LESSON **21**

Motion on a Roller Coaster

PHOTO BY DAN FEICHT, CEDAR POINT AMUSEMENT PARK/RESORT

The laws of physics in action!

INTRODUCTION

When you enjoy the thrill of a ride on a roller coaster, you are experiencing the laws of physics and energy and motion in action. In this lesson, you will use the roller coaster and roller coaster car your class built in Lesson 20. You will investigate energy transformations as the roller coaster car moves along the roller coaster track. You will also compare the motion of the roller coaster car with the motions of the fan car and the mousetrap car that you built in previous lessons.

OBJECTIVES FOR THIS LESSON

Observe and describe the motion of the roller coaster car as it moves along the roller coaster track.

Predict the motion of the roller coaster car when it is released at different points along the track.

Measure the speed of the roller coaster car at several points on the track.

Describe the energy changes in the roller coaster car as it moves along the track.

Getting Started

1. If you have not read "Potential and Kinetic Energy" on pages 216–217, read it at this time.

2. On the basis of what you read in "Potential and Kinetic Energy," answer the following questions in your science notebook:

   A. What does it mean for something to have potential energy?

   B. If a book weighs 15.0 N, what is its gain in gravitational potential energy when it is lifted onto a shelf 2.0 m above the floor?

   C. How can you tell whether something has kinetic energy?

   D. Do you ever have kinetic energy? How do you get it? How do you lose it?

3. Have your science notebook ready so you can write your predictions, observations, and answers in it as you perform the inquiry.

MATERIALS FOR LESSON 21

For the class

- 1 roller coaster
- 1 roller coaster car
- 1 0- to 10-N spring scale
- 1 meterstick
- 1 student timer
- 1 piece of masking tape

POTENTIAL AND KINETIC ENERGY

You have investigated energy and changes in energy throughout this module. You have seen how energy can be stored in batteries and springs. You have also seen how energy can be transformed into different forms, such as light, heat, motion, and electrical energy.

Storing Energy

When work is done on something, its energy changes. For instance, when you set the spring in the mousetrap car, you did work on the spring because you exerted a force on the spring when you wound it around the axle of the car. The spring gained energy and stored it for later use. Scientists call this stored energy *potential energy.*

When you let go of the car, the spring released the potential energy. The force of the spring did work on the mousetrap car and increased its speed. The stored energy in the spring became *kinetic energy,* or energy of motion. Some of the energy in the spring also became heat energy because of friction. Eventually, friction stopped the car, and the kinetic energy of the car was transformed into *heat energy.*

The batteries you used earlier in this module also stored energy. The batteries stored the energy as *chemical potential energy* that became *electric potential energy.* When the batteries were connected in a circuit, the electric potential energy was transformed to other forms of energy in lightbulbs and motors.

Energy can be stored in other ways, too. You can store energy in an object by lifting it. Whenever you pick up an object, you do work on it, because your muscles exert a force on an object through a distance. Your muscles changed the chemical energy in your body into energy in the lifted object. But what kind of energy is associated with the lifted object?

Gravitational Potential Energy

The energy an object gains when it is lifted is called *gravitational potential energy.* It is called *gravitational* potential energy because you must work against gravity to lift an object to a higher position above the ground (earth). Any object above the ground has gravitational potential energy that can be released.

The amount of gravitational potential energy an object has depends on how much it weighs and how high above the ground it is. For example, it hurts more if a heavy book falls from your desk and hits your foot than if a light book falls and hits you from that same height. If you drop the same book from different heights, however, you will find that the higher the book's starting position, the more your foot hurts when the book hits it.

To calculate the gravitational potential energy of an object, you multiply its weight by its height above the ground, as shown in the following equation:

Gravitational potential energy = Weight × Height

Weight is measured in newtons, and height is measured in meters; therefore, the unit of measure for potential energy is newton-meters. Newton-meters are also called joules. Thus, the units for energy are the same as the units for work. Remember: *Energy is the ability to do work.*

Kinetic Energy

Moving objects have another kind of energy. It is called *energy of motion,* or *kinetic energy.* Any time an object moves, it has kinetic energy. The kinetic energy of an object depends on how fast it is moving and how much mass it has. The greater the speed of an object, the greater its kinetic energy. The greater the mass of an object, the greater its kinetic energy.

Kinetic energy is also measured in newton-meters, or joules. In fact, all forms of energy can be measured using these units.

In this lesson, you will study how gravitational potential energy and kinetic energy change as a car travels along a roller coaster. You will learn how to put gravitational potential energy in the car, and you will observe how energy converts from one form to another as the car moves along the track.

Inquiry 21.1
Observing the Motion of a Roller Coaster Car

PROCEDURE

1. Discuss the following questions with your group. Then share your answers with the class.

   A. What kind of energy would the roller coaster car gain if you lifted it to the top of the roller coaster?

   B. How does it get this energy?

2. Before you place the roller coaster car on the track, make the following predictions about what the speed of the car would be if it were released from the top of the track:

   A. At what point along the track will the car have the fastest speed? The slowest speed? Why do you think so?

   B. Where will the car have its greatest kinetic energy?

   C. How do you think the car gained its kinetic energy?

   D. Is it possible for the car to have both kinds of energy anywhere on the track?

3. Place the car at the highest point on the roller coaster track. Let it roll down. Compare your observations of its motion with your predictions. Discuss this with your group.

4. On the basis of your observations and what you have learned about energy, discuss with the class why the car moves the way it does along the track.

5. Predict what the motion would be if you were to place the car at the top of the lower hill and allow it to move back toward the higher hill.

6. Test your prediction by observing the car's motion. Answer this question in your science notebook: On the basis of what you have learned about energy, how do you account for the car's motion when the car is released from the lower hill? Then discuss your ideas with the class.

Inquiry 21.2
Measuring the Speed of the Roller Coaster Car

PROCEDURE

1. You will measure the roller coaster car's speed at different points along the track. Before you make speed measurements, consider these questions:

   A. What force "pulls" on the car as it moves along the track?

   B. Do any other forces act on the car as it moves along the track? If so, what are they? How do they affect the motion?

2. Use a spring scale to measure the weight of the roller coaster car.

3. How much work must you do to lift the car from the tabletop to the top of the highest hill on the roller coaster? Write out your calculation.

4. Working with your group, develop a plan to measure the speed of the car from at least three different points along the roller coaster track. Determine how the speed of the car changes as it moves along the track.

5. Carry out your plan. Be sure to discuss the following questions:

   A. How did your group select points along the track? What methods did your classmates use?

   B. How did your speed values compare with those of the other groups?

REFLECTING ON WHAT YOU'VE DONE

1. Write responses to the following questions in your science notebook:

   A. What have you learned about the motion of the roller coaster car as it moves along the track?

   B. What energy changes took place as the car moved along the track?

   C. What changes could you make in the roller coaster to make the roller coaster car go faster?

   D. How does the motion of the roller coaster car compare with the motion of the fan car and the mousetrap car? How are these motions alike? How are they different?

2. Discuss your answers with the class.

Twists, Turns, and Loops

Kuh-chink, kuh-chink, kuh-chink. The train lurches slowly up the first hill of the roller coaster. You give the lap bar one last tug. Then you round the first corner, pick up speed, and … Aaaaaaggghh!

You may not be thinking about the fundamentals of physics while you're riding a roller coaster. But those fundamentals, especially the laws dealing with energy and motion, are what keep you in your seat. They ensure that your ride is safe—as well as fun.

A roller coaster is a fairly simple machine. A chain that is attached to a motor pulls a train of cars filled with people to the top of a steep hill. When the cars are released, the thrills begin!

At the top of the hill, a roller coaster train and its riders have a large amount of stored, or potential, energy. The work the motor did to drag its load against the force of gravity to the top of the hill stored energy in the train and riders as it pulled them to the top. The higher the hill and the more work the motor did, the more gravitational potential energy it stored in the train and riders.

When the train and riders crest the hill and begin to rush downward, their gravitational potential energy begins turning into kinetic energy. The shape of the track and the height of the hills control the train's changes in speed and direction.

PHOTO BY DAN FEICHT, CEDAR POINT AMUSEMENT PARK/RESORT

Each roller coaster uses different combinations of twists, turns, dips, and dives to convert gravitational potential energy into kinetic energy.

PHOTO BY DAN FEICHT, CEDAR POINT AMUSEMENT PARK/RESORT

Going around a loop on a roller coaster. The tighter the loop, the harder your seat pushes against you. Why?

As the train and riders descend farther and farther, more and more gravitational potential energy turns to kinetic energy. That means the train and riders go faster and faster. As they rise, the train and riders gain back some of their gravitational potential energy and lose kinetic energy and slow down. Tight curves, which provide sudden direction changes, add to the thrills.

The first roller coasters were made from wood. They were not as efficient in converting potential energy into kinetic energy as today's coasters are. Roller coasters made of steel do a better job because there is less energy lost to heat and more energy to be spent on thrills.

Other improvements have been made in roller coaster design. Most of today's steel coasters include at least one bit of looped track that momentarily turns your world upside down. The looped track exerts a force on the train cars and on you and the other riders that sends you around the loop. Many coasters have multiple loops and corkscrews to maximize the fun.

Finally, your ride is over. You've been up and down and all around—a very energetic experience indeed! ☐

PHOTO BY DAN FEICHT, CEDAR POINT AMUSEMENT PARK/RESORT

Energy and sudden turns provide plenty of thrills as you ride the coaster.

ISAAC NEWTON GOES SKIING

CORBIS/GALEN ROWELL

This cross-country skier may not know it, but Newton's laws of motion are at work.

We don't know whether Sir Isaac Newton ever tried skiing. It's entirely possible, because skis were invented before his birth in 1642. Skis have been in use for more than 2000 years—long before Newton ever thought about gravity or came up with his laws of motion.

Even though Newton may never have made the connection between skiing and his three laws of motion, you can. In fact, knowing Newton's laws of motion is useful if you go skiing. Knowing about gravity helps too.

The First Law

Take Newton's First Law of Motion: An object at rest will remain at rest, and an object in motion will remain in motion with the same speed and direction, unless acted upon by an outside force. That means it takes a force to start you moving and another force to make you stop. You also need to apply a force if you want to change the direction in which you're moving. If no forces act on you, you just keep moving along at the same speed and in the same direction.

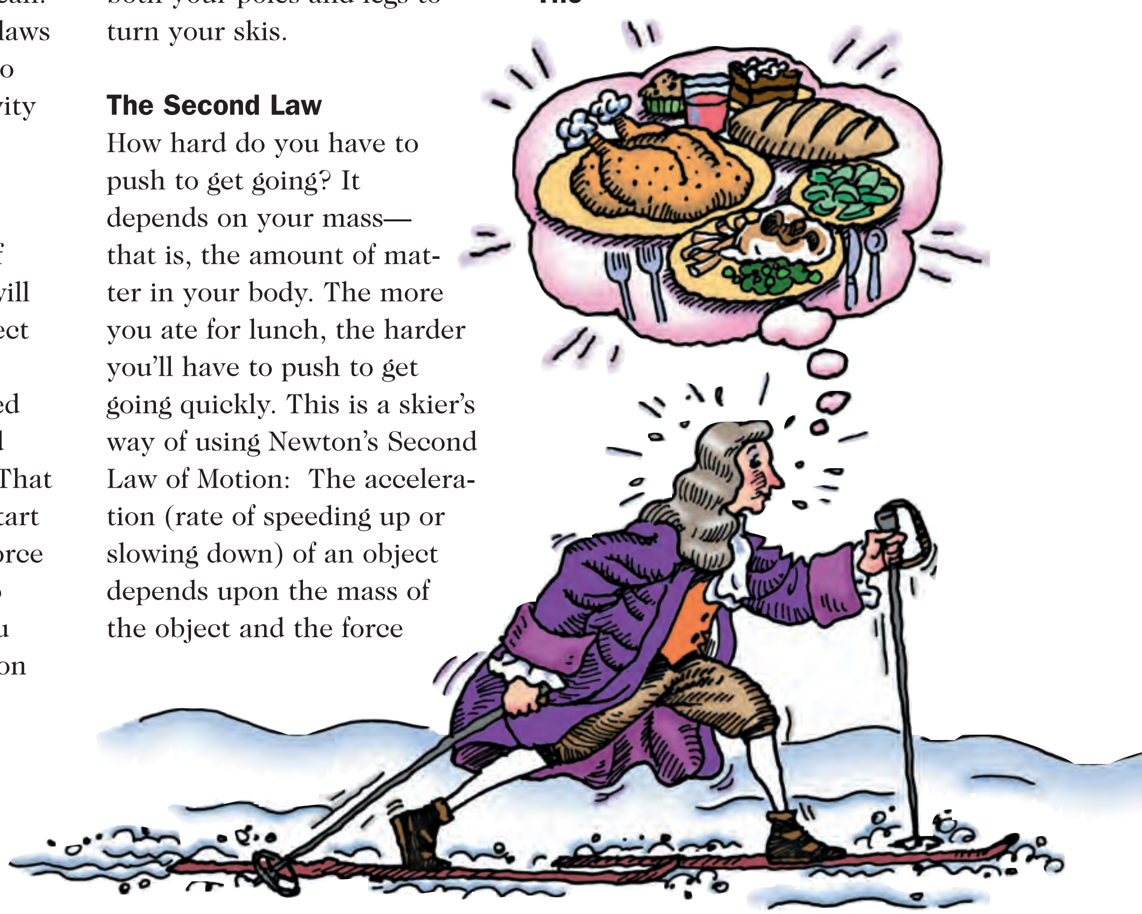
How does this apply to skiing? If you're skiing across flat terrain (cross-country skiing), you have to exert a force to get yourself moving. You do that by pushing with your poles. You keep moving because there is not much friction (an outside force) to work against you and bring you to a stop. (To make the friction even less, you can wax your skis.) To change direction, you have to push with both your poles and legs to turn your skis.

The Second Law

How hard do you have to push to get going? It depends on your mass—that is, the amount of matter in your body. The more you ate for lunch, the harder you'll have to push to get going quickly. This is a skier's way of using Newton's Second Law of Motion: The acceleration (rate of speeding up or slowing down) of an object depends upon the mass of the object and the force acting upon it.

You can start moving by pushing with a small force, but it will take you longer to reach the same speed than if you'd pushed harder. Regardless of how you choose to get going, what you're doing is putting to work some of that chemical potential energy from the food you ate at lunch and changing it into kinetic energy.

The



Third Law

After you are in motion, you can coast for quite a long time, unless you hit another skier… or a tree! If you collide with another skier on the slopes, you may bounce off each other before coming to a stop. Newton had a law for that, too. It's his Third Law of Motion: For every action, there is an equal and opposite reaction.

What Else Is Happening?

As you glide down those slopes, forces other than the ones you exert are helping you. One of them—you guessed it—is gravity. Gravity works in your favor when it comes to downhill skiing. In downhill skiing, you've got the whole mass of the earth helping you along.

The rate at which you speed up depends on a number of things, including the angle of the slope, how slippery your skis are, and another force—the friction created between your body and the air as you race along.

The smaller the amount of friction, the faster you'll accelerate. If you're wearing tight ski gear, you'll go even faster.

The whole time you're going downhill, gravity is working to change your gravitational potential energy into kinetic energy.

What happens when you ski uphill? Gravity works against your upward motion, and you slow down. If the hill is higher than the one you start-ed on, you won't make it to the top. If the second hill is lower than the one you started on, however, you have enough energy to go up and over the top and start down again.

AP/WIDE WORLD PHOTOS

Skillful use of opposing forces lets you come to a safe stop.

CORBIS/KARL WEATHERLY

Downhill skiers enjoy the ride as gravity transforms potential energy into kinetic energy.

When you're skiing, why can it be so hard to stop? One reason is that there's not much friction between the icy slopes and your well-waxed skis. Since there is not much friction, you just keep on going. If you want to stop, you have to apply a force against your motion. That means that, at least if you're like most first-time skiers, you fall when you're trying to come to a graceful stop.

At that moment, friction kicks in. The friction between your body and the snow slows you down. Your kinetic energy is converted to heat—so much heat, in fact, that as you slide, your body melts some of the snow! A more expert method of reducing your speed is to turn your skis so that they dig into the snow.

Would an understanding of the laws of motion, of gravity, and of friction have helped Sir Isaac be a better skier? It's hard to say. Skiing is one sport that requires a good deal of skill and athletic ability. But knowing what's happening as you glide along is a definite advantage. Sir Isaac might not have had skills equal to those of an Olympic contender, but he probably would have managed to keep his balance, even when his wig was blowing in the wind. □

QUESTION

In what ways is skiing like riding a roller coaster?