and spread into outer space, and notices that the heat continues to exist forever—it is never destroyed. Further, the amount of heat energy exactly equals the amount of chemical energy released from the fuel (such as gas, oil, or wood). The company does not bill us because we destroy energy. We pay the electric and gas bill because we use a particularly convenient form of stored energy and change the energy into a form that is much less useful. (Sussman, 2000)

**7. Where Does Energy Come From, and Where Does It Go?**

To better understand the law of energy conservation, think of Earth's energy as part of a very large balanced global system. Like a family budget in which money comes in and goes out each month (hopefully in about the same amounts), so, too, Earth has an energy budget. Most of the energy on Earth comes from the Sun. The rest—a tiny amount compared to the Sun's energy—comes from deep inside Earth. This heat is left over from Earth's creation billions of years ago and from the ongoing decay of radioactive materials deep within Earth's core. The surface derives energy from these two sources every minute of every day. The amount of energy that flows into Earth's surface from the Sun and Earth's core is exactly equal to the amount of energy that flows from the surface and atmosphere as heat into outer space.

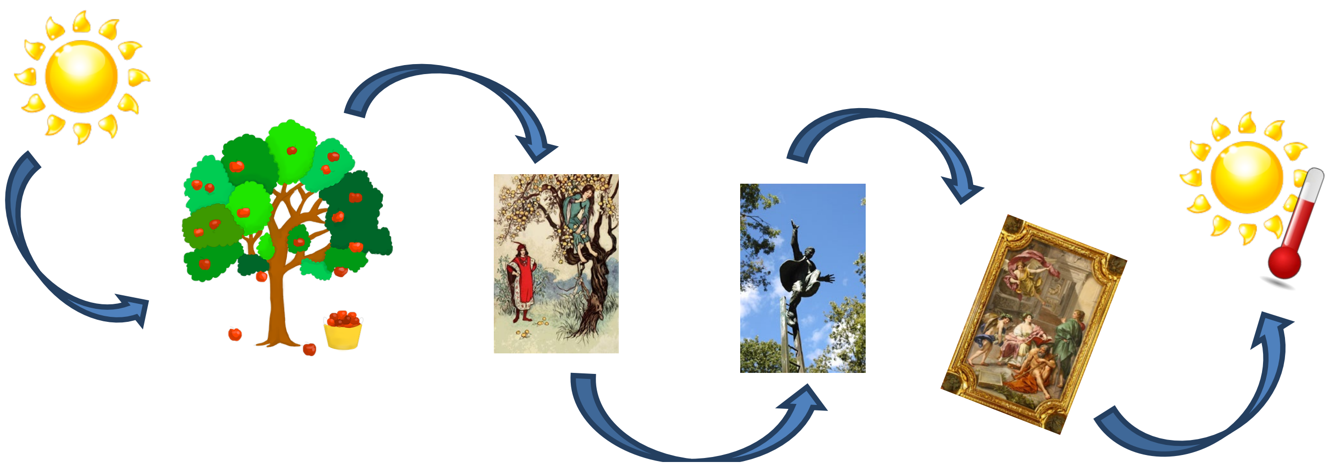
With this larger view in mind, we can begin to trace energy from the Sun (and to a much smaller degree from inside Earth) to the everyday experiences we have with energy. We can account for energy as it flows from the Sun to some part of Earth and then goes through a variety of changes and ultimately ends up as heat that escapes Earth's global system into outer space.

Here's a simple example that might help clarify this complex idea: Plants capture a very tiny amount of the sunlight that reaches Earth, and they convert it to chemical energy. We know this as the process of *photosynthesis*. Plants use water, carbon dioxide, and energy from the Sun to make basic building blocks for living things, and in the process, they store energy in chemical bonds that hold together the atoms and molecules that make up the plants. This chemical energy was described earlier as *potential energy* that is stored because of the position of the atoms and electrons relative to one another.

Imagine that this chemical energy, created by capturing the incoming energy of the Sun, is being stored in a bright, juicy, delicious apple. When you eat this apple for lunch, your body releases the energy in the apple and uses it in a variety of ways. Some of it turns into heat that radiates from your body and eventually escapes into outer space. Some of it is used as fuel that allows your muscles to move. If you use some of that energy to climb a ladder, you haven't destroyed it. Some of it was changed into potential energy, because now, at the top of the ladder with gravity pulling on you, you have the potential to fall to the ground with a big THUD. Because of your position off the ground, this potential energy (which came from climbing the ladder, which came from the food you ate, which came from the Sun) could once again turn into kinetic (motion) energy when you fall. Let's say you break a picture frame when you fall. Some of the energy from your fall knocked the picture frame over and then rearranged the pieces of wood and glass as the frame shattered into a hundred pieces.

After all this, is the energy gone? Was it finally used up? No! Remember that the law of energy conservation says that energy is never used up. Most of the energy ultimately turned into heat after friction between the frame, the air, and the ground, and the picture frame released this energy into the ground and air as heat, much as the heat from your home furnace eventually escapes into the atmosphere. This is why it's common to hear the phrase "Energy flows." Energy isn't created or destroyed but, rather, undergoes many changes and eventually transforms into heat that radiates into outer space.

We can visualize these changes in energy in the following diagram (figure 2):



Photos courtesy of Pixabay.com

**Figure 2.** Energy changes in a system

Or we could create a diagram to track how energy moves from object to object in this system.

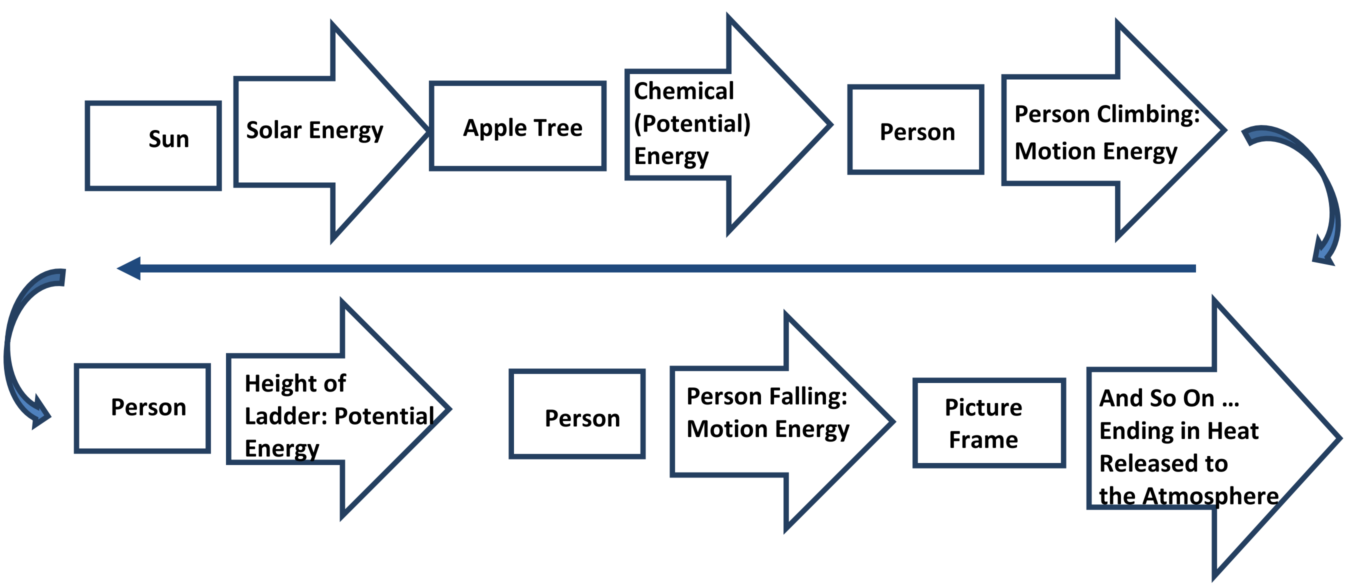



**Figure 3.** Tracking the movement of energy from object to object in a system

Figure 3 shows energy flowing from object to object and becoming evident in a variety of different ways. Following the arrows in this energy diagram gives us a cause-and-effect storyline for what happens to the Sun's energy, the energy from the broken picture frame, and beyond.

This diagram doesn't capture all of the energy changes. For example, it doesn't describe the heat energy that leaves your body as you climb the ladder, or the sound energy you hear when you land on the floor with a THUD. It doesn't describe the small amount of heat transferred to the ladder as friction holds your foot in place when you climb the ladder step by step. Describing each of these small energy interactions would make the diagram more complete (and complex) and would account for the ways energy is neither created nor destroyed but changes as objects (like your foot and the ladder) interact with each other.

**8. Energy Moves from Place to Place and Object to Object**

Energy can move from place to place or object to object when objects interact with one another. When objects collide, energy can be transferred from one object to another, thereby changing their motion. If you place a marble at the top of a ramp (see figure 4), the marble has potential energy. As it rolls down the ramp, it loses potential energy and gains kinetic energy. If that marble collides with another marble, the first marble slows down and eventually stops, and the second marble starts to move (and also eventually stops). The first marble transferred some of its kinetic energy to the second marble through the collision you could see. After the collision, the first marble slows down but continues rolling because it hasn't transferred all of its kinetic energy to the second marble; the fact that the first marble continues to roll indicates that it still has some kinetic energy. Both marbles eventually stop because of microscopic collisions that occur when the marbles roll across the floor. These tiny collisions, called *friction*, transfer energy from the marbles to the floor, causing an imperceptible motion in the molecules in the floor, which in turn raise the temperature of the floor very slightly. Other microscopic collisions take place between the moving marble and the air it passes through, resulting in a very small increase in air temperature. If you were to measure every transfer of energy caused by collisions between objects—from marble to marble, from the marble to the floor, and from the marble to the air—you would find that *exactly* the same amount of energy is transferred in these collisions as the amount of energy it took your body to lift the marble to the top of the ramp, which started the marble rolling in the first place! There it is again, the law of energy conservation.

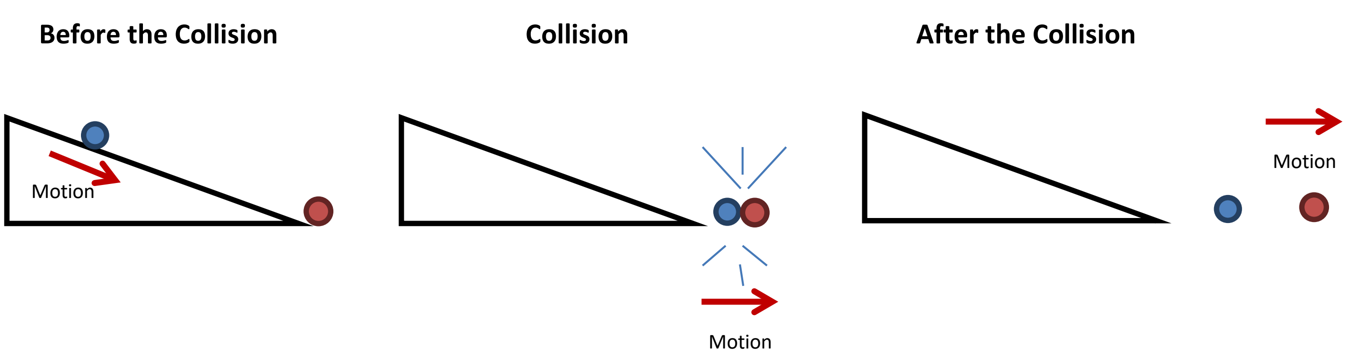



**Figure 4.** Energy transfer in a collision of two marbles

You can use the idea of the collision that occurred between the two marbles to better understand why a cup of hot tea sitting on a counter gets cold over time. Moving molecules of hot tea collide with air molecules. As these collisions take place, the molecules in the air move faster. In other words, they get warmer. The thermal energy of the tea is transferred to the air. You can feel this if you hold your hand over the cup of tea. These collisions continue until the cup of tea is the same temperature as the air around it. Collisions between the air molecules and the molecules of liquid in the teacup continue even after the tea has cooled. But now, the air molecules are transferring just as much energy to the tea as the tea is transferring to the air. The air molecules and the tea molecules reach equilibrium, so there is no longer any change in temperature from the continuing collisions. The energy leaving and entering each system is the same. Understanding how energy is transferred from marble to marble in a collision can help paint a visual image of what is happening at a microscopic level when objects collide that are much too small to see, such as the molecules in our cooling teacup.

Energy can move from place to place in other ways as well. Light transfers energy from place to place but doesn't need the collision of objects to do so. Magnetic and electrical fields also have the potential to move objects without collisions. Electrical currents can transfer energy from place to place, producing motion, sound, heat, or light. The electrical currents themselves may have been produced by transforming the energy of motion (steam turning a turbine or a stream flowing through a generator in a hydroelectric dam) into electrical energy. The law of energy conservation is at work again. Objects can transfer energy to each other or to their surroundings, but the energy can't be created or destroyed.

Because students have been told that energy doesn't disappear, they might have the impression that evidence of energy, such as heat, light, sound, and motion, is somehow lurking around after something happens, waiting to reappear somehow to be used again. In actuality, all energy transfers eventually result in energy changing to heat, which either leaves Earth's system or is reflected back to Earth.

**STOP AND THINK**

Can you think of an example of energy transferring from object to object in your everyday life? Consider turning on a radio, putting on your clothes, cooking dinner, or driving a car. Can you trace the energy interactions involved in these everyday activities back to the Sun? Can you trace the flow of energy to explain how it will eventually escape Earth as heat into outer space?

### 9. Using Systems to Think about the Conservation of Energy

Systems thinking is a useful alternative way to make sense of the conservation of energy. For example, consider the system involving a student and a hand-crank flashlight (figure 5).

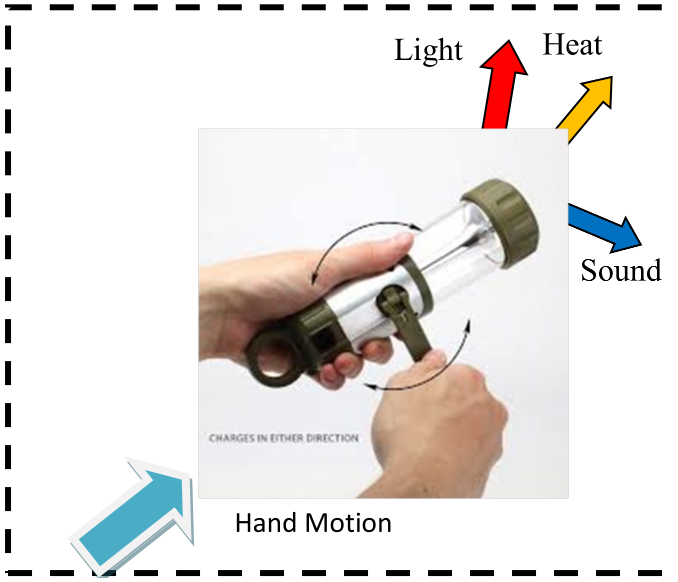



Photo courtesy of BSCS

**Figure 5.** System involving a student and a hand-crank flashlight

First, notice the dashed line forming a box around the flashlight. This line represents the imaginary boundary of the system. The system is composed of the student's hands and the flashlight, and the four arrows represent energy. These arrows are one way of showing how energy moves and changes within this system. In this example, the kinetic (motion) energy of the student's hand changes to light, heat, and sound. Within the system, energy transfers from object to object and transforms but isn't created or destroyed.

### 10. If Energy Is Never Destroyed, Why Do We Need to Conserve It?

We often talk about conserving energy, but this phrase has an entirely different meaning for scientists. Many people today are quite concerned about running out of the fossil fuels that are necessary in modern society for heating our homes and powering our cars. We don't want to run out of this valuable source of energy. But a *source* of energy isn't the same thing as energy. Fossil fuels are a source of energy; they have potential energy because of the position of their atoms and molecules. This energy can be released as the atoms and molecules are rearranged in a chemical reaction—a reaction that occurs when spark plugs fire and cause your car engine to run.

**STOP AND THINK**

How did the coal, natural gas, and oil that we use as common sources of fuel start with energy from the Sun? How do they ultimately end up as additional heat moving from Earth to outer space?

We know that coal, oil, and natural gas—sources of energy referred to as fossil fuels—come from materials that were once plants and animals on Earth. The energy held in the once-living matter of leaves, wood, muscles, and flesh was stored as it changed over time into oil, gas, and coal. In today's industrial age, we use these stored-energy resources much faster than the millions of years it took to create them. When we talk in everyday terms about conserving energy, we're really talking about the fact that we're using the stored energy in these fuel sources faster than they can be replenished by the natural processes that captured and stored energy from the Sun over millions—and billions—of years. That's one reason why people talk about relying more on "renewable" energy resources, such as solar energy, wind energy, hydroelectric energy, or geothermal energy. These sources of energy are newly generated every day and don't require many thousands, millions, or billions of years to turn into a usable form.

Now that you have a deeper understanding of energy and energy transfer, how would you answer the following questions?

- What is energy?
- Where does energy come from, and where does it go?
- How does energy flow from object to object or system to system?
- If energy is never destroyed, why do we need to conserve energy?

Do you have a better definition of *energy*, and can you explain some of the things you experience every day using this definition? Do you have a better understanding of what scientists mean by the conservation of energy and how this is different from your family conserving energy by turning out the lights when you leave a room? What new questions do you have about energy in the world around you? Keep track of these questions and talk to your colleagues and PD leaders to broaden, deepen, and enrich your energy knowledge throughout this year in the RESPeCT PD program.

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