Chapter 6

Newton's Laws of Motion

In January of 1993, the 53rd space shuttle mission crew brought some toys on board. During the flight, crew members played with the toys to see how they would work in "microgravity." Can you imagine trying to shoot a ball through a hoop while floating around in the space shuttle? Would a toy car be able to race around a loop track in space? You can learn how the toys behaved in space by doing an Internet search using the keywords "toys in space." But by reading this chapter first, you may be able to predict how the toys worked in space. This chapter presents the laws of motion as stated by Sir Isaac Newton (1642–1727). Newton discovered answers to many questions about motion. Many historians believe Newton's ideas about motion were the beginning of modern science.

Key Questions

- ✔ Why is a bowling ball harder to move than a golf ball?
- ✔ How is acceleration related to force and mass?
- ✔ What would happen if Sir Isaac Newton had a skateboard contest with an elephant?

Photo courtesy of NASA

6.1 Newton's First Law

People who study science consider Sir Isaac Newton to be one of the most brilliant scientists who has ever lived. His three laws of motion are among the most widely used natural laws in all of science. Newton's laws are not complicated math equations. They are brilliantly simple rules that show us an elegant way to make sense of how our world works.

Force changes motion

Force changes an object's motion When playing miniature golf, what do you do to move the golf ball toward the hole? Do you tell the ball to move? Of course not! You hit the ball with the golf club to get it rolling. In physics, "hit the ball" means the golf club applies a force to the ball. This force is what changes the ball from being at rest to being in motion (Figure 6.1). *Motion can change only through the action of a force.* This statement is the beginning of Newton's first law.

Why do things stop moving? Once moving, the ball rolls some, slows down, and eventually stops. For a long time, scientists thought the natural state of all things was to be at rest (stopped). They believed force had to be applied to keep an object moving and that constant motion required a constant force. *They were wrong!*

The real explanation The golf ball stops because the force of friction keeps acting on it until there is no longer any motion. Suppose the golf course were perfectly level and had no friction. After being hit with the golf club, the ball would keep moving in a straight line at a constant speed *forever.* The ball would neither slow down nor change direction *unless another force acted on it*. Being stopped or moving with constant speed and direction are *both* natural states of motion and *neither one requires any force to sustain it.*

Net force When you hit a golf ball, the force from the club is not the only force that acts on the ball (Figure 6.2). The ball's weight, the normal force from the ground, and friction are also acting. The ball moves according to the net force acting on the ball. The golf club causes the ball to move because its force overcomes the friction force keeping the ball in place. Newton's first law is written in terms of the *net force* because that is what affects motion.

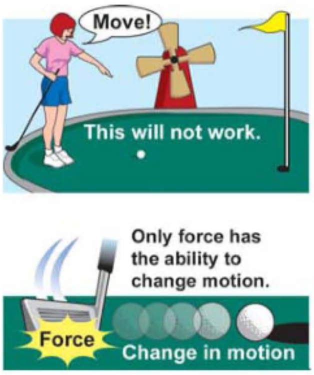


Figure 6.1: *Force has the ability to change the motion of an object.*

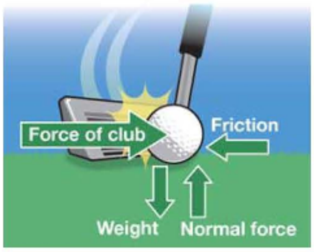


Figure 6.2: *Four forces act on a golf ball. The net force determines how the ball moves.*

The first law: The law of inertia

Newton's first law

Newton's first law says objects continue the motion they already have *unless* they are acted on by a net force (the sum of all forces acting on an object at any given time). When the net force is zero, objects at rest stay at rest, and objects that are moving keep moving in the same direction with the same speed.

When the net force is zero, objects at rest stay at rest and objects in motion keep moving with the same speed and direction.

Force is required to change motion

The first law says there can be no change in motion without a net force. *That includes slowing down!* It takes a net force (often friction) to make things slow down. If forces are truly balanced, a moving object will keep moving forever with the same speed, in the same direction.

Balanced and unbalanced forces

Changes in motion come from **unbalanced forces**. Forces are "unbalanced" when the net force is NOT exactly zero. A rolling golf ball on a grassy golf course is not in equilibrium because friction is an unbalanced force. Forces are "balanced" when they add up to zero net force. An object is in equilibrium if all of the forces on it are balanced.

Inertia

The first law is often called the "law of inertia" because **inertia** is the property of an object that resists changes in motion. Inertia comes from mass. Objects with more mass have more inertia. To understand inertia, imagine moving a bowling ball and a golf ball that are both at rest (Figure 6.3). A golf ball has a mass of 0.05 kilogram, and suppose the bowling ball has a mass of 5 kilograms. The bowling ball has 100 times more mass than the golf ball, so it has 100 times more inertia too. Which needs more force to start moving? If you push for the same distance, the bowling ball takes *much* more force to get it moving the same speed as the golf ball. The bowling ball needs more force because the bowling ball has more inertia than the golf ball. The greater an object's inertia, the greater the force needed to change its motion.

VOCABULARY

Newton's first law - a law of motion that states that an object at rest will stay at rest and an object in motion will stay in motion with the same velocity unless acted on by an unbalanced force.

unbalanced forces - forces that result in a net force on an object and can cause changes in motion.

inertia - the property of an object that resists changes in its motion.

Figure 6.3: *The bowling ball has more mass than the golf ball. The bowling ball is harder to move because it has more inertia.*

Solving Problems: Net Force and the First Law

A car drives along the highway at constant velocity. Find the car's weight and the friction force if the engine produces a force of 2,000 N between the tires and the road and the normal force on the car is 12,000 N (Figure 6.4).

1. Looking for: You are asked for the car's weight and the friction force.

2. Given: You are given the normal force and forward force between the road and tires. The normal force is 12,000 N and the forward force is 2,000 N. The car is moving at a constant velocity.

3. Relationships: Newton's first law states that if the car is moving at a constant velocity, the net force must be zero.

4. Solution: The weight of the car balances the normal force. Therefore, the weight of the car is a downward force: 12,000 N. The forward force balances the friction force so the friction force is 2,000 N in the opposite direction of the car's motion.

Your turn...

a. Identify the forces on the same car if it is stopped at a red light on level ground.

b. While the car is moving forward, a gust of wind gives it a big push from behind. Since most of the friction on a car (at highway speeds) is from the air, the friction force is reduced from 2,000 N to 1,500 N. What is the net force on the car if the engine force remains at 2,000 N? Does it still move at constant velocity?

c. What is the normal force on the car if 1,000 N of luggage is added?

d. As you sit on the passenger seat of the car, the seat exerts a normal force of 550 N on you. If you weigh 600 N, what is the normal force of the car's floorboard on your feet?

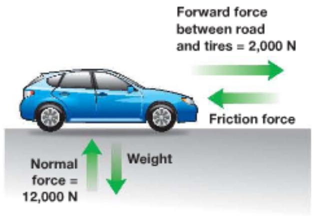


Figure 6.4: *The forces on the car.*

SOLVE FIRST LOOK LATER

a. When stopped, the car experiences a normal force of 12,000 N and its weight of 12,000 N.

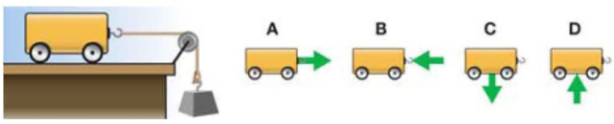
b. The net force is 500 N. No, while the wind is blowing, the car is not moving at constant velocity since it is experiencing a net force.

c. The normal force is 13,000 N.

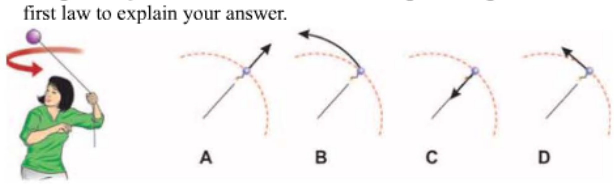
d. The normal force of the floorboard on your feet is 50 N.

Section 6.1 Review

1. For each of the following situations, identify what creates one of the forces that creates the motion described (there may be many).
   a. A flag flaps back and forth at the top of a flagpole.
   b. A soccer ball is passed from one player to another.
   c. A large piece of hail falls toward the ground.
   d. The ocean tide goes from high to low at the seashore. (You might have to do a little research to get this one if you don't know already.)
2. Which has more inertia—a shopping cart full of groceries or an empty shopping cart?
3. In the following situation, which diagram (A, B, C, or D) best illustrates the net force experienced by the cart when the weight pulls downward?



4. Forces contribute to the net force on a car rolling down a ramp.
   a. Which force supports the car's weight?
   b. Which force accelerates the car down the ramp?
   c. Which force acts against the motion of the car?
5. Imagine whirling a ball on a string over your head. Suppose the knot holding the ball comes loose and the ball is instantly released from the string. What path does the ball take after leaving the string? Use Newton's first law to explain your answer.



TECHNOLOGY

Mass Transportation

Cars and planes with more inertia take more force to accelerate. Since inertia is related to mass, in order to reduce inertia you must reduce mass. The mass of a car or plane is a trade-off between inertia and the strength of materials of the car or plane. We want strong materials, but we don't want them so heavy that it takes too much energy (fuel) just to get the car or plane moving!

1. Research how cars or planes have been designed to have less mass.
2. How is the balance between strength and mass resolved when designing cars or planes?