Chapter 5
Force

Every year, all over the world, competitions are held that require strength and a knowledge of force. Athletes compete in events with names like the Giant Log Lift, the Pillars of Hercules, the Atlas Stones, and the Plane Pull. As you might imagine, moving a giant log or a plane requires a tremendous amount of force. How can athletes achieve these amazing feats? There is a good chance that during their training, they thought about how best to apply force so that they could lift a giant log, pull a plane, or lift a 160-kilogram Atlas Stone.

Forces are created and applied every time something moves. Forces, such as weight, are even present when objects are not moving. Your body uses forces even when your heart is beating and when you are walking upstairs. And force is necessary when you want to pick up or move something that is very heavy. Understanding forces is fundamental to understanding how tasks are best accomplished in nature and by people. Read this chapter to learn more about how forces are created, measured, described, and used in daily life.

Key Questions

- ✔ *How are you affected by forces right now?*
- ✔ *What is friction and how is it useful?*
- ✔ *What happens when an object experiences net force?*

5.1 Forces

Force is a very important concept in physics and in everyday life. In this chapter, you will learn where forces come from, how they are measured, and how they are added and subtracted.

VOCABULARY

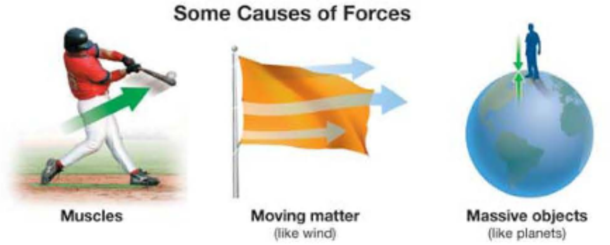
force - a push or a pull, or any action that involves the interaction of objects and has the ability to change motion.

The cause of forces

What are forces? A **force** is a push or a pull. Technically, force is the *action* that has the ability to change motion. You need force to start an object moving. You also need force to change an object's motion if it is already moving. Forces can increase or decrease the speed of a moving 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 baseball bat. On a windy day, the movement of air can create forces. Earth's gravity creates a force called *weight* that pulls on everything around you. Each of these actions creates forces and through those forces, each can change an object's motion.

Some Causes of Forces



The four elementary forces All of the forces we know of in the universe come from four elementary forces. Figure 5.1 describes the four elementary forces. If you study physics or chemistry, you will learn more about the strong and weak forces. These forces are only important inside the atom and in certain types of radioactivity. However, the electromagnetic force and gravity are important in almost all areas of human life, including technology.

The Four Elementary Forces

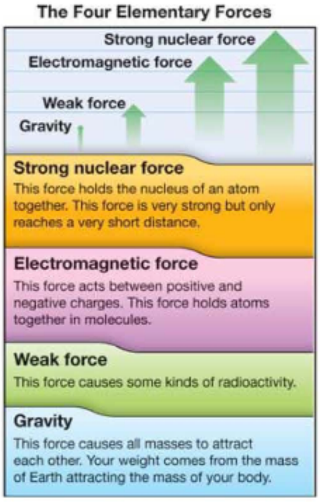


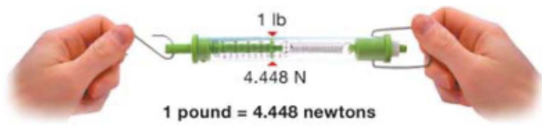
Figure 5.1: *All forces in the universe come from only four elementary forces.*

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** (lb) is a unit of force commonly used in the United States. When you measure weight in pounds on a scale, you are measuring the force of gravity acting on an object (Figure 5.2). 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." This 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 an SI 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 (or slow down) by 1 m/s each second (Figure 5.2).
We call the SI unit of force the *newton* because force 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.



Unit conversions The newton is a smaller unit of force than the pound. One pound of force equals 4.448 newtons. That makes the newton a little less than a quarter of a pound. This is about the weight of a stick of butter. As another example, a 100-pound person weighs 444.8 newtons. In SI units, the mass of a 100-pound person (on Earth) is about 45 kilograms. If you do the math (444.8 ÷ 45) you will find that 1 kg of mass has a weight of 9.8 newtons of force.

VOCABULARY

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

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

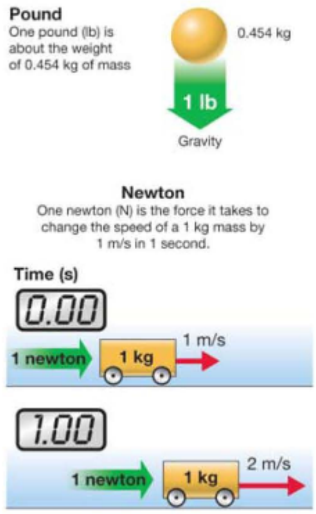


Figure 5.2: *The definitions of* newton *and* pound.

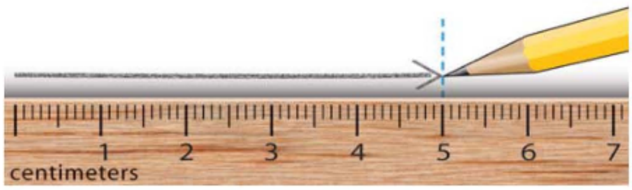
The force vector

Force is a vector The direction of a force makes a big difference in what the force can do. That means force is a *vector*, like velocity or position. To predict the effect of a force, you need to know both its *strength* and its *direction*. Strength is usually measured in newtons. Direction may be given in words, such as 5 newtons *down*, or in symbols. Arrows are often used to show the direction of forces in diagrams (Figure 5.3).

Using positive and negative numbers Forces may be assigned positive and negative values to tell their directions. For example, suppose a person pushes with a force of 10 newtons to the right (Figure 5.3). 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 that 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, to the north, or to the east.

Drawing a force vector It is sometimes helpful to show both 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 to show its strength, you must choose a scale. For example, suppose you want to draw a force of 5 N pointing straight up (*y*-direction). You might use a scale of 1 cm = 1 N. At this scale, the force vector is a 5-cm long arrow pointing up, along the *y*-axis on your graph (Figure 5.4). A 5 N horizontal force would be drawn along the *x*-axis with a 5-cm long arrow pointing to the right.



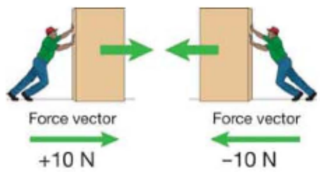


Figure 5.3: *Positive and negative numbers are used to indicate the direction of force vectors.*

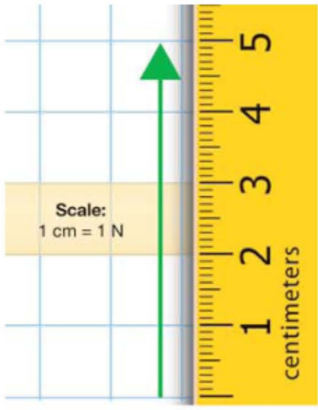


Figure 5.4: *You must use a scale when drawing a vector.*

How forces act

Contact forces There are two ways that objects can affect each other through forces. One way is the result of direct contact. The force between two people pulling on a rope is a good example of a force that occurs through direct contact (Figure 5.5). A contact force is transmitted by matter directly touching other matter. The wind acting to slow a parachute is also a contact force because air is matter. The force comes from air contacting the parachute. In the next section, you will learn about *friction*, another contact force.

Forces that act through space Now think about Earth and the Moon. If Earth were to disappear, the Moon would sail off into space by itself. The Moon doesn't fly off because a force exists between Earth and the Moon. That force is called *gravity*. Gravity provides the force that keeps Earth and the Moon together in orbit. But, exactly how does "gravity" get from Earth to the Moon? Space is empty of matter, so the force cannot be a contact force.

Some examples The force of gravity between Earth and the Moon appears to be what people once called "action-at-a-distance." The force between two magnets is another force that acts at a distance. So is the force that causes electricity. Table 5.1 summarizes the two types of forces.

Table 5.1: Types of Forces

Contact Forces	"At-a-distance" Forces
friction	gravity
normal force	electricity
tension, air resistance, spring	magnetism

The force field Today, we know that a true "action-at-a-distance" force is impossible. The force of gravity actually acts in two steps. First, the mass of Earth creates a *gravitational field* that fills the space around Earth with potential energy. Second, the gravitational field of Earth creates a force on the Moon. The gravitational force is carried from Earth to the Moon by a *force field*. In fact, if Earth were to vanish instantly, the Moon would continue to be affected by Earth's gravity for a few seconds. This is because the force field "flows" between Earth and the Moon quickly, *but not instantly.*

Figure 5.5: *Contact forces and a force that acts through a force field.*

STUDY SKILLS

Defining Forces

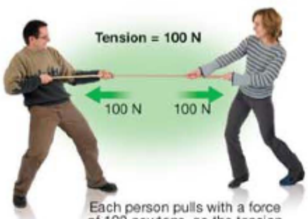
Pick a term that is listed in Table 5.1 but that is not described on this page (friction, normal force, or spring force). Find out what the term means. You can do research and find the answer on your own or ask someone who is knowledgeable on the subject.

Contact forces from ropes and springs

Two ways contact forces occur

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.

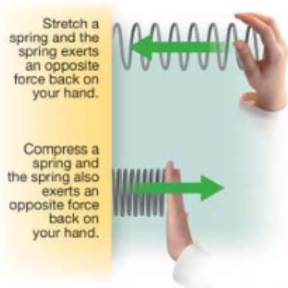
Tension



Each person pulls with a force of 100 newtons, so the tension is 100 newtons.

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. The two people in the diagram at the left are each pulling on the rope with a force of 100 newtons. Tension is defined as the force with which a rope is pulled in *each* direction, so the tension in the rope is 100 newtons. Ropes do *not* carry pushing forces. This is obvious if you have ever tried pushing a rope!

Spring forces



Springs are used to make or control forces. A spring creates a force when you stretch it or squeeze it away from its resting shape. The force from a spring always acts to return the spring to its resting shape. If you stretch a spring (**extension**), the spring acts to make itself shorter, pulling back on your hand. If you squeeze a spring (**compression**), the spring tries to get longer again and pushes back on your hand.

Spring forces vary in strength

The force created by a spring is proportional to the ratio of the extended or compressed length divided by the original (resting) length. If you stretch a spring twice as much, it makes a force that is twice as strong.

VOCABULARY

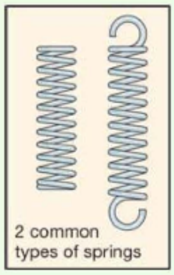
tension - a pulling force that acts in a rope, string, or other object.

extension - a "stretch," or increase in size.

compression - a "squeeze," or decrease in size.

TECHNOLOGY

Springs

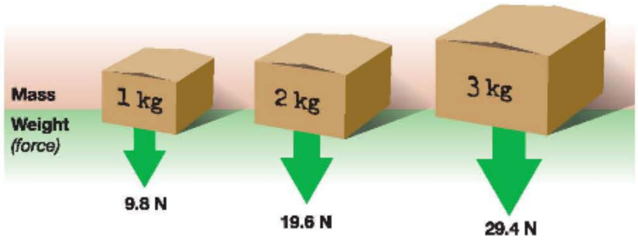


Two of the many types of springs are extension springs and compression springs. Extension springs are designed to be stretched. They often have loops on either end. Compression springs are designed to be squeezed. They are usually flat on both ends. Can you find both types in springs in your classroom?

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

Gravity

Gravitational 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. Therefore, on Earth, the weight of any object is its mass multiplied by 9.8 N/kg. For example, 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. Because weight is a force, it is measured in units of force such as newtons and pounds.



Weight vs. mass Weight and mass are not the same. Mass is a fundamental property of matter measured in kilograms (kg). Weight is a *force* measured in *newtons* (N). Weight depends on mass *and* gravity. For example, how much you weigh depends on your mass and the strength of gravity at your location. It is easy to confuse mass and weight because they seem similar. Heavy objects (more weight) have lots of mass and light objects (less weight) have little mass. But, it's important to remember the difference when doing physics.

Weight is a force that depends on mass and gravity.

Weight is less on the Moon A 10-kilogram rock has the same mass no matter where it is in the universe. The rock's *weight*, however, depends on where it is located. On Earth, the rock weighs 98 newtons. But on the Moon, it weighs only 16 newtons (Figure 5.6). On the Moon, the rock's weight would be one-sixth the rock's weight on Earth because the strength of gravity on the Moon is one-sixth the strength of gravity on Earth.

Figure 5.6: *A 10-kilogram rock weighs 98 newtons on Earth but only 16 newtons on the Moon.*

Calculating weight

The weight formula

The weight formula lets you calculate the weight of an object if you know the object's mass and the strength of gravity at the object's location. Three forms of the weight formula are given in Table 5.2. Use the appropriate form to find weight, mass, or the strength of gravity if you know any two of the three values.

WEIGHT

$$W = mg$$

Weight (N) — W; *Mass* (kg) — m; *Strength of gravity* (N/kg) — g

***g* is the symbol for gravity**

The strength of gravity at Earth's surface is so important to our everyday life that we give it a special symbol, the lowercase letter g. When you see a g in a formula you can usually substitute the value $g = 9.8$ N/kg. Of course, that assumes the formula is being applied at the surface of Earth! Elsewhere in the universe g has different values. You sometimes see g written with units of m/s^2, for example, $g = 9.8$ m/s^2. This is really the same g expressed as the acceleration of a 1-kg mass under the influence of gravity.

Table 5.2: Different Forms of the Weight Formula

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)

STUDY SKILLS

Different Ways to Show "Divided By"

Below are three different ways to show the equation "mass equals weight divided by gravity." Notice the different ways to show "divided by." You should familiarize yourself with all three versions.

Mass = weight divided by gravity

$m = W/g$

$m = \frac{W}{g}$

$m = W \div g$

Some Notes about Drawing Force Vectors

1. Force vectors should always be drawn in the direction of the force they represent.
2. Force vectors should be drawn to scale if possible, with length proportional to strength.
3. A force on a surface can be shown as pointing toward the surface or away from it. What matters is that the direction is clear so you know what the net force is in a certain direction.

Solving Problems: Weight and Mass

Calculate the weight of a 60-kilogram person (in newtons) on Earth and on Mars (g = 3.7 N/kg on Mars) (Figure 5.7).

1. Looking for: You are asked for a person's weight on Earth and on 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:
$W = mg$
$W = (60\text{ kg})(9.8\text{ N/kg}) = 588$ newtons

For the person on Mars:
$W = mg$
$W = (60\text{ kg})(3.7\text{ N/kg}) = 222$ 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 N on Earth.

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

Figure 5.7: *How does the weight of a person on Earth compare to the weight of the same person on Mars?*

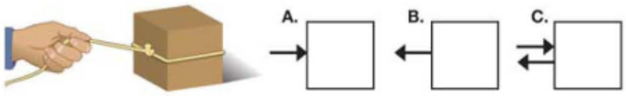
SOLVE FIRST LOOK LATER

a. 2,000 kg

b. 25 N/kg

Section 5.1 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. A rope is used to apply a force to a box. Which drawing shows the force vector drawn correctly?



5. What is the difference between contact forces and forces that act through a force field?
6. A spring is stretched as shown. Which drawing shows the force exerted *by the spring*? (Hint: *Not* the force *on* the spring.)

7. 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.
8. 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?
9. What is the weight (in newtons) of a bowling ball that has a mass of 3 kilograms?

SOLVE IT!

Calculating Mass from Weight

Use the steps on page 105 to solve the following problems.

1. What is the mass of an object with a weight of 35 newtons? Assume the object is on Earth's surface.
2. Which is greater: A force of 100 N or the weight of 50 kilograms on Earth's surface?
3. The mass of a bag of potatoes is 0.5 kg. Calculate the weight of the potatoes in newtons.

SCIENCE FACT

Contact forces are actually acting through force fields too! When you push a box, the atoms in your hand are electrically repelling the atoms in the box. The force is carried between the atoms of your hand and the atoms of the box by trillions of tiny electrical force fields. In reality, ALL forces act through force fields once you get to the atomic level! We don't notice because atoms are so small.