

## Reflect

Does anything happen without a cause? Many people would say yes, because that often seems to be our experience. A cup near the edge of a table suddenly crashes to the floor. An apple falls from a tree on a clear, windless day. An enormous bank of snow breaks loose from a mountainside and comes roaring down the slope as an avalanche, leveling trees that stand in its path.



These events do not “just happen.” Any change in motion is the result of a force. The forces that cause change are not always obvious, but they are always present. Relationships between force and change in motion follow three precise laws. What are these laws? How do they help us understand force and motion?

## Force and Motion

*State of motion* is an important concept. These are the four states we will consider:

- Constant
  1. motionless
  2. moving at constant speed in a straight line
- Changing
  3. increasing or decreasing speed
  4. changing direction at a constant speed

Changing an object’s state of motion from one category to another requires a change in the force or forces acting on the object.

There are two types of forces, *balanced* and *unbalanced*. When all the forces acting on an object cancel each other out, they are balanced. In other words, the *net force* is zero. This is the case for the two categories of constant motion, motionless and moving at a constant speed in a straight line.



An unbalanced force set this avalanche in motion.

force is not zero. These are referred to as unbalanced forces. Unbalanced forces cause motion to change from one state to another.

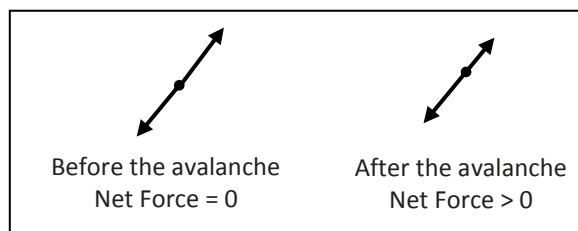
Consider the avalanche. Before the avalanche, the force of gravity acting on the snow was equal to the force of friction between snowflakes (and any other force acting in opposition to gravity). The forces were balanced and the state of motion was motionless. Some event, such as melting, reduced the frictional force so that

it was less than the gravitational force. The net force became unbalanced and the snow began to move and increase its speed.

Both the strength and direction of a force must be stated to know what effect the force will have on an object. In a diagram, an arrow is often used to represent a force. The arrow's length represents the strength of the force. An arrow twice as long as another arrow represents a force twice as strong. A force arrow points in the direction in which the force acts. The diagram below shows the forces acting on the snow before and after the avalanche:

### Newton's First Law

It was mentioned earlier in the lesson that three basic laws explain relationships between force and motion. These are Newton's three laws of motion. Newton's first law, the law of inertia, addresses the case of objects in a constant state of motion. The objects are either motionless or moving at a constant speed in a straight line. The law states that an object at rest stays at rest, and an object in motion stays in motion until unbalanced forces act upon it.



*Inertia* refers to an object's resistance to a change in motion. Inertia is directly related to mass. The more mass an object has, the more inertia it has, and the more it resists a change in motion. Think about trying to move objects that have different masses, such as a lamp and a sofa. Obviously the lamp is much easier to move.



The need for seatbelts is related to inertia and the first law of motion.

It is not as obvious that an object will continue to move in a straight line at a constant speed if the forces on it are balanced. Everyday experiences seem to contradict the law of inertia. Every moving thing we see slows down if we don't make some effort to keep it moving. Things slow down naturally because unbalanced forces of friction and air resistance always act on them. If you kick a soccer ball across a field, for example, the ball slows down because friction between the ball and the grass is an unbalanced force. If there were no friction, the ball would continue to roll without slowing down. For things that do travel at constant speed, some force acting on the object exactly balances the forces of friction and air resistance, resulting in a net force of zero. A train, for example, can travel at a constant speed because the force of the engine acts on it.

### What Do You Think?

When you are riding in a car and it comes to a sudden stop, why do you lurch forward? Has the net force on you changed? What is the tendency of objects moving at a constant speed in a straight line? The answer is related to the need for seatbelts and infant car seats.

### Newton's Second Law

Newton's second law of motion states that when an unbalanced force acts on an object, the object accelerates at a rate equal to the net force on the object, divided by the object's mass. This law is expressed by the equation:

$$a = F/m.$$

In this equation, the acceleration ( $a$ ) is expressed in meters per second per second, which is meters per second squared ( $m/s^2$ ). The net force ( $F$ ) is in newtons (N), and the mass ( $m$ ) is in kilograms (kg.) The equation is more often seen in the form:

$$F = ma.$$

As long as a net force acts on an object, the object will continue to accelerate. In many everyday events, an unbalanced force will only act briefly, as in the case of hitting, kicking, or throwing a ball. One familiar exception is the force of gravity acting on a falling object. Falling objects continue to accelerate until the force of air resistance equals the force of gravity.

Suppose you wanted to design a car that could accelerate from 0 to 60 mph (miles per hour) in 10 seconds. How much force would the engine have to exert? The mass of a car is about 1,500 kg, and 60 mph  $\approx$  27 m/s. Recall that acceleration is the change in velocity divided by the change in time.

$$\begin{aligned}\text{Acceleration} &= \text{change in velocity}/\text{time} \\ &= (27 \text{ m/s} - 0 \text{ m/s})/10 \text{ s} \\ &= (27 \text{ m/s})/10 \text{ s} \\ &= 2.7 \text{ m/s}^2\end{aligned}$$

Since you know the acceleration, you can use the second law of motion to calculate the force required to cause this acceleration.

$$\begin{aligned}F &= ma \\ &= (1,500 \text{ kg})(2.7 \text{ m/s}^2) \\ &= 4,050 \text{ m}\cdot\text{kg/s}^2 \\ &= 4,050 \text{ N}\end{aligned}$$

**Look Out!**

Slowing down is also acceleration. It is often referred to as deceleration, but in scientific terms, it is called negative acceleration. When something slows down it is because an unbalanced force is acting in a direction opposite of the object's motion. In most cases, this unbalanced force is the force of friction.

**Newton's Third Law**

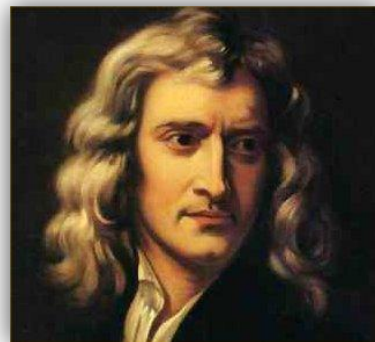
Newton's third law of motion is often stated, "For every action force there is an equal and opposite reaction force." You may think, "Wait, that does not make sense!" But it is true. All forces occur in pairs, and no force exists alone. You push on a door to open it, and the door pushes back with an equal force in the opposite direction. After all, you can feel the door, can't you? As you walk, you push on the pavement with the sole of your shoe. The pavement pushes in the opposite direction, sending you forward.

It may seem more logical if you think of force pairs as an interaction between objects. An object always interacts with another object. Think about two ice skaters facing each other. If one skater pushes on the other's hands, both skaters move backward. The first skater's action force caused a reaction force from the other skater, even though the second skater did not try to push back.

**Scientists in the Spotlight: Isaac Newton**

Sir Isaac Newton, an Englishman who lived from 1642 to 1727, made an amazing number of important contributions to science. In addition to developing his three laws of motion, Newton developed the law of universal gravitation. This law explains how gravitational force varies with the masses of two objects and the distance between them. The greater the mass of the objects, the greater the gravitational force is between them. The greater the distance between two objects, the weaker the gravitational force between them.

Newton also did important work in the fields of optics, astronomy, and chemistry. He also wrote extensively on religious topics. He was influential in establishing the main ideas of the scientific method, and he argued that the laws of science apply to objects in space in the same way they apply on Earth. His ideas were slow to be accepted by some scientists. The idea that a force, like gravity, could act at a distance without contact between objects sounded too mysterious and magical for many scientists to believe.



Sir Isaac Newton made important contributions to our understanding of forces and motion.

**What Do You Know?**

Everyday objects illustrate Newton's three laws of motion in countless ways. The chart below lists some examples of the laws in action. For each example, write which law it **best** illustrates and explain your answer.

Examples of Laws of Motion	Which Law is Best Illustrated? Why?
Maya hits a curb while riding her bike. The bike stops moving, but Maya is thrown into the air for a split second.	
A bird flaps its wings, using them to push air downward. Air pushes upward on the bird, allowing the bird to fly.	
Peter pushes on two boxes with equal force. The first box is filled with books and the second box is filled with balloons. The second box accelerates at a greater rate than the first box.	

**Connecting With Your Child: Force and Motion in Olympic Events**

To help your child learn more about Newton's three laws of motion, begin with a review of each law:

- The first law is the law of inertia. This law states that an object at rest tends to stay at rest, and an object in motion tends to stay in motion at constant speed in a straight line. That is, the state of motion of an object does not change unless it is acted upon by an unbalanced force. Therefore, if the net force is 0, nothing happens.
- The second law of motion states that the relationship between force ( $F$ ), mass ( $m$ ), and acceleration ( $a$ ) is  $F = ma$ . This equation can also be written as  $a = F/m$ . More force makes things accelerate at a greater rate, and more mass slows the rate of acceleration.
- The third law of motion is the law of action-reaction. For every action force there is an equal and opposite reaction force. Forces always occur in pairs, never alone. When you push on something, it pushes back with an equal amount of force in the opposite direction.

Now you are ready to observe the laws in action! A good place to observe forces at work is at a track meet or gymnastics competition. If you cannot visit one of these, try to watch videos of the Olympics or find pictures of the equipment involved. Alternatively, you and your child could visit a school that competes in track or gymnastics.

Study several events and observe how the three laws of motion describe the forces and motion involved. Here are some examples of events to consider:

- Shot put: What are the acting forces? What is the effect of the shot put's mass?
- Discus: In which ways does the discus change its state of motion?
- Javelin: Why does it go farther than the shot put? What are the forces involved?
- Foot races: When are the racers accelerating?

For all of the events, discuss the effects of force and mass on acceleration. Identify action and reaction forces, and try to find the causes of positive and negative acceleration.

Here are some questions to discuss with students:

1. A girl throws a ball to a dog, and the dog catches it in his mouth. At what point does the force exerted by the girl's hand stop affecting the motion of the ball?
2. One child is pushing two other children on a sled. One child gets off the sled and helps to push. Explain two ways this change affects the motion of the sled in terms of the s
3. Identify the action force and the reaction force acting on a person sitting in a chair.