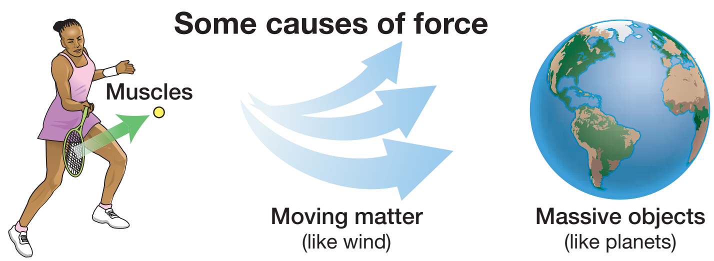
4.1 Forces

We have talked about *forces* since Chapter 1. However, since force is such an important idea, this whole chapter is about forces. You will learn where forces come from, how they are measured, and how they are added and subtracted.

The cause of forces

What are forces? A force is a push or pull, or any action that has the ability to change motion. The key word here is *action*. Force is an action. You need force to start things moving. You also need force to make any change to an object's motion once it is moving. Forces can increase or decrease the speed of an object. Forces can also change the direction in which an object is moving.

How are forces created? Forces are created in many ways. For example, your muscles create force when you swing a tennis racket. Earth's gravity creates a force called **weight** that pulls on everything around you. On a windy day, the movement of air can create forces. Each of these actions can create force because they all can change an object's motion.



The four elementary forces All of the forces we know of in the universe come from four elementary forces. Figure 4.1 describes the four elementary forces. Unless you go on to study physics or chemistry you may never need to know anything about the strong or weak force. These forces are only important inside the atom and in certain kinds of radioactivity. However, the electromagnetic force and gravity are important in almost all areas of human life and technology.

VOCABULARY

weight - a force that comes from gravity pulling down on any object with mass.

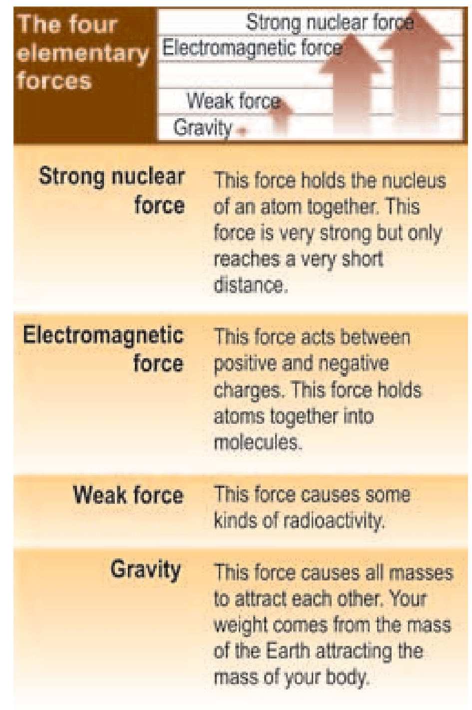


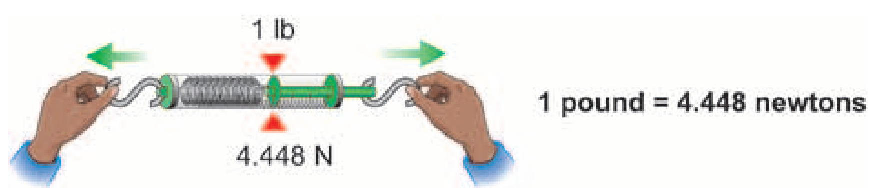
Figure 4.1: *All forces in the universe come from only four elementary forces.*

Units of force

Pounds Imagine mailing a package at the post office. How does the postal clerk know how much you should pay? You are charged a certain amount for every pound of *weight*. The **pound** is a unit of force commonly used in the United States. When you measure weight in pounds on a postal scale, you are measuring the force of gravity acting on the object (Figure 4.2). For smaller amounts, pounds are divided into ounces (oz). There are 16 ounces in 1 pound.

The origin of the pound The pound is based on the Roman unit *libra*, which means "balance." That is why the abbreviation for pound is "lb". The word *pound* comes from the Latin *pondus*, meaning "weight." The definition of a pound has varied over time and from country to country.

Newtons Although we use pounds all the time in our everyday life, scientists prefer to measure forces in *newtons*. The **newton** (N) is a metric unit of force. The newton is defined by how much a force can change the motion of an object. A force of 1 newton is the exact amount of force needed to cause a mass of 1 kilogram to speed up by 1 m/s each second (Figure 4.2). We call the unit of force the newton because force in the metric system is defined by Newton's laws. The newton is a useful way to measure force because it connects force directly to its effect on motion.



Converting newtons and pounds The newton is a smaller unit of force than the pound. One pound of force equals 4.448 newtons. How much would a 100-pound person weigh in newtons? Recall that 1 pound = 4.448 newtons. Therefore, a 100-pound person weighs 444.8 newtons.

VOCABULARY

pound - the English unit of force equal to 4.448 newtons.

newton - the metric unit of force, equal to the force needed to make a 1 kg object accelerate at 1 m/s^2.

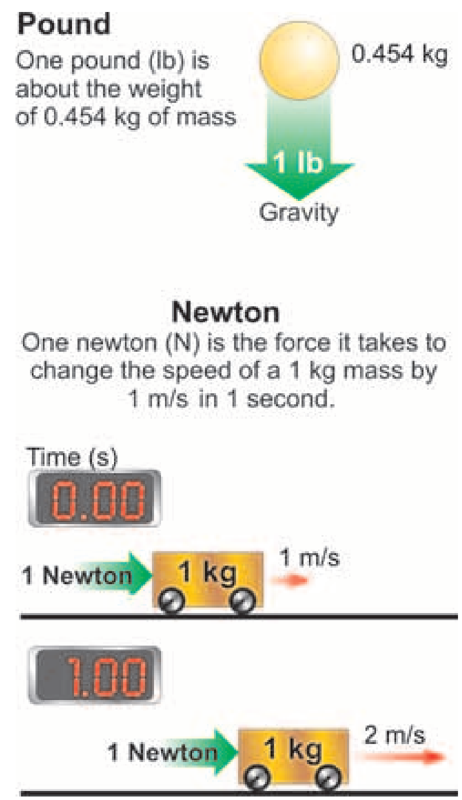
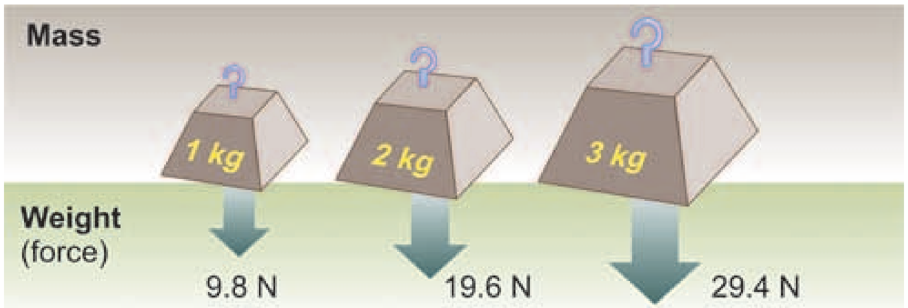


Figure 4.2: *The definitions of the newton and pound.*

Gravity and weight

Gravity's force depends on mass

The force of gravity on an object is called *weight*. At Earth's surface, gravity exerts a force of 9.8 N on every kilogram of mass. That means a 1-kilogram mass has a weight of 9.8 N, a 2-kilogram mass has a weight of 19.6 N, and so on. On Earth's surface, the weight of any object is its mass multiplied by 9.8 N/kg. Because weight is a force, it is measured in units of force such as newtons and pounds.



At Earth's surface each kg of mass feels **9.8** N of weight from Earth's gravity.

Weight and mass are not the same thing

People often confuse *weight* and *mass* in conversation. However, *weight and mass are not the same*. Mass is a fundamental property of matter measured in kilograms (kg). Weight is a *force* caused by mass. You have weight because the huge mass of Earth is right next to you. It is easy to confuse mass and weight because heavy objects (more weight) have lots of mass and light objects (less weight) have little mass. Always remember the difference when doing physics. Weight is a *force* measured in *newtons* (N*)* that depends on mass and gravity.

Weight is a force measured in newtons.

Weight is less on the Moon

A 10-kilogram rock has the same mass no matter where it is in the universe. A 10-kilogram rock's weight however, depends completely on where it is. On Earth, the rock weighs 98 newtons. But on the Moon, it only weighs 16 newtons (Figure 4.3)! The same rock weighs 6 times less on the Moon because gravity is weaker on the Moon.

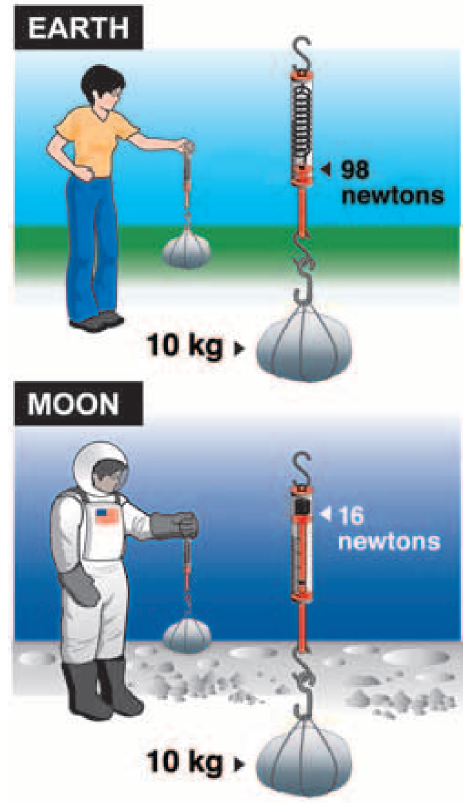


Figure 4.3: *A 10-kilogram rock weighs 98 newtons on Earth but only 16 newtons on the Moon.*

Calculating weight

The weight formula

The weight formula (Figure 4.4), weight = mass × strength of gravity, can be rearranged into three forms. You can use this formula to find weight, mass, or the strength of gravity if you know any two of the three values.

Use. . .	if you want to find. . .	and you know. . .
$W = mg$	weight (W)	mass (m) and strength of gravity (g)
$m = W/g$	mass (m)	weight (W) and strength of gravity (g)
$g = W/m$	strength of gravity (g)	weight (W) and mass (m)

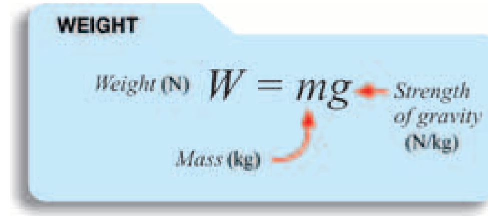


Figure 4.4: *The weight formula.*

Weight and mass

Calculate the weight of a 60-kilogram person (in newtons) on Earth and on Mars (g = 3.7 N/kg).

1. Looking for: You are asked for a person's weight on Earth and Mars.
2. Given: You are given the person's mass and the value of g on Mars.
3. Relationships: $W = mg$
4. Solution: For the person on Earth:
   $W = mg$
   W = (60 kg)(9.8 N/kg) = 588 newtons

   For the person on Mars:
   $W = mg$
   W = (60 kg)(3.7 N/kg) = 222 newtons

   Notice that while the masses are the same, the weight is much less on Mars.

Your turn...

a. Calculate the mass of a car that weighs 19,600 newtons on Earth. **Answer:** 2,000 kg

b. A 70-kg person travels to a planet where he weighs 1,750 N. What is the value of g on that planet? **Answer:** 25 N/kg

The force vector

What is a force vector? The direction of a force makes a big difference in what the force does. That means force is a *vector*, like velocity or position. To predict the effect of a force, you need to know its *strength* and its *direction*. Sometimes the direction of a force is given in words such as 5 newtons down. In diagrams, arrows are used to show direction.

Using positive and negative numbers Forces are assigned positive and negative values to tell their direction. For example, suppose a person pushes with a force of 10 newtons to the right (Figure 4.5). The force vector is +10 N. A person pushing with the same force to the left would create a force vector of –10 N. The negative sign indicates the –10 N force is in the opposite direction from the +10 N force. We usually choose positive values to represent forces directed up, to the right, north or east.

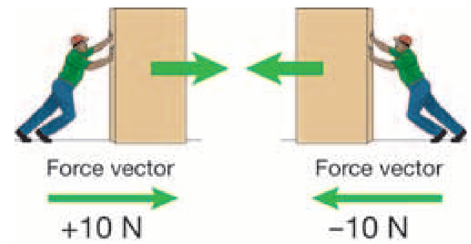
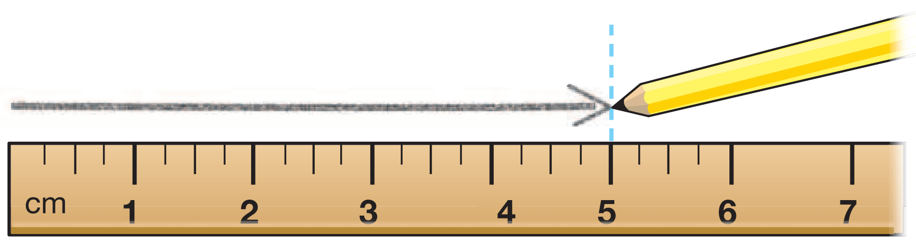


Figure 4.5: *Positive and negative numbers are used to indicate the direction of force vectors.*

Drawing a force vector It is sometimes helpful to show the strength and direction of a force vector as an arrow on a graph. The length of the arrow represents the strength of the force. The arrow points in the direction of the force. The x- and y-axes show the strength of the force in the x and y directions.

Scale When drawing a force vector, you must choose a scale. For example, if you are drawing a vector showing a force of 5 N pointing straight up (y-direction) you might use a scale of 1 cm = 1 N. You would draw the arrow five centimeters long pointing along the y-direction on your graph (Figure 4.6). A 5 N horizontal force (x-direction) would be drawn with a 5 cm line, as shown below.



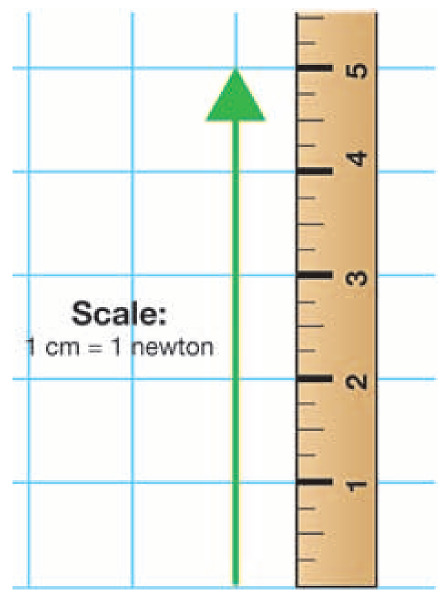


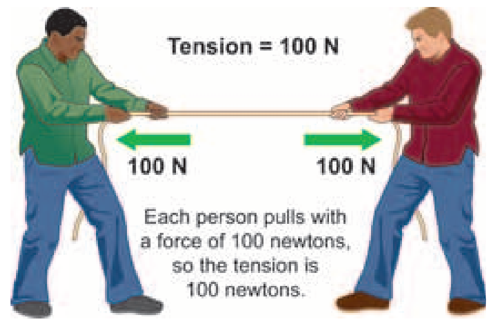
Figure 4.6: *You must use a scale when drawing a vector.*

Forces from springs and ropes

Types of forces

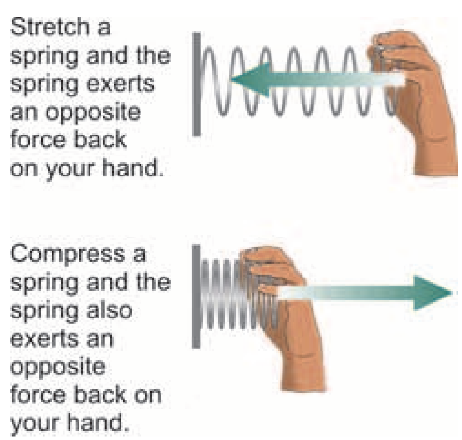
Ropes and springs are often used to make and apply forces. Ropes are used to transfer forces or change their direction. Springs are used to make and control forces.

Tension forces



The pulling force carried by a rope is called **tension**. *Tension always acts along the direction of the rope.* A rope carrying a tension force is stretched tight and pulls with equal strength on either end. For example, the two people in the diagram at the left are each pulling on the rope with a force of 100 newtons. The tension in the rope is 100 newtons. Ropes or strings do *not* carry pushing forces. This is obvious if you have ever tried pushing a rope!

The force from springs



Springs are used to make or control forces. A spring creates a force when you stretch it or squeeze it away from its natural shape. The force created by a spring always acts to push or pull the spring back to its natural length. When you stretch a spring, it pulls back on your hand. When you squeeze a spring, called **compression**, the spring gets shorter. As it gets shorter the spring pushes back on your hand.

Spring forces vary in strength

The force created by a spring is proportional to the amount the spring is stretched or compressed. If you stretch a spring twice as much, it makes a force that is twice as strong.

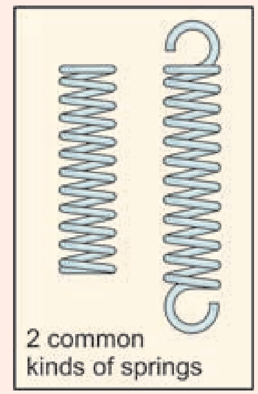
VOCABULARY

tension - a pulling force that acts in a rope, string, or other object.

compression - a squeezing force that can act on a spring.

TECHNOLOGY

Springs

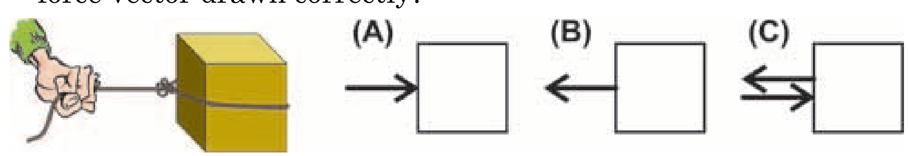


Springs are used in many devices to make controlled amounts of force. Two of the many kinds of springs are extension springs and compression springs. Extension springs are designed to be stretched. They often have loops on either end. Compression springs are designed to be squeezed. They are usually flat on both ends. Can you find both types in springs in your classroom?

1. What is the spring used for?
2. What would happen if the spring broke?

4.1 Section Review

1. Name three situations in which force is created. Describe the cause of the force in each situation.
2. Which of the following are units of force?
   a. kilograms and pounds
   b. newtons and pounds
   c. kilograms and newtons
3. Which is greater: a force of 10 N or a force of 5 lbs?
4. Does the mass of an object change if the object is moved from one planet to another? Explain your answer.
5. What is the weight (in newtons) of a bowling ball which has a mass of 3 kilograms?
6. If the strength of gravity is 9.8 newtons per kilogram, that means:
   a. each newton of force equals 9.8 pounds.
   b. each pound of force equals 9.8 newtons.
   c. each newton of mass weighs 9.8 kilograms
   d. each kilogram of mass weighs 9.8 newtons.
7. An astronaut in a spacesuit has a mass of 100 kilograms. What is the weight of this astronaut on the surface of the Moon where the strength of gravity is approximately 1/6 that of Earth?
8. A rope is used to apply a force to a box. Which drawing shows the force vector drawn correctly?



9. A spring is stretched as shown. Which drawing shows the force exerted *by the spring*? (Hint: *Not* the force *on* the spring.)

Calculating mass from weight

What is the mass of an object with a weight of 35 newtons? Assume the object is on the Earth's surface.

1. Looking for: Mass
2. Given: Weight = 35 N
3. Relationships: The weight equation $W = mg$
4. Solution: $m = W/g$ $= (35\ N)/(9.8\ N/kg)$ $= 3.57\ kg$

Your turn...

a. Which is greater: A force of 100 N or the weight of 50 kilograms at Earth's surface? **Answer**: The weight of 50 kg is greater.
b. The mass of a potato is 0.5 kg. Calculate its weight in newtons. **Answer**: 4.9 N