4.2 Common Forces

SECTION OUTCOMES

- Use vectors to represent forces.
- Use instruments effectively and accurately for collecting data.
- Describe and evaluate the design of a technological solution using scientific principles.
- Describe the nature of gravitational and frictional forces.
- Investigate and describe different interactions between objects.
- Calculate frictional forces acting on objects.
- Analyze the motion of objects using free-body diagrams.

KEY TERMS

- contact force
- non-contact force
- weight
- acceleration due to gravity
- static frictional force
- kinetic frictional force
- coefficient of friction
- normal force
- net force
- free body diagram

Objects interact with other objects by exerting forces on each other. You move your pencil across your page, the desk at which you are sitting supports your books, and the air you breathe circulates around the room. Your desk is in direct contact with your books, so this interaction is an example of a **contact force**. Conversely, **non-contact forces** act over a distance, as is the case when two magnets attract or repel each other without touching.

Gravitational Force

Figure 4.3 Vince Carter is able to exert a large force in a short period of time, allowing him to jump extremely high, as he demonstrated during the 2000 Olympics in Sydney.

In Section 4.1, you studied an important property of matter — inertia. You learned that the inertia of an object was directly related to its mass. You also learned that inertial mass and gravitational mass are basically the same. Any two masses exert a mutual gravitational attractive force on each other. If you hold a tennis ball in each hand, you do not notice any force acting between them because gravitational forces are very weak. It is only because Earth has such an enormous mass that you are aware that it is exerting a strong force on you. Did you know, however, that you are exerting an equal force on Earth? Gravitational forces always act in pairs.

According to Newton's law of universal gravitation which you will study in detail in Chapter 12, the mutual attractive force between any two masses acts along a line joining their centres. Therefore, the force of gravity between Earth and any object is directed along a line between the centre of the object and the centre of Earth. Newton's law also states that the strength of the gravitational attractive force diminishes as the distance between their centres increases. The lengths of the arrows in Figure 4.4 represent the relative strength of the gravitational attractive force at different distances from Earth's centre. Although the attractive force decreases with distance it never truly reaches zero. The force of gravity, although relatively weak, has an infinite range. It is, therefore, a non-contact force.

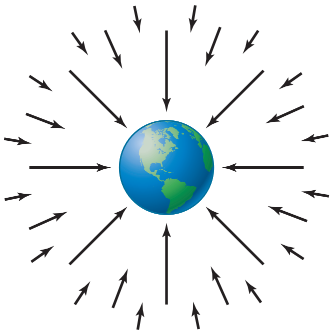


Figure 4.4 The gravitational force exerted by Earth on an object diminishes as the object's distance from Earth increases.

Conceptual Problem

- Consider the last sentence in the preceding paragraph. If it is true, then compare, qualitatively, the *force of gravity* acting on you due to the mass *of Earth* when you are on Earth's surface to
  - **(a)** the force of gravity acting on you when you are aboard the International Space Station,
  - **(b)** the force of gravity acting on you when you are out past the orbit of Pluto.

Weight

You have probably seen pictures of astronauts bouncing along the surface of the Moon. Even in their bulky space suits and oxygen tanks, they can jump significantly higher and drop back down more slowly than they could on Earth. What makes the difference? If an astronaut had a mass of 60 kg on Earth, he or she would still have a mass 60 kg when arriving on the Moon. However, astronauts weigh much less on the Moon than on Earth. The distinction between mass and weight becomes clear when you compare the effects of Earth's gravity to the Moon's gravity. You have a specific mass regardless of where you are located — on Earth, the Moon, or in intergalactic space. Your weight, however, is influenced by the force of gravity. In fact, **weight** is defined as the force of gravity acting on a mass. Therefore, your weight would be much lower on the Moon than it is on Earth. On the other hand, if Jupiter had a surface that astronauts could walk on, they would find themselves pinned to the ground weighing 2.5 times more than they weigh on Earth.

TRY THIS...

Poke a small hole in the side of a plastic cup near the bottom. Predict what will happen when you fill the cup with water and then allow it to fall toward the ground in the upright position. Record your prediction with the aid of a diagram. Test your prediction. Explain the results.

Figure 4.5 Acceleration due to gravity does not depend on mass, as demonstrated by the example of the feather and the coin in a vacuum tube.

As you know, the force of gravity is influenced by the masses of the two interacting objects as well as the distance between their centres. Thus you might expect that the relationship between an object's mass and the force of gravity acting on it would be very complex. Fortunately, it is not. There is a common factor that was also a topic of contemplation for Aristotle and Galileo. Aristotle believed that more massive objects fall faster than less massive objects. He predicted that a mass ten times greater than another mass would fall ten times faster. Galileo reasoned that a large mass would have more inertia than a small mass and therefore a greater force would be required to change the motion of larger mass than the smaller mass. Since the gravitational force on a large mass is greater than the gravitational force on a small mass, the masses should move in the same way under the influence of gravity. He conducted the experiment and found that all objects fell at almost exactly the same rate. He attributed the slight difference in falling time to air resistance. Galileo concluded, correctly, that, at any given location, and in the absence of air resistance, all objects will fall with the same acceleration. Physicists now call this the **acceleration due to gravity** and give it the symbol, g. You may have seen a demonstration of a coin and a feather falling at exactly the same rate when enclosed in an evacuated tube like the one shown in Figure 4.5 on the previous page.

Since the value of g is influenced by both the mass of Earth and the distance from Earth's centre, the value of g varies with location. On Earth's surface, g is approximately 9.81 m/s^2, but actually ranges from 9.7805 m/s^2 at the equator to 9.8322 m/s^2 at the poles because Earth is not perfectly round. It is really a flattened sphere that bulges in the middle. Consequently, objects at the poles are closer to the centre of Earth than are objects located at the equator. Some values of g are listed in Table 4.3 for comparison.

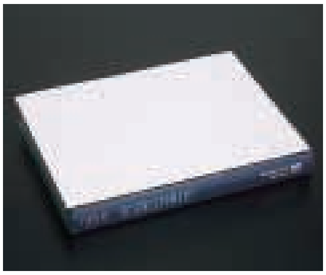
Table 4.3 Free-Fall Accelerations Due to Gravity on Earth

Location	Acceleration due to gravity (m/s^2)	Altitude (m)	Distance from Earth's centre (km)
North Pole	9.8322	0 (sea level)	6357
equator	9.7805	0 (sea level)	6378
Mt. Everest (peak)	9.7647	8850	6387
Mariana Ocean Trench* (bottom)	9.8331	11 034 (below sea level)	6367
International Space Station*	9.0795	250 000	6628

*These values are calculated.

TRY THIS...

Predict what will happen when you simultaneously drop an old textbook and a sheet of paper. Test your predictions. Why did the sheet of paper take longer to fall to the floor? Now place the paper on top of the textbook, ensuring that no part of the sheet is extending over the edge of the textbook. Predict what will happen when you drop the stacked pair. Test your predictions and explain.



COURSE CHALLENGE: SPACE-BASED POWER

What does "Weightless" Mean?

The term weightless is often used to describe astronauts in orbit. Describe a series of observations you could use to convince people that objects in Earth orbit are not truly weightless.

Because the mass and radius of the planets vary significantly, the acceleration due to gravity is quite different from planet to planet. Values of *g* for the Moon and a few planets are listed in Table 4.4.

Table 4.4 Free-Fall Accelerations Due to Gravity in the Solar System

Location	Acceleration due to gravity (m/s^2)
Earth	9.81
Moon	1.64
Mars	3.72
Jupiter	25.9

To summarize, you have discovered that weight is the force of gravity acting on a mass. You have also seen that the acceleration due to gravity incorporates all of the properties of the gravitational attractive force, except the mass of the object, that affect the strength of the force of gravity — mass of the planet and the distance between the centre of the object and the planet. Now you are ready to put them together in the form of a mathematical equation.

WEIGHT

An object's weight, $\vec{F}_g$, is the product of its mass, *m*, and the acceleration due to gravity, *g*.

$$\vec{F}_g = m\vec{g}$$

Quantity	Symbol	SI unit
force of gravity (weight)	$\vec{F}_g$	N (newton)
mass	m	kg (kilogram)
acceleration due to gravity	$\vec{g}$	$\frac{m}{s^2}$ (metres per second squared)

Unit Analysis

(mass) (acceleration) = $kg\frac{m}{s^2} = N$

Note: The symbol *g* is reserved for acceleration due to gravity on Earth. In this textbook, *g* with an appropriate subscript will denote acceleration due to gravity on a celestial object other than Earth, for example, g_{Moon}.

Web Link

www.mcgrawhill.ca/links/atlphysics

Do you have a dramatic flair? Check out the Internet site above to read about — and perhaps even test — Galileo's arguments of logic refuting Aristotle's teachings concerning falling objects. Galileo actually wrote the words! He presented the arguments using two fictitious characters. Salviati voiced the beliefs of Galileo, while Aristotle's ideas were embodied in Simplicio. If you enjoy a good debate, this English translation will captivate you.

MISCONCEPTION

Mass is not Weight

Everyday language often confuses an object's mass with its weight. You may have a *mass* of 78 kg, but you do not *weigh* 78 kg. Your weight would be $\vec{F}_g = m\vec{g} =$ (78 kg)(9.81 m/s^2) = 765 N[down]. Many scales and balances convert the newton reading to a mass equivalent on Earth. A spring scale designed for use on Earth would give incorrect results on the Moon.

INVESTIGATION 4-A

Interactions of Objects

TARGET SKILLS

- **Predicting**
- **Analyzing and interpreting**
- **Communicating results**

The language of forces can sometimes seem to complicate a concept that you already understand. Attempt to *describe* the interactions between the objects listed below in terms of forces.

Problem

What interactions exist between objects and how would things change if some interactions were removed?

Hypothesis

Form a hypothesis about which interactions will always exist between these common objects, regardless of where you might go to test them, including intergalactic space.

Equipment

- small mass (for example, a pop can)
- feather
- hockey puck
- magnets (2)
- string

Procedure

1. Place the pop can on the lab bench. How are the pop can and the lab bench interacting?
   - **(a)** Describe how the pop can interacts with the lab bench.
   - **(b)** Describe how the lab bench interacts with the pop can.
2. Drop the feather from 2.0 m above the floor.
   - **(a)** During its descent, is the feather interacting with any objects?
   - **(b)** What interaction causes the feather to fall?
   - **(c)** Describe what would happen if the feather did not interact with any objects other than Earth during its descent.
3. Slide the hockey puck across the lab bench.
   - **(a)** Describe three interactions affecting the hockey puck as it slides.
   - **(b)** Describe one interaction between the puck and the lab bench.
4. Attach two magnets to strings. Hold the magnets by the strings and allow them to approach each other but do not allow them to touch.
   - **(a)** Describe the interaction between the magnets.
   - **(b)** Describe the interaction between the strings and the magnets.
   - **(c)** What would happen if the interaction between the strings and magnets was removed?

Analyze and Conclude

1. List the interactions that are contact forces.
2. List the interactions that are non-contact forces.
3. Did your hypothesis include each interaction that you discovered during the activity?
4. Did you describe any interactions that could not be classified as a force?

Apply and Extend

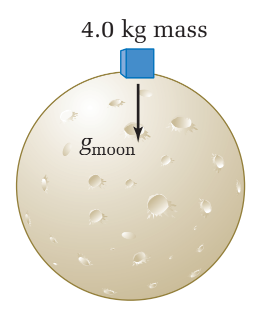
5. **(a)** Describe the forces acting on a skydiver as she falls to Earth with the parachute not yet deployed.
   - **(b)** Is the skydiver accelerating during the entire descent before deploying the parachute?
   - **(c)** Describe what force acts on the skydiver when the parachute is deployed.
6. A baseball is thrown high into the air. Describe the forces acting on the ball: **(a)** as it rises, **(b)** at the highest point, and **(c)** during the fall back to Earth.

Weight and Mass Calculations

1. Calculate the weight of a 4.0 kg mass on the surface of the Moon.

Frame the Problem

- The object is on the surface of the *Moon*.
- Its *weight* is the *force* of *gravity* acting on it.
- *Weight* is related to *mass* through the *acceleration* due to *gravity*.
- The *acceleration* due to *gravity* on the *Moon* is given in Table 4.4.



Identify the Goal

Weight, or force of gravity, $\vec{F}_g$, acting on a mass on the Moon

Variables and Constants

Known	**Implied**	**Unknown**
$m = 4.0$ kg	$\vec{g}_{\text{Moon}} = 1.64\ \frac{\text{m}}{\text{s}^2}[\text{down}]$	$\vec{F}_g$

Strategy

The acceleration due to gravity is known for the surface of the Moon.

Use the equation for weight.

Substitute in the variables and solve.

1 kg$\frac{\text{m}}{\text{s}^2}$ is equivalent to 1 N.
Convert to the appropriate number of significant digits.

The 4.0 kg mass would weigh 6.6 N[down] on the surface of the Moon.

Calculations

$$\vec{F}_{g\ \text{Moon}} = m\vec{g}_{\text{Moon}}$$

$$\vec{F}_{g\ \text{Moon}} = (4.0\ \text{kg})\left(1.64\frac{\text{m}}{\text{s}^2}\right)[\text{down}]$$

$$\vec{F}_{g\ \text{Moon}} = 6.56\ \text{kg}\frac{\text{m}}{\text{s}^2}[\text{down}]$$

$$\vec{F}_{g\ \text{Moon}} \cong 6.6\ \text{N}[\text{down}]$$

Validate

Weight is a force and, therefore, should have units of newtons, N.

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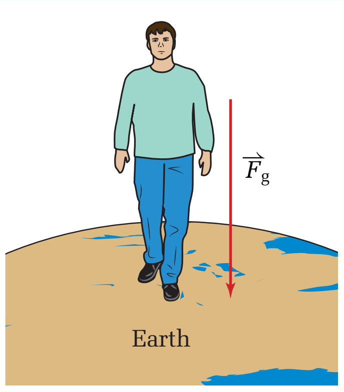
2. A student standing on a scientific spring scale on Earth finds that he weighs 825 N. Find his mass.



Frame the Problem

- *Weight* is defined as the *force of gravity* acting on a *mass*.
- If you know the *weight* and the *acceleration* due to *gravity*, you can find the *mass*.
- The *acceleration* due to *gravity on Earth* is given in Table 4.4.

Identify the Goal

The mass, m, of the student

Variables and Constants

Known	**Implied**	**Unknown**
$\vec{F}_g = 825$ N[down]	$\vec{g} = 9.81\ \frac{m}{s^2}$[down]	m

Strategy

Use the equation for the force of gravity.

Calculations

$$\vec{F}_g = m\vec{g}$$

Substitute first

$$825\ \text{N[down]} = m\ 9.81\frac{\text{m}}{\text{s}^2}\text{[down]}$$

Simplify.

$$\frac{825\ \text{N}}{9.81\frac{\text{m}}{\text{s}^2}} = \frac{m\ \cancel{9.81\frac{\text{m}}{\text{s}^2}\text{[down]}}}{\cancel{9.81\frac{\text{m}}{\text{s}^2}\text{[down]}}}$$

Express N as $\text{kg}\frac{\text{m}}{\text{s}^2}$ in order to cancel units.

$$m = 84.1\frac{\text{kg}\cancel{\frac{\text{m}}{\text{s}^2}}}{\cancel{\frac{\text{m}}{\text{s}^2}}}$$

$$m = 84.1\ \text{kg}$$

Solve for *m* first

$$\frac{\vec{F}}{\vec{g}} = \frac{m\cancel{\vec{g}}}{\cancel{\vec{g}}}$$

$$m = \frac{\vec{F}}{\vec{g}}$$

$$m = \frac{825\ \text{N[}\cancel{\text{down}}\text{]}}{9.81\frac{\text{m}}{\text{s}^2}\text{[}\cancel{\text{down}}\text{]}}$$

$$m = 84.1\ \frac{\text{kg}\cancel{\frac{\text{m}}{\text{s}^2}}}{\cancel{\frac{\text{m}}{\text{s}^2}}}$$

$$m = 84.1\ \text{kg}$$

The student has a mass of 84.1 kg.

Validate

Force has units of newtons and mass has units of kilograms. The result, 84.1 kg, is a reasonable value for a mass of a person.

PRACTICE PROBLEMS

1. Find the weight of a 2.3 kg bowling ball on Earth.

2. You have a weight of 652.58 N[down] while standing on a spring scale on Earth near the equator.

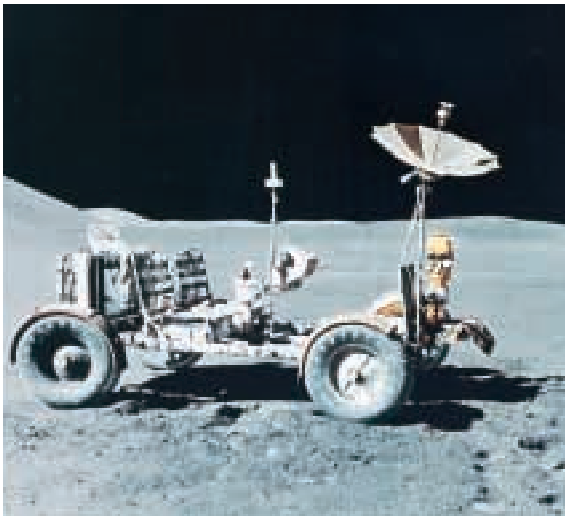
(a) Calculate your mass.

(b) Determine your weight on Earth near the North Pole.

(c) Determine your weight on the International Space Station. Why would this value be impossible to verify experimentally?

3. The lunar roving vehicle (LRV) pictured here has a mass of 209 kg regardless of where it is, but its weight is much less on the surface of the Moon than on Earth. Calculate the LRV's weight on Earth and on the Moon.

4. A 1.00 kg mass is used to determine the acceleration due to gravity of a distant, city-sized asteroid. Calculate the acceleration due to gravity if the mass has a weight of 3.25×10^{-2} N[down] on the surface of the asteroid.



Friction

When Galileo developed his principles of mechanics, he attributed many phenomena to frictional forces. Hundreds of years of observations have supported his conclusions. Since frictional forces are involved in essentially all mechanical movements, a more detailed understanding of these forces is critical to making predictions and describing motion. Unlike gravity and magnetism, frictional forces are contact forces.

Frictional forces inhibit relative motion between objects in contact with each other. In this section, you will focus on friction between surfaces. The frictional forces that act on an object moving through a fluid such as air or water are much more complex and you will not deal with them quantitatively in this chapter.

Two types of frictional forces are involved when you slide an object over a surface. A **static frictional force** exists when you start to move an object from rest. A **kinetic frictional force** exists while the object is moving. You probably discovered that the static frictional force that you must overcome to start an object moving is larger than the kinetic frictional force. Figure 4.6 on the next page shows a graph of actual experimental data obtained by slowly

TRY THIS...

Push a large mass horizontally across the lab bench with only one finger. Start pushing gently. Gradually increase the force you exert on the mass until it begins moving, then try to keep it moving with a constant velocity. Compare the force required to start the mass moving to the force that you must exert to keep it moving. Repeat the process until you can conclude whether there is any difference in these two forces. (You may have already experienced a similar effect if you have ever tried to slide a large box across a room.) Comment on and attempt to explain any difference in the force needed to start an object sliding and the force needed to keep the object in motion.

increasing an applied force on an object. Once the object started to move, it maintained a constant speed. The graph clearly demonstrates how the static frictional force increases to a maximum before the object gives way and begins to move. The object then requires a smaller force to keep it moving at a constant speed.

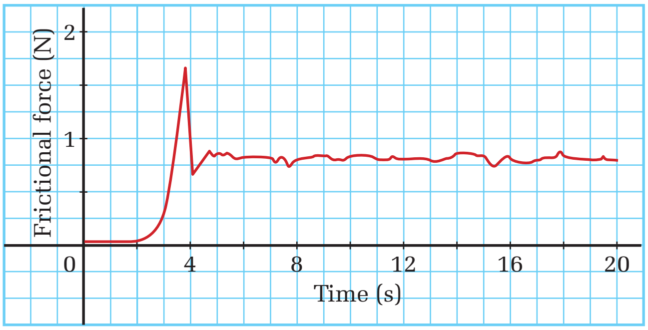


Figure 4.6 Sensitive equipment and careful experimentation yield results that clearly show how a static frictional force increases until the object begins moving. The kinetic frictional force is less than the maximum static frictional force.

QUICK LAB

How Sticky Is Your Shoe?

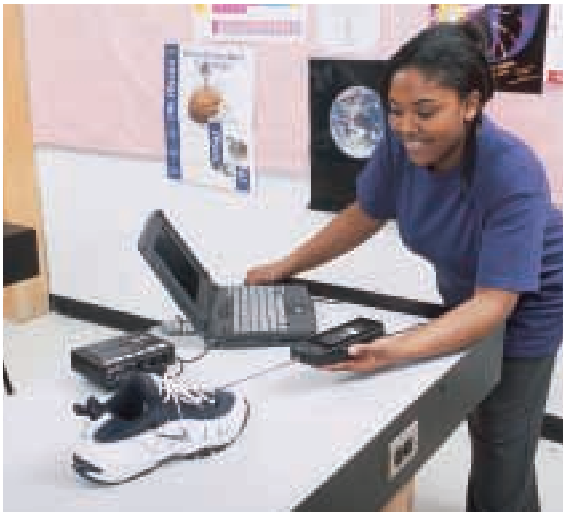
TARGET SKILLS

- **Initiating and planning**
- **Analyzing and interpreting**
- **Communicating results**

Using a force probe and a computer, determine the maximum static frictional force that you can cause your shoe to exert. Predict what factors might affect your shoe's "stickiness." Conduct an experiment to test your predictions on a variety of surfaces. (This experiment can also be conducted using a Newton spring scale.)

Analyze and Conclude

1. Describe the nature of the surfaces on which you tested your shoe.
2. Did some surfaces cause your shoe to be "stickier" than others? Offer an explanation about the differences in these surfaces.
3. Compare the static frictional force with the kinetic frictional force. Describe the results of your comparison.
4. What steps might you take to ensure that your shoe is as sticky as it possibly can be?



The strength of a frictional force between two surfaces depends on the nature of the surfaces. Although some surfaces create far more friction than others, all surfaces create some friction. The appearance of smooth surfaces can be deceiving. The photograph in Figure 4.7 shows a magnified section of a highly polished steel surface. The jagged peaks are far too small to see with the unaided eye or to feel with your hand, yet they are high enough to interact with objects that slide over them.

The force of friction is actually an electromagnetic force acting between the surface atoms of one object and those of another. In fact, if two blocks of highly polished steel were cleaned and placed together in a perfect vacuum, they would weld themselves together and become one block of steel. In reality, small amounts of air, moisture, and contaminants accumulate on surfaces and prevent such "ideal" interactions.

When two surfaces are at rest and in contact, the surface atoms interact to form relatively strong attractive forces. When you push on one object, static friction "pushes back" with exactly the same magnitude as an applied force until the applied force is great enough to break the attractive force between the surface atoms. When the object begins to move, new "bonds" are continually being formed and broken in what you could call a stick-and-slip process. Once the object is in motion, the stick-and-slip process repeats itself over and over in rapid succession. This process is responsible for the noise produced when two objects slide past one another. The squealing of tires on dry pavement and chalk scraping on a blackboard are examples of such noises.

Figure 4.8 illustrates how surfaces appear to make contact. The amount of contact and the types of atoms and molecules making up the materials passing over one another play a significant role in determining how large a frictional force will be. Sliding a 5.0 kg block of ice on a sheet of ice requires much less force than sliding the same block across rubber. Experimentation yields a "stickiness" value called a **coefficient of friction** for specific combinations of surfaces. Table 4.5 lists *coefficients of static friction* for objects at rest and *coefficients of kinetic friction* for objects in motion. Coefficients of friction are experimentally obtained and depend entirely on the *two* interacting surfaces.

Figure 4.7 Highly polished steel that feels very smooth still has bumps and valleys that will collide with other surface imperfections when rubbed together.

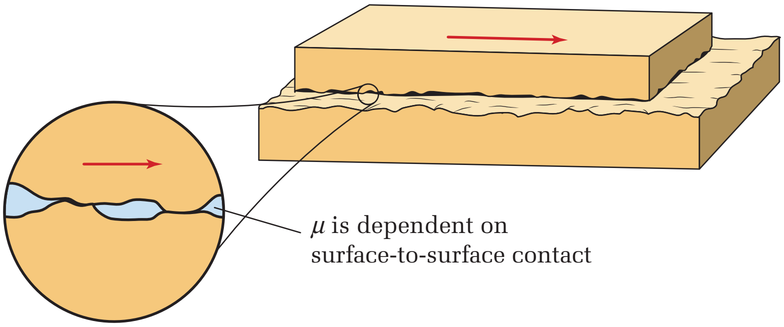


Figure 4.8 The coefficient of friction depends on each of the two surfaces in contact and must be experimentally obtained.

TRY THIS...

Hold a book against a flat wall by holding one hand under the book. With your other hand, gently press the book against the wall. Move your hand that is under the book. Catch the book if it begins to slip. Repeat the process but exert a little more pressure on the book toward the wall until the book does not fall when you remove your hand from beneath it. Summarize what your observations tell you about frictional forces.

Table 4.5 Coefficients of Friction

Surfaces	Coefficient of Static Friction μ_s	Coefficient of Kinetic Friction μ_k
rubber on dry solid surfaces	1 – 4	1
rubber on dry concrete	1.00	0.80
rubber on wet concrete	0.70	0.50
glass on glass	0.94	0.40
steel on steel (unlubricated)	0.74	0.57
steel on steel (lubricated)	0.15	0.06
wood on wood	0.40	0.20
ice on ice	0.10	0.03
Teflon™ on steel in air	0.04	0.04
lubricated ball bearings	< 0.01	< 0.01
synovial joint in humans	0.01	0.003

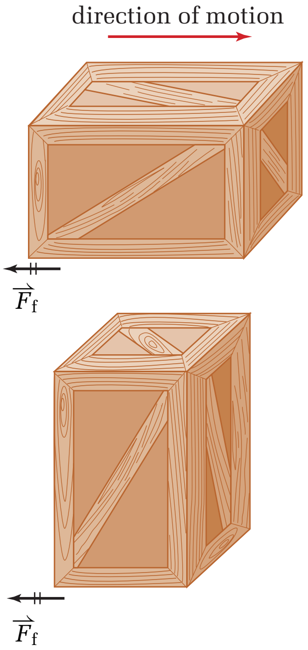


Figure 4.9 The uniform distribution of mass will yield approximately the same frictional force regardless of the side in contact with the floor.

The force of friction depends not only on the types of surfaces that are in contact, but also on the magnitude of the forces that are pressing the two surfaces together. Whenever any object exerts a force on a flat surface such as a wall, floor, or road surface, that surface will exert a force back on the object in a direction perpendicular to the surface. Such a force is called a **normal force**. If you have ever attempted to slide a dresser full of clothes across a carpeted floor, you will know that by removing the drawers as well as the clothes the job gets much easier. A full dresser weighs significantly more than an empty one. The carpeted floor must support the weight of the dresser, and does so with a normal force. By reducing the weight of the dresser, you are also reducing the normal force.

An observation that might be surprising is that the force of surface friction is independent of velocity. Fluid friction, on the other hand, is affected by velocity in a complex way. A second, possibly surprising observation is that the force of friction is independent of the area of contact. Consider the crate in Figure 4.9. If you measured the forces required to slide the crate along any of its sides, you would find that they were all the same.

When the crate was placed on sides having different areas, the materials in contact were still the same, and the weight and therefore normal forces were the same. Experiments and observations have shown that these two factors, alone, determine the magnitude of the frictional force between surfaces.

Friction is caused by a large variety of atomic and molecular interactions. These reactions are so varied that firm "laws" do not apply. The relationships that have been developed are consistent but can be applied only under the following conditions. If the conditions are met, you can consider the results of calculations to be very good approximations, but not exact predictions.

- The force of friction is independent of surface area *only* if the mass of the object is evenly distributed.
- Certain plastics and rubbers have natural properties that often do not fit the standard model of friction, (for example, adhesive tape, "ice-gripping" tires).
- The two interacting surfaces must be flat. If such things as spikes or ridges are present that penetrate the opposite surface, the principles discussed above no longer apply (See Figure 4.10).

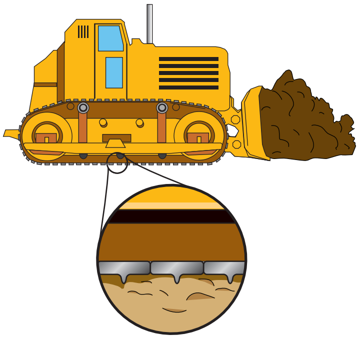


Figure 4.10 The ridges on the bulldozer tracks are penetrating the soil, creating interactions that cannot be considered as simple surface friction.

SURFACE FRICTION

The magnitude of the force of surface friction is the product of the coefficient of friction and the magnitude of the normal force. The direction of the force of friction is always opposite to the direction of the motion.

$$F_{\mathrm{f}} = \mu F_{\mathrm{N}}$$

Quantity	**Symbol**	**SI unit**
force of friction	F_{f}	N (newton)
coefficient of friction	μ	none (coefficients of friction are unitless)
normal force	F_{N}	N (newton)

Note: Since the direction of the normal force is perpendicular to the direction of the force of friction, vector notations are omitted.

MODEL PROBLEMS

Working with Friction

1. During the winter, owners of pickup trucks often place sandbags in the rear of their vehicles. Calculate the increased static force of friction between the rubber tires and wet concrete resulting from the addition of 200 kg (2.00×10^2 kg) of sandbags in the back of the truck.

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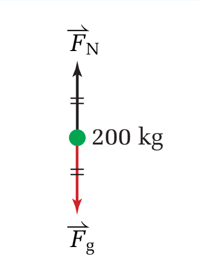
Frame the Problem



- Sketch the problem.
- The addition of the sandbags will not change the *coefficient of friction* between the tires and the wet road.
- The sandbags will increase the weight of the truck, thereby increasing the *normal* force.
- The equation relating *frictional force* to the coefficient of friction and the normal force applies to this problem.

Identify the Goal

The increase in the frictional force, F_f, resulting from placing sandbags in the back of the truck

Variables and Constants

Known	**Implied**	**Unknown**
$m_{\text{sandbags}} = 2.00 \times 10^2$ kg	$g = 9.81 \ \frac{\text{m}}{\text{s}^2}$	$F_{\text{g sandbags}}$
	$\mu_s = 0.70$	F_N $\quad F_f$

Strategy	Calculations
In this case, the additional normal force is equal to the weight of the sandbags.	$F_N = F_g$
Use the equation for weight to find the weight and thus the normal force.	$F_g = mg$
Substitute and solve.	$F_g = (2.00 \times 10^2 \text{ kg})\left(9.81 \frac{\text{m}}{\text{s}^2}\right)$
$\frac{\text{kg} \cdot \text{m}}{\text{s}^2}$ is equivalent to N.	$F_g = 1.962 \times 10^3 \ \frac{\text{kg} \cdot \text{m}}{\text{s}^2}$ $F_N = 1.962 \times 10^3$ N
All of the values needed to find the additional frictional force are known so substitute into the equation for frictional forces.	$F_f = \mu_s F_N$ $F_f = (0.70)(1.962 \times 10^3 \text{ N})$ $F_f = 1.373 \times 10^3$ N
The sandbags increased the force of friction of the tires on the road by 1.4×10^3 N.	

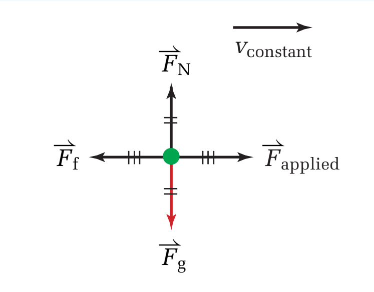
Validate

The force of friction should increase with the addition of weight, which it did.

2. **A horizontal force of 85 N is required to pull a child in a sled at constant speed over dry snow to overcome the force of friction. The child and sled have a combined mass of 52 kg. Calculate the coefficient of kinetic friction between the sled and the snow.**

Frame the Problem

- Sketch the forces acting on the child and sled.
- The applied force just overcomes the force of friction, therefore, the *applied force* must be *equal* to the *frictional force*.
- The sled is neither sinking into the snow, nor is it rising off of the snow; therefore, the *weight* of the sled must be exactly equal to the *normal force* supporting it.



Identify the Goal

The coefficient of kinetic friction, μ_k

Variables and Constants

Known	Implied	Unknown
$m = 52\ \text{kg}$	$g = 9.81\ \frac{\text{m}}{\text{s}^2}$	F_g
$F_{applied} = 85\ \text{N}$		F_f
		F_N
		μ_k

Strategy	Calculations
The conditions for the equation describing surface friction are met, so use the equation.	$F_f = \mu_k F_N$
Since the normal force is equal to the weight, use the equation for weight.	$F_N = Fg$
Solve.	$F_g = mg$
	$F_N = mg$
	$F_N = (52\ \text{kg})\left(9.81\frac{\text{m}}{\text{s}^2}\right)$
$\frac{\text{kg} \cdot \text{m}}{\text{s}^2}$ is equivalent to N.	$F_N = 510.12\ \frac{\text{kg} \cdot \text{m}}{\text{s}^2}$
	$F_N = 510.12\ \text{N}$
Apply the equation for a frictional force.	$F_f = \mu_k F_N$

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Strategy

Calculations

Substitute first

$F_f = \mu_k F_N$

$85\ \text{N} = \mu_k 510.12\ \text{N}$

$$\frac{85\ \text{N}}{510.12\ \text{N}} = \frac{\mu_k \cancel{510.12\ \text{N}}}{\cancel{510.12\ \text{N}}}$$

$\mu_k = 0.1666$

Solve for μ_k first

$$\frac{F_f}{F_N} = \frac{\mu_k \cancel{F_N}}{\cancel{F_N}}$$

$$\mu_k = \frac{85\ \text{N}}{510.12\ \text{N}}$$

$\mu_k = 0.1666$

Therefore, the coefficient of kinetic friction between the sled and the snow is 0.17.

Validate

The coefficient of friction between a sled and snow should be relatively small, which it is.

PRACTICE PROBLEMS

5. A friend pushes a 600 g (6.00×10^2 g) textbook along a lab bench at constant velocity with 3.50 N of force.

- **(a)** Determine the normal force supporting the textbook.
- **(b)** Calculate the force of friction and coefficient of friction between the book and the bench.
- **(c)** Which coefficient of friction have you found, μ_s or μ_k?

6. A 125 kg crate full of produce is to be slid across a barn floor.

- **(a)** Calculate the normal force supporting the crate.
- **(b)** Calculate the minimum force required to start the crate moving if the coefficient of static friction between the crate and the floor is 0.430.
- **(c)** Calculate the minimum force required to start the crate moving if half of the mass is removed from the crate before attempting to slide it.

7. Avalanches often result when the top layer of a snow pack behaves like a piece of glass, and begins sliding over the underneath layer. Calculate the force of static friction between two layers of horizontal ice on the top of Mount Everest, if the top layer has a mass of 2.00×10^2 kg. (Refer to Table 4.5 for the coefficient of friction.)

8. Assume that, in the "Try This" experiment on page 140, you discovered that you had to push the book against the wall with a force of 63 N in order to prevent it from falling. Assume the mass of the book to be 2.2 kg. What is the coefficient of static friction between the book and the wall? (Hint: Be careful to correctly identify the source of the normal force and the role of the frictional force in this situation.)

Concept Organizer

The types of surfaces in contact directly affect the magnitude of the force of friction.

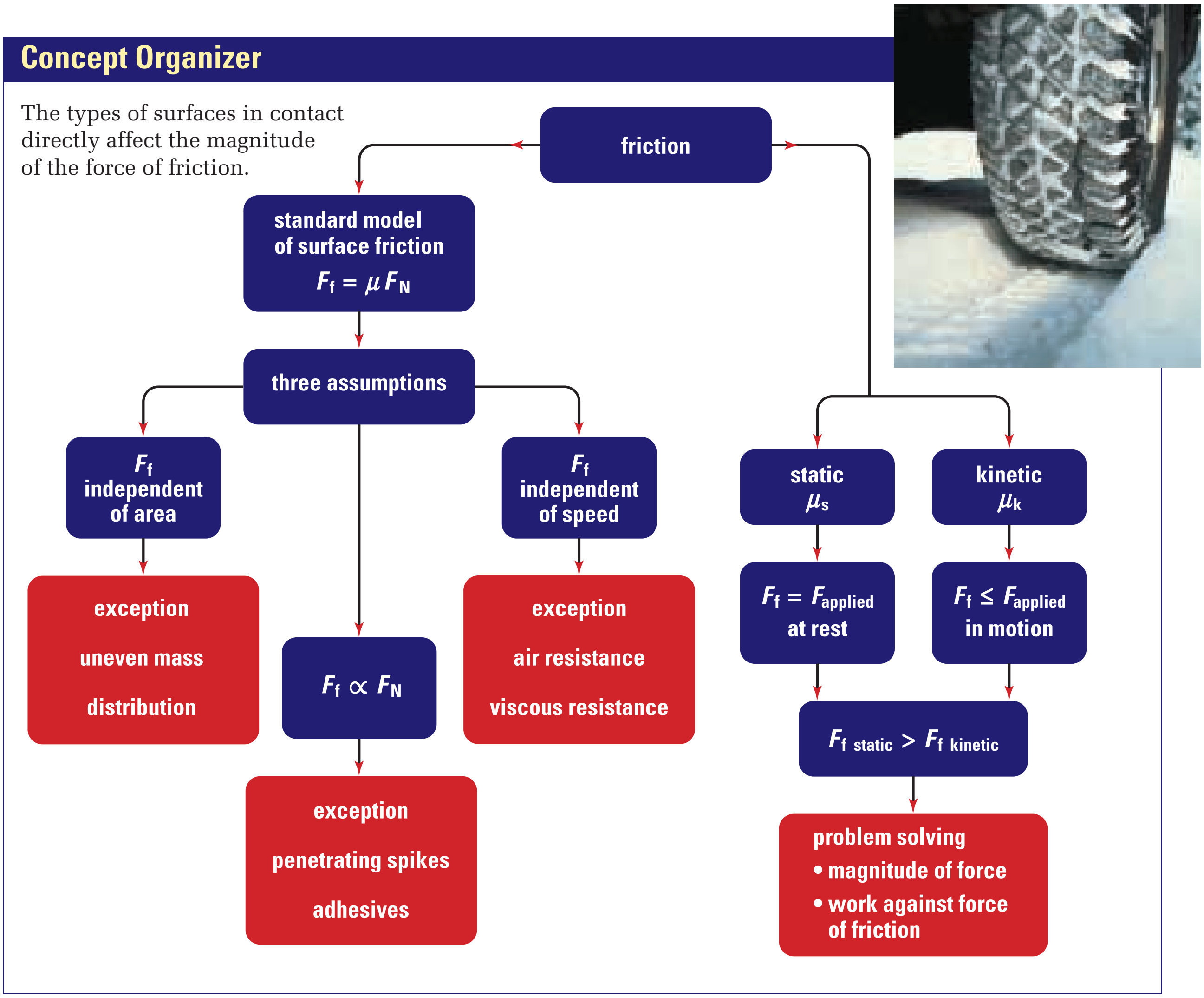


Figure 4.11 Understanding the standard model of friction and the exceptions.

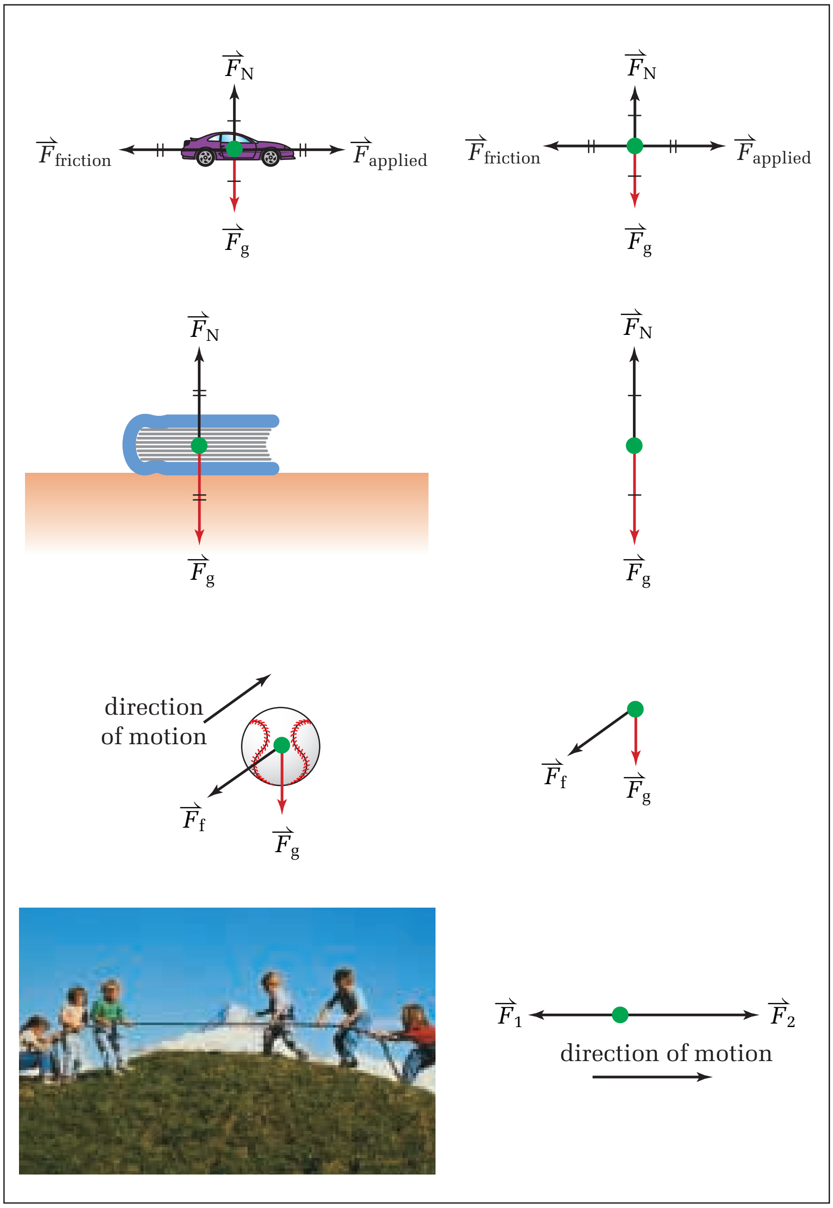
Free Body Diagrams

You have seen many cases in which more than one force was acting on an object. You also learned that, according to Galileo's concepts of inertia, the motion of a body will change only if an external force is applied to it. When several forces are acting, how do you know which force might change an object's state of motion? The answer is, "All of them acting together." You must look at every force that is acting on an object and find the vector sum of all of the forces before you can predict the motion of an object. This vector sum is the **net force** on the object. A free body diagram is an excellent tool to help you keep track of all of the forces.

Free body diagrams represent all forces *acting on* one object, and only the forces acting on the object. Forces that the object exerts on other objects do not appear in free body diagrams because they have no effect on the motion of the object itself.

In drawing a free body diagram, you represent the object as a single dot to help focus interest on the forces involved and not on the creator's artistic flair. You will represent each force *acting* on the object with an arrow. The arrow's direction shows the direction of the force and the arrow's relative length provides information about the magnitude of the force. Forces that have the same magnitude should be sketched with approximately the same length, forces that are larger should be longer, and smaller forces should be shorter. Study the examples in Figure 4.12.

Figure 4.12 Free body diagrams for some everyday objects.



4.2 Section Review

1. K/U Describe how and why acceleration due to gravity varies around the globe.

2. K/U A Ping Pong™ ball is struck with a paddle, sails over the net, bounces off of the table, and continues to the floor. Describe the forces acting on the ball throughout the trip.

3. C Explain the difference between contact and non-contact forces and provide examples of each.

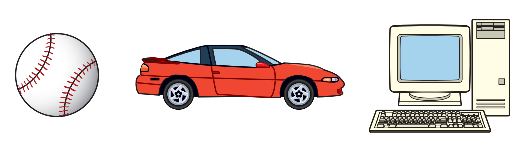
4. C Explain, using force arguments, how it is possible for a feather and a coin in a vacuum to fall toward Earth with the same acceleration.

5. C A news reporter states that the winning entry in a giant pumpkin-growing contest "had a weight of 354 kg." Explain the error in this statement and provide values for both the weight and mass of the winning pumpkin.

6. C Describe the forces acting on a bag of chips resting on a tabletop.

7. C Explain why the coefficient of static friction is greater than the coefficient of kinetic friction.

8. K/U Imagine that all of the objects pictured are on the Moon, where there is no atmosphere.



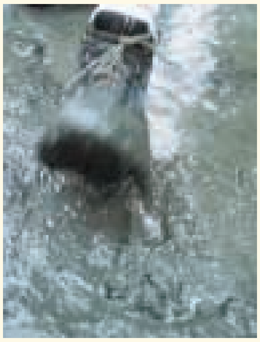
(a) Rank the objects in order of weight, putting the heaviest object first.

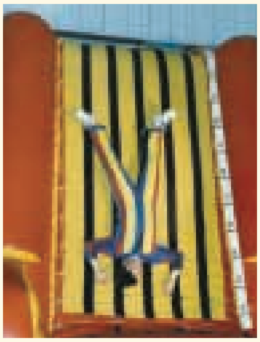
(b) Rank the objects from largest to smallest according to the magnitude of the force of gravity acting on each of them.

(c) If each object was dropped simultaneously, which would hit the Moon's surface first?

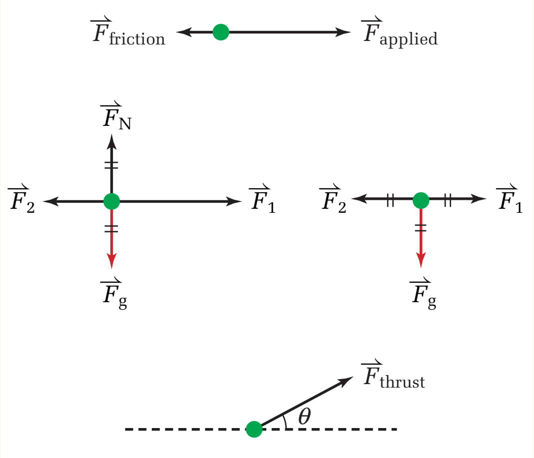
9. C **(a)** State three assumptions implied by the friction equation: $F_{\text{f}} = \mu F_{\text{N}}$.

(b) Discuss whether or not these assumptions are valid for each situation shown in the following pictures.





10. K/U Predict the motion that each object would undergo based on the free body diagrams illustrated.



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11. K/U **(a)** Why is a dot used in a free body diagram?

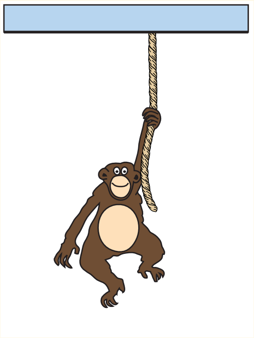
(b) Why are the lengths of the force vector sketches important?

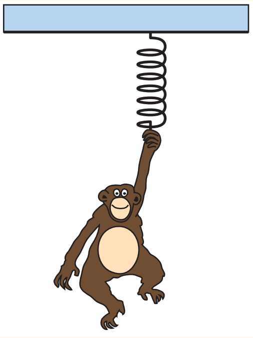
(c) Describe the purpose of a free body diagram.

12. K/U Draw a free body diagram showing the forces acting on a monkey that is hanging at rest

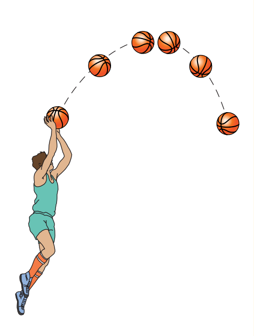
(a) from a vine

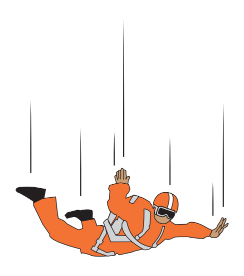
(b) from a spring





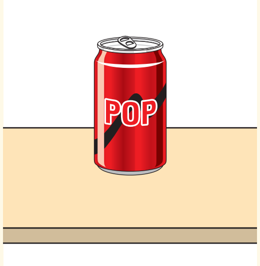
13. K/U **(a)** Draw a free body diagram showing the forces acting on the ball during its flight.

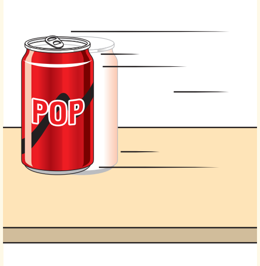




(b) Draw a free body diagram showing the forces acting on the skydiver before he deploys his parachute.

14. K/U Draw a free body diagram showing the forces acting on the pop can.





15. K/U Draw a free body diagram for each of the following situations.

(a) A submarine moves horizontally with constant velocity through deep water.

(b) A car accelerates from a stoplight.

(c) A pail is lifted from a deep well at constant velocity using a rope.

(d) A neon sign hangs motionless, suspended by two cables. One cable runs horizontally, connecting the sign to a wall; the other cable runs up and away from the wall, connecting the sign to the ceiling.