GOD'S DESIGN®

# Physical World

Machines & Motion | Heat & Energy | Inventions & Technology

MASTERBOOKS CURRICULUM

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*God's Design® for the Physical World* is a complete life science curriculum for grades 3–8. The books in this series are designed for use in the Christian school and homeschool, and provide easy-to-use lessons that will encourage children to see God's hand in everything around them.

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# Machines & Motion

# Heat & Energy

# Inventions & Technology

# Welcome to GOD'S DESIGN®

## PHYSICAL WORLD

**You are about to start an exciting series** of lessons on physical science. *God's Design® for the Physical World* consists of: *Machines and Motion*, *Heat and Energy*, and *Inventions and Technology*. It will give you insight into how God designed and created our world and the universe in which we live.

No matter what grade you are in, third through eighth grade, you can use this book.

## 3rd–5th grade

Read the lesson.

- Do the activity in the light blue box (worksheets will be provided by your teacher).
- Test your knowledge by answering the **What did we learn?** questions.
- Assess your understanding by answering the **Taking it further** questions.

Be sure to read the special features and do the final project.

There are also unit quizzes and a final test to take.

## 6th–8th grade

Read the lesson.

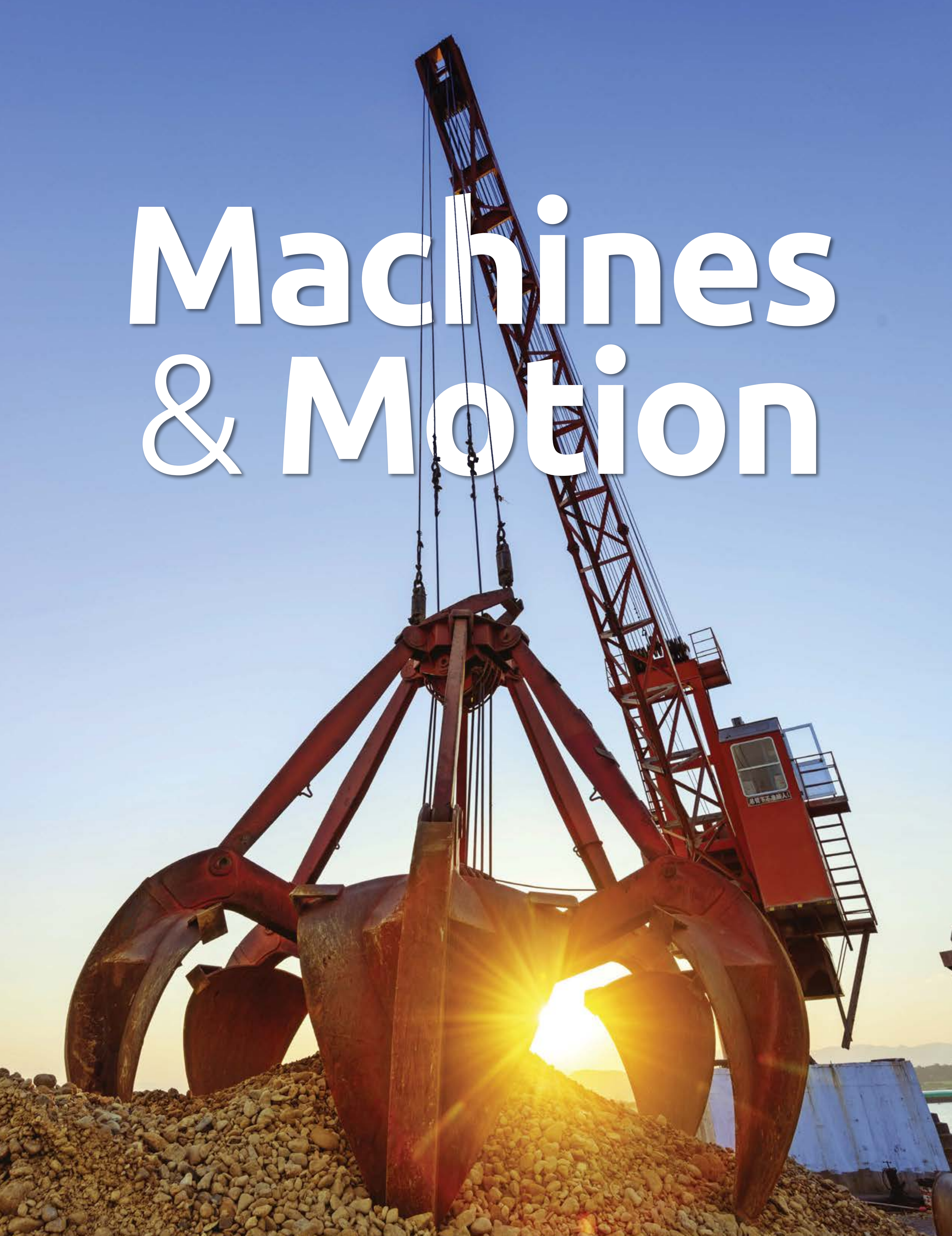
- Do the activity in the light blue box (worksheets will be provided by your teacher).
- Test your knowledge by answering the **What did we learn?** questions.
- Assess your understanding by answering the **Taking it further** questions.
- Do the Challenge section in the light green box. This part of the lesson will challenge you to do more advanced activities and learn additional interesting information.

Be sure to read the special features and do the final project.

There are also unit quizzes and a final test to take.

When you truly understand how God has designed everything in our universe to work together, then you will enjoy the world around you even more. So let's get started!

# Machines & Motion



# UNIT 1

# Mechanical Forces



- ◊ **Distinguish** between kinetic and potential energy.
- ◊ **Describe** how energy and matter are related to one another.
- ◊ **Explain** how momentum is conserved in collisions.
- ◊ **Describe** how force, work, power, and friction are related.



1

# Introduction to Mechanical Energy

Let's get moving!

## What is mechanical energy?

### Words to know:

mechanics

energy

mechanical energy

### Challenge words:

physical laws

**Sit very, very still. Try not to move at all.** Try to imagine what the world would be like if nothing moved. It would be a very boring place. Thankfully, God loves motion and created a universe full of movement. There are certainly times to be still. Psalm 46:10 says, "Be still, and know that I am God." However, the world around us is in constant motion.

The scientific study of motion is called **mechanics**, or the study of mechanical energy. In this book, you will learn about the different ways things move, why they move, and many ways to use that motion. Motion can be in a straight line or in an arc. If something is moving around an axis, it is said to have circular motion. Gravity plays a large role in how things move on earth. So we will be studying gravity in this book.

**Mechanical energy** is one of the most visible types of energy. Other types of energy include chemical, electrical, light, nuclear, and thermal (heat). Unlike chemical, nuclear, and electrical energy, which all take place on a microscopic and atomic level, mechanical energy is easily seen, measured, and tested. You see things and people move all around you.

Like all forms of **energy**, from a scientific viewpoint, mechanical energy is the ability to perform work. You perform work when you move something. You use mechanical energy in countless ways. You use it to brush your teeth and comb your hair. You use mechanical energy to ride a bike or mow the lawn. Mechanical energy swings a bat to hit a home run and allows you to slide down a snowy hill.

People have also learned to build machines that allow them to do much more work than they could without the machines. Using a machine to increase your ability to do work is called mechanical advantage. Mechanical advantage allows people to build bridges, skyscrapers, aircraft carriers, and airplanes. You will enjoy your study of mechanics—so let's get moving.

## Experimenting with motion

Let's examine the different ways that objects move. Complete the activities described on the "Types of Motion" worksheet. Record your observations and answer the questions as you do them.

## What did we learn?

- What is mechanics?
- What is energy?
- What are some ways that objects move?

## Taking it further

- What force greatly affects motion on earth?
- List three or more ways that mechanical advantage is being used around you.



## Physical laws

All objects in the universe move according to specific laws. For example, all objects obey the law of gravity. Everything on earth is pulled toward the center of the earth. We will be studying many of the scientific or **physical laws** that govern movements of objects. These physical laws are different from other types of laws.

1. Physical laws were not invented by men—they are only described by men.
2. Physical laws cannot be broken or changed.
3. Physical laws apply throughout the entire universe.
4. Physical laws were set in place by God.

Based on your observations throughout your life, write down what physical laws you think apply to moving objects.

Some of the things you have probably observed include objects always fall toward the earth, objects slow down if nothing is pushing them, objects only move in a circle if something is pulling them toward the center of the circle, when objects collide they change direction and one may slow down as the other speeds up. These are just a few observations that are governed by physical laws. We will learn much more about the laws that cause these things to happen in the lessons to come.

2

# Potential & Kinetic Energy

Ready to move

## How do potential and kinetic energy differ?

## Words to know:

kinetic energy

potential energy

**Energy can exist in one of two forms.** Either it is being used or it is being stored. Energy that is being used is called **kinetic energy**. Energy that is being stored is called **potential energy**.

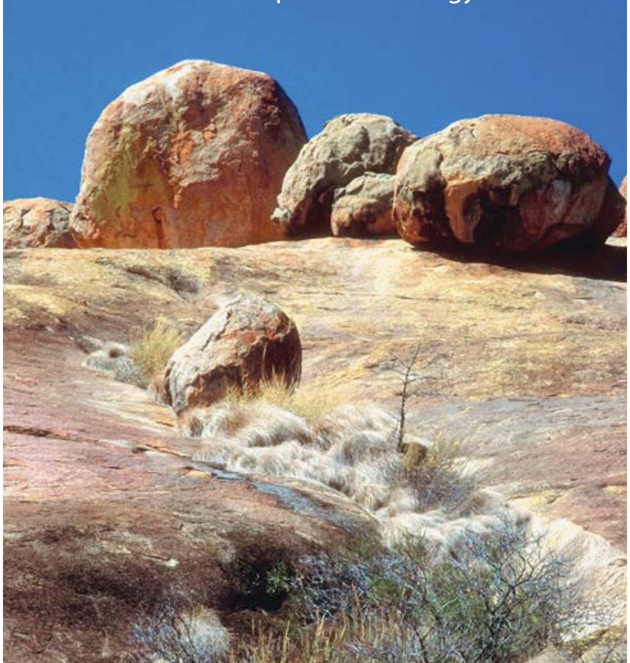
Mechanical energy is the energy of motion. Mechanical energy is being used if an object is moving. A moving object has kinetic energy. If an object is not moving, but has the ability to move, it has potential energy. For example, a rock at the top of a hill may not be moving, but it has the ability to roll down the hill so it has potential energy.

Potential energy is stored energy. It is related to an object's position or condition. In the previous example, the rock has potential energy because of its position at the top of the hill. Objects that are above ground level have potential energy because gravity is pulling down on them and giving them the potential to move downward—this is called gravitational potential energy.

Other objects have potential energy because of their condition. A stretched spring has potential energy because it is stretched beyond its natural resting position. Similarly, a compressed spring also has potential energy. In either case, if the force holding the spring is released, the spring will move back to its natural position, thus converting the potential energy into kinetic energy.

As you can see from the spring example, potential energy can be easily converted into kinetic energy. Another example of this conversion is a swinging pendulum. At the top of its swing, a pendulum is not moving so all it has is potential energy. During the swing, the pendulum has some potential and some kinetic energy. At the bottom of the

These boulders have potential energy.



## Conversion of energy

Hold a book a few inches above the table and drop it. Describe the conversion of energy that just occurred.

**Purpose:** To have fun with potential energy by making and playing a rubber band target game

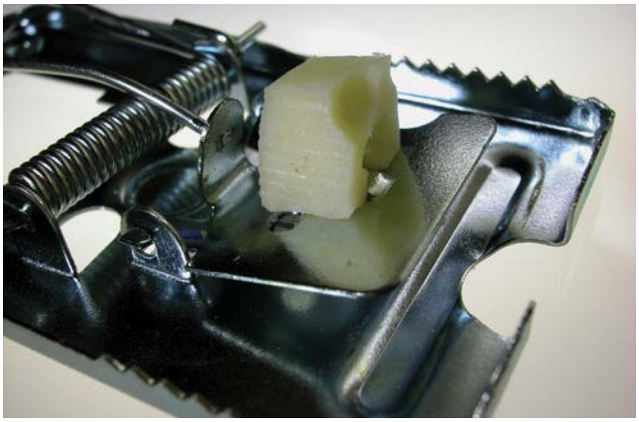
**Materials:** Paper or cardboard, drawing compass, pencil, markers, rubber bands

**Procedure:**

1. Use a compass to draw a target with several circles inside each other. If you don't have a compass, trace around several different sized round objects.
2. Label the circles with point numbers. For example, place a 100 inside the smallest circle. The next circle could be worth 50 points, the next largest circle could be 25 points, and so on.
3. Place the target across the room and take turns shooting rubber bands at the target.
4. Keep track of who gets the highest score.

Describe the conversion of energy that is occurring as you shoot a rubber band.

swing, all the potential energy has been converted into kinetic energy. Once the pendulum begins to move upward, the kinetic energy begins to be converted into potential energy again.



When a trap is set, the spring has potential energy.

## What did we learn?

- What is potential energy?
- What is kinetic energy?
- Give several examples of objects with potential energy.
- Give several examples of objects with kinetic energy.

## Taking it further

- Describe the transfer of energy between kinetic and potential energy that occurs during a roller coaster ride.
- Explain how a wind-up clock uses potential and mechanical energy.

## Fun Fact

Potential energy does not just refer to mechanical energy. Other forms of energy can be stored as well. Some other forms of potential energy include:

- A charged battery
- Chemical bonds
- Atomic bonds

These forms of potential energy are then changed into kinetic energy.

- The flow of electricity
- Breaking of chemical bonds can release heat
- Breaking of atomic bonds releases huge amounts of heat and light

# Calculating energy

The amount of gravitational potential energy contained in an object can be calculated if you know the object's mass and its height above the surface to which it would fall. The gravitational potential energy of an object is equal to its mass times its height times the acceleration due to gravity. This relationship is expressed in the equation, P.E. = mgh, where *P.E.* represents potential energy (in joules), *m* is mass (in kilograms; note: 1 kg = 2.2 pounds), *g* is acceleration due to gravity (in meters/second$^2$), and *h* is height (in meters). The acceleration due to gravity is the same for all objects on earth and is equal to 9.8 meters/second$^2$.

This book has a mass of approximately 0.4 kilograms. If you hold it 0.5 meters above the table its potential energy will be (0.4 kg)(9.8 m/s$^2$)(0.5m) which is 1.96 Joules. If you were to move the book away from the table so that it is at the same height but is now above the floor the book would now have a height of approximately 1.5 meters above the floor. This would change its potential energy to (0.4 kg)(9.8 m/s$^2$)(1.5m) or 5.88 Joules. Gravitational potential energy depends on the height the object is above a surface.

Kinetic energy can be calculated by the equation K.E. = ½ mv$^2$. Like potential energy, kinetic energy is measured in Joules. And in this equation, *m* is mass in kilograms and *v* is velocity in meters per second. If you throw a 2-kilogram softball at a velocity of 5 meters per second, its kinetic energy will be (0.5)(2kg)(5 m/s)$^2$, which is equal to 25 Joules. If you throw the same ball at a speed of 10 meters per second, its kinetic energy would be (0.5)(2kg)(10 m/s)$^2$, which is 100 Joules.

Kinetic energy increases four times when the velocity is doubled because velocity is squared in the equation. This is important to understand. A car traveling at 80 m/s has four times as much kinetic energy as a car traveling at 40 m/s and would require much more than twice as much distance to stop. This is why it is important to allow more distance between your car and the car in front of you when you are traveling faster.

To gain some practice using these equations, complete the "Calculating Energy" worksheet. For a fun project, design a boat, car, or other object that uses the potential energy stored in a stretched rubber band as its power source.

# 3

# Conservation of Energy

Can it be used up?



## How are mass and energy related?

### Words to know:

law of conservation of energy

first law of thermodynamics

law of conservation of mass

**As you learned in the previous lesson,** potential energy is easily converted into kinetic energy, and kinetic energy is easily converted into potential energy. We see examples of this energy conversion all around us, from elevators and escalators to clocks and scales. Not only does potential energy get converted into kinetic energy, but different forms of energy are converted into other forms. For example, when you eat food you are adding chemical energy to your body. That chemical energy is converted into heat and mechanical energy. When you use a telephone, the sound energy in your voice is converted into electricity on your end and the electricity is converted back into sound energy on the other end of the call.

Scientists have studied the changing forms of energy for hundreds of years and have discovered that although energy frequently changes form, it does not get used up. This is called conservation of energy. Conservation of energy is a very important concept. If even a little bit of energy were used up every time energy changed form, in a short period of time all of the energy would be gone and this world would cease to exist. However, God designed the world so that energy is conserved.

The definition of the **law of conservation of energy** states that energy cannot be created or destroyed; it can only change form. This leads to a very important question. If energy cannot be created by any known natural processes, where did all

### Fun Fact

Electrical energy is the most versatile form of energy. It can easily be converted into most other forms of energy. What forms of energy is electricity being converted into in your house? Other forms of energy are not as useful. Heat from friction is considered waste heat because it cannot easily be captured and turned into any other form of energy. Similarly, most sound and light energy eventually become heat and cannot be reused. So although the energy still exists, it may not exist in a useful form.

the energy around us come from? There are various ideas about how the universe came to be the way it is. Many evolutionists claim that the stars and planets were formed through a process that took billions of years. But none of the evolutionary ideas can explain where the energy came from to begin with. On the other hand, the Bible explains that God spoke the universe into existence. He put all of the energy into the universe to begin with, and then designed it so that the energy could not be destroyed.

Albert Einstein and other scientists discovered that there is a close relationship between mass and energy. This relationship is expressed in the famous equation $E=mc^2$, where $E$ is energy, $m$ is mass, and $c$ is the speed of light. This means that all mass has energy, and all energy has mass. Mass and energy are each conserved in any reaction. The **first law of thermodynamics** is a generalized form of the law of conservation of energy. It states that in a closed system, energy can neither be created nor destroyed, only transformed or transferred. In other words, energy is conserved.

Scientists have discovered a similar law relating to mass. When chemical reactions take place, the atoms are rearranged, but no atoms are destroyed or lost. None of the mass is lost in these reactions. The **law of conservation of mass** states that matter cannot be created or destroyed; it can only change forms.

God created all matter and energy, and then set physical laws in place so that the universe is the ultimate recycling machine.



## What did we learn?

- What is the law of conservation of energy?
- What is the first law of thermodynamics?
- What is the law of conservation of mass?
- What happens to mechanical energy that causes a moving object to slow down and eventually stop?

## Taking it further

- If we lived in a world with no friction, what would happen to a toy car when you pushed it across the floor?
- What famous equation did Einstein publish that explains how mass and energy are related?
- Based on your observations, what is the most likely final form of energy?

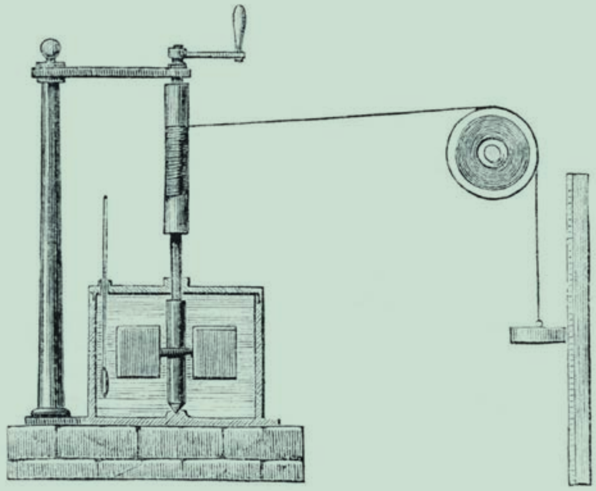
## Energy transformations

Complete the "Energy Conservation" worksheet, and then discuss the answers.

# Joule's experiment

James Joule was the first scientist to show that heat is a form of energy that can be converted from mechanical energy. Joule's experiment of the 1840s consisted of a brass paddle wheel stirring water in a copper vessel. The paddle wheel was turned by falling weights. As the paddle wheel turned, the temperature of the water rose by an amount that depended on how far the weights fell. Different weights produced different changes in temperature. Joule showed a direct relationship between the mechanical force of each weight and the change in the temperature of the water. Energy was conserved in this experiment.

Explain how the movement of the paddles increases the temperature of the water.



4

# Conservation of Momentum

Moving masses

Mechanical Forces

## What is momentum?

## Words to know:

momentum

law of conservation of momentum

**Moving objects are said to have momen-**tum. Momentum is a function of an object's mass and its velocity. Because velocity is speed in a particular direction, **momentum** is movement in a particular direction. If two objects have the same mass and are moving in the same direction, the object with the greater velocity will have the greater momentum. As an object's velocity increases, so does its momentum.

Similarly, if two objects are traveling at the same velocity, the object with the greater mass will have the greater momentum. For example, if a small car and a tractor-trailer are both traveling down the highway at 60 mph (97 km/h), the truck will have significantly more momentum than the car because it has more mass. This is why a tractor-trailer requires a much longer stopping distance than a small car.

In a given isolated system, momentum must be conserved. This means that if two objects are traveling toward each other and collide, the total momentum after the collision must be the same as the total momentum before the collision. We observe this happening all around us but may not recognize this as a law of physics. Consider the batter in a baseball game. As he swings the bat, it has a certain mass and velocity so it has momentum. The pitcher pitches the ball. As the ball is moving toward the batter, it has mass and velocity so it also has momentum. As the ball connects with the bat, most of the momentum from the bat is transferred to the ball, causing it to change direction and increase in velocity. The rest of the bat's momentum carries it through the completion of the swing. The **law of conservation of momentum** states that changes of momentum in an isolated system must be equal. Therefore, if the momentum of the bat and the ball were added up just prior to the hit and just after the hit, they would have to be equal. After the hit, the ball has more momentum and the bat has less, but the total amount is the same. The amount of momentum gained by the ball is equal to the amount of momentum lost by the bat.

Because momentum is a function of mass and velocity, if a heavier object hits a lighter object, the lighter object will be accelerated more than the heavier object decelerates. The baseball bat has more mass than the ball, so it causes the ball

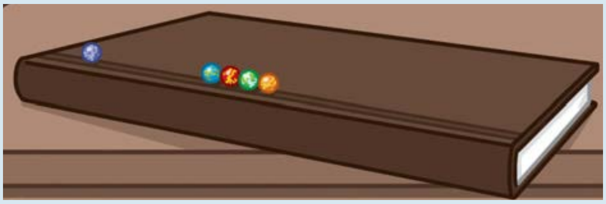
# Observing momentum

**Purpose:** To observe the effects of momentum in several different ways

**Materials:** Six marbles, hardback book, dominoes, ping-pong ball, golf ball

**Procedure:**

1. Place 4 marbles that are the same size on the edge of a hardbound book, so that they are all touching each other (see illustration).
2. Roll a fifth marble along the edge of the book. What happened when the moving marble collided with the still marbles? Why did this happen?



3. What would you expect to see happen if you rolled two marbles together toward the stationary marbles? Try this and see what happens.
4. Set up a row of dominoes in a way that if the first one falls, they will all fall in turn. Predict what will happen if you roll a ping-pong ball toward the first domino.
5. Gently roll the ball toward the dominoes. What did you observe? What do you think will happen if you roll a golf ball toward the dominoes instead? Try it and see.

**Questions:**

- Why was the ping-pong ball unable to knock over the dominoes?
- Why was the golf ball able to knock over the dominoes?



to change directions and accelerate. If you have ever played marbles, you probably know that the shooter is larger than the other marbles so that its momentum can cause the smaller marbles to accelerate and move out of the circle. Another example is when two people jump on a trampoline together. If one person is significantly heavier than the other, the bounce from the heavier person will cause the smaller person to shoot into the air at a much faster speed.

These are all examples of transfer of momentum. And in each case, the total momentum of the objects after the collision is the same as the total momentum before. If you add up the momentum of the people before they hit the trampoline and again after they bounce, you will find that the total momentum did not change.

# What did we learn?

- What is momentum?
- What two quantities affect an object's momentum?
- What is the law of conservation of momentum?

# Taking it further

- If a large football player and a small soccer player are running toward each other, what is likely to happen to the speed and direction of each player when they collide?
- What will happen if you shoot a penny across a smooth table into a stationary penny?
- How might a ping-pong ball be made to knock over a heavy domino?
- If a golf ball is rolled very slowly, will it still knock over the dominoes?

# Calculating momentum

Momentum is described mathematically as $p = mv$, where $p$ is the momentum, $m$ is mass, and $v$ is velocity. A car with a mass of 1,000 kilograms, traveling east at 50 km/h would have an eastward momentum of 50,000 kg-km/h. There are no special units for momentum—it is described in units of mass and velocity. Use the momentum equation to calculate the momentum for each of the following objects.

- Object 1: A 50 kg boy running 4 meters/second in a race.
- Object 2: A 45 kg girl running 4 m/s in the same race.
- Who has more momentum, the boy or the girl?
- Object 3: A 5 kg bowling ball rolling down the lane at 8 m/s.
- Object 4: A 0.05 kg bullet flying through the air at 1,000 m/s.

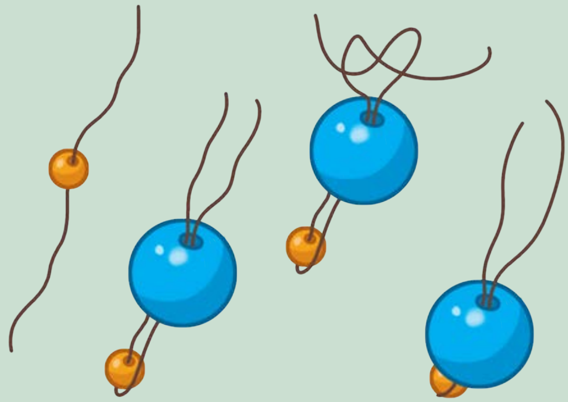
How does the momentum of the bullet compare to that of the bowling ball?

**Purpose:** To make a Newton's Cradle and observe the conservation of momentum

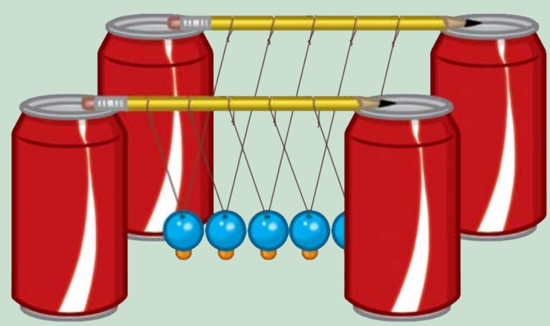
**Materials:** Five large and five small glass beads, ruler, two pencils, knife, thread, four cans

**Procedure:**

1. Use a ruler to measure the diameter of five large beads.
2. Make five equally-spaced marks on two pencils. The marks should be the same distance apart as the diameter of the large beads.
3. Using a small knife, carefully cut a notch at each mark.
4. Cut five pieces of thread each 9 inches long and put one end through a small bead. Adjust the bead so that it is in the center of the thread. Then push both ends of the thread through a large bead. Tie the thread at the top of the large bead to hold the beads together. (See illustration.)



5. Tie each end of the thread to one of the notches in each pencil and suspend each pencil between two cans as shown.



Now you can play with your "cradle." Draw the end bead back a short distance and let it go. What happens when it hits the other beads? Try drawing two beads back at the same time? What happens when you pull back three beads? How does this demonstrate conservation of momentum?

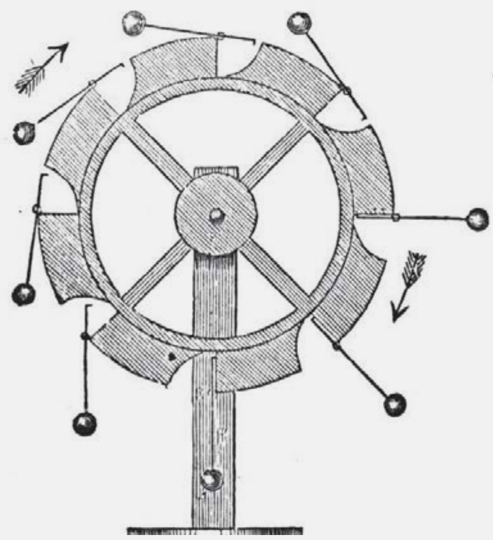
# Perpetual Motion

"Nihil ex nihilo: nothing will produce nothing."

SPECIAL FEATURE

**For centuries people have sought to build** a perpetual motion machine—a machine which, once started, would continue to run forever. The hope was that if a wheel could be made to turn without adding energy, that motion could be used for other purposes such as grinding grain. But is a perpetual motion machine possible? Can we get something from nothing? For about the last 700 years, many men have believed this to be true; they believed we could get energy from nothing. Let's look at a couple of examples.

The earliest known drawings of a perpetual motion machine came from Villard de Honnecort whose professional career lasted between 1225 and 1250. The design was a wheel with several hammers hanging around the outside of the wheel, called an "overbalanced wheel" (see diagram above). The idea was that as a hammer fell, it would give the wheel enough energy to rotate far enough for the next hammer to fall, thus the wheel would perpetually spin. There is no evidence that he ever built this wheel, but many other people have tried this method without success.



Leonardo da Vinci studied several versions of the overbalanced wheel and showed in his writings why they would not work. He is quoted as saying, "Oh, ye seekers after perpetual motion, how many vain chimeras have you pursued? Go and take your place with the alchemists." [A *chimera* is a mythological monster with the head of a lion, the body of a goat, and the tail of a serpent. *Alchemists* are people who sought to turn lead into gold]. He obviously did not consider designers of perpetual motion machines to be real scientists.

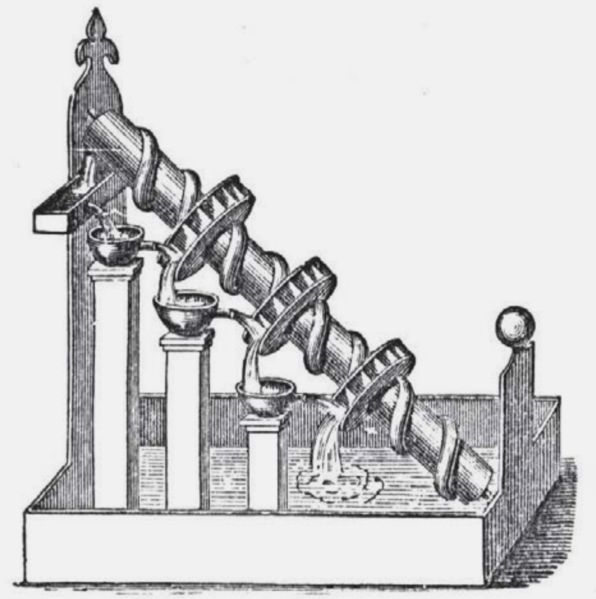
Between 1712 and 1719, Johann Ernst Bassler, a clock maker, studied and experimented with hundreds of perpetual motion designs. He then claimed to have come up with his own design that supposedly worked. Four of his designs were publicly demonstrated and many people saw them. In 1717 he built his largest machine and gave permission to test it. The machine was put into a room on November 12, 1717. Once it was started, the room was sealed for two weeks. When the door was opened two weeks later, the machine was still running. The door was sealed again and not opened until January 4, 1718, fifty-three days after the first time the door was sealed. The witnesses said the machine was running at about the same speed.

It was natural that he was suspected of being a fraud in this matter. One of the stories that floated around was that he had a servant in the next room turning a crank to keep the wheel in motion. To eliminate this claim, Bassler set up the machine in the middle of a large room. Others suspected that springs were hidden inside the wheel or a large shaft to keep it going. No one knows exactly how this machine worked because he only allowed a few people to look inside, and they could only see part of the machine. Also, they had to sign papers saying they would not tell what they saw.

Bassler died without letting anyone know how the machines worked, and at the time of his death, he had destroyed all the working machines, so no one can prove or disprove his claims.

Still today, some people hope to make a perpetual motion machine, to get something from nothing. But no design has been shown to work. The major problem with perpetual motion machines is that some of the energy is constantly being lost due to friction. For example, as the overbalanced wheel (shown on the previous page) turns, some energy is turned into heat where the wheel turns on the axle and some energy is turned into heat due to collision with air molecules. In the diagram below, some energy is lost due to the friction between the water and the screw, and between the water and the chute and bowls. Also, there is friction between the wheel and axle, and all moving parts are colliding with air molecules.

God designed the universe with His laws in place. Energy and momentum are always conserved, so if some energy is turned into heat due to friction, the machine must eventually stop moving. Even if we could find a way to eliminate all friction, the energy could not be used for another purpose without slowing down the wheel. If energy could be made from nothing then the universe itself could run out of control. God designed a universe that is balanced and takes care of itself, and God put all the energy into it that we will need.



This idea shows up in many different places. The waterwheel turns the pump that pumps the water up the pipe. The water then falls into a trench and flows back to the waterwheel, turning it and pumping more water back up the pipe.

# 5

# Force

## Tug of war



### What is a force, and how do we measure it?

### Words to know:

force

tension

tensile strength

buoyancy

net force

### Challenge words:

Hooke's law

**We have been discussing moving objects** such as a car or a person running in a race. But we have not yet discovered what makes things move. An object's motion changes because of a force that is applied to it. A **force** is defined as a push or a pull. Can you think of any examples of a push type of force? You push the grocery cart or a baby stroller. You also push down on your bike pedals when you ride a bike. Can you think of a pull type of force? You pull on a door to open it, and you pull out a drawer. These types of forces are mechanical forces and they affect our lives every day.

Other forces also exist. Gravity is a force that pulls down on everything on earth. We will examine gravity more in a later lesson. Electricity and magnetism also exert forces on objects. Electricity exerts force on electrons. And magnetism exerts force on magnetic materials such as iron and steel. However, in this book we will primarily be studying the mechanical forces that make objects move.

Some forces, like pushing a stroller, are easily seen. Other forces, however, are less visible. For example, consider a suspension bridge like the one shown above. The large cables are stretched very tightly to hold up the bridge. This force is a pulling force called **tension**. This force is constantly there, keeping the cables tight. However, if the tension were suddenly released, we would instantly see the effects of the loss of force as the cable fell down.

Different materials are able to withstand different amounts of tension. If you pulled on both ends of a piece of sewing thread, it is likely that you could snap the thread. However, if you pulled on both ends of a thick rope, it is unlikely that you could break the rope. The amount of tension that a material can withstand is called its **tensile strength**. The tensile strength of a steel cable is much higher than the tensile strength of a cloth rope. Structural engineers must understand the tensile strength of various materials when designing bridges and other structures.

Another special type of mechanical force is called buoyancy. **Buoyancy** is a force that is exerted

## Testing forces

**Purpose:** To test the tensile strength of various materials

**Materials:** Sewing thread, two pencils, kite string, rope, molding clay

**Procedure:**

1. Cut a piece of sewing thread at least 12 inches long.
2. Tie one end of the thread to one pencil and the other end to a second pencil.
3. Grasp one pencil in each hand and quickly pull the pencils apart until the thread breaks. How difficult was this to do?
4. Replace the sewing thread with kite string.
5. Try pulling the pencils apart until the string breaks. Were you able to break the string?
6. You will not need to tie the rope to a pencil, but you will need a partner to help you pull on a piece of rope. If you and your partner pull as hard as you can, do you break the piece of rope?

**Conclusion:** The rope has a much higher tensile strength than the other materials you tested and can withstand much higher tension.

**Testing buoyancy:** You can test buoyancy by shaping modeling clay into various shapes. Which shapes will float? Which shapes will sink? Why do some shapes sink and others float?



by liquids and gases. The force exerted by water is equal to the weight of the water that is displaced. A boat can float because it displaces enough water to cause enough force to push up on the boat to keep it from sinking. The heavier the boat, the more water it must displace in order to float.

Most objects do not experience only one force at a time. Most objects experience several forces. For example, when you throw a ball in the air, the ball experiences a push from your hand (while it is in contact with your hand) as well as a pull from the gravity of the earth. The sum of all the forces on an object is called the **net force**. A ball initially accelerates upward from the force of your throw, but it is constantly slowing down because of the pull of gravity. At the top of its flight, it stops moving as it changes direction. However, the force of gravity continues to pull down, so the ball begins to accelerate downward until it hits the ground where it again experiences a change of direction as the ground pushes up, and then it begins to go up again.

## Fun Fact

It is believed that the concept of buoyancy was first understood by Archimedes while he was bathing at a public bath. He reasoned that the weight of the water displaced by his body was equal to the force of the water on his body. This principle is called the Archimedes principle in his honor. Tradition has it that Archimedes jumped from the bath and ran down the street crying, “Eureka!”

## What did we learn?

- What is mechanical force?
- What is tension?
- What is tensile strength?
- What is buoyancy?

## Taking it further

- What are some of the forces that are being exerted during a basketball game?
- Why can you float more easily in the ocean than you can in a fresh water swimming pool?
- What would happen to a boat that was moving upstream at the same speed as the current was moving downstream?
- What are the forces exerted on and by a skier moving downhill?

# More forces

Mechanical forces can be measured using a spring scale. The metric units for these measurements are called newtons in honor of Sir Isaac Newton who was considered to be one of the greatest physicists of all time. A spring stretches or compresses a certain length that is proportional to the force or weight that is applied. This is called **Hooke's law** and is what allows us to calibrate and use a spring scale. The amount the spring moves depends on the material that the spring is made from, but it is always proportional to the force exerted.

Your bathroom scale probably gives your weight in pounds not newtons. Pounds are the common unit for weight in the United States. Most other parts of the world use kilograms for weight. Although in the metric system kilograms are technically a unit of mass not weight, in most cases mass and weight are used interchangeably. When you take a high school physics course you will learn more about the difference between mass and weight. For the purposes of this exercise you can use whatever units your scale uses. The number given by your scale will indicate how much force is being exerted by whatever is on the scale. The greater the number on the scale, the more the spring is being compressed inside.

**Purpose:** To measure the amount of force exerted by various objects

**Materials:** Bathroom scale

**Procedure:**

1. Use your hand to push on the scale as hard as you can.
2. Stand on the scale and see the effect of gravity pulling down on your body.
3. Put a book on the scale and see the effect of gravity pulling down on it.

**Conclusion:** Which item compressed the spring the most? This is the item that weighed the most.

Net force is the sum of all the forces acting on an object. If forces are acting in the same direction, they are added together. If forces are acting in the opposite direction, they are subtracted from each other.

Now complete the "Sum of Forces" worksheet.

# 6

# Friction

## Opposing movement

### What is friction, and why is it important?

### Words to know:

friction    lubricant

**We all know that if you are roller blading** or skateboarding on a flat surface you have to keep pushing if you don't want to stop moving. Why do you slow down and stop? It is because a force is acting against the movement of your wheels. This force is called **friction**. Friction is defined as a force that resists movement. Friction results from the rubbing of two objects. Try rubbing your hands together very quickly. They become warm because of the friction between the skin of your hands.

Friction is an important force all around us. It can be useful and it can be harmful. Think about how difficult it would be to walk if your feet had no friction with the ground. Your feet would slip out from under you and you would not be able to go where you want to go. You may have experienced this when you stepped onto an icy sidewalk and suddenly slipped. Similarly, friction between a car's brakes and its wheels is absolutely necessary for stopping the vehicle. Also, friction between the car's tires and the road allows the driver to have control over where the car goes. Friction is helpful in many other situations as well.

However, friction generally changes mechanical energy into heat energy and too much heat can have very damaging effects. In a car's engine, the moving parts can generate a great amount of heat. They can generate so much heat, in fact, that the metal parts can begin to melt. This can cause severe damage to the engine. Therefore, the amount of friction inside an engine must be minimized. This can be done by covering the engine parts with a substance that does not resist movement or has less friction. One type of substance used for this purpose is oil. Oil has a special molecular structure that allows the molecules to easily move over one another. That is why oil feels so slippery. Substances that reduce friction are called **lubricants**. It is vitally important that your car engine have enough oil to keep all of the moving parts lubricated to prevent too much heat from being generated. Even with lubricants, some friction still exists and produces heat. This is why cars usually have radiators to help transfer heat away from the engine.

Because there are frictional forces between nearly all objects, in order for an object to move it is necessary to overcome those frictional forces. A wagon will not roll until enough force is added

## Measuring friction

Complete the "Friction" worksheet. Save the block of wood with the hook in it. You will be using it in several other lessons.

to overcome the wagon's inertia as well as to overcome the friction between the wheels and the ground and the wheels and their axles. (Inertia is an object's tendency to stay in its present condition—we will learn more about this in lesson 21.) Air molecules are constantly pushing against moving objects so energy is needed to overcome this frictional force as well. Engineers who design cars, airplanes, and other vehicles are very careful to design them so that the air molecules will have a minimal impact—to make them aerodynamic. This improves the fuel efficiency of the vehicle. The shape of the vehicle is one of the primary factors in how much air resistance will affect the motion of the vehicle. Rounded surfaces allow the air to flow more easily than flat or square surfaces. Also, smooth surfaces allow air to flow more easily than bumpy or uneven surfaces. A great deal of thought is put into how friction will affect vehicles. And although you may not think about it, friction affects every movement you make.

## What did we learn?

- What is friction?
- What is the cause of friction?
- How can friction be useful?
- How can friction be damaging?

## Taking it further

- When would street maintenance people try to increase friction on the streets?
- How do they try to increase the friction?
- Why do drag racers use very wide treadless tires in a race?

## Reducing friction

Design a way to reduce the friction between the block of wood and the various surfaces over which you pulled it.

7

# Work

Everyone has to do it



## What is work, and how do we measure it?

## Words to know:

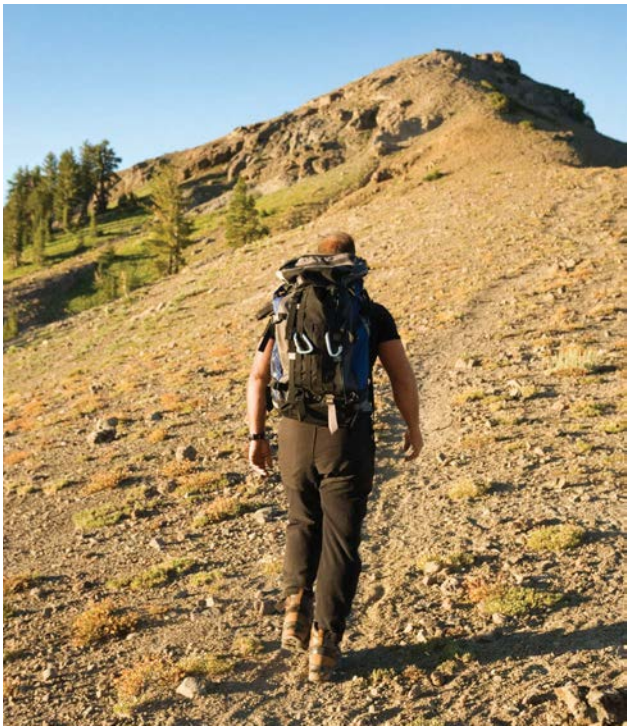
work

**What do you think of when you hear the** word *work*? Do you think about your dad's job? Maybe you think about the chores you do around the house or maybe you think about your school work. These are all tasks that many people consider to be work. However, from a scientific point of view, work has a different meaning. The scientific definition of **work** is a change in position due to an applied force.

Recall that a force is a push or a pull. So in order for work to be done, a push or a pull must make an object move. Work is described mathematically as force times distance. Let's look at the work done when you pick up your soccer ball. If you pick it up off the floor and set in on a table you do some work. If you pick it up and set it on the top shelf of your closet you do more work. The force needed to lift the ball is the same in either case because you are lifting the same ball each time, but in the second case you have lifted it a greater distance so you have done more work.

Force is directly related to mass. It takes more force to lift a heavy object than it does to lift a light object. Therefore, if you lift a volleyball from the floor to the table you will do less work than if you lift a bowling ball from the floor to the table. The distance you move each ball is the same. However, because the bowling ball has more mass, you must exert a greater force to lift it, and so you are doing more work.

The path taken to move an object does not affect the amount of work done. For example, if a hiker is climbing the side of a hill, he can climb straight up the hill or he can walk back and forth



## Performing work

**Purpose:** To understand the relationship of force, distance, and work

**Materials:** Three boxes, various items, chair

### Activity 1—Procedure:

1. Place three identical boxes on the floor.
2. Put items of various weights inside the boxes so that they are all different weights.
3. Lift the first box from the floor to your waist. Think about the force that was required to lift that box.
4. Return the first box to the floor and lift the second box to waist level. Which box required the most force to lift?
5. Return that box to the floor and lift the third box to waist level. Of the three boxes, which one required the most force to lift? Which box required you to do the most work to lift it?

### Activity 2—Procedure:

1. Lift the first box and set it on a chair.
2. Place the box back on the floor.
3. Now lift the same box and place it on a kitchen counter. Which action required you to do more work?

### Activity 3—Procedure:

1. Hold the first box in your arms for 1 minute. How much work are you doing to hold the box?



across the hill going up a little at a time. Once he reaches the top he has done the same amount of work either way. The work done is equal to his weight times the height that he climbed. It probably seems harder to climb straight up the hill, but the total amount of work done is the same either way.

Also, since work requires that an object be moved, no work is done if nothing is moved, even if a force is being applied to something. Consider the bridge cables that we talked about in lesson 5. There is a constant force applied to the cables, yet nothing is moving, so no work is being done. Work was done to put the cables in place, but once they are in place no additional work is being done. You can also think about a weight lifter. He performs work to lift the weights above his head. But once he has the bar there, he does not perform any work to keep it above his head. He has to continually apply force, but because the weights are not moving, no work is being done. You may think that it is very hard work to hold weights above your head, but according to the scientific definition of work, it doesn't take any work at all.

## What did we learn?

- What is the scientific definition of work?
- Force is directly related to what physical property?

### Fun Fact

The human heart is working and resting alternately 24 hours per day. The work done by your heart each day to move the blood in your body is equivalent to the work done when lifting a small car 50 feet (15 m) in the air. God designed your heart to be a mighty worker!

# Taking it further

- Does work always have to be done in a vertical direction?
- If one student pushes very hard on a wall and a second student picks up a pencil, which student is doing the most work?
- Is there any work being done as you coast downhill on your bike?
- Is there any work being done as a space probe moves through space?

# Calculating work

Work is measured in units call joules. One joule is equal to one newton-meter. The mathematical equation for work is:

$$W = F \times D$$

Where *W* is work in newton-meters, *F* is force in newtons, and *D* is distance in meters.

**Purpose:** To calculate work

**Materials:** Boxes from previous activity, scale, meter stick, "Work Calculation" worksheet

## Activity 1 — Procedure:

1. Use a bathroom scale to measure the weight of each box. Convert the weight into newtons using one of the following relationships:
   a. 1 pound = 4.45 newtons
   b. 1 kilogram = 9.81 newtons
2. Record this number in the first column of the "Work Calculation" worksheet.
3. Next, measure the height of a chair seat using a meter stick. Record this height in the second column of the worksheet.
4. Calculate the work done when you lift each box and place it on the chair by multiplying its weight times the height of the chair seat. Record this number in the third column.

## Activity 2 — Procedure:

1. Record the weight of box 1 in the first column of the worksheet.
2. Measure the height of a chair and the height of a shelf and record these heights in the second column.
3. Calculate the work done when you lift the box to each of these heights. Record these numbers in the third column.

## Activity 3 — Procedure:

1. Record the weight of the box in the first column.
2. Hold the box without moving it for one minute.
3. Calculate how much work you did while holding the box and record this number in the third column.

Answer the questions on the worksheet.

# 8

# Power

Getting the job done quickly



## What is power, and how do we measure it?

## Words to know:

power

### How long does it take to clean your room?

If you fool around and work slowly it could take a long time. If you work hard, you can accomplish a lot more in a shorter period of time. This is the idea of power. **Power** is work done over time or the rate at which work is done. Power is measured in joules per second, which are also known as watts.

If more power is applied, more work can be accomplished in a given time period, or the same amount of work can be accomplished in less time. Let's look at an example. When you walk 1,000 meters (0.6 miles) down the street you are performing work. It may take you several minutes to walk that distance. Your legs have a certain amount of power that allows you to walk at a comfortable pace. However, you could travel the same distance in a car in a much shorter period of time. The work done by the car's engine to move you 1,000 meters is the same as the work done by your body to move you that distance. However, the car's engine has much more power than your legs so it can move you at a much faster pace. The more powerful engine can perform the same amount of work in a shorter period of time.

Let's look at the example in another way. If you walked for 5 minutes you could travel a certain distance. But if you ride in a moving car for 5 minutes you will travel a much greater distance. Since your mass is the same in either case, the force to move you is the same. Therefore, the work done by the car is greater because you moved a greater distance. The car can perform more work in the same period of time than your body because it has more power.

## Power scavenger hunt

Many electrical appliances don't perform work in the way you might think. Electrical power is calculated by the number of electrons that are moved per second instead of how far an object is moved. The work done by electricity is often converted into other types of energy such as light or heat. Keep this in mind as you search for power around your house and complete the "Power Scavenger Hunt" worksheet.

Mechanical Forces

Many machines have been invented that are much more powerful than human bodies. These machines allow humans to accomplish much more work in a shorter period of time than could otherwise be accomplished. This has greatly improved our lives. Consider how much food can be grown by one farmer today with the use of modern farm equipment compared with the amount of food that was grown when a farmer could only use a horse-drawn plow. And consider how quickly that food can be transported to the people who need it. This allows people to eat more and better food, thus improving their lives. God has given people incredible creativity when it comes to using the resources He gave us to improve our lives.

## What did we learn?

- What is the scientific definition of power?
- How do machines use power to improve our lives?

## Taking it further

- Why is a car more powerful than a bicycle?
- When a car is moving your body, the car is actually performing more work than when you walk the same distance. Why?

## Calculating power

Complete the "Calculating Power" worksheet to calculate how long you could run each item if you had 10,000 joules of energy. Recall that 1 watt of power is equal to 1 joule per second. So a 100-watt light bulb will use 10,000 joules of energy in 100 seconds. You simply divide the number of joules by the number of watts to determine the number of seconds each item would run on the given amount of energy. Which item requires the least amount of energy to use? Which requires the greatest amount?