Chapter 4 Forces in One Dimension

What You'll Learn

- You will use Newton's laws to solve problems.
- You will determine the magnitude and direction of the net force that causes a change in an object's motion.
- You will classify forces according to the agents that cause them.

Why It's Important

Forces act on you and everything around you at all times.

Sports A soccer ball is headed by a player. Before play began, the ball was motionless. During play, the ball started, stopped, and changed directions many times.

Think About This ▶

What causes a soccer ball, or any other object, to stop, start, or change direction?

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LAUNCH Lab

Which force is stronger?

Question

What forces can act on an object that is suspended by a string?

Procedure

1. Tie a piece of heavy cord around the middle of a book. Tie one piece of lightweight string to the center of the cord on the top of the book. Tie another piece to the bottom.
2. While someone holds the end of the top lightweight string so that the book is suspended in the air, pull very slowly, but firmly, on the end of the bottom lightweight string. Record your observations. ***CAUTION: Keep feet clear of falling objects.***
3. Replace the broken string and repeat step 2, but this time pull very fast and very hard on the bottom string. Record your observations.

Analysis

Which string broke in step 2? Why? Which string broke in step 3? Why?

Critical Thinking Draw a diagram of the experimental set-up. Use arrows to show the forces acting on the book.

4.1 Force and Motion

Imagine that a train is speeding down a railroad track at 80 km/h when suddenly the engineer sees a truck stalled at a railroad crossing ahead. The engineer applies the brakes to try to stop the train before it crashes into the truck. Because the brakes cause an acceleration in the direction opposite the train's velocity, the train will slow down. Imagine that, in this case, the engineer is able to stop the train just before it crashes into the truck. But what if instead of moving at 80 km/h the train had been moving at 100 km/h? What would have to happen for the train to avoid hitting the truck? The acceleration provided by the train's brakes would have to be greater because the engineer still has the same distance in which to stop the train. Similarly, if the train was going 80 km/h but had been much closer to the truck when the engineer started to apply the brake, the acceleration also would need to be greater because the train would need to stop in less time.

Objectives

- **Define** force.
- **Apply** Newton's second law to solve problems.
- **Explain** the meaning of Newton's first law.

Vocabulary

force
free-body diagram
net force
Newton's second law
Newton's first law
inertia
equilibrium

Horizons Companies

Force and Motion

What happened to make the train slow down? A **force** is a push or pull exerted on an object. Forces can cause objects to speed up, slow down, or change direction as they move. When an engineer applies the brakes, the brakes exert a force on the wheels and cause the train to slow down. Based on the definitions of velocity and acceleration, this can be restated as follows: a force exerted on an object causes that object's velocity to change; that is, a force causes an acceleration.

Consider a textbook resting on a table. How can you cause it to move? Two possibilites are that you can push on it or you can pull on it. The push or pull is a force that you exert on the textbook. If you push harder on an object, you have a greater effect on its motion. The direction in which the force is exerted also matters—if you push the book to the right, the book moves in a different direction from the direction it would move if you pushed it to the left. The symbol $\mathbf{F}$ is a vector and represents the size and direction of a force, while F represents only the magnitude.

When considering how a force affects motion, it is important to identify the object of interest. This object is called the system. Everything around the object that exerts forces on it is called the external world. In the case of the book in **Figure 4-1,** the book is the system. Your hand and gravity are parts of the external world that can interact with the book by pushing or pulling on it and potentially causing its motion to change.

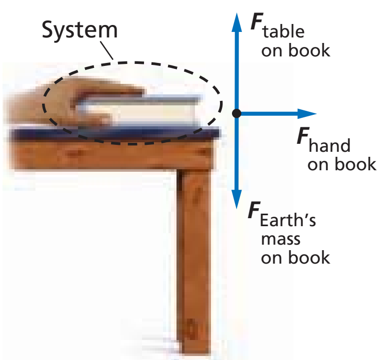

Figure 4-1 The book is the system. The table, the hand, and Earth's mass (through gravity) all exert forces on the book.

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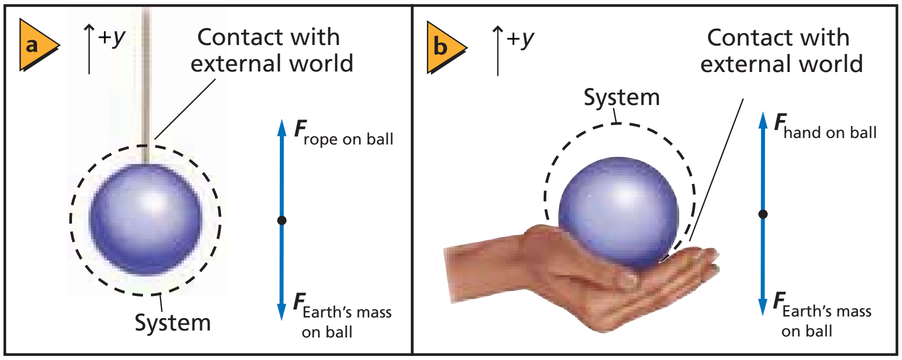
Contact Forces and Field Forces

Again, think about the different ways in which you could move a textbook. You could touch it directly and push or pull it, or you could tie a string around it and pull on the string. These are examples of contact forces. A contact force exists when an object from the external world touches a system and thereby exerts a force on it. If you are holding this physics textbook right now, your hands are exerting a contact force on it. If you place the book on a table, you are no longer exerting a force on the book. The table, however, is exerting a force because the table and the book are in contact.

There are other ways in which you could change the motion of the textbook. You could drop it, and as you learned in Chapter 3, it would accelerate as it falls to the ground. The gravitational force of Earth acting on the book causes this acceleration. This force affects the book whether or not Earth is actually touching it. This is an example of a field force. Field forces are exerted without contact. Can you think of other kinds of field forces? If you have ever experimented with magnets, you know that they exert forces without touching. You will investigate magnetism and other similar forces in more detail in future chapters. For now, the only field force that you need to consider is the gravitational force.

Forces result from interactions; thus, each force has a specific and identifiable cause called the agent. You should be able to name the agent exerting each force, as well as the system upon which the force is exerted. For example, when you push your textbook, your hand (the agent) exerts a force on the textbook (the system). If there are not both an agent and a system, a force does not exist. What about the gravitational force? If you allow your textbook to fall, the agent is the mass of Earth exerting a field force on the book.



■ **Figure 4-2** To make a physical model of the forces acting on an object, apply the particle model and draw an arrow to represent each force. Label each force, including its agent.

Concepts In Motion

Interactive Figure To see an animation on free-body diagrams, visit physicspp.com.

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Free-body diagrams Just as pictorial models and motion diagrams are useful in solving problems about motion, similar representations will help you to analyze how forces affect motion. The first step in solving any problem is to create a pictorial model. For example, to represent the forces on a ball tied to a string or held in your hand, sketch the situations, as shown in **Figures 4-2a** and **4-2b.** Circle the system and identify every place where the system touches the external world. It is at these places that contact forces are exerted. Identify the contact forces. Then identify any field forces on the system. This gives you the pictorial model.

To make a physical representation of the forces acting on the ball in Figures 4-2a and 4-2b, apply the particle model and represent the object with a dot. Represent each force with a blue arrow that points in the direction that the force is applied. Try to make the length of each arrow proportional to the size of the force. Often, you will draw these diagrams before you know the magnitudes of all the forces. In such cases, make your best estimate. Always draw the force arrows pointing away from the particle, even when the force is a push. Make sure that you label each force. Use the symbol $\boldsymbol{F}$ with a subscript label to identify both the agent and the object on which the force is exerted. Finally, choose a direction to be positive and indicate this off to the side of your diagram. Usually, you select the positive direction to be in the direction of the greatest amount of force. This typically makes the problem easiest to solve by reducing the number of negative values in your calculations. This type of physical model, which represents the forces acting on a system, is called a **free-body diagram.**

PRACTICE Problems

• Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

For each of the following situations, specify the system and draw a motion diagram and a free-body diagram. Label all forces with their agents, and indicate the direction of the acceleration and of the net force. Draw vectors of appropriate lengths.

1. A flowerpot falls freely from a windowsill. (Ignore any forces due to air resistance.)

2. A sky diver falls downward through the air at constant velocity. (The air exerts an upward force on the person.)

3. A cable pulls a crate at a constant speed across a horizontal surface. The surface provides a force that resists the crate's motion.

4. A rope lifts a bucket at a constant speed. (Ignore air resistance.)

5. A rope lowers a bucket at a constant speed. (Ignore air resistance.)

Force and Acceleration

How does an object move when one or more forces are exerted on it? One way to find out is by doing experiments. As before, begin by considering a simple situation. Once you fully understand that situation, then you can add more complications to it. In this case, begin with one controlled force exerted horizontally on an object. The horizontal direction is a good place to start because gravity does not act horizontally. Also, to reduce complications resulting from the object rubbing against the surface, do the experiments on a very smooth surface, such as ice or a very well-polished table, and use an object with wheels that spin easily. In other words, you are trying to reduce the resistance to motion in the situation.

To determine how force, acceleration, and velocity are related, you need to be able to exert a constant and controlled force on an object. How can you exert such a controlled force? A stretched rubber band exerts a pulling force; the farther you stretch it, the greater the force with which it pulls back. If you always stretch the rubber band the same amount, you always exert the same force. **Figure 4-3a** shows a rubber band, stretched a constant 1 cm, pulling a low-resistance cart. If you perform this experiment and determine the cart's velocity for some period of time, you could construct a graph like the one shown in **Figure 4-3b.** Does this graph look different from what you expected? What do you notice about the velocity? The constant increase in the velocity is a result of the constant acceleration the stretched rubber band gives the cart.

How does this acceleration depend upon the force? To find out, repeat the experiment, this time with the rubber band stretched to a constant 2 cm, and then repeat it again with the rubber band stretched longer and longer each time. For each experiment, plot a velocity-time graph like the one in Figure 4-3b, calculate the acceleration, and then plot the accelerations and forces for all the trials to make a force-acceleration graph, as shown in **Figure 4-4a.** What is the relationship between the force and acceleration? It's a linear relationship where the greater the force is, the greater the resulting acceleration. As you did in Chapters 2 and 3, you can apply the straight-line equation $y = mx + b$ to this graph.

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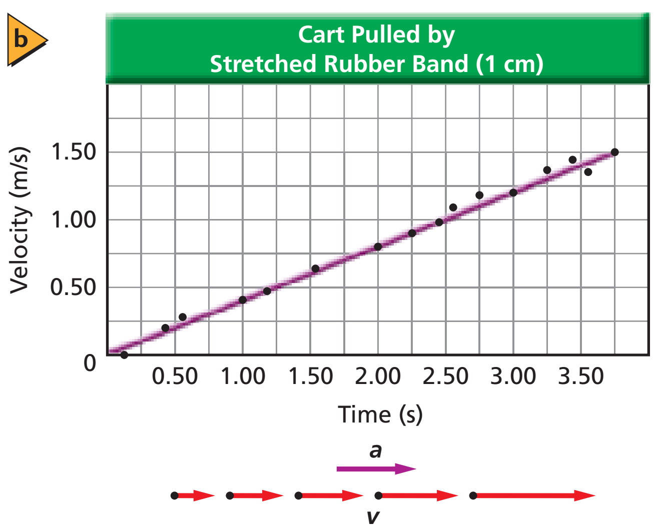
Figure 4-3 Because the rubber band is stretched a constant amount, it applies a constant force on the cart, which is designed to be low-friction **(a).** The cart's motion can be graphed and shown to be a linear relationship **(b).**



Matt Meadows

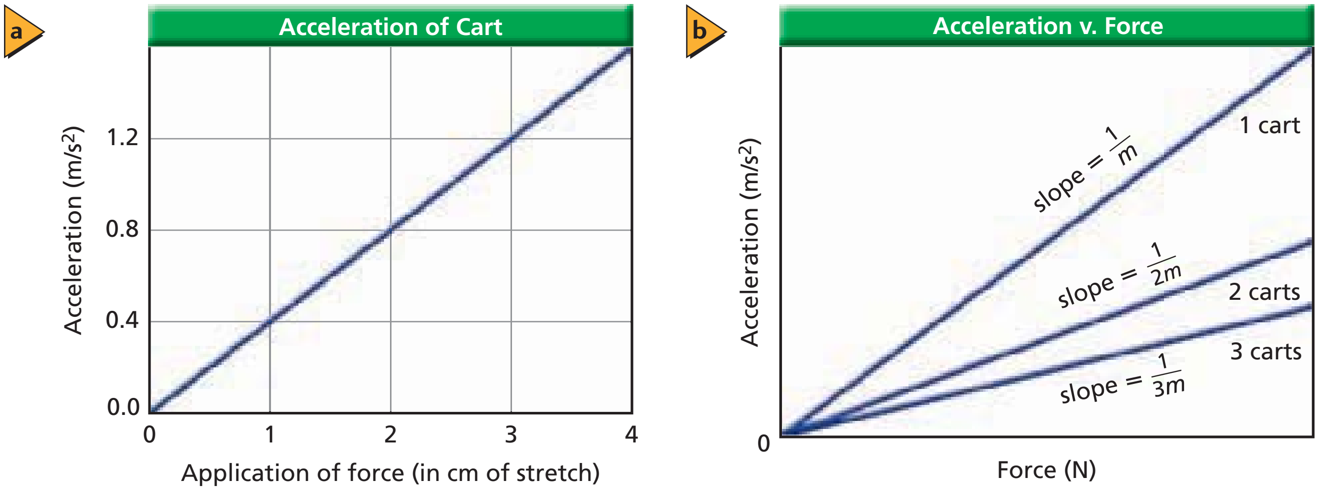


Figure 4-4 The graph shows that as the force increases, so does the acceleration **(a).** You can see that the slope of the force-acceleration graph depends upon the number of carts **(b).**

What is the physical meaning of this slope? Perhaps it describes something about the object that is accelerating. What happens if the object changes? Suppose that a second, identical cart is placed on top of the first, and then a third cart is added. The rubber band would be pulling two carts, and then three. A plot of the force versus acceleration for one, two, and three carts is shown in **Figure 4-4b.** The graph shows that if the same force is applied in each situation, the acceleration of two carts is $\frac{1}{2}$ the acceleration of one cart, and the acceleration of three carts is $\frac{1}{3}$ the acceleration of one cart. This means that as the number of carts is increased, a greater force is needed to produce the same acceleration. In this example, you would have to stretch the rubber band farther to get a greater amount of force. The slopes of the lines in Figure 4-4b depend upon the number of carts; that is, the slope depends on the total mass of the carts. If the slope, k in this case, is defined as the reciprocal of the mass ($k = 1/m$), then $a = F/m$, or $F = ma$.

What information is contained in the equation $a = F/m$? It tells you that a force applied to an object causes that object to experience a change in motion—the force causes the object to accelerate. It also tells you that for the same object, if you double the force, you will double the object's acceleration. Lastly, if you apply the same force to several different objects, the one with the most mass will have the smallest acceleration and the one with the least mass will have the greatest acceleration.

What are the proper units for measuring force? Because $F = ma$, one unit of force causes a 1-kg mass to accelerate at 1 m/s^2, so one force unit has the dimensions 1 kg·m/s^2. The unit 1 kg·m/s^2 is called the newton, represented by N. One newton of force applied to a 1-kg object will cause it to have an acceleration of 1 m/s^2. Do these units make sense? Think about a sky diver who is falling through the air. The properties affecting his motion are his mass and the acceleration due to the gravitational force, so these units do make sense. **Table 4-1** shows the magnitude of some common forces.

Table 4-1

Common Forces

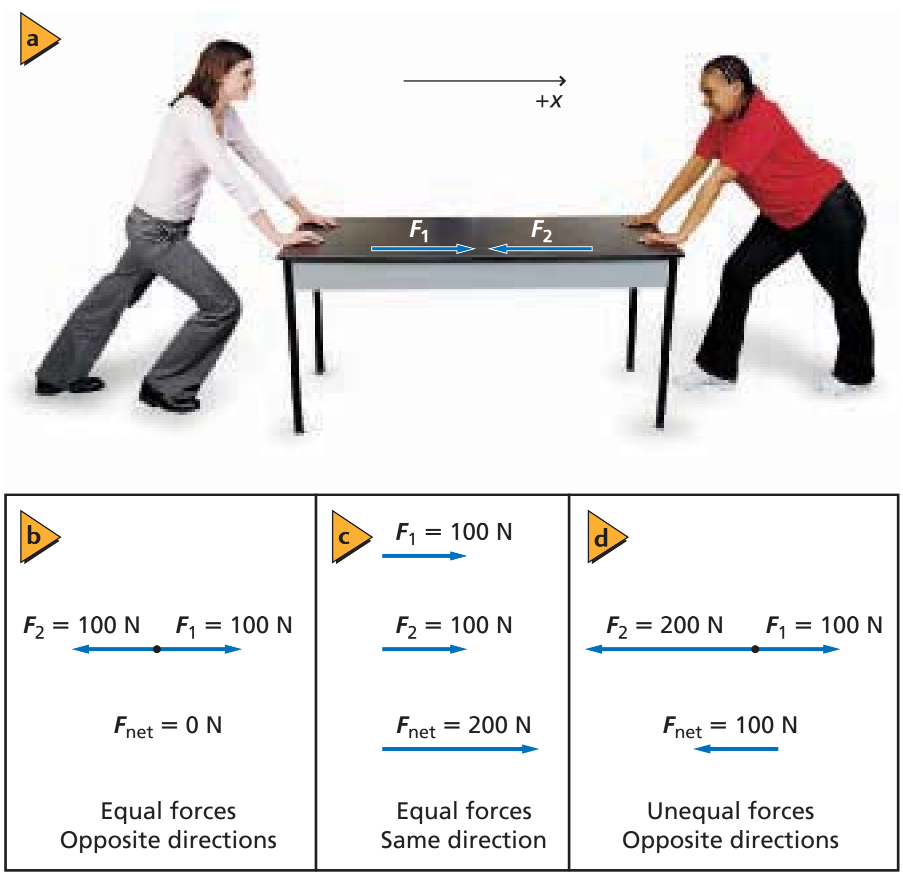
Description	***F* (N)**
Force of gravity on a coin (nickel)	0.05
Force of gravity on 1 lb (0.45 kg) of sugar	4.5
Force of gravity on a 150-lb (70-kg) person	686
Force of an accelerating car	3000
Force of a rocket motor	5,000,000

Combining Forces

What happens if you and a friend each push a table and exert 100 N of force on it? When you and your friend push together, you give the table a greater acceleration than when you push against each other. In fact, when you push together, you give the table twice the acceleration that it would have if just one of you applied 100 N of force. When you push on the table in opposite directions with the same amount of force, as in **Figure 4-5a,** the table does not move at all.

Figure 4-5b and **c** show free-body diagrams for these two situations. **Figure 4-5d** shows a third free-body diagram in which your friend pushes on the table twice as hard as you in the opposite direction. Below each free-body diagram is a vector representing the total result of the two forces. When the force vectors are in the same direction, they can be replaced by one vector with a length equal to their combined length. When the forces are in opposite directions, the resulting vector is the length of the difference between the two vectors. Another term for the vector sum of all the forces on an object is the **net force.**

You also can analyze the situation mathematically. Assume that you are pushing the table in the positive direction with a 100 N force in the above cases. In the first case, your friend is pushing with a negative force of 100 N. Adding them together gives a total force of 0 N, which means there is no acceleration. In the second case, your friend's force is 100 N, so the total force is 200 N in the positive direction and the table accelerates in the positive direction. In the third case, your friend's force is −200 N, so the total force is −100 N and the table will accelerate in the negative direction.



■ **Figure 4-5** Pushing on the table with equal force in opposite directions **(a)** results in no net force on the table, as shown by the vector addition in the free-body diagram **(b).** However, there is a net force applied in **(c)** and **(d),** as shown by the free-body diagrams.

Aaron Haupt

Newton's Second Law

You could conduct a series of experiments in which you and your friend vary the net force exerted on the table and measure the acceleration in each case. You would find that the acceleration of the table is proportional to the net force exerted on it and inversely proportional to its mass. In other words, if the net force of you and your friend acting on the table is 100 N, the table will experience the same acceleration as it would if only you were acting on it with a force of 100 N. Taking this into account, the mathematical relationship among force, mass, and acceleration can be rewritten in terms of the net force. The observation that the acceleration of an object is proportional to the net force and inversely proportional to the mass of the object being accelerated is **Newton's second law,** which is represented by the following equation.

Newton's Second Law $\boldsymbol{a} = \frac{\boldsymbol{F}_{net}}{m}$

The acceleration of an object is equal to the sum of the forces acting on the object, divided by the mass of the object.

Notice that Newton's second law can be rearranged to the form $F = ma$, which you learned about previously. If the table that you and your friend were pushing was 15.0 kg and the two of you each pushed with a force of 50.0 N in the same direction, what would be the acceleration of the table? To find out, calculate the net force, 50.0 N + 50.0 N = 100.0 N, and apply Newton's second law by dividing the net force of 100.0 N by the mass of the table, 15.0 kg, to get an acceleration of 6.67 m/s^2.

Here is a useful strategy for finding how the motion of an object depends on the forces exerted on it. First, identify all the forces acting on the object. Draw a free-body diagram showing the direction and relative strength of each force acting on the system. Then, add the forces to find the net force. Next, use Newton's second law to calculate the acceleration. Finally, if necessary, use kinematics to find the velocity or position of the object. When you learned about kinematics in Chapters 2 and 3, you studied the motion of objects without regard for the causes of motion. You now know that an unbalanced force, a net force, is the cause of a change in velocity (an acceleration).

PRACTICE Problems

• Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

6. Two horizontal forces, 225 N and 165 N, are exerted on a canoe. If these forces are applied in the same direction, find the net horizontal force on the canoe.

7. If the same two forces as in the previous problem are exerted on the canoe in opposite directions, what is the net horizontal force on the canoe? Be sure to indicate the direction of the net force.

8. Three confused sleigh dogs are trying to pull a sled across the Alaskan snow. Alutia pulls east with a force of 35 N, Seward also pulls east but with a force of 42 N, and big Kodiak pulls west with a force of 53 N. What is the net force on the sled?

Newton's First Law

What is the motion of an object with no net force acting on it? A stationary object with no net force acting on it will stay at its position. Consider a moving object, such as a ball rolling on a surface. How long will the ball continue to roll? It will depend on the quality of the surface. If the ball is rolled on a thick carpet that offers much resistance, it will come to rest quickly. If it is rolled on a hard, smooth surface that offers little resistance, such as a bowling alley, the ball will roll for a long time with little change in velocity. Galileo did many experiments, and he concluded that in the ideal case of zero resistance, horizontal motion would never stop. Galileo was the first to recognize that the general principles of motion could be found by extrapolating experimental results to the ideal case, in which there is no resistance to slow down an object's motion.

In the absence of a net force, the motion (or lack of motion) of both the moving ball and the stationary object continues as it was. Newton recognized this and generalized Galileo's results in a single statement. This statement, "an object that is at rest will remain at rest, and an object that is moving will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero," is called **Newton's first law.**

Table 4-2

Some Types of Forces

Force	Symbol	Definition	Direction
Friction	$\boldsymbol{F}_{\mathrm{f}}$	The contact force that acts to oppose sliding motion between surfaces	Parallel to the surface and opposite the direction of sliding
Normal	$\boldsymbol{F}_{\mathrm{N}}$	The contact force exerted by a surface on an object	Perpendicular to and away from the surface
Spring	$\boldsymbol{F}_{\mathrm{sp}}$	A restoring force; that is, the push or pull a spring exerts on an object	Opposite the displacement of the object at the end of the spring
Tension	$\boldsymbol{F}_{\mathrm{T}}$	The pull exerted by a string, rope, or cable when attached to a body and pulled taut	Away from the object and parallel to the string, rope, or cable at the point of attachment
Thrust	$\boldsymbol{F}_{\mathrm{thrust}}$	A general term for the forces that move objects such as rockets, planes, cars, and people	In the same direction as the acceleration of the object, barring any resistive forces
Weight	$\boldsymbol{F}_{\mathrm{g}}$	A field force due to gravitational attraction between two objects, generally Earth and an object	Straight down toward the center of Earth

Inertia Newton's first law is sometimes called the law of inertia. Is inertia a force? No. **Inertia** is the tendency of an object to resist change. If an object is at rest, it tends to remain at rest. If it is moving at a constant velocity, it tends to continue moving at that velocity. Forces are results of interactions between two objects; they are not properties of single objects, so inertia cannot be a force. Remember that because velocity includes both the speed and direction of motion, a net force is required to change either the speed or direction of an object's motion.

Equilibrium According to Newton's first law, a net force is something that causes the velocity of an object to change. If the net force on an object is zero, then the object is in **equilibrium.** An object is in equilibrium if it is at rest or if it is moving at a constant velocity. Note that being at rest is simply a special case of the state of constant velocity, $v = 0$. Newton's first law identifies a net force as something that disturbs a state of equilibrium. Thus, if there is no net force acting on the object, then the object does not experience a change in speed or direction and is in equilibrium.

By understanding and applying Newton's first and second laws, you can often figure out something about the relative sizes of forces, even in situations in which you do not have numbers to work with. Before looking at an example of this, review **Table 4-2,** which lists some of the common types of forces. You will be dealing with many of these throughout your study of physics.

When analyzing forces and motion, it is important to keep in mind that the world is dominated by resistance. Newton's ideal, resistance-free world is not easy to visualize. If you analyze a situation and find that the result is different from a similar experience that you have had, ask yourself if this is because of the presence of resistance. In addition, many terms used in physics have everyday meanings that are different from those understood in physics. When talking or writing about physics issues, be careful to use these terms in their precise, scientific way.

APPLYING PHYSICS

▶ **Shuttle Engine Thrust** The Space Shuttle Main Engines (SSMEs) each are rated to provide 1.6 million N of thrust. Powered by the combustion of hydrogen and oxygen, the SSMEs are throttled anywhere from 65 percent to 109 percent of their rated thrust. ◀

4.1 Section Review

9. Force Identify each of the following as either **a, b,** or **c:** weight, mass, inertia, the push of a hand, thrust, friction, air resistance, spring force, and acceleration.

a. a contact force

b. a field force

c. not a force

10. Inertia Can you feel the inertia of a pencil? Of a book? If you can, describe how.

11. Free-Body Diagram Draw a free-body diagram of a bag of sugar being lifted by your hand at a constant speed. Specifically identify the system. Label all forces with their agents and make the arrows the correct lengths.

12. Direction of Velocity If you push a book in the forward direction, does this mean its velocity has to be forward?

13. Free-Body Diagram Draw a free-body diagram of a water bucket being lifted by a rope at a decreasing speed. Specifically identify the system. Label all forces with their agents and make the arrows the correct lengths.

14. Critical Thinking A force of 1 N is the only force exerted on a block, and the acceleration of the block is measured. When the same force is the only force exerted on a second block, the acceleration is three times as large. What can you conclude about the masses of the two blocks?

4.2 Using Newton's Laws

▶ **Objectives**

- **Describe** how the weight and the mass of an object are related.
- **Differentiate** between actual weight and apparent weight.

▶ **Vocabulary**

apparent weight
weightlessness
drag force
terminal velocity

Newton's second law describes the connection between the cause of a change in an object's velocity and the resulting displacement. This law identifies the relationship between the net force exerted on an object and the object's acceleration.

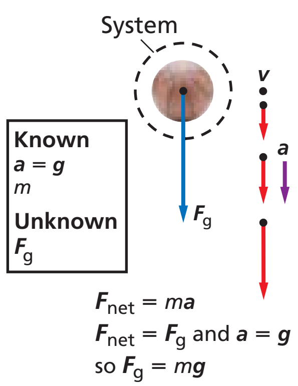
Using Newton's Second Law

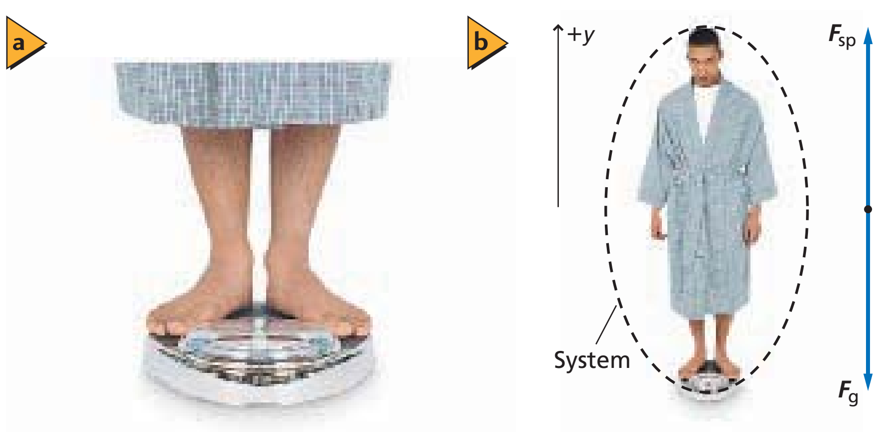
What is the weight force, $\boldsymbol{F}_g$, exerted on an object of mass m? Newton's second law can help answer this question. Consider the pictorial and physical models in **Figure 4-6,** which show a free-falling ball in midair. With what objects is it interacting? Because it is touching nothing and air resistance can be neglected, the only force acting on it is $\boldsymbol{F}_g$. You know from Chapter 3 that the ball's acceleration is $\boldsymbol{g}$. Newton's second law then becomes $\boldsymbol{F}_g = m\boldsymbol{g}$. Both the force and the acceleration are downward. The magnitude of an object's weight is equal to its mass times the acceleration it would have if it were falling freely. It is important to keep in mind that even when an object is not experiencing free-fall, the gravitational force of Earth is still acting on the object.

This result is true on Earth, as well as on any other planet, although the magnitude of g will be different on other planets. Because the value of g is much less on the Moon than on Earth, astronauts who landed on the Moon weighed much less while on the Moon, even though their mass had not changed.

Scales A bathroom scale contains springs. When you stand on the scale, the scale exerts an upward force on you because you are in contact with it. Because you are not accelerating, the net force acting on you must be zero. Therefore, the spring force, F_{sp}, pushing up on you must be the same magnitude as your weight, F_g, pulling down on you, as shown in the pictorial and physical models in **Figure 4-7.** The reading on the scale is determined by the amount of force the springs inside it exert on you. A spring scale, therefore, measures weight, not mass. If you were on a different planet, the compression of the spring would be different, and consequently, the scale's reading would be different. Remember that the proper unit for expressing mass is kilograms and because weight is a force, the proper unit used to express weight is the newton.

■ **Figure 4-6** The net force on the ball is the weight force, $\boldsymbol{F}_g$.





■ **Figure 4-7** The upward force of the spring in the scale is equal to your weight when you step on the bathroom scale **(a).** The free-body diagram in **(b)** shows that the system is in equilibrium because the force of the spring is equal to your weight.

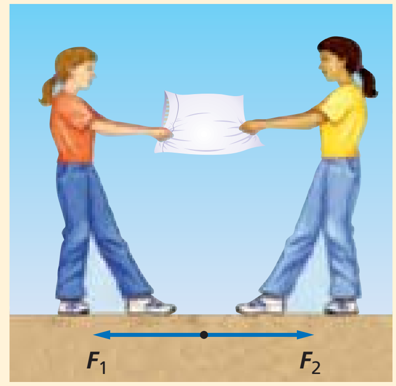
Aaron Haupt

▶ EXAMPLE Problem 1

Fighting Over a Pillow Anudja is holding a pillow, with a mass of 0.30 kg, when Sarah decides that she wants it and tries to pull it away from Anudja. If Sarah pulls horizontally on the pillow with a force of 10.0 N and Anudja pulls with a horizontal force of 11.0 N, what is the horizontal acceleration of the pillow?

1 Analyze and Sketch the Problem

- Sketch the situation.
- Identify the pillow as the system and the direction in which Anudja pulls as positive.
- Draw the free-body diagram. Label the forces.



Known:

$m = 0.30$ kg

$F_{\text{Anudja on pillow}} = 11.0$ N

$F_{\text{Sarah on pillow}} = 10.0$ N

Unknown:

$a = ?$

2 Solve for the Unknown

$F_{\text{net}} = F_{\text{Anudja on pillow}} + (-F_{\text{Sarah on pillow}})$

Use Newton's second law.

$$a = \frac{F_{\text{net}}}{m}$$

$$= \frac{F_{\text{Anudja on pillow}} + (-F_{\text{Sarah on pillow}})}{m}$$

Substitute $F_{\text{net}} = F_{\text{Anudja on pillow}} + (-F_{\text{Sarah on pillow}})$

$$= \frac{11.0\text{ N} - 10.0\text{ N}}{0.30\text{ kg}}$$

Substitute $F_{\text{Anudja on pillow}} = 11.0$ N, $F_{\text{Sarah on pillow}} = 10.0$ N, $m = 0.30$ kg

$$= 3.3\text{ m/s}^2$$

$\mathbf{a} = 3.3\text{ m/s}^2$ toward Anudja

Math Handbook
Operations with Significant Digits
pages 835–836

3 Evaluate the Answer

- **Are the units correct?** m/s^2 is the correct unit for acceleration.
- **Does the sign make sense?** The acceleration is in the positive direction, which is expected, because Anudja is pulling in the positive direction with a greater force than Sarah is pulling in the negative direction.
- **Is the magnitude realistic?** It is a reasonable acceleration for a light pillow.

▶ PRACTICE Problems

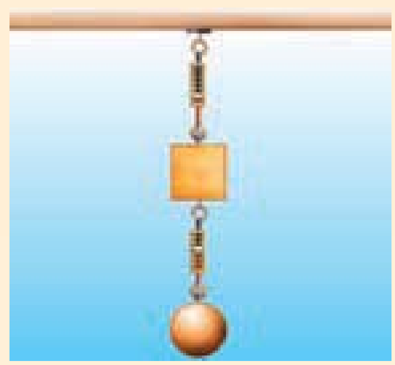
• Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

15. You place a watermelon on a spring scale at the supermarket. If the mass of the watermelon is 4.0 kg, what is the reading on the scale?

16. Kamaria is learning how to ice-skate. She wants her mother to pull her along so that she has an acceleration of 0.80 m/s². If Kamaria's mass is 27.2 kg, with what force does her mother need to pull her? (Neglect any resistance between the ice and Kamaria's skates.)

17. Taru and Reiko simultaneously grab a 0.75-kg piece of rope and begin tugging on it in opposite directions. If Taru pulls with a force of 16.0 N and the rope accelerates away from her at 1.25 m/s², with what force is Reiko pulling?

18. In **Figure 4-8,** the block has a mass of 1.2 kg and the sphere has a mass of 3.0 kg. What are the readings on the two scales? (Neglect the masses of the scales.)



■ **Figure 4-8**

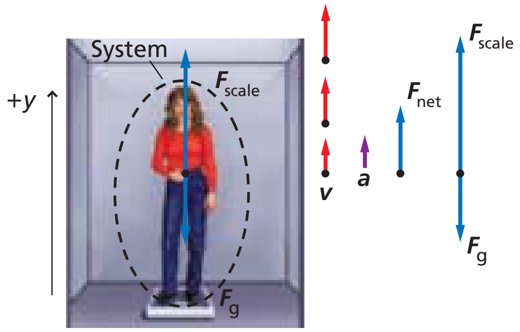


Figure 4-9 If you stand on a scale in an elevator accelerating upward, the scale must exert an upward force greater than the downward force of your weight.

Concepts In Motion

Interactive Figure To see an animation on apparent weight, visit physicspp.com.

CLICK HERE

Apparent weight What is weight? Because the weight force is defined as $\mathbf{F}_g = m\mathbf{g}$, $\mathbf{F}_g$ changes when $\mathbf{g}$ varies. On or near the surface of Earth, $\mathbf{g}$ is approximately constant, so an object's weight does not change appreciably as it moves around near Earth's surface. If a bathroom scale provides the only upward force on you, then it reads your weight. What would it read if you stood with one foot on the scale and one foot on the floor? What if a friend pushed down on your shoulders or up on your elbows? Then there would be other contact forces on you, and the scale would not read your weight.

What happens if you stand on a scale in an elevator? As long as the elevator is in equilibrium, the scale will read your weight. What would the scale read if the elevator accelerates upward? **Figure 4-9** shows the pictorial and physical models for this situation. You are the system, and upward is the positive direction. Because the acceleration of the system is upward, the upward force of the scale must be greater than the downward force of your weight. Therefore, the scale reading is greater than your weight. If you ride in an elevator like this, you would feel heavier because the floor would press harder on your feet. On the other hand, if the acceleration is downward, then you would feel lighter, and the scale would have a lower reading. The force exerted by the scale is called the apparent weight. An object's **apparent weight** is the force an object experiences as a result of all the forces acting on it, giving the object an acceleration.

Imagine that the cable holding the elevator breaks. What would the scale read then? The scale and you would both accelerate with $\mathbf{a} = -\mathbf{g}$. According to this formula, the scale would read zero and your apparent weight would be zero. That is, you would be weightless. However, **weightlessness** does not mean that an object's weight is actually zero; rather, it means that there are no contact forces pushing up on the object, and the object's apparent weight is zero.

PROBLEM-SOLVING Strategies

Force and Motion

When solving force and motion problems, use the following strategies.

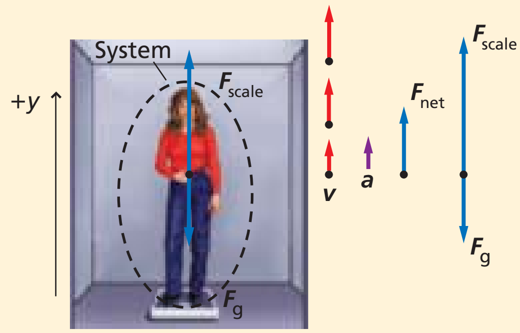
1. Read the problem carefully, and sketch a pictorial model.
2. Circle the system and choose a coordinate system.
3. Determine which quantities are known and which are unknown.
4. Create a physical model by drawing a motion diagram showing the direction of the acceleration, and create a free-body diagram showing the net force.
5. Use Newton's laws to link acceleration and net force.
6. Rearrange the equation to solve for the unknown quantity.
7. Substitute known quantities with their units into the equation and solve.
8. Check your results to see if they are reasonable.

▶ EXAMPLE Problem 2

Real and Apparent Weight Your mass is 75.0 kg, and you are standing on a bathroom scale in an elevator. Starting from rest, the elevator accelerates upward at 2.00 m/s^2 for 2.00 s and then continues at a constant speed. Is the scale reading during acceleration greater than, equal to, or less than the scale reading when the elevator is at rest?

1 Analyze and Sketch the Problem

- Sketch the situation.
- Choose a coordinate system with the positive direction as upward.
- Draw the motion diagram. Label $\mathbf{v}$ and $\mathbf{a}$.
- Draw the free-body diagram. The net force is in the same direction as the acceleration, so the upward force is greater than the downward force.



Known:

$m = 75.0$ kg

$a = 2.00$ m/s^2

$t = 2.00$ s

$g = 9.80$ N

Unknown:

$F_{scale} = ?$

2 Solve for the Unknown

$F_{net} = ma$

$F_{net} = F_{scale} + (-F_g)$ — **F_g is negative because it is in the negative direction defined by the coordinate system.**

Solve for F_{scale}.

$F_{scale} = F_{net} + F_g$

Elevator at rest:

$F_{scale} = F_{net} + F_g$ — **The elevator is not accelerating. Thus, $F_{net} = 0.00$ N.**

$= F_g$ — **Substitute $F_{net} = 0.00$ N**

$= mg$ — **Substitute $F_g = mg$**

$= (75.0 \text{ kg})(9.80 \text{ m/s}^2)$ — **Substitute $m = 75.0$ kg, $g = 9.80$ m/s^2**

$= 735$ N

Acceleration of the elevator:

$F_{scale} = F_{net} + F_g$

$= ma + mg$ — **Substitute $F_{net} = ma$, $F_g = mg$**

$= m(a + g)$ — **Substitute $m = 75.0$ kg, $a = 2.00$ m/s^2, $g = 9.80$ m/s^2**

$= (75.0 \text{ kg})(2.00 \text{ m/s}^2 + 9.80 \text{ m/s}^2)$

$= 885$ N

The scale reading when the elevator is accelerating (885 N) is larger than the scale reading at rest (735 N).

3 Evaluate the Answer

- **Are the units correct?** kg·m/s^2 is the force unit, N.
- **Does the sign make sense?** The positive sign agrees with the coordinate system.
- **Is the magnitude realistic?** F_{scale} is larger than it would be at rest when F_{scale} would be 735 N, so the magnitude is reasonable.

Physics Online

Personal Tutor For an online tutorial on real and apparent weight, visit physicspp.com.

PRACTICE Problems • Additional Problems, Appendix B • Solutions to Selected Problems, Appendix C

19. On Earth, a scale shows that you weigh 585 N.

a. What is your mass?

b. What would the scale read on the Moon ($g = 1.60$ m/s^2)?

20. Use the results from Example Problem 2 to answer questions about a scale in an elevator on Earth. What force would be exerted by the scale on a person in the following situations?

a. The elevator moves at constant speed.

b. It slows at 2.00 m/s^2 while moving upward.

c. It speeds up at 2.00 m/s^2 while moving downward.

d. It moves downward at constant speed.

e. It slows to a stop at a constant magnitude of acceleration.

Drag Force and Terminal Velocity

It is true that the particles in the air around an object exert forces on it. Air actually exerts a huge force, but in most cases, it exerts a balanced force on all sides, and therefore it has no net effect. Can you think of any experiences that help to prove that air exerts a force? When you stick a suction cup on a smooth wall or table, you remove air from the "inside" of it. The suction cup is difficult to remove because of the net force of the air on the "outside."

So far, you have neglected the force of air on an object moving through the air. In actuality, when an object moves through any fluid, such as air or water, the fluid exerts a drag force on the moving object in the direction opposite to its motion. A **drag force** is the force exerted by a fluid on the object moving through the fluid. This force is dependent on the motion of the object, the properties of the object, and the properties of the fluid that the object is moving through. For example, as the speed of the object increases, so does the magnitude of the drag force. The size and shape of the object also affects the drag force. The drag force is also affected by the properties of the fluid, such as its viscosity and temperature.

CHALLENGE PROBLEM

An air-track glider passes through a photoelectric gate at an initial speed of 0.25 m/s. As it passes through the gate, a constant force of 0.40 N is applied to the glider in the same direction as its motion. The glider has a mass of 0.50 kg.

1. What is the acceleration of the glider?

2. It takes the glider 1.3 s to pass through a second gate. What is the distance between the two gates?

3. The 0.40-N force is applied by means of a string attached to the glider. The other end of the string passes over a resistance-free pulley and is attached to a hanging mass, m. How big is m?

4. Derive an expression for the tension, T, in the string as a function of the mass, M, of the glider, the mass, m, of the hanging mass, and g.

If you drop a table-tennis ball, as in **Figure 4-10,** it has very little velocity at the start, and thus only a small drag force. The downward force of gravity is much stronger than the upward drag force, so there is a downward acceleration. As the ball's velocity increases, so does the drag force. Soon, the drag force equals the force of gravity. When this happens, there is no net force, and so there is no acceleration. The constant velocity that is reached when the drag force equals the force of gravity is called the **terminal velocity.**

When light objects with large surface areas are falling, the drag force has a substantial effect on their motion, and they quickly reach terminal velocity. Heavier, more-compact objects are not affected as much by the drag force. For example, the terminal velocity of a table-tennis ball in air is 9 m/s, that of a basketball is 20 m/s, and that of a baseball is 42 m/s. Competitive skiers increase their terminal velocities by decreasing the drag force on them. They hold their bodies in an egg shape and wear smooth clothing and streamlined helmets. Sky divers can increase or decrease their terminal velocity by changing their body orientation and shape. A horizontal, spread-eagle shape produces the slowest terminal velocity, about 60 m/s. Because a parachute changes the shape of the sky diver when it opens, a sky diver becomes part of a very large object with a correspondingly large drag force and a terminal velocity of about 5 m/s.

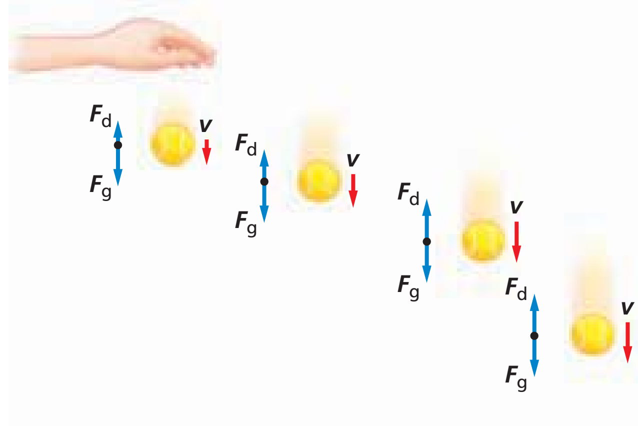


Figure 4-10 The drag force on an object increases as its velocity increases. When the drag force increases to the point that it equals the force of gravity, the object will no longer be accelerated.

4.2 Section Review

21. Lunar Gravity Compare the force holding a 10.0-kg rock on Earth and on the Moon. The acceleration due to gravity on the Moon is 1.62 m/s^2.

22. Real and Apparent Weight You take a ride in a fast elevator to the top of a tall building and ride back down while standing on a bathroom scale. During which parts of the ride will your apparent and real weights be the same? During which parts will your apparent weight be less than your real weight? More than your real weight? Sketch free-body diagrams to support your answers.

23. Acceleration Tecle, with a mass of 65.0 kg, is standing by the boards at the side of an ice-skating rink. He pushes off the boards with a force of 9.0 N. What is his resulting acceleration?

24. Motion of an Elevator You are riding in an elevator holding a spring scale with a 1-kg mass suspended from it. You look at the scale and see that it reads 9.3 N. What, if anything, can you conclude about the elevator's motion at that time?

25. Mass Marcos is playing tug-of-war with his cat using a stuffed toy. At one instant during the game, Marcos pulls on the toy with a force of 22 N, the cat pulls in the opposite direction with a force of 19.5 N, and the toy experiences an acceleration of 6.25 m/s^2. What is the mass of the toy?

26. Acceleration A sky diver falls at a constant speed in the spread-eagle position. After he opens his parachute, is the sky diver accelerating? If so, in which direction? Explain your answer using Newton's laws.

27. Critical Thinking You have a job at a meat warehouse loading inventory onto trucks for shipment to grocery stores. Each truck has a weight limit of 10,000 N of cargo. You push each crate of meat along a low-resistance roller belt to a scale and weigh it before moving it onto the truck. However, right after you weigh a 1000-N crate, the scale breaks. Describe a way in which you could apply Newton's laws to figure out the approximate masses of the remaining crates.

4.3 Interaction Forces

Objectives
- **Define** Newton's third law.
- **Explain** the tension in ropes and strings in terms of Newton's third law.
- **Define** the normal force.
- **Determine** the value of the normal force by applying Newton's second law.

Vocabulary

interaction pair
Newton's third law
tension
normal force

You have learned that when an agent exerts a net force upon an object, the object undergoes acceleration. You know that this force can be either a field force or a contact force. But what causes the force? If you experiment with two magnets, you can feel each magnet pushing or pulling the other. Similarly, if you pull on a lever, you can feel the lever pulling back against you. Which is the agent and which is the object?

Identifying Interaction Forces

Imagine that you and a friend are each wearing in-line skates (with all the proper safety gear), and your friend is standing right in front of you, with his back to you. You push your friend so that he starts rolling forward. What happens to you? You move backwards. Why? Recall that a force is the result of an interaction between two objects. When you push your friend forward, you come into contact with him and exert a force that moves him forward. However, because he is also in contact with you, he also exerts a force on you, and this results in a change in your motion.

Forces always come in pairs. Consider you (Student A) as one system and your friend (Student B) as another. What horizontal forces act on each of the two systems? **Figure 4-11** shows the free-body diagram for the systems. Looking at this diagram, you can see that each system experiences a force exerted by the other. The two forces, $\boldsymbol{F}_{\text{A on B}}$ and $\boldsymbol{F}_{\text{B on A}}$, are the forces of interaction between the two of you. Notice the symmetry in the subscripts: A on B and B on A. What do you notice about the directions of these forces? What do you expect to be true about their relative magnitudes?

Figure 4-11 When you exert a force on your friend to push him forward, he exerts an equal and opposite force on you, which causes you to move backwards.

The forces $\boldsymbol{F}_{\text{A on B}}$ and $\boldsymbol{F}_{\text{B on A}}$ are an interaction pair. An **interaction pair** is two forces that are in opposite directions and have equal magnitude. Sometimes, this also is called an action-reaction pair of forces. This might suggest that one causes the other; however, this is not true. For example, the force of you pushing your friend doesn't cause your friend to exert a force on you. The two forces either exist together or not at all. They both result from the contact between the two of you.

Newton's Third Law

The force of you on your friend is equal in magnitude and opposite in direction to the force of your friend on you. This is summarized in **Newton's third law,** which states that all forces come in pairs. The two forces in a pair act on different objects and are equal in strength and opposite in direction.

Newton's Third Law $\boldsymbol{F}_{\text{A on B}} = -\boldsymbol{F}_{\text{B on A}}$

The force of A on B is equal in magnitude and opposite in direction of the force of B on A.

Consider the situation of you holding a book in your hand. Draw one free-body diagram each for you and for the book. Are there any interaction pairs? When identifying interaction pairs, keep in mind that they always will occur in two different free-body diagrams, and they always will have the symmetry of subscripts noted on the previous page. In this case, there is one interaction pair, $\boldsymbol{F}_{\text{book on hand}}$ and $\boldsymbol{F}_{\text{hand on book}}$. Notice also that each object has a weight. If the weight force is due to an interaction between the object and Earth's mass, then shouldn't each of these objects also exert a force on Earth? If this is the case, shouldn't Earth be accelerating?

Consider a soccer ball sitting on a table. The table, in turn, is sitting on Earth, as shown in **Figure 4-12.** First, analyze the forces acting on the ball. The table exerts an upward force on the ball, and the mass of Earth exerts a downward gravitational force on the ball. Even though these forces are in the opposite direction on the same object, they are not an interaction pair. They are simply two forces acting on the same object, not the interaction between two objects. Consider the ball and the table together. In addition to the upward force exerted by the table on the ball, the ball exerts a downward force on the table. This is one pair of forces. The ball and Earth also have an interaction pair. Thus, the interaction pairs related to the soccer ball are $\boldsymbol{F}_{\text{ball on table}} = -\boldsymbol{F}_{\text{table on ball}}$ and $\boldsymbol{F}_{\text{ball on Earth}} = -\boldsymbol{F}_{\text{Earth on ball}}$. It is important to keep in mind that an interaction pair must consist of two forces of equal magnitude pointing in opposite directions. These opposing forces must act on two different objects that can exert a force against each other.

The acceleration caused by the force of an object interacting with Earth is usually a very small number. Under most circumstances, the number is so small that for problems involving falling or stationary objects, Earth can be treated as part of the external world rather than as a second system. Consider Example Problem 3 using the following problem-solving strategies.

Figure 4-12 A soccer ball on a table on Earth is part of two interaction pairs—the interaction between the ball and table and the interaction between the ball and Earth. (Not to scale)

PROBLEM-SOLVING Strategies

Interaction Pairs

Use these strategies to solve problems in which there is an interaction between objects in two different systems.

1. Separate the system or systems from the external world.
2. Draw a pictorial model with coordinate systems for each system and a physical model that includes free-body diagrams for each system.
3. Connect interaction pairs by dashed lines.
4. To calculate your answer, use Newton's second law to relate the net force and acceleration for each system.
5. Use Newton's third law to equate the magnitudes of the interaction pairs and give the relative direction of each force.
6. Solve the problem and check the units, signs, and magnitudes for reasonableness.

MINI LAB

Tug-of-War Challenge

In a tug-of-war, predict how the force you exert on your end of the rope compares to the force your opponent exerts if you pull and your opponent just holds the rope.

1. Predict how the forces compare if the rope moves in your direction.

2. Test your prediction. ***CAUTION: Do not suddenly let go of the rope.***

Analyze and Conclude

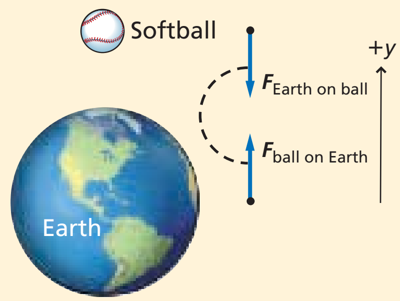
3. Compare the force on your end of the rope to the force on your opponent's end of the rope. What happened when you started to move your opponent's direction?

EXAMPLE Problem 3

Earth's Acceleration When a softball with a mass of 0.18 kg is dropped, its acceleration toward Earth is equal to g, the acceleration due to gravity. What is the force on Earth due to the ball, and what is Earth's resulting acceleration? Earth's mass is 6.0×10^{24} kg.

1 Analyze and Sketch the Problem

- Draw free-body diagrams for the two systems: the ball and Earth.
- Connect the interaction pair by a dashed line.



Known:

$m_{ball} = 0.18$ kg

$m_{Earth} = 6.0\times10^{24}$ kg

$g = 9.80$ m/s^2

Unknown:

$F_{Earth\ on\ ball} = ?$

$a_{Earth} = ?$

2 Solve for the Unknown

Use Newton's second law to find the weight of the ball.

$$F_{Earth\ on\ ball} = m_{ball}a$$
$$= m_{ball}(-g) \quad \text{Substitute } a = -g$$
$$= (0.18\text{ kg})(9.80\text{ m/s}^2) \quad \text{Substitute } m_{ball} = 0.18\text{ kg}, g = 9.80\text{ m/s}^2$$
$$= -1.8\text{ N}$$

Use Newton's third law to find $F_{ball\ on\ Earth}$.

$$F_{ball\ on\ Earth} = -F_{Earth\ on\ ball}$$
$$= -(-1.8\text{ N}) \quad \text{Substitute } F_{Earth\ on\ ball} = -1.8\text{ N}$$
$$= +1.8\text{ N}$$

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Use Newton's second law to find a_{Earth}.

$$a_{Earth} = \frac{F_{net}}{m_{Earth}}$$
$$= \frac{1.8\text{ N}}{6.0\times10^{24}\text{ kg}} \quad \text{Substitute } F_{net} = 1.8\text{ N}, m_{Earth} = 6.0\times10^{24}\text{ kg}$$
$$= 2.9\times10^{-25}\text{ m/s}^2 \text{ toward the softball}$$

3 Evaluate the Answer

- **Are the units correct?** Dimensional analysis verifies force in N and acceleration in m/s^2.
- **Do the signs make sense?** Force and acceleration should be positive.
- **Is the magnitude realistic?** Because of Earth's large mass, the acceleration should be small.

PRACTICE Problems

- Additional Problems, Appendix B
- Solutions to Selected Problems, Appendix C

28. You lift a relatively light bowling ball with your hand, accelerating it upward. What are the forces on the ball? What forces does the ball exert? What objects are these forces exerted on?

29. A brick falls from a construction scaffold. Identify any forces acting on the brick. Also identify any forces that the brick exerts and the objects on which these forces are exerted. (Air resistance may be ignored.)

30. You toss a ball up in the air. Draw a free-body diagram for the ball while it is still moving upward. Identify any forces acting on the ball. Also identify any forces that the ball exerts and the objects on which these forces are exerted.

Figure 4-13

31. A suitcase sits on a stationary airport luggage cart, as in **Figure 4-13.** Draw a free-body diagram for each object and specifically indicate any interaction pairs between the two.

Forces of Ropes and Strings

Tension is simply a specific name for the force exerted by a string or rope. A simplification within this textbook is the assumption that all strings and ropes are massless. To understand tension in more detail, consider the situation in **Figure 4-14,** where a bucket hangs from a rope attached to the ceiling. The rope is about to break in the middle. If the rope breaks, the bucket will fall; thus, before it breaks, there must be forces holding the rope together. The force that the top part of the rope exerts on the bottom part is $\boldsymbol{F}_{\text{top on bottom}}$. Newton's third law states that this force must be part of an interaction pair. The other member of the pair is the force that the bottom part exerts on the top, $\boldsymbol{F}_{\text{bottom on top}}$. These forces, equal in magnitude but opposite in direction, also are shown in Figure 4-14.

Think about this situation in another way. Before the rope breaks, the bucket is in equilibrium. This means that the force of its weight downward must be equal in magnitude but opposite in direction to the tension in the rope upward. Similarly, if you look at the point in the rope just above the bucket, it also is in equilibrium. Therefore, the tension of the rope below it pulling down must be equal to the tension of the rope above it pulling up. You can move up the rope, considering any point in the rope, and see that the tension forces are pulling equally in both directions. Because the very bottom of the rope has a tension equal to the weight of the bucket, the tension everywhere in the rope is equal to the weight of the bucket. Thus, the tension in the rope is the weight of all objects below it. Because the rope is assumed to be massless, the tension everywhere in the rope is equal to the bucket's weight.

Tension forces also are at work in a tug-of-war, like the one shown in **Figure 4-15.** If team A, on the left, is exerting a force of 500 N and the rope does not move, then team B, on the right, also must be pulling with a force of 500 N. What is the tension in the rope in this case? If each team pulls with 500 N of force, is the tension 1000 N? To decide, think of the rope as divided into two halves. The left-hand end is not moving, so the net force on it is zero. Thus, $F_{\text{A on rope}} = F_{\text{right on left}} = 500$ N. Similarly, $F_{\text{B on rope}} = F_{\text{left on right}} = 500$ N. But the two tensions, $F_{\text{right on left}}$ and $F_{\text{left on right}}$, are an interaction pair, so they are equal and opposite. Thus, the tension in the rope equals the force with which each team pulls, or 500 N. To verify this, you could cut the rope in half, tie the ends to a spring scale, and ask the two teams each to pull with 500 N of force. You would see that the scale reads 500 N.

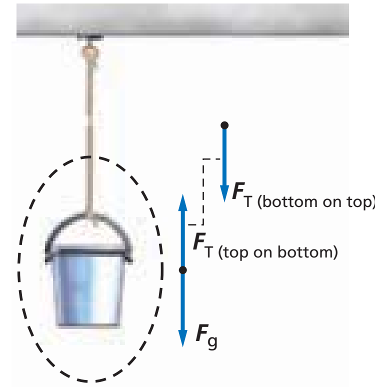


Figure 4-14 The tension in the rope is equal to the weight of all the objects hanging from it.

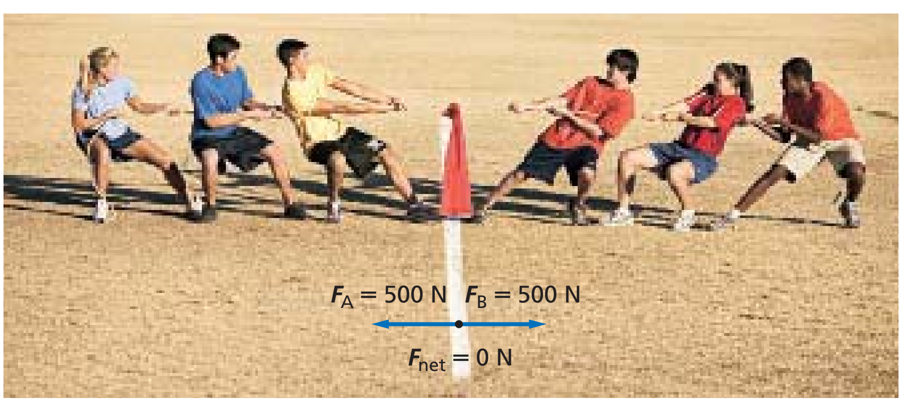


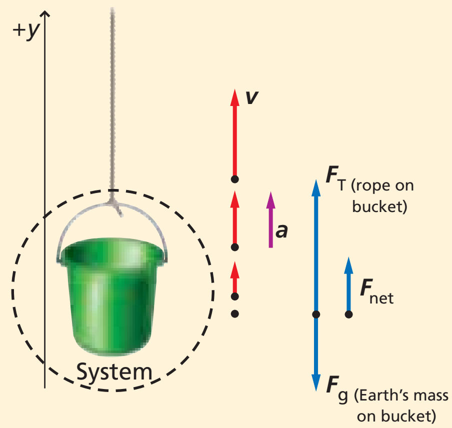
Figure 4-15 In a tug-of-war, the teams exert equal and opposite forces on each other via the tension in the rope.

EXAMPLE Problem 4

Lifting a Bucket A 50.0-kg bucket is being lifted by a rope. The rope will not break if the tension is 525 N or less. The bucket started at rest, and after being lifted 3.0 m, it is moving at 3.0 m/s. If the acceleration is constant, is the rope in danger of breaking?

1 Analyze and Sketch the Problem

- Draw the situation and identify the forces on the system.
- Establish a coordinate system with the positive axis upward.
- Draw a motion diagram including v and a.
- Draw the free-body diagram, labeling the forces.



Known:		Unknown:
$m = 50.0$ kg	$v_f = 3.0$ m/s	$F_T = ?$
$v_i = 0.0$ m/s	$d = 3.0$ m	

2 Solve for the Unknown

F_{net} is the sum of the positive force of the rope pulling up, F_T, and the negative weight force, $-F_g$, pulling down as defined by the coordinate system.

$$F_{net} = F_T + (-F_g)$$
$$F_T = F_{net} + F_g$$
$$= ma + mg \quad \text{Substitute } F_{net} = ma,\ F_g = mg$$
$$= m(a + g)$$

v_i, v_f, and d are known. Use this motion equation to solve for a.

$$v_f^2 = v_i^2 + 2ad$$
$$a = \frac{v_f^2 - v_i^2}{2d}$$
$$= \frac{v_f^2}{2d} \quad \text{Substitute } v_i = 0.0 \text{ m/s}^2$$

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$$F_T = m(a + g)$$
$$= m\left(\frac{v_f^2}{2d} + g\right) \quad \text{Substitute } a = \frac{v_f^2}{2d}$$
$$= (50.0 \text{ kg})\left(\frac{(3.0 \text{ m/s})^2}{2(3.0 \text{ m})} + 9.80 \text{ m/s}^2\right) \quad \text{Substitute } m = 50.0 \text{ kg},\ v_f = 3.0 \text{ m/s},\ d = 3.0 \text{ m},\ g = 9.80 \text{ m/s}^2$$
$$= 570 \text{ N}$$

The rope is in danger of breaking because the tension exceeds 525 N.

3 Evaluate the Answer

- **Are the units correct?** Dimensional analysis verifies kg·m/s^2, which is N.
- **Does the sign make sense?** The upward force should be positive.
- **Is the magnitude realistic?** The magnitude is a little larger than 490 N, which is the weight of the bucket. $F_g = mg = (50.0 \text{ kg})(9.80 \text{ m/s}^2) = 490$ N

PRACTICE Problems

• Additional Problems, Appendix B
• Solutions to Selected Problems, Appendix C

32. You are helping to repair a roof by loading equipment into a bucket that workers hoist to the rooftop. If the rope is guaranteed not to break as long as the tension does not exceed 450 N and you fill the bucket until it has a mass of 42 kg, what is the greatest acceleration that the workers can give the bucket as they pull it to the roof?

33. Diego and Mika are trying to fix a tire on Diego's car, but they are having trouble getting the tire loose. When they pull together, Mika with a force of 23 N and Diego with a force of 31 N, they just barely get the tire to budge. What is the magnitude of the strength of the force between the tire and the wheel?

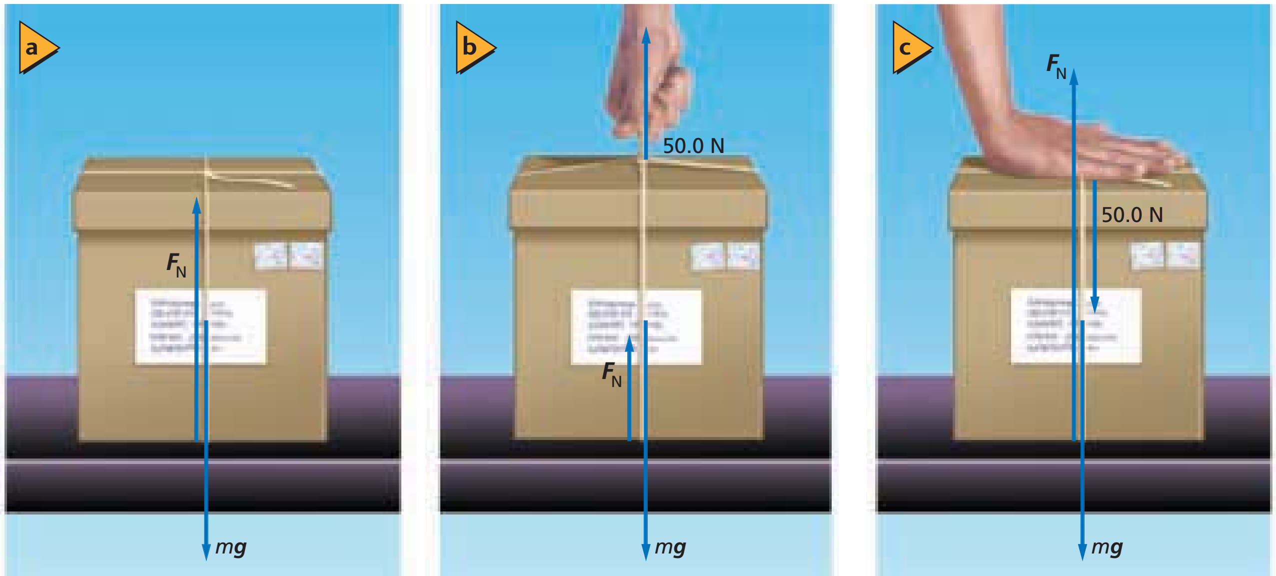


Figure 4-16 The normal force on an object is not always equal to its weight. In **(a)** the normal force is equal to the object's weight. In **(b)** the normal force is less than the object's weight. In **(c)** the normal force is greater than the object's weight.

The Normal Force

Any time two objects are in contact, they each exert a force on each other. Think about a box sitting on a table. There is a downward force due to the gravitational attraction of Earth. There also is an upward force that the table exerts on the box. This force must exist, because the box is in equilibrium. The **normal force** is the perpendicular contact force exerted by a surface on another object.

The normal force always is perpendicular to the plane of contact between two objects, but is it always equal to the weight of an object as in **Figure 4-16a?** What if you tied a string to the box and pulled up on it a little bit, but not enough to move the box, as shown in **Figure 4-16b?** When you apply Newton's second law to the box, you see that $F_N + F_{\text{string on box}} - F_g = ma = 0$, which rearranges to $F_N = F_g - F_{\text{string on box}}$.

You can see that in this case, the normal force exerted by the table on the box is less than the box's weight, F_g. Similarly, if you pushed down on the box on the table as shown in **Figure 4-16c,** the normal force would be more than the box's weight. Finding the normal force will be important in the next chapter, when you begin dealing with resistance.

4.3 Section Review

34. Force Hold a book motionless in your hand in the air. Identify each force and its interaction pair on the book.

35. Force Lower the book from problem 34 at increasing speed. Do any of the forces or their interaction-pair partners change? Explain.

36. Tension A block hangs from the ceiling by a massless rope. A second block is attached to the first block and hangs below it on another piece of massless rope. If each of the two blocks has a mass of 5.0 kg, what is the tension in each rope?

37. Tension If the bottom block in problem 36 has a mass of 3.0 kg and the tension in the top rope is 63.0 N, calculate the tension in the bottom rope and the mass of the top block.

38. Normal Force Poloma hands a 13-kg box to 61-kg Stephanie, who stands on a platform. What is the normal force exerted by the platform on Stephanie?

39. Critical Thinking A curtain prevents two tug-of-war teams from seeing each other. One team ties its end of the rope to a tree. If the other team pulls with a 500-N force, what is the tension? Explain.

PHYSICS LAB • Internet

Forces in an Elevator

Alternate CBL instructions can be found on the Web site.
physicspp.com

Have you ever been in a fast-moving elevator? Was the ride comfortable? How about an amusement ride that quickly moves upward or one that free-falls? What forces are acting on you during your ride? In this experiment, you will investigate the forces that affect you during vertical motion when gravity is involved with a bathroom scale. Many bathroom scales measure weight in pounds mass (lbm) or pounds force (lbf) rather than newtons. In the experiment, you will need to convert weights measured on common household bathroom scales to SI units.

QUESTION

What one-dimensional forces act on an object that is moving in a vertical direction in relation to the ground?

Objectives

- **Measure** Examine forces that act on objects that move vertically.
- **Compare and Contrast** Differentiate between actual weight and apparent weight.
- **Analyze and Conclude** Share and compare data of the acceleration of elevators.

Safety Precautions

- **Use caution when working around elevator doors.**
- **Do not interfere with normal elevator traffic.**
- **Watch that the mass on the spring scale does not fall and hit someone's feet or toes.**

Materials

elevator
bathroom scale
spring scale
mass

Procedure

1. Securely attach a mass to the hook on a spring scale. Record the force of the mass in the data table.
2. Accelerate the mass upward, then move it upward at a constant velocity, and then slow the mass down. Record the greatest amount of force on the scale, the amount of force at constant velocity, and the lowest scale reading.
3. Get your teacher's permission and proceed to an elevator on the ground floor. Before entering the elevator, measure your weight on a bathroom scale. Record this weight in the data table.

Laura Sifferlin

Data Table	
Force (step 1)	
Highest Reading (step 2)	
Reading at Constant Velocity (step 2)	
Lowest Reading (step 2)	
Your Weight (step 3)	
Highest Reading (step 4)	
Reading at Constant Velocity (step 5)	
Lowest Reading (step 6)	

4. Place the scale in the elevator. Step on the scale and record the mass at rest. Select the highest floor that the elevator goes up to. Once the elevator starts, during its upward acceleration, record the highest reading on the scale in the data table.
5. When the velocity of the elevator becomes constant, record the reading on the scale in the data table.
6. As the elevator starts to decelerate, watch for the lowest reading on the scale and record it in the data table.

Analyze

1. **Explain** In step 2, why did the mass appear to gain weight when being accelerated upward? Provide a mathematical equation to summarize this concept.
2. **Explain** Why did the mass appear to lose weight when being decelerated at the end of its movement during step 3? Provide a mathematical equation to summarize this concept.
3. **Measure in SI** Most bathroom scales read in pounds mass (lbm). Convert your reading in step 4 in pounds mass to kilograms. (1 kg = 2.21 lbm) (Note: skip this step if your scale measures in kilograms.)
4. **Measure in SI** Some bathroom scales read in pounds force (lbf). Convert all of the readings you made in steps 4–6 to newtons. (1 N = 0.225 lbf)
5. **Analyze** Calculate the acceleration of the elevator at the beginning of your elevator trip using the equation $F_{scale} = ma + mg$.
6. **Use Numbers** What is the acceleration of the elevator at the end of your trip?

Conclude and Apply

How can you develop an experiment to find the acceleration of an amusement park ride that either drops rapidly or climbs rapidly?

Going Further

How can a bathroom scale measure both pounds mass (lbm) and pounds force (lbf) at the same time?

Real-World Physics

Forces on pilots in high-performance jet airplanes are measured in *g*'s or *g*-force. What does it mean if a pilot is pulling 6 *g*'s in a power climb?

Share Your Data

Communicate You can visit **physicspp.com/internet_lab** to post the acceleration of your elevator and compare it to other elevators around the country, maybe even the world. Post a description of your elevator's ride so that a comparison of acceleration versus ride comfort can be evaluated.

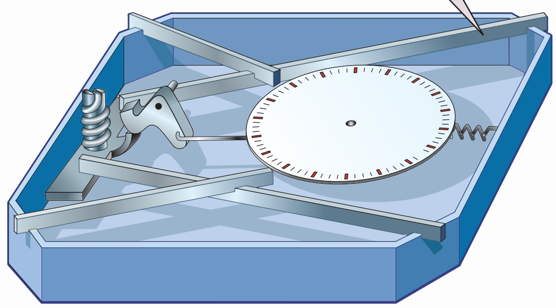
Physics Online

To find out more about forces and acceleration, visit the Web site: **physicspp.com**

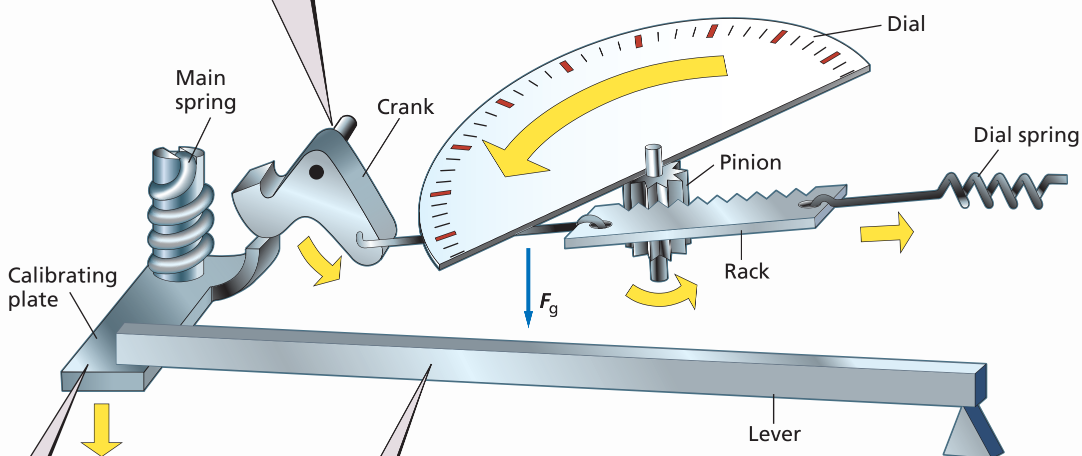
HOW it WORKS Bathroom Scale

The portable weighing scale was patented in 1896 by John H. Hunter. People used coin-operated scales, usually located in stores, to weigh themselves until the advent of the home bathroom scale in 1946. How does a bathroom scale work?

1 There are two long and two short levers that are attached to each other. Brackets in the lid of the scale sit on top of the levers to help evenly distribute your weight on the levers.



3 As the calibrating plate is pushed down by weight on the scale, the crank pivots. This, in turn, moves the rack and rotates the pinion. As a result, the dial on the scale rotates.



4 When the spring force, F_{sp}, from the main spring being stretched is equal to F_g, the crank, rack, and pinion no longer move, and your weight is shown on the dial.

2 The long levers rest on top of a calibrating plate that has the main spring attached to it. When you step on the scale, your weight, F_g, is exerted on the levers, which, in turn, exert a force on the calibrating plate and cause the main spring to stretch.

Thinking Critically

1. **Hypothesize** Most springs in bathroom scales cannot exert a force larger than 20 lbs (89 N). How is it possible that you don't break the scale every time you step on it? *(Hint: Think about exerting a large force near the pivot of a see-saw.)*
2. **Solve** If the largest reading on most scales is 240 lbs (1068 N) and the spring can exert a maximum of 20 lbs (89 N), what ratio does the lever use?

Chapter 4

Study Guide

4.1 Force and Motion

Vocabulary

- force (p. 88)
- free-body diagram (p. 89)
- net force (p. 92)
- Newton's second law (p. 93)
- Newton's first law (p. 94)
- inertia (p. 95)
- equilibrium (p. 95)

Key Concepts

- An object that experiences a push or a pull has a force exerted on it.
- Forces have both direction and magnitude.
- Forces may be divided into contact and field forces.
- In a free-body diagram, always draw the force vectors leading away from the object, even if the force is a push.
- The forces acting upon an object can be added using vector addition to find the net force.
- Newton's second law states that the acceleration of a system equals the net force acting on it, divided by its mass.

$$\boldsymbol{a} = \frac{\boldsymbol{F}_{\text{net}}}{m}$$

- Newton's first law states that an object that is at rest will remain at rest, and an object that is moving will continue to move in a straight line with constant speed, if and only if the net force acting on that object is zero.
- An object with no net force acting on it is in equilibrium.

4.2 Using Newton's Laws

Vocabulary

- apparent weight (p. 98)
- weightlessness (p. 98)
- drag force (p. 100)
- terminal velocity (p. 101)

Key Concepts

- The weight of an object depends upon the acceleration due to gravity and the mass of the object.
- An object's apparent weight is the force an object experiences as a result of the contact forces acting on it, giving the object an acceleration.
- An object with no apparent weight experiences weightlessness.
- The effect of drag on an object's motion is determined by the object's weight, size, and shape.
- If a falling object reaches a velocity such that the drag force is equal to the object's weight, it maintains that velocity, called the terminal velocity.

4.3 Interaction Forces

Vocabulary

- interaction pair (p. 102)
- Newton's third law (p. 102)
- tension (p. 105)
- normal force (p. 107)

Key Concepts

- All forces result from interactions between objects.
- Newton's third law states that the two forces that make up an interaction pair of forces are equal in magnitude, but opposite in direction and act on different objects.

$$\boldsymbol{F}_{\text{A on B}} = -\boldsymbol{F}_{\text{B on A}}$$

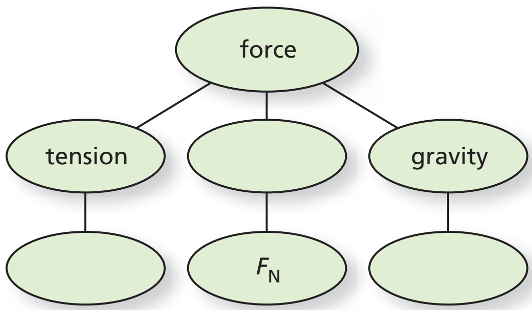
- In an interaction pair, $\boldsymbol{F}_{\text{A on B}}$ does not cause $\boldsymbol{F}_{\text{B on A}}$. The two forces either exist together or not at all.
- Tension is the specific name for the force exerted by a rope or string.
- The normal force is a support force resulting from the contact of two objects. It is always perpendicular to the plane of contact between the two objects.

Chapter 4

Assessment

Concept Mapping

40. Complete the following concept map using the following term and symbols: *normal*, F_T, F_g.



Mastering Concepts

41. A physics book is motionless on the top of a table. If you give it a hard push with your hand, it slides across the table and slowly comes to a stop. Use Newton's laws to answer the following questions. (4.1)

a. Why does the book remain motionless before the force of your hand is applied?

b. Why does the book begin to move when your hand pushes hard enough on it?

c. Under what conditions would the book remain in motion at a constant speed?

42. Cycling Why do you have to push harder on the pedals of a single-speed bicycle to start it moving than to keep it moving at a constant velocity? (4.1)

43. Suppose that the acceleration of an object is zero. Does this mean that there are no forces acting on it? Give an example supporting your answer. (4.2)

44. Basketball When a basketball player dribbles a ball, it falls to the floor and bounces up. Is a force required to make it bounce? Why? If a force is needed, what is the agent involved? (4.2)

45. Before a sky diver opens her parachute, she may be falling at a velocity higher than the terminal velocity that she will have after the parachute opens. (4.2)

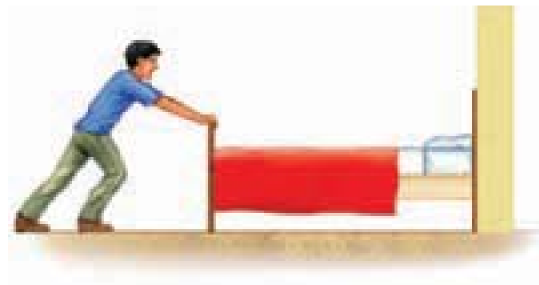
a. Describe what happens to her velocity as she opens the parachute.

b. Describe the sky diver's velocity from when her parachute has been open for a time until she is about to land.

46. If your textbook is in equilibrium, what can you say about the forces acting on it? (4.2)

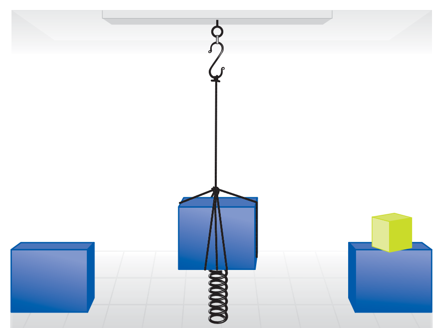
47. A rock is dropped from a bridge into a valley. Earth pulls on the rock and accelerates it downward. According to Newton's third law, the rock must also be pulling on Earth, yet Earth does not seem to accelerate. Explain. (4.3)

48. Ramon pushes on a bed that has been pushed against a wall, as in **Figure 4-17.** Draw a free-body diagram for the bed and identify all the forces acting on it. Make a separate list of all the forces that the bed applies to other objects. (4.3)



■ **Figure 4-17**

49. Figure 4-18 shows a block in three different situations. Rank them according to the magnitude of the normal force between the block and the surface, greatest to least. Specifically indicate any ties. (4.3)



■ **Figure 4-18**

50. Explain why the tension in a massless rope is constant throughout it. (4.3)

51. A bird sits on top of a statue of Einstein. Draw free-body diagrams for the bird and the statue. Specifically indicate any interaction pairs between the two diagrams. (4.3)

52. Baseball A slugger swings his bat and hits a baseball pitched to him. Draw free-body diagrams for the baseball and the bat at the moment of contact. Specifically indicate any interaction pairs between the two diagrams. (4.3)

Applying Concepts

53. Whiplash If you are in a car that is struck from behind, you can receive a serious neck injury called whiplash.

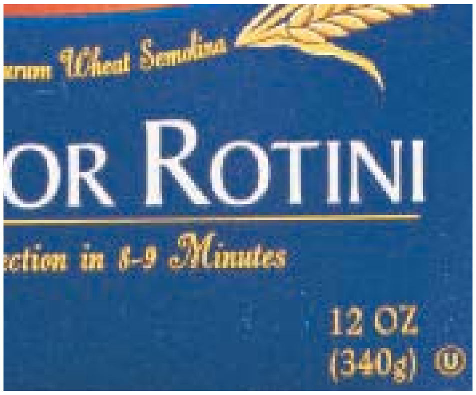
a. Using Newton's laws, explain what happens to cause such an injury.

b. How does a headrest reduce whiplash?

 For more problems, go to Additional Problems, Appendix B.

54. **Space** Should astronauts choose pencils with hard or soft lead for making notes in space? Explain.

55. When you look at the label of the product in **Figure 4-19** to get an idea of how much the box contains, does it tell you its mass, weight, or both? Would you need to make any changes to this label to make it correct for consumption on the Moon?



■ **Figure 4-19**

56. From the top of a tall building, you drop two table-tennis balls, one filled with air and the other with water. Both experience air resistance as they fall. Which ball reaches terminal velocity first? Do both hit the ground at the same time?

57. It can be said that 1 kg is equivalent to 2.21 lb. What does this statement mean? What would be the proper way of making the comparison?

58. You toss a ball straight up into the air.
   a. Draw a free-body diagram for the ball at three points during its motion: on the way up, at the very top, and on the way down. Specifically identify the forces acting on the ball and their agents.
   b. What is the velocity of the ball at the very top of the motion?
   c. What is the acceleration of the ball at this same point?

Mastering Problems

4.1 Force and Motion

59. What is the net force acting on a 1.0-kg ball in free-fall?

60. **Skating** Joyce and Efua are skating. Joyce pushes Efua, whose mass is 40.0-kg, with a force of 5.0 N. What is Efua's resulting acceleration?

61. A car of mass 2300 kg slows down at a rate of 3.0 m/s^2 when approaching a stop sign. What is the magnitude of the net force causing it to slow down?

62. **Breaking the Wishbone** After Thanksgiving, Kevin and Gamal use the turkey's wishbone to make a wish. If Kevin pulls on it with a force 0.17 N larger than the force Gamal pulls with in the opposite direction, and the wishbone has a mass of 13 g, what is the wishbone's initial acceleration?

4.2 Using Newton's Laws

63. What is your weight in newtons?

64. **Motorcycle** Your new motorcycle weighs 2450 N. What is its mass in kilograms?

65. Three objects are dropped simultaneously from the top of a tall building: a shot put, an air-filled balloon, and a basketball.
   a. Rank the objects in the order in which they will reach terminal velocity, from first to last.
   b. Rank the objects according to the order in which they will reach the ground, from first to last.
   c. What is the relationship between your answers to parts a and b?

66. What is the weight in pounds of a 100.0-N wooden shipping case?

67. You place a 7.50-kg television on a spring scale. If the scale reads 78.4 N, what is the acceleration due to gravity at that location?

68. **Drag Racing** A 873-kg (1930-lb) dragster, starting from rest, attains a speed of 26.3 m/s (58.9 mph) in 0.59 s.
   a. Find the average acceleration of the dragster during this time interval.
   b. What is the magnitude of the average net force on the dragster during this time?
   c. Assume that the driver has a mass of 68 kg. What horizontal force does the seat exert on the driver?

69. Assume that a scale is in an elevator on Earth. What force would the scale exert on a 53-kg person standing on it during the following situations?
   a. The elevator moves up at a constant speed.
   b. It slows at 2.0 m/s^2 while moving upward.
   c. It speeds up at 2.0 m/s^2 while moving downward.
   d. It moves downward at a constant speed.
   e. It slows to a stop while moving downward with a constant acceleration.

70. A grocery sack can withstand a maximum of 230 N before it rips. Will a bag holding 15 kg of groceries that is lifted from the checkout counter at an acceleration of 7.0 m/s^2 hold?

71. A 0.50-kg guinea pig is lifted up from the ground. What is the smallest force needed to lift it? Describe its resulting motion.

Aaron Haupt

72. **Astronomy** On the surface of Mercury, the gravitational acceleration is 0.38 times its value on Earth.
- **a.** What would a 6.0-kg mass weigh on Mercury?
- **b.** If the gravitational acceleration on the surface of Pluto is 0.08 times that of Mercury, what would a 7.0-kg mass weigh on Pluto?

73. A 65-kg diver jumps off of a 10.0-m tower.
- **a.** Find the diver's velocity when he hits the water.
- **b.** The diver comes to a stop 2.0 m below the surface. Find the net force exerted by the water.

74. **Car Racing** A race car has a mass of 710 kg. It starts from rest and travels 40.0 m in 3.0 s. The car is uniformly accelerated during the entire time. What net force is exerted on it?

4.3 Interaction Forces

75. A 6.0-kg block rests on top of a 7.0-kg block, which rests on a horizontal table.
- **a.** What is the force (magnitude and direction) exerted by the 7.0-kg block on the 6.0-kg block?
- **b.** What is the force (magnitude and direction) exerted by the 6.0-kg block on the 7.0-kg block?

76. **Rain** A raindrop, with mass 2.45 mg, falls to the ground. As it is falling, what magnitude of force does it exert on Earth?

77. A 90.0-kg man and a 55-kg man have a tug-of-war. The 90.0-kg man pulls on the rope such that the 55-kg man accelerates at 0.025 m/s^2. What force does the rope exert on the 90.0-kg man?

78. Male lions and human sprinters can both accelerate at about 10.0 m/s^2. If a typical lion weighs 170 kg and a typical sprinter weighs 75 kg, what is the difference in the force exerted on the ground during a race between these two species?

79. A 4500-kg helicopter accelerates upward at 2.0 m/s^2. What lift force is exerted by the air on the propellers?

80. Three blocks are stacked on top of one another, as in **Figure 4-20.** The top block has a mass of 4.6 kg, the middle one has a mass of 1.2 kg, and the bottom one has a mass of 3.7 kg. Identify and calculate any normal forces between the objects.

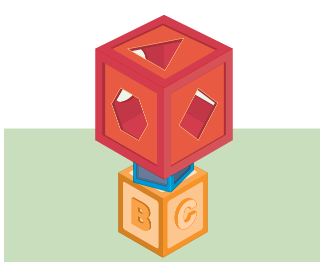


Figure 4-20

Mixed Review

81. The dragster in problem 68 completed a 402.3-m (0.2500-mi) run in 4.936 s. If the car had a constant acceleration, what was its acceleration and final velocity?

82. **Jet** A 2.75×10^6-N catapult jet plane is ready for takeoff. If the jet's engines supply a constant thrust of 6.35×10^6 N, how much runway will it need to reach its minimum takeoff speed of 285 km/h?

83. The dragster in problem 68 crossed the finish line going 126.6 m/s. Does the assumption of constant acceleration hold true? What other piece of evidence could you use to determine if the acceleration was constant?

84. Suppose a 65-kg boy and a 45-kg girl use a massless rope in a tug-of-war on an icy, resistance-free surface as in **Figure 4-21.** If the acceleration of the girl toward the boy is 3.0 m/s^2, find the magnitude of the acceleration of the boy toward the girl.

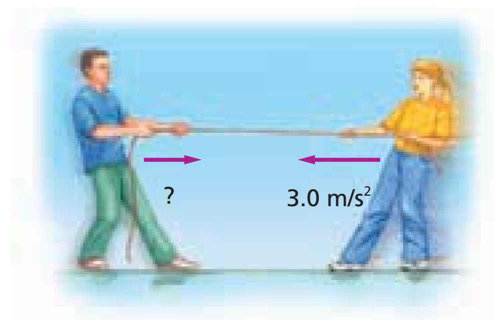


Figure 4-21

85. **Space Station** Pratish weighs 588 N and is weightless in a space station. If she pushes off the wall with a vertical acceleration of 3.00 m/s^2, determine the force exerted by the wall during her push off.

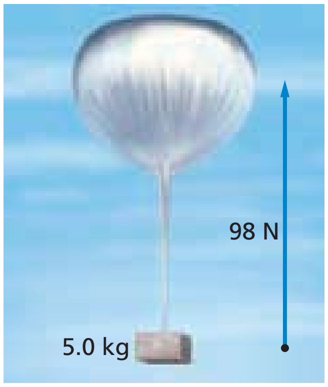
86. **Baseball** As a baseball is being caught, its speed goes from 30.0 m/s to 0.0 m/s in about 0.0050 s. The mass of the baseball is 0.145 kg.
- **a.** What is the baseball's acceleration?
- **b.** What are the magnitude and direction of the force acting on it?
- **c.** What are the magnitude and direction of the force acting on the player who caught it?

87. **Air Hockey** An air-hockey table works by pumping air through thousands of tiny holes in a table to support light pucks. This allows the pucks to move around on cushions of air with very little resistance. One of these pucks has a mass of 0.25 kg and is pushed along by a 12.0-N force for 9.0 s.
- **a.** What is the puck's acceleration?
- **b.** What is the puck's final velocity?

 For more problems, go to Additional Problems, Appendix B.

88. A student stands on a bathroom scale in an elevator at rest on the 64th floor of a building. The scale reads 836 N.
a. As the elevator moves up, the scale reading increases to 936 N. Find the acceleration of the elevator.
b. As the elevator approaches the 74th floor, the scale reading drops to 782 N. What is the acceleration of the elevator?
c. Using your results from parts a and b, explain which change in velocity, starting or stopping, takes the longer time.

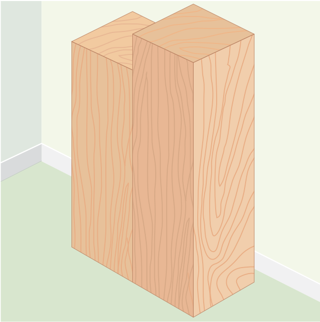
89. Weather Balloon The instruments attached to a weather balloon in **Figure 4-22** have a mass of 5.0 kg. The balloon is released and exerts an upward force of 98 N on the instruments.
a. What is the acceleration of the balloon and instruments?
b. After the balloon has accelerated for 10.0 s, the instruments are released. What is the velocity of the instruments at the moment of their release?
c. What net force acts on the instruments after their release?
d. When does the direction of the instruments' velocity first become downward?



■ **Figure 4-22**

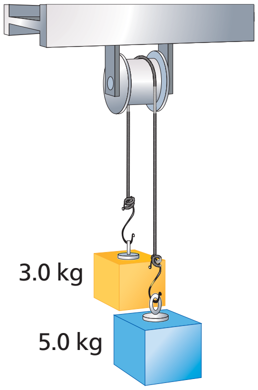
90. When a horizontal force of 4.5 N acts on a block on a resistance-free surface, it produces an acceleration of 2.5 m/s^2. Suppose a second 4.0-kg block is dropped onto the first. What is the magnitude of the acceleration of the combination if the same force continues to act? Assume that the second block does not slide on the first block.

91. Two blocks, masses 4.3 kg and 5.4 kg, are pushed across a frictionless surface by a horizontal force of 22.5 N, as shown in **Figure 4-23.**
a. What is the acceleration of the blocks?
b. What is the force of the 4.3-kg block on the 5.4-kg block?
c. What is the force of the 5.4-kg block on the 4.3-kg block?



■ **Figure 4-23**

92. Two blocks, one of mass 5.0 kg and the other of mass 3.0 kg, are tied together with a massless rope as in **Figure 4-24.** This rope is strung over a massless, resistance-free pulley. The blocks are released from rest. Find the following.
a. the tension in the rope
b. the acceleration of the blocks
Hint: you will need to solve two simultaneous equations.



■ **Figure 4-24**

Thinking Critically

93. Formulate Models A 2.0-kg mass, m_A, and a 3.0-kg mass, m_B, are connected to a lightweight cord that passes over a frictionless pulley. The pulley only changes the direction of the force exerted by the rope. The hanging masses are free to move. Choose coordinate systems for the two masses with the positive direction being up for m_A and down for m_B.
a. Create a pictorial model.
b. Create a physical model with motion and free-body diagrams.
c. What is the acceleration of the smaller mass?

94. Use Models Suppose that the masses in problem 93 are now 1.00 kg and 4.00 kg. Find the acceleration of the larger mass.

95. Infer The force exerted on a 0.145-kg baseball by a bat changes from 0.0 N to 1.0×10^4 N in 0.0010 s, then drops back to zero in the same amount of time. The baseball was going toward the bat at 25 m/s.

a. Draw a graph of force versus time. What is the average force exerted on the ball by the bat?

b. What is the acceleration of the ball?

c. What is the final velocity of the ball, assuming that it reverses direction?

96. Observe and Infer Three blocks that are connected by massless strings are pulled along a frictionless surface by a horizontal force, as shown in **Figure 4-25.**

a. What is the acceleration of each block?

b. What are the tension forces in each of the strings?

Hint: Draw a separate free-body diagram for each block.

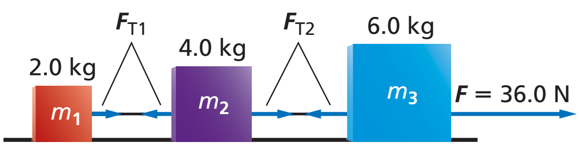


Figure 4-25

97. Critique Using the Example Problems in this chapter as models, write a solution to the following problem. A block of mass 3.46 kg is suspended from two vertical ropes attached to the ceiling. What is the tension in each rope?

98. Think Critically Because of your physics knowledge, you are serving as a scientific consultant for a new science-fiction TV series about space exploration. In episode 3, the heroine, Misty Moonglow, has been asked to be the first person to ride in a new interplanetary transport for use in our solar system. She wants to be sure that the transport actually takes her to the planet she is supposed to be going to, so she needs to take a testing device along with her to measure the force of gravity when she arrives. The script writers don't want her to just drop an object, because it will be hard to depict different accelerations of falling objects on TV. They think they'd like something involving a scale. It is your job to design a quick experiment Misty can conduct involving a scale to determine which planet in our solar system she has arrived on. Describe the experiment and include what the results would be for Pluto (g = 0.30 m/s^2), which is where she is supposed to go, and Mercury (g = 3.70 m/s^2), which is where she actually ends up.

99. Apply Concepts Develop a CBL lab, using a motion detector, that graphs the distance a free-falling object moves over equal intervals of time. Also graph velocity versus time. Compare and contrast your graphs. Using your velocity graph, determine the acceleration. Does it equal g?

Writing in Physics

100. Research Newton's contributions to physics and write a one-page summary. Do you think his three laws of motion were his greatest accomplishments? Explain why or why not.

101. Review, analyze, and critique Newton's first law. Can we prove this law? Explain. Be sure to consider the role of resistance.

102. Physicists classify all forces into four fundamental categories: gravitational, electromagnetic, strong nuclear, and weak nuclear. Investigate these four forces and describe the situations in which they are found.

Cumulative Review

103. Cross-Country Skiing Your friend is training for a cross-country skiing race, and you and some other friends have agreed to provide him with food and water along his training route. It is a bitterly cold day, so none of you wants to wait outside longer than you have to. Taro, whose house is the stop before yours, calls you at 8:25 A.M. to tell you that the skier just passed his house and is planning to move at an average speed of 8.0 km/h. If it is 5.2 km from Taro's house to yours, when should you expect the skier to pass your house? (Chapter 2)

104. Figure 4-26 is a position-time graph of the motion of two cars on a road. (Chapter 3)

a. At what time(s) does one car pass the other?

b. Which car is moving faster at 7.0 s?

c. At what time(s) do the cars have the same velocity?

d. Over what time interval is car B speeding up all the time?

e. Over what time interval is car B slowing down all the time?

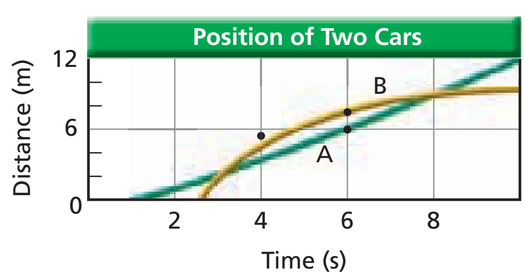


Figure 4-26

105. Refer to Figure 4-26 to find the instantaneous speed for the following: (Chapter 3)

a. car B at 2.0 s

b. car B at 9.0 s

c. car A at 2.0 s

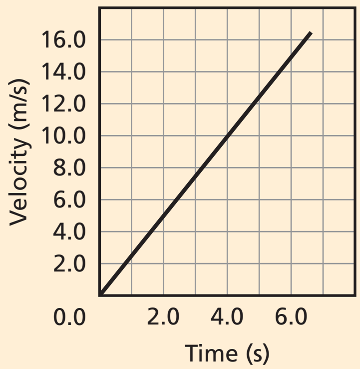
 For more problems, go to Additional Problems, Appendix B.

Standardized Test Practice

Multiple Choice

1. What is the acceleration of the car described by the graph below?

- (A) 0.20 m/s^2
- (B) 0.40 m/s^2
- (C) 1.0 m/s^2
- (D) 2.5 m/s^2



2. What distance will the car described by the above graph have traveled after 4.0 s?

- (A) 13 m
- (B) 40 m
- (C) 80 m
- (D) 90 m

3. If the car in the above graph maintains a constant acceleration, what will its velocity be after 10 s?

- (A) 10 km/h
- (B) 25 km/h
- (C) 90 km/h
- (D) 120 km/h

4. In a tug-of-war, 13 children, with an average mass of 30 kg each, pull westward on a rope with an average force of 150 N per child. Five parents, with an average mass of 60 kg each, pull eastward on the other end of the rope with an average force of 475 N per adult. Assuming that the whole mass accelerates together as a single entity, what is the acceleration of the system?

- (A) 0.62 m/s^2 E
- (B) 2.8 m/s^2 W
- (C) 3.4 m/s^2 E
- (D) 6.3 m/s^2 W

5. What is the weight of a 225-kg space probe on the Moon? The acceleration of gravity on the Moon is 1.62 m/s^2.

- (A) 139 N
- (B) 364 N
- (C) 1.35×10^3 N
- (D) 2.21×10^3 N

6. A 45-kg child sits on a 3.2-kg tire swing. What is the tension in the rope that hangs from a tree branch?

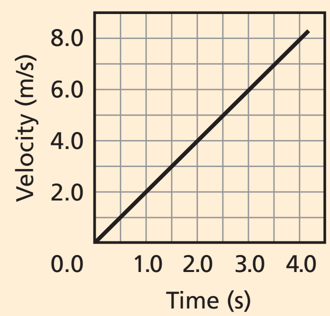
- (A) 310 N
- (B) 4.4×10^2 N
- (C) 4.5×10^2 N
- (D) 4.7×10^2 N

7. The tree branch in problem 6 sags and the child's feet rest on the ground. If the tension in the rope is reduced to 220 N, what is the value of the normal force being exerted on the child's feet?

- (A) 2.2×10^2 N
- (B) 2.5×10^2 N
- (C) 4.3×10^2 N
- (D) 6.9×10^2 N

8. According the graph below, what is the force being exerted on the 16-kg cart?

- (A) 4 N
- (B) 8 N
- (C) 16 N
- (D) 32 N



Extended Answer

9. Draw a free-body diagram of a dog sitting on a scale in an elevator. Using words and mathematical formulas, describe what happens to the apparent weight of the dog when: the elevator accelerates upward, the elevator travels at a constant speed downward, and the elevator falls freely downward.

Test-Taking TIP

Maximize Your Score

If possible, find out how your standardized test will be scored. In order to do your best, you need to know if there is a penalty for guessing, and if so, what the penalty is. If there is no random-guessing penalty at all, you should always fill in an answer, even if you have not read the question.