E8 Newton's Laws of Motion

READING

Isaac Newton was a British scientist whose accomplishments included important discoveries about light, motion, and gravity. You may have heard the legend about how he "discovered" gravity when he was sitting under an apple tree and an apple fell on his head. He didn't really discover gravity, but he did realize that there is a gravitational force that constantly pulls objects toward the center of Earth. This force makes objects fall toward Earth if no other force is there to hold them up.

CHALLENGE

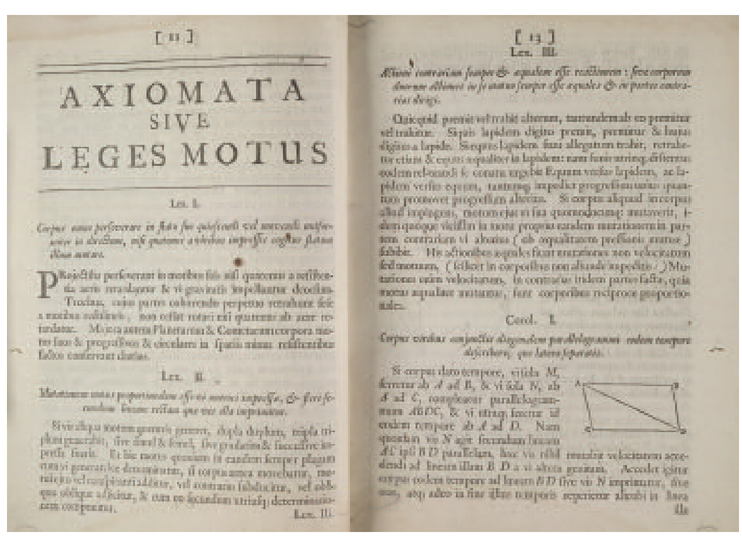
What relationships between force and motion did Newton discover?

MATERIALS

For each student

1 **Student Sheet E8.1, "Anticipation Guide: Newton's Laws of Motion"**

This image of Isaac Newton appears in one of his books, published in the 1600s.



AXIOMATA
SIVE
LEGES MOTUS

Newton wrote Laws of Motion *in Latin. The original book shown here is in the collection of the Library of Congress in Washington, D.C.*

READING

Use Student Sheet E8.1, "Anticipation Guide: Newton's Laws of Motion," to prepare you for the following reading.

Force and Motion

People have probably always observed objects in motion and have made objects move around. For many centuries, scientists thought they knew everything about this. However, the Italian scientist Galileo Galilei, who lived from 1564 to 1642, began to think about motion in a new way. Isaac Newton, who was born the year Galileo died, built upon his discoveries and developed three laws. Newton's laws were revolutionary, as they seemed to go against everyday experience and observation. Today, parts of Newton's three laws are still the basis for understanding motion.

Newton's First Law: The Law of Inertia

Newton's first law, also known as the Law of Inertia, can be difficult to fully understand. It describes an object's resistance to changing its motion and its tendency to keep doing whatever it is doing. A change in motion can be a change in an object's speed, direction, or both. For example, a car that speeds up to pass another car, or that turns a corner is changing its motion. Newton's first law states that an object's motion cannot change unless a force acts on the object. In other words, it takes a force to overcome an object's inertia and to make the object go faster, slower, or change direction.

STOPPING TO THINK 1

Which has more inertia: a heavy ball or a light ball rolling at the same speed in the same direction? Think about which one is more resistant to a change in motion.

Since you may already know that it takes a force to change motion, you might be wondering, "What's so hard to understand about Newton's first law?" The difficulty is that this law also says that no force is needed to keep something moving. According to Newton's first law, if something is moving at a certain speed, it will keep on moving at that speed forever. It will not slow down and stop unless something pulls or pushes on it. The idea also applies to an object that is not moving. It will remain motionless until a force acts on it.

Newton's first law seems to contradict everyday experience. You've seen for yourself that when you kick, throw, or bat a ball along the ground it eventually stops by itself. And when you ride a sled or a scooter down a hill, you don't keep going forever; you slow down and stop. How can Newton's first law be correct?

Friction

What is not stated in Newton's first law, but plays an important role in motion, is the idea of **friction** (FRICK-shun). Friction is a force that exists at the boundary between any two pieces of matter that are in contact with each other. Friction is a force that opposes the motion of an object. For example, the friction between a rolling ball and the ground causes the ball to slow down and stop rolling. Friction between a sliding sled and snow causes the sled to slow down and stop sliding. Here on the earth, where there is friction everywhere, a force must be applied to an object in order to keep it moving.

If there were no friction, the inertia of a moving object would keep it moving the same way forever or until a force changes its motion. In

There is less friction between the puck and the ice (left) than there is between the ball and the rougher grass (right).

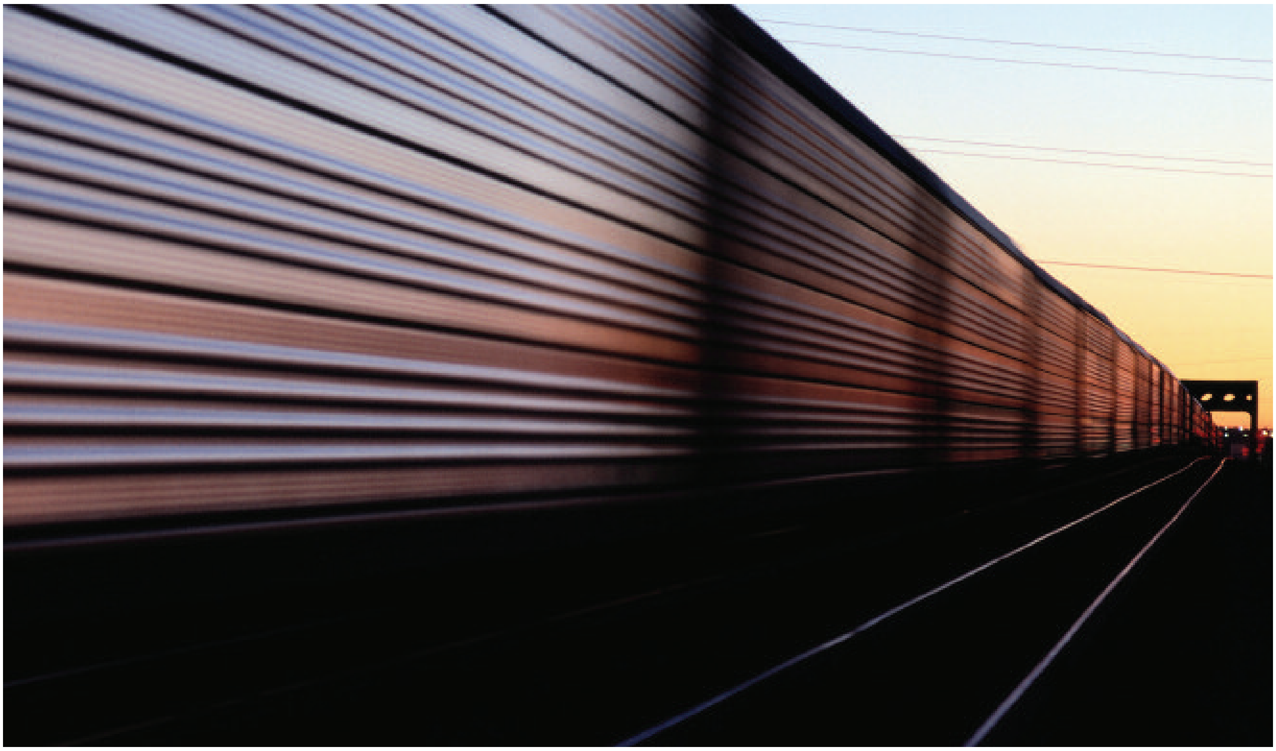
outer space, which has no ground, water, or air to create friction, an object would keep moving forever at the same speed and in the same direction. This explains why the moons and the planets and other space objects have been moving for billions of years and will keep moving for billions more!

STOPPING TO THINK 2

What would happen to a baseball if you could throw it in outer space? Explain in terms of inertia and friction.

To keep a car moving, its engine has to keep pushing it to overcome the friction in several places, such as the road and the tires, and the windshield and the air. Many features on vehicles are designed to reduce friction as much as possible. Shapes are streamlined to reduce air friction, and oil and grease reduce friction between moving parts. If there is less friction to overcome, the engine doesn't need to apply as much force. Other vehicle features are designed to increase friction. Tires need to have friction so that they can "grab" the road and brakes need a lot of friction to make the wheels stop turning.

The bobsled and its passengers try to reduce friction. Snow tires increase friction to bring the wheels to a stop.



As the train travels at constant speed, the engine must produce enough force to equal the friction caused by the air and the wheels on the track.

Balanced Forces

To keep an object moving at a constant speed in the presence of frictional force, a force needs to be applied that is equal in size to, but in the opposite direction of, the frictional force. This applied force balances the force of friction so that the combined force acting on the object, or the **net force**, is zero (0). The engine of a car that is moving at a constant speed is applying a force exactly equal to the frictional forces that are pushing against it. When the net force is zero, there are balanced forces and there is no change in motion, just as Newton's first law states.

STOPPING TO THINK 3

A car travels along a straight road at a steady 40 MPH. Are the forces on the car balanced or unbalanced? Explain.

Newton's Second Law: The Relationship Between Force, Mass, and Acceleration

Unlike the first law, Newton's second law is confirmed by our everyday experiences and is easier to understand. It states that:

1. To equally change the motion of two objects of different mass, more force must be applied to the more massive object. For example, when you add weight to a wagon, you have to push it harder to speed it up because it has more inertia.

2. The bigger the force that is applied to an object, the greater the resulting acceleration. For example, if you give a soccer ball a soft tap with your foot (a small force over a short period of time) it doesn't speed up much. If you give it a hard kick (a larger force over an equally short period of time) it speeds up more.

Newton summed up these ideas with a single equation that shows the the net force (F) needed to accelerate (a) any mass (m):

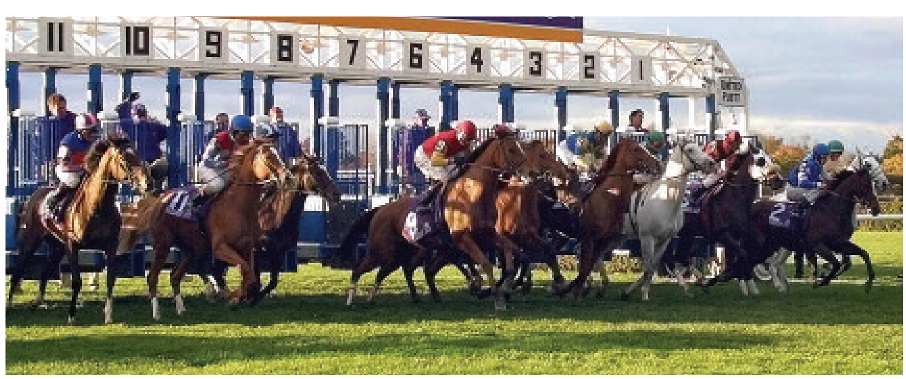
$$\mathbf{F = ma}$$

STOPPING TO THINK 4

Can a light object that was hit with a small force accelerate as rapidly as a heavier object hit with a big force? Why or why not?

Unbalanced Forces

Newton's second law describes the change in motion that is a result of unbalanced forces. If net force on an object is not zero, the forces are unbalanced and the object accelerates. Even a tiny force will cause an object to speed up if it is not balanced by another force. In a frictionless world, an object that has a continually applied force would speed up until it is traveling as fast as it possibly can.



Race horses accelerate out of the starting gate.

Newton's Third Law: Action-Reaction with Two Objects

Newton was the first one to notice that it is impossible to have a single force. Forces always happen in pairs. Newton's third law, also know as the Law of Action-Reaction explains how a pair of forces work. It states that when one object applies a force on a second object, the second object applies the same size force in the opposite direction, and for the same amount of time, on the first object. Another way to think about this is that when one object pushes or pulls on another object the other object will always push or pull back with the same force. An example Newton used was that if you push a rock with your hand, the rock pushes back on your hand. Another example is a launching rocket. It is propelled because, at the same time as the rocket is pushing the gases down, the force of the gases is pushing the rocket up.

The force of the gases pushes downward at the same time that the gases push the rocket upwards.

It may seem that the third law contradicts the second law. If there are always equal and opposite forces, how can there ever be an unbalanced force? In the second law, Newton talks about the net force acting on *a single object.* The opposing forces in Newton's third law are two forces acting on a pair of *different* objects. When the second law is used to describe motion, the action-reaction forces are still there, but they are often ignored since they are equal and opposite.

STOPPING TO THINK 5

If you hold a backpack in your hand, the force of gravity pulls it downward. What force keeps it from falling to the ground?

ANALYSIS

1. Spaceships that travel millions of miles into outer space use very little fuel. How can they go so far on so little fuel?

2. Use Newton's laws to explain why it is easier to turn a truck when it is empty than when it is carrying a heavy load.

3. An engine can exert a force of 1,000 newtons. How fast can this engine accelerate:

   a. a 1,000-kg car?

   b. a 2,000-kg car?

4. Use Newton's third law to explain why a blown up but untied balloon will fly around the room when you let it go.

5. Motor oil, axle grease, and other lubricants are slippery. Why do you think people spend the money to put these lubricants in their cars?