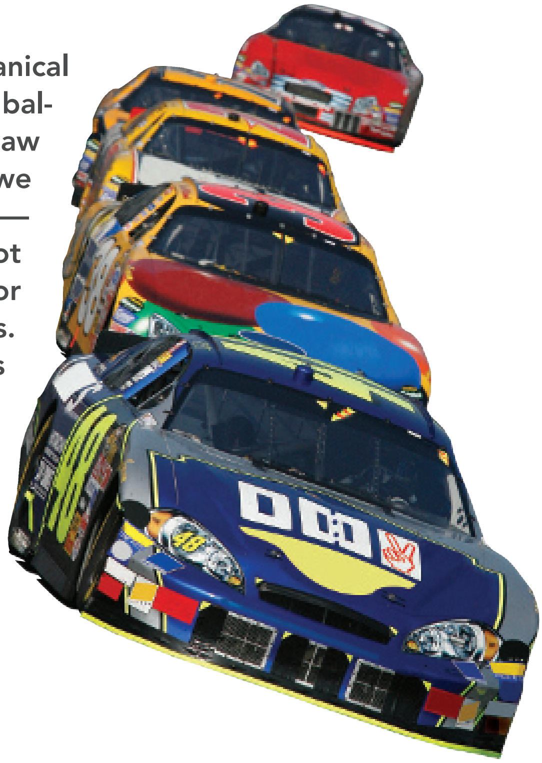
6 NEWTON'S SECOND LAW OF MOTION—FORCE AND ACCELERATION

THE BIG IDEA An object accelerates when a net force acts on it.



In Chapter 2, we discussed the concept of mechanical equilibrium, $\Sigma F = 0$, which means that forces are balanced. In Chapter 3, we extended this idea to the law of inertia, again with balanced forces. In this chapter we consider what happens when forces aren't balanced—when the net force is *not* zero—when an object is not in equilibrium. The net force on a kicked football, for example, is greater than zero, and the ball accelerates. Its path through the air is not a straight line but curves downward due to gravity—again an acceleration. Most of the motion we see undergoes change. This chapter covers *changes* in motion—accelerated motion.

We learned that acceleration describes how quickly velocity changes. Specifically, it is the change in velocity per unit of time. Recall the definition of acceleration:

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time interval}}$$

We will now focus on the *cause* of acceleration: *force*.

discover!

What Effect Does Air Resistance Have on Falling Objects?

1. Use a stopwatch to determine the time required for a single coffee filter to fall one meter.
2. Determine the time required for four coffee filters nested inside one another to fall two meters.
3. Determine the time required for nine nested filters to fall a distance of three meters.
4. If possible, measure the time of fall for sixteen nested filters dropped from a height of four meters.

Analyze and Conclude

1. **Observing** What did you observe about the motion of a single filter as it fell? Did it appear to accelerate or did it move with a constant velocity? How did the time of fall compare for each of the four trials?
2. **Predicting** How long do you think it would take for twenty-five nested coffee filters to fall through a distance of five meters?
3. **Making Generalizations** What determines the speed of similarly shaped objects falling under the influence of gravity and air resistance?

6.1 Force Causes Acceleration

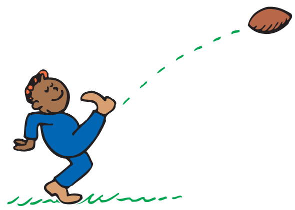


FIGURE 6.1 ▲
Kick a football and it neither remains at rest nor moves in a straight line.

Consider an object at rest, such as a hockey puck on perfectly smooth ice. The forces on it (gravity and the support force) are balanced, so the puck is in equilibrium. Hit the puck (that is, apply an unbalanced force to it) and the puck experiences a change in motion—it accelerates. When the hockey stick is no longer pushing it, there are no unbalanced forces and the puck moves at constant velocity. Apply another force by striking the puck again, and the puck's motion changes again. **Unbalanced forces acting on an object cause the object to accelerate.**

Most often, the force we apply is not the only force acting on an object. For example, after the boy kicks the football in Figure 6.1, both gravity and air resistance act on the football. Recall from the previous chapter that the combination of forces acting on an object is the *net force*. Acceleration depends on the *net force*. To increase the acceleration of an object, you must increase the net force acting on it. Double the force on an object and its acceleration doubles. If you triple the force, its acceleration triples. We say an object's acceleration is directly proportional to the net force acting on it. We write

$$\text{acceleration} \sim \text{net force}$$

The symbol ~ stands for "is directly proportional to."

CONCEPT CHECK What causes an object to accelerate?

6.2 Mass Resists Acceleration

FIGURE 6.2 ▲
The acceleration produced depends on the mass that is pushed.

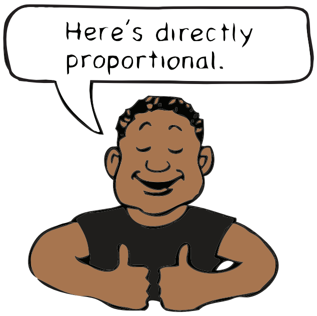
Push on an empty shopping cart. Then push equally hard on a heavily loaded shopping cart, as shown in Figure 6.2. The loaded shopping cart will accelerate much less than the empty cart. Acceleration depends on the mass being pushed. **For a constant force, an increase in the mass will result in a decrease in the acceleration.** The same force applied to twice as much mass results in only half the acceleration. For three times the mass, one-third the acceleration results. In other words, for a given force, the acceleration produced is *inversely proportional* to the mass. This relationship can be written as an equation:

$$\text{acceleration} \sim \frac{1}{\text{mass}}$$

Inversely means that the two values change in opposite directions. Mathematically we see that as the denominator increases, the whole quantity decreases by the same factor.

CONCEPT CHECK How does an increase in mass affect acceleration?

6.3 Newton's Second Law



Newton was the first to realize that the acceleration produced when we move something depends not only on how hard we push or pull, but also on the object's mass. He came up with one of the most important rules of nature ever proposed, his second law of motion. **Newton's second law** describes the relationship among an object's mass, an object's acceleration, and the net force on an object. **Newton's second law states that the acceleration produced by a net force on an object is directly proportional to the magnitude of the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object.**

This relationship can be written as an equation:

$$\text{acceleration} \sim \frac{\text{net force}}{\text{mass}}$$

By using consistent units, such as newtons (N) for force, kilograms (kg) for mass, and meters per second squared (m/s^2) for acceleration, we get the exact equation

$$\text{acceleration} = \frac{\text{net force}}{\text{mass}}$$

In briefest form, where a is acceleration, F is net force, and m is mass,

$$a = \frac{F}{m}$$

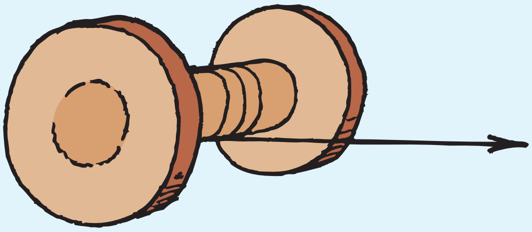
The acceleration is equal to the net force divided by the mass. From this relationship we see that doubling the net force acting on an object doubles its acceleration. Suppose instead that the mass is doubled. Then acceleration will be halved. If both the net force and the mass are doubled, the acceleration will be unchanged.

CONCEPT CHECK **What is the relationship among an object's mass, an object's acceleration, and the net force on an object?**

discover!

Acceleration, Which Way?

1. Pull a spool of thread horizontally to the right by the thread. The thread should be at the bottom of the spool. Which direction does the spool roll?
2. Repeat step one with the thread at the top of the spool. Which direction does the spool roll?
3. Are the net force on an object and an object's acceleration always in the same direction? Why?



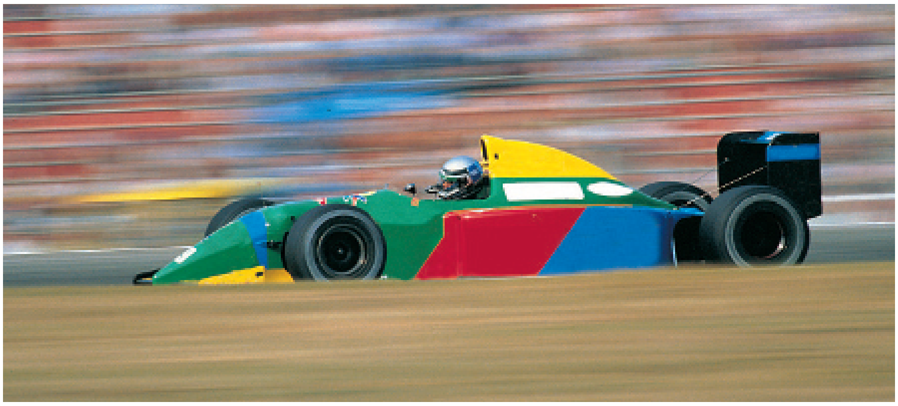


FIGURE 6.3 ▲
The great acceleration of the racing car is due to its ability to produce large forces.

think!

If a car can accelerate at 2 m/s^2, what acceleration can it attain if it is towing another car of equal mass?
Answer: 6.3

do the math!

A car has a mass of 1000 kg. What is the acceleration produced by a force of 2000 N?

You can use Newton's second law to solve for the car's acceleration.

$$a = \frac{F}{m} = \frac{2000\text{ N}}{1000\text{ kg}} = \frac{2000\text{ kg}\cdot\text{m/s}^2}{1000\text{ kg}} = 2\text{ m/s}^2$$

If the force is 4000 N, what is the acceleration?

$$a = \frac{F}{m} = \frac{4000\text{ N}}{1000\text{ kg}} = \frac{4000\text{ kg}\cdot\text{m/s}^2}{1000\text{ kg}} = 4\text{ m/s}^2$$

Doubling the force on the same mass simply doubles the acceleration.

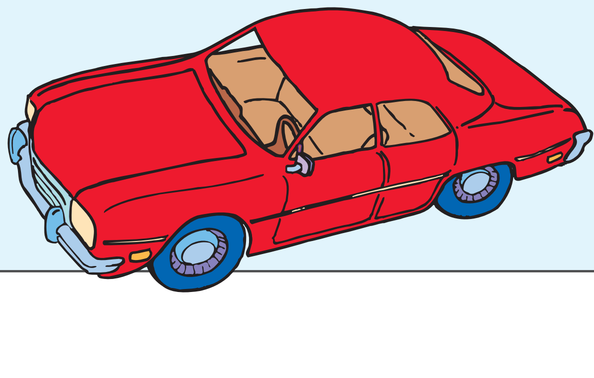
Physics problems are often more complicated than these. We don't focus on solving complicated problems in this book. Instead we emphasize equations as guides to thinking about the relationships of basic physics concepts. The Plug and Chug problems at the ends of many chapters familiarize you with equations, and the Think and Solve problems go a step or two further for more challenge. Solving problems is an important skill in physics. But first, learn the concepts! Then problem solving will be more meaningful.

How much force, or thrust, must a 30,000-kg jet plane develop to achieve an acceleration of 1.5 m/s^2?

If you know the mass of an object in kilograms (kg) and its acceleration in meters per second (m/s^2), then the force will be expressed in newtons (N). One newton is the force needed to give a mass of one kilogram an acceleration of one meter per second squared. You can arrange Newton's second law to read

$$\begin{aligned} \text{force} &= \text{mass} \times \text{acceleration} \\ F &= ma \\ &= (30{,}000\text{ kg})(1.5\text{ m/s}^2) \\ &= 45{,}000\text{ kg}\cdot\text{m/s}^2 \\ &= 45{,}000\text{ N} \end{aligned}$$

The dot between kg and m/s^2 means that the units are multiplied together.



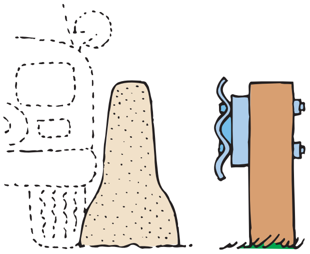


FIGURE 6.4 ▲
A concrete road divider has a better design than a steel road divider for slowing an out-of-control, sideswiping car.

6.4 Friction

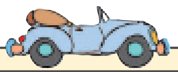
Friction is a force like any other force and affects motion. Friction acts on materials that are in contact with each other, and it always acts in a direction to oppose relative motion. When two solid objects come into contact, the friction is mainly due to irregularities in the two surfaces. When one object slides against another, it must either rise over the irregular bumps or else scrape them off. Either way requires force.

The force of friction between the surfaces depends on the kinds of material in contact and how much the surfaces are pressed together. For example, rubber against concrete produces more friction than steel against steel. That's why concrete road dividers have replaced steel rails. The friction produced by a tire rubbing against the concrete is more effective in slowing the car than the friction produced by a steel car body sliding against a steel rail. Notice in Figure 6.4 that the concrete divider is wider at the bottom to ensure that the tire of a sideswiping car will make contact with the divider before the steel car body does.

Friction is not restricted to solids sliding or tending to slide over one another. Friction also occurs in liquids and gases. Both liquids and gases are called **fluids** because they flow. Fluid friction occurs as an object pushes aside the fluid it is moving through. Have you ever tried running a 100-m dash through waist-deep water? The friction of liquids is appreciable, even at low speeds. **Air resistance** is the friction acting on something moving through air. Air resistance is a very common form of fluid friction. You usually don't notice air resistance when walking or jogging, but you do notice it at the higher speeds that occur when riding a bicycle or skiing downhill.

think!

Two forces act on a book resting on a table: its weight and the support force from the table. Does a force of friction act as well?
Answer: 6.4



Link to TECHNOLOGY

Automobile Design The first automobiles were little more than horse carriages with engines. Over time, engineers came to realize that by reducing the frontal surface of cars and eliminating parts that stick out, the air resistance force on a car could be reduced. When a car cruises at a constant speed, the net force on the car is zero. By lowering the air resistance force at any speed, the amount of force needed by the engine is reduced, meaning better fuel economy. Over the years, cars have gotten sleeker, with teardrop-shaped bodies, and teardrop shapes around side mirrors. Door handles are set into the doors. Even wheel wells and the undersides of cars have been smoothed. Automotive engineers use computers to design cars with less air resistance and use wind tunnels to measure the cars' air resistance.

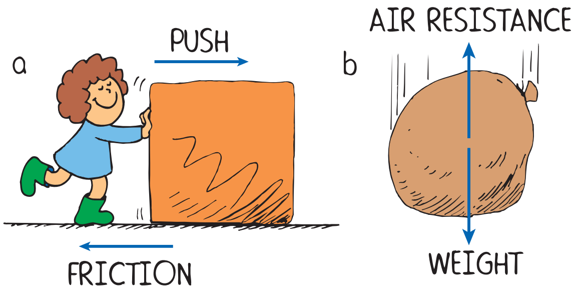


FIGURE 6.5 The direction of the force of friction always opposes the direction of motion. **a.** Push the crate to the right and friction acts toward the left. **b.** The sack falls downward and air friction acts upward.

When friction is present, an object may move with a constant velocity even when an outside force is applied to it. In such a case, the friction force just balances the applied force. The net force is zero, so there is no acceleration. For example, in Figure 6.5 the crate moves with a constant velocity when the force pushing it just balances the force of friction. The sack will also fall with a constant velocity once the force due to air resistance balances the sack's weight. A diagram showing all the forces acting on an object is called a **free-body diagram.**

CONCEPT CHECK What factors affect the force of friction between surfaces?

6.5 Applying Force—Pressure

Look at Figure 6.6. No matter how you place a book on a table, the force of the book on the table is the same. You can check this by placing a book in any position on a bathroom scale. You'll read the same weight in all cases. Balance a book in different positions on the palm of your hand. Although the force is always the same, you'll notice differences in the way the book presses against your palm. These differences are due to differences in the area of contact for each case. **For a constant force, an increase in the area of contact will result in a decrease in the pressure.** The amount of force *per unit of area* is called **pressure.** More precisely, when the force is perpendicular to the surface area,

$$\text{pressure} = \frac{\text{force}}{\text{area of application}}$$

In equation form,

$$P = \frac{F}{A}$$

where P is the pressure and A is the area over which the force acts. Force, which is measured in newtons, is different from pressure. Pressure is measured in newtons per square meter, or **pascals** (Pa). One newton per square meter is equal to one pascal.

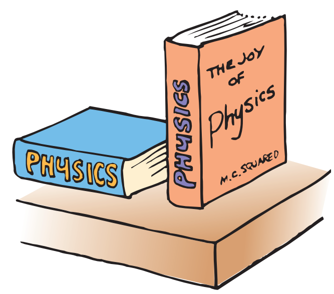


FIGURE 6.6 The upright book exerts the same force, but greater pressure, against the supporting surface.

FIGURE 6.7 ▲
The author applies a force to fellow physics teacher Paul Robinson, who is bravely sandwiched between beds of sharp nails. The driving force per nail is not enough to puncture the skin.
CAUTION: Do not attempt this on your own!

You exert more pressure against the ground when you stand on one foot than when you stand on both feet. This is due to the decreased area of contact. Stand on one toe like a ballerina and the pressure is huge. The smaller the area supporting a given force, the greater the pressure on that surface.

You can calculate the pressure you exert on the ground when you are standing. One way is to moisten the bottom of your foot with water and step on a clean sheet of graph paper. Count the number of squares on the graph paper contained within your footprint. Divide your weight by this area and you have the average pressure you exert on the ground when standing on one foot. How will this pressure compare with the pressure you exert when you stand on two feet?

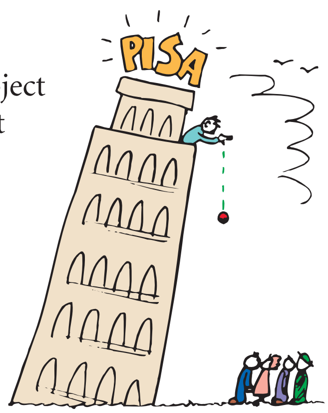
A dramatic illustration of pressure is shown in Figure 6.7. The author applies appreciable force when he breaks the cement block with the sledgehammer. Yet his friend (the author of the lab manual) sandwiched between two beds of sharp nails is unharmed. The friend is unharmed because much of the force is distributed over the more than 200 nails that make contact with his body. The combined surface area of this many nails results in a tolerable pressure that does not puncture the skin. **CAUTION:** *This demonstration is quite dangerous. Do not attempt it on your own.*

think!

In attempting to do the demonstration shown in Figure 6.7, would it be wise to begin with a few nails and work upward to more nails?
Answer: 6.5

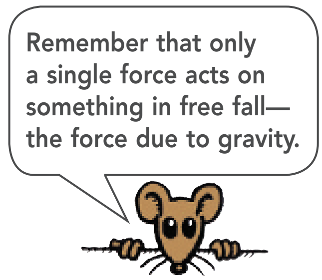
CONCEPT CHECK **How does the area of contact affect the pressure a force exerts on an object?**

6.6 Free Fall Explained



◀ **FIGURE 6.8**
In Galileo's famous demonstration, a 10-kg cannonball and a 1-kg stone strike the ground at practically the same time.

Recall that free fall occurs when a falling object encounters no air resistance. Also recall that Galileo showed that falling objects accelerate equally, regardless of their masses. This is *strictly* true if air resistance is negligible, that is, if the objects are in free fall. It is *approximately* true when air resistance is very small compared with the mass of the falling object. For example, a 10-kg cannonball and a 1-kg stone dropped from an elevated position at the same time will fall together and strike the ground at practically the same time. This experiment, said to be done by Galileo from the Leaning Tower of Pisa and shown in Figure 6.8, demolished the Aristotelian idea that an object that weighs ten times as much as another should fall ten times faster than the lighter object. Galileo's experiment and many others that showed the same result were convincing. But Galileo couldn't say *why* the accelerations were equal. The explanation is a straightforward application of Newton's second law and is the topic of the cartoon "Backyard Physics." Let's treat it separately here.



Recall that mass (a quantity of matter) and weight (the force due to gravity) are proportional. A 2-kg bag of nails weighs twice as much as a 1-kg bag of nails. So a 10-kg cannonball experiences 10 times as much gravitational force (weight) as a 1-kg stone. The followers of Aristotle believed that the cannonball should accelerate at a rate ten times that of the stone, because they considered only the cannonball's ten-times-greater weight. However, Newton's second law tells us to consider the mass as well. A little thought will show that ten times as much force acting on ten times as much mass produces the same acceleration as the smaller force acting on the smaller mass. In symbolic notation,

$$\frac{\scriptstyle F}{\scriptstyle m} = \frac{F}{m}$$

where F stands for the force (weight) acting on the cannonball, and m stands for the correspondingly large mass of the cannonball. The small $\scriptstyle F$ and $\scriptstyle m$ stand for the smaller weight and smaller mass of the stone. As Figure 6.9 shows, the *ratio* of weight to mass is the same for these or any objects. All freely falling objects undergo the same acceleration at the same place on Earth. In Chapter 4 we introduced the symbol g for the acceleration.

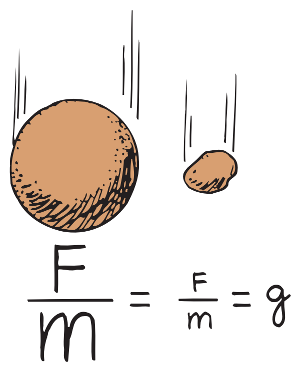
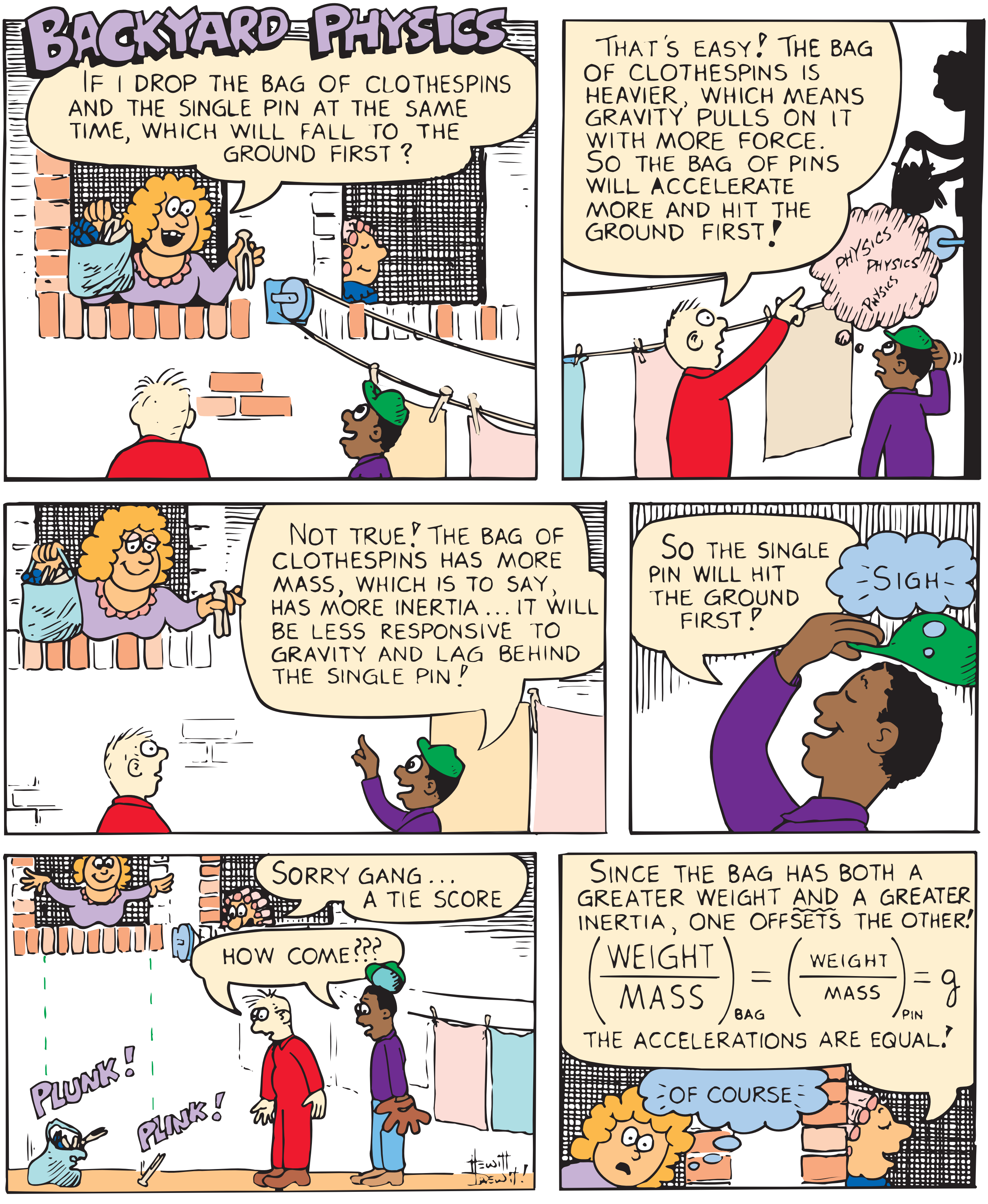


FIGURE 6.9 ▲
The ratio of weight (F) to mass (m) is the same for the 10-kg cannonball and the 1-kg stone.


BACKYARD PHYSICS
IF I DROP THE BAG OF CLOTHESPINS AND THE SINGLE PIN AT THE SAME TIME, WHICH WILL FALL TO THE GROUND FIRST?
THAT'S EASY! THE BAG OF CLOTHESPINS IS HEAVIER, WHICH MEANS GRAVITY PULLS ON IT WITH MORE FORCE. SO THE BAG OF PINS WILL ACCELERATE MORE AND HIT THE GROUND FIRST!
PHYSICS PHYSICS PHYSICS
NOT TRUE! THE BAG OF CLOTHESPINS HAS MORE MASS, WHICH IS TO SAY, HAS MORE INERTIA ... IT WILL BE LESS RESPONSIVE TO GRAVITY AND LAG BEHIND THE SINGLE PIN!
SO THE SINGLE PIN WILL HIT THE GROUND FIRST!
SIGH
SORRY GANG ... A TIE SCORE
HOW COME???
PLUNK!
PLINK!
SINCE THE BAG HAS BOTH A GREATER WEIGHT AND A GREATER INERTIA, ONE OFFSETS THE OTHER!
(WEIGHT / MASS) BAG = (WEIGHT / MASS) PIN = g
THE ACCELERATIONS ARE EQUAL!
OF COURSE
Hewitt

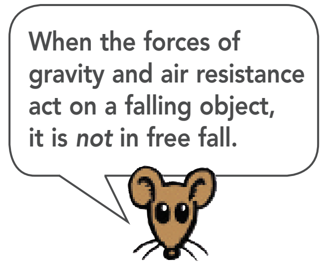
We can show the same result with numerical values. The weight of a 1-kg stone is 10 N at Earth's surface. The weight of a 10-kg cannonball is 100 N at Earth's surface. The force acting on a falling object is the force due to gravity—the object's weight. Using Newton's second law, the acceleration of the stone is

$$a = \frac{F}{m} = \frac{\text{weight}}{m} = \frac{10\text{ N}}{1\text{ kg}} = \frac{10\text{ kg}\cdot\text{m/s}^2}{1\text{ kg}} = 10\text{ m/s}^2 = g$$

and the acceleration of the cannonball is

$$a = \frac{F}{m} = \frac{\text{weight}}{m} = \frac{100\text{ N}}{10\text{ kg}} = \frac{100\text{ kg}\cdot\text{m/s}^2}{10\text{ kg}} = 10\text{ m/s}^2 = g$$

In the famous coin-and-feather-in-a-vacuum-tube demonstration discussed in Chapter 4, the reason for the equal accelerations was not discussed. Now we know why the acceleration of the coin and the feather are the same. ✓ **All freely falling objects fall with the same acceleration because the net force on an object is only its weight, and the ratio of weight to mass is the same for all objects.**



CONCEPT CHECK Why do all freely falling objects fall with the same acceleration?

6.7 Falling and Air Resistance

The feather and coin fall with equal accelerations in a vacuum, but very unequally in the presence of air. When falling in air, the coin falls quickly while the feather flutters to the ground. The force due to air resistance diminishes the net force acting on the falling objects.

Go Online SCI LINKS NSTA
For: Links on Air-Resistance
Visit: www.SciLinks.org
Web Code: csn – 0607

Speed and Area The force due to air resistance is experienced when you stick your hand out of the window of a moving car. If the car moves faster, the force on your hand increases, indicating that air resistance force depends on speed. If instead of just your hand, you hold your physics book out the window with the large side facing forward, exposing maximum frontal area for the book, the air resistance force is much larger than it was on your hand at the same speed. You find that the force of air resistance is also proportional to the frontal area of the moving object. ✓ **The air resistance force an object experiences depends on the object's speed and area.** An expression describes the relationship between speed, area, and air resistance:

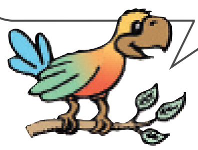
$$\text{Air resistance force} \sim \text{speed} \times \text{frontal area}$$

The expression shows that the air resistance force is directly proportional to the speed and frontal area of an object.

think!
Which experiences a greater air resistance force, a falling piece of paper or a falling elephant?
Answer: 6.7.1

FIGURE 6.10 ▶
Sky divers reach terminal speed when air resistance equals weight.

It's important to emphasize that zero acceleration does not mean zero velocity. Zero acceleration means that the object will maintain the velocity it happens to have, neither speeding up nor slowing down nor changing direction.

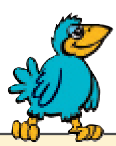


Terminal Speed When the air resistance force on a falling object, like the sky divers shown in Figure 6.10, builds up to the point where it equals the weight of the object, then the net force on the object is zero and the object stops accelerating. We say that the object has reached its terminal speed. **Terminal speed** is the speed at which the acceleration of a falling object is zero because friction balances the weight. If we are concerned with direction, which is down for falling objects, we say it has reached its terminal velocity. **Terminal velocity** is terminal speed together with the direction of motion.

A falling feather reaches its terminal speed quite quickly. Its area is large relative to its very small weight. Even at small speeds the air resistance has a large effect on the feather's motion. A coin, however, has a relatively small area compared to its weight, so the coin will have to fall faster than a feather to reach its terminal speed.

The terminal speed for a sky diver varies from about 150 to 200 km/h, depending on the weight and orientation of the body. A heavier person will attain a greater terminal speed than a lighter person. The greater weight is more effective in "plowing through" air. Body orientation also makes a difference. More air is encountered when the body is spread out and surface area is increased, like that of the flying squirrel in Figure 6.11.

FIGURE 6.11 ▲
The flying squirrel increases its area by spreading out. This increases air resistance and decreases the speed of its fall.



Link to LIFE SCIENCE

Terminal Velocity Skydivers and flying squirrels are not alone in increasing their surface areas when falling. When the paradise tree snake (Chysopelea paradisi) jumps from a tree branch it doubles its width by flattening itself. It acquires a slightly concave shape and maneuvers itself by undulating in a graceful S-shape, traveling more than 20 meters in a single leap.

discover!

How Does Air Resistance Affect the Motion of Falling Objects?

1. Drop a sheet of paper and a book side-by-side at the same time. Does either of them hit the ground first, or do they land at the same time?
2. Place the piece of paper against the bottom surface of the horizontally held book. Drop them at the same time. Does either of them hit the ground first, or do they land at the same time?
3. Repeat Step 2 with the piece of paper on top of the book.
4. **Think** Explain the effect of air resistance on the motion of the piece of paper and the book in Steps 1–3.

Terminal speed can be controlled by variations in body orientation. A heavy sky diver and a light sky diver can remain in close proximity to each other if the heavy person spreads out like a flying squirrel while the light person falls head or feet first. A parachute greatly increases air resistance, and cuts the terminal speed down to 15 to 25 km/h, slow enough for a safe landing.

If you hold a baseball and tennis ball at arm's length and release them at the same time, you'll see them strike the floor at the same time. But if you drop them from the top of a building, you'll notice the heavier baseball strikes the ground first. This is due to the buildup of air resistance at higher speeds. At low speeds, air resistance is often negligible, but at high speeds, it can make quite a difference. The effect of air resistance is more pronounced on the lighter tennis ball than on the heavier baseball, so the acceleration of the fall is less for the tennis ball. The tennis ball behaves more like a parachute than the baseball does. Figure 6.12 shows that a golf ball has a greater acceleration falling in air than a foam ball.

When Galileo reportedly dropped the objects of different weights from the Leaning Tower of Pisa, the heavier object *did* get to the ground first. However, the time difference was only a split second, rather than the pronounced time difference expected by the followers of Aristotle. The behavior of falling objects was never really understood until Newton announced his second law of motion.

Isaac Newton truly changed our way of seeing the world by showing how concepts connect to one another. The connection between acceleration, force, and mass, discovered by Newton in the 1600s, led to men landing on the moon in the 1900s. Newton's second law was primarily responsible for this feat.

CONCEPT CHECK **What factors determine the air resistance force on an object?**

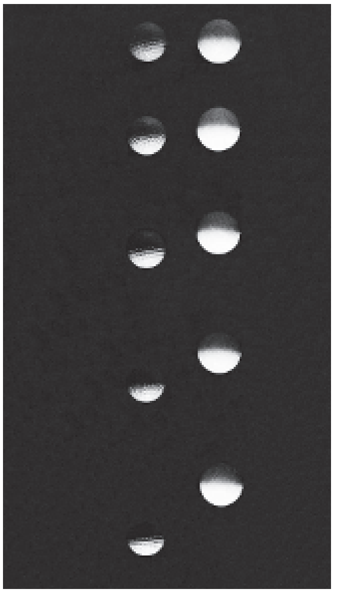


FIGURE 6.12 ▲
This stroboscopic photo shows a golf ball and a foam ball falling in air. The heavier golf ball is more effective in overcoming air resistance, so its acceleration is greater.

think!

If a heavy person and a light person open their parachutes together at the same altitude and each wears the same size parachute, who will reach the ground first?
Answer: 6.7.2

6 REVIEW

Go Online PHSchool.com
For: Self-Assessment
Visit: PHSchool.com
Web Code: csa – 0600

Concept Summary

- Unbalanced forces acting on an object cause the object to accelerate.
- For a constant force, an increase in the mass will result in a decrease in the acceleration.
- Newton's second law states that the acceleration produced by a net force on an object is directly proportional to the magnitude of the net force, is in the same direction as the net force, and is inversely proportional to the mass of the object.
- The force of friction between two surfaces depends on the kinds of material in contact and how much the surfaces are pressed together.
- For a constant force, an increase in the area of contact will result in a decrease in the pressure.
- All freely falling objects fall with the same acceleration because the net force on an object is only its weight, and the ratio of weight to mass is the same for all objects.
- The air resistance force on an object depends on the object's speed and area.

Key Terms

inversely *(p. 87)*
Newton's second law *(p. 88)*
fluid *(p. 90)*
air resistance *(p. 90)*
free-body diagram *(p. 91)*
pressure *(p. 91)*
pascal *(p. 91)*
terminal speed *(p. 96)*
terminal velocity *(p. 96)*

think! Answers

6.3 The same force on twice the mass produces half the acceleration, or 1 m/s^2.

6.4 No, not unless the book tends to slide or does slide across the table. For example, if it is pushed toward the left by another force, then friction between the book and table will act toward the right. Friction forces occur only when an object tends to slide or is sliding. (More about this in the Concept-Development Practice Book.)

6.5 No, no, no! There would be one less physics teacher if the demonstration were performed with fewer nails. The resulting greater pressure would cause harm.

6.7.1 The elephant! It has a greater frontal area and falls faster than a piece of paper—both of which mean the elephant pushes more air molecules out of the way. The effect of the air resistance force on each, however, is another story!

6.7.2 The heavy person will reach the ground first. Like a feather, the light person reaches terminal speed sooner, while the heavy person continues to accelerate until a greater terminal speed is reached. The heavy person moves ahead of the light person, and the separation continues to increase as they descend.

6 ASSESS

Check Concepts

Section 6.1

1. What produces acceleration?

2. In Chapter 4 we defined acceleration as the time rate of change of velocity. What other equation for acceleration is given in this chapter?

Section 6.2

3. Is acceleration directly proportional to mass, or is it inversely proportional to mass?

4. If two quantities are inversely proportional to each other, does that mean as one increases the other increases also?

Section 6.3

5. If the net force acting on a sliding block is tripled, what happens to the acceleration?

6. If the mass of a sliding block is tripled at the same time the net force on it is tripled, how does the resulting acceleration compare with the original acceleration?

Section 6.4

7. Motion is affected by solid objects in contact. In what other situations does friction affect motion?

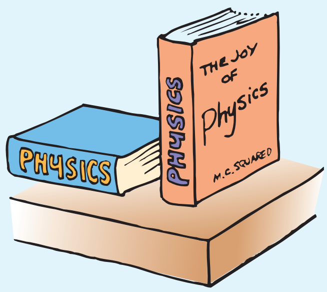
8. Suppose you exert a horizontal push on a crate that rests on a level floor, and it doesn't move. How much friction acts compared with your push?

9. How great is the air resistance that acts on a 10-N sack that falls in air at constant velocity?

Section 6.5

10. Distinguish between force and pressure.

11. When do you produce more pressure on the ground, standing or lying down?



12. Why is it important that many nails are in the boards of Figure 6.7?

Section 6.6

13. What is meant by *free fall?*

14. The ratio of circumference/diameter for all circles is π. What is the ratio of force/mass for all freely-falling bodies?

15. Why doesn't a heavy object accelerate more than a light object when both are freely falling?

6 ASSESS *(continued)*

Section 6.7

16. Does air resistance on a falling object increase or does it decrease with increasing speed?

17. If two objects of the same size fall through air at different speeds, which encounters the greater air resistance?

18. What is the acceleration of a falling object that has reached its terminal velocity?

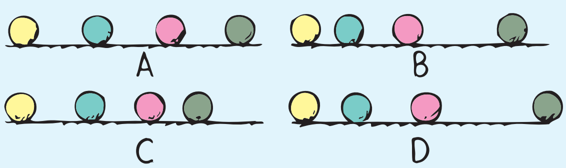
19. What, besides speed, affects the air resistance on a skydiver?

20. How much air resistance acts on a falling 100-N box of nails when it reaches terminal velocity?

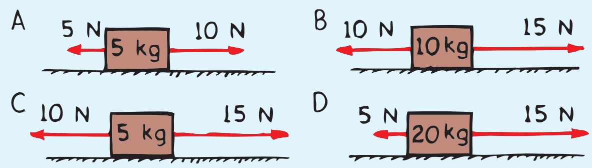
Think and Rank

Rank each of the following sets of scenarios in order of the quantity or property involved. List them from left to right. If scenarios have equal rankings, then separate them with an equal sign. (e.g., A = B)

21. Each diagram shows a ball traveling from left to right. The position of the ball each second is indicated by the second. Rank the net forces from greatest to least required to produce the motion indicated in each diagram. Right is positive and left is negative.



22. Boxes of various masses are on a friction-free level table.

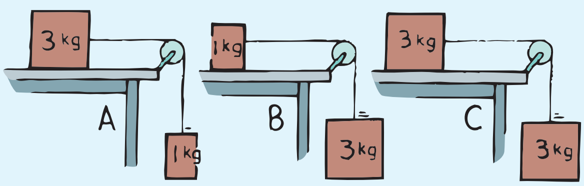


Rank each of the following from greatest to least.

a. the net forces on the boxes

b. the accelerations of the boxes

23. Each block on the friction-free lab bench is connected by a string and pulled by a second falling block.

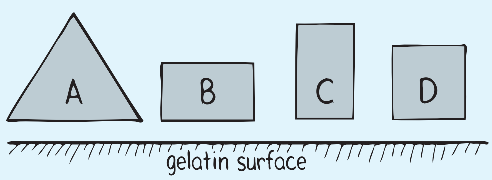


Rank each of the following from greatest to least.

a. the acceleration of the two-block systems

b. the tension in the strings

24. All the aluminum blocks have the same mass and are gently lowered onto a gelatin surface, which easily supports them. All have square bottom surfaces. Rank them by how much they dent into the surface, from greatest to least depth.



Plug and Chug

These questions are to familiarize you with the key equations of the chapter.

$$\text{Acceleration} = \frac{\text{net force}}{\text{mass}}$$

$$a = \frac{F}{m}$$

25. Calculate the acceleration of a 40-kg crate of softball gear when pulled sideways with a net force of 200 N.

26. Calculate the acceleration of a 2000-kg, single-engine airplane as it begins its takeoff with an engine thrust of 500 N.

27. Calculate the acceleration of a 300,000-kg jumbo jet just before takeoff when the thrust for each of its four engines is 30,000 N.

28. Calculate the acceleration if you push with a 20-N horizontal force against a 2-kg block on a horizontal friction-free air table.

$$F = ma$$

29. Calculate the horizontal force that must be applied to a 1-kg puck to make it accelerate on a horizontal friction-free air table with the same acceleration it would have if it were dropped and fell freely.

30. Calculate the horizontal force that must be applied to produce an acceleration of 1.8*g* for a 1.2-kg puck on a horizontal friction-free air table.

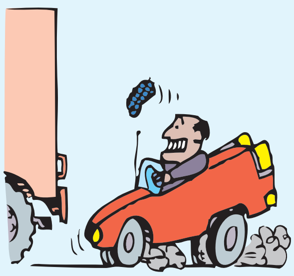
Think and Explain

31. If you push horizontally on your book with a force of 1 N to make the book slide at constant velocity, how much is the force of friction on the book?

32. Terry says that if an object has no acceleration, then no forces are exerted on it. Sherry doesn't agree, but can't provide an explanation. They both look to you. What do you say?

33. When a car is moving in reverse, backing from a driveway, the driver applies the brakes. In what direction is the car's acceleration?

34. The auto in the sketch moves forward as the brakes are applied. A bystander says that during the interval of braking, the auto's velocity and acceleration are in opposite directions. Do you agree or disagree?

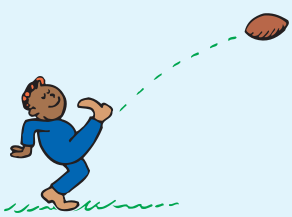


35. What is the difference between saying that one quantity is proportional to another and saying it is equal to another?

6 ASSESS (continued)

36. What is the acceleration of a rock at the top of its trajectory when thrown straight upward? Explain whether or not the answer is zero by using the equation $a = F/m$ as a guide to your thinking.

37. When blocking in football, why does a defending lineman often attempt to get his body under that of his opponent and push upward? What effect does this have on the friction force between the opposing lineman's feet and the ground?

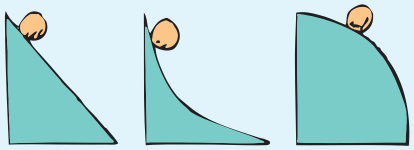


38. An aircraft gains speed during takeoff due to the constant thrust of its engines. When is the acceleration during takeoff greatest—at the beginning of the run along the runway or just before the aircraft lifts into the air? Think, then explain.

39. A rocket becomes progressively easier to accelerate as it travels through outer space. Why is this so? (*Hint*: About 90 percent of the mass of a newly launched rocket is fuel.)

40. A common saying goes, "It's not the fall that hurts you; it's the sudden stop." Translate this into Newton's laws of motion.

41. On which of these hills does the ball roll down with increasing speed and decreasing acceleration along the path? (Use this example if you wish to explain to someone the difference between speed and acceleration.)



42. Why does a sharp knife cut better than a dull knife?

43. When Helen lifts one foot and remains standing on a bathroom scale, pressure on the scale is doubled. Does the weight reading change?

44. Aristotle claimed the speed of a falling object depends on its weight. We now know that objects in free fall, whatever their weights, gain speed at the same rate. Why does weight not affect acceleration?

45. After learning why objects of different mass have the same acceleration in free fall, Erik wonders if objects tied to equal lengths of string would swing together in unison. Lisa wonders if objects of different masses would slide at equal speeds down a friction-free inclined plane. What is your thinking on these hypotheses?

46. In a vacuum, a coin and a feather fall side by side. Would it be correct to say that in a vacuum equal forces of gravity act on both the coin and the feather?

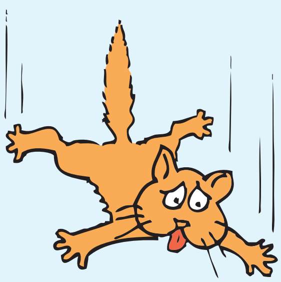
47. As a sky diver falls faster and faster through the air (before reaching terminal speed), does the net force on her increase, decrease, or remain unchanged? Does her acceleration increase, decrease, or remain unchanged? Defend your answers.

48. After she jumps, a sky diver reaches terminal speed after 10 seconds. Does she gain more speed during the first second of fall or the ninth second of fall? Compared with the first second of fall, does she fall a greater or a lesser distance during the ninth second?

49. Can you think of a reason why the acceleration of an object thrown downward through the air would actually be less than 10 m/s^2?

50. How does the weight of a falling body compare with the air resistance it encounters just before it reaches terminal velocity? Just after it reaches terminal velocity?

51. Why does a cat that falls from a 50-story building hit the safety net with no more speed than if it fell from the 20th story?



52. A regular tennis ball and another one filled with sand are dropped at the same time from the top of a high building. Your friend says that even though air resistance is present, both balls should hit the ground at the same time because they are the same size and pass through the same amount of air. What do you say?

53. If you drop an object, its acceleration toward the ground is 10 m/s^2. If you throw it downward instead, will its acceleration after throwing be greater than 10 m/s^2? Why or why not? (Ignore air resistance.)

54. Suzy Skydiver, who has mass m, steps from the basket of a high-flying balloon of mass M and does a sky dive.
   a. What is the net force on Suzy at the moment she steps from the basket?
   b. What is the net force on her when air resistance builds up to equal *half* her weight?
   c. What is the net force on her when she reaches terminal speed v?
   d. What is the net force on her after she opens her parachute and reaches a new terminal speed $0.1v$?

Think and Solve

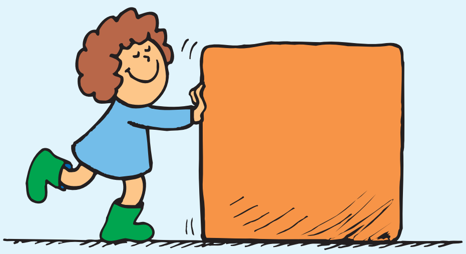
55. What is the acceleration during takeoff of a jumbo jet with a mass of 30,000 kg when the thrust for each of its *four* engines is 30,000 N?

56. A net force on a 2-kg cart accelerates the cart at 3 m/s^2. How much acceleration will the same net force produce on a 4-kg cart?

57. A net force of 10.0 N is exerted by Irene on a 6.7-kg cart for 3.0 seconds. Show that the cart will have an acceleration of 1.5 m/s^2.

58. Toby Toobad, who has a mass of 100 kg, is skateboarding at 9.0 m/s when he smacks into a brick wall and comes to a dead stop in 0.2 s. Show that his deceleration is 45 m/s^2 (that's 4.5 times *g*—ouch!).

59. A net force of 10.0 N on a box of plastic foam causes it to accelerate at 2.0 m/s^2. Show that the mass of the box is 5.0 kg.



60. Austin's truck has a mass of 2000 kg. When traveling at 22.0 m/s, it brakes to a stop in 4.0 s. Show that the magnitude of the braking force acting on the truck is 11,000 N.

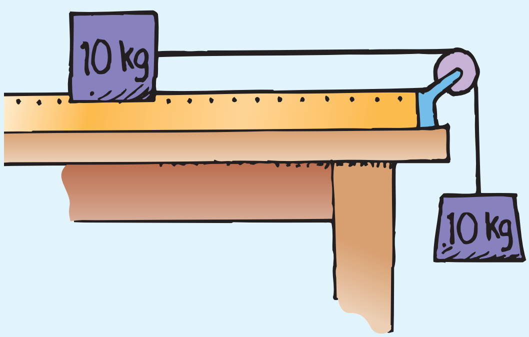
61. If a loaded truck that can accelerate at 1 m/s^2 loses its load and has three-fourths of its original mass, what acceleration can it attain if the same driving force acts on it?

62. An occupant of a car can survive a crash if the deceleration during the crash is less than 30*g*. Calculate the force on a 70-kg person decelerating at this rate.

63. What is the pressure on a table when a 20-N book with a 0.05-m^2 cover lies flat on it? What is the pressure when the book stands on its end (area 0.01 m^2)?

64. A falling 50-kg parachutist experiences an upward acceleration of 6.2 m/s^2 when she opens her parachute. Show that the drag force is 810 N when this occurs.

65. A 10-kg mass on a horizontal friction-free air track is accelerated by a string attached to another 10-kg mass hanging vertically from a pulley as shown. What is the force due to gravity, in newtons, on the hanging 10-kg mass? What is the acceleration of the system of both masses?

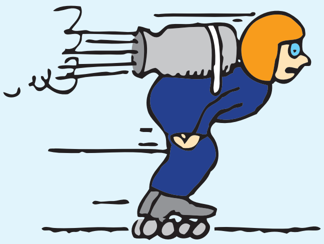


66. Suppose the masses described in problem 65 are 1 kg and 100 kg, respectively. Compare the accelerations when they are interchanged, that is, for the case where the 1-kg mass dangles over the pulley, and then for the case where the 100-kg mass dangles over the pulley. What does this indicate about the maximum acceleration of such a system of masses?

67. Skelly the skater is propelled by rocket power. Skelly and the rocket together have a mass of 25 kg. The thrusting force is 100 N and friction is 20 N.

a. What is Skelly's acceleration?

b. How far does he go in 5 s if he starts from rest?



Activities

68. Drop a sheet of paper and a coin at the same time. Which reaches the ground first? Why? Now crumple the paper into a small, tight wad and again drop it with the coin. Explain the difference observed. Will the coin and paper fall together if dropped from a second-, third-, or fourth-story window? Try it and explain your observations.

69. Glue a penny to a string. When in a moving automobile, hang the string and penny out a window. It will be swept backward due to air resistance. When the string makes an angle of 45°, easily seen with a protractor, the air resistance on the coin equals the weight of the coin. A look at the speedometer tells you the coin's terminal speed in air! Do you see why the angle makes a difference?

70. The net force acting on an object and the resulting acceleration are always in the same direction. You can demonstrate this with a spool. If the spool is gently pulled horizontally to the right, in which direction will it roll?

71. Write a letter to a friend who has not yet studied physics and tell what you've learned about Galileo introducing the concepts of acceleration and inertia. Tell of how Galileo was also familiar with forces, but didn't see the connection among these three concepts. Tell how Isaac Newton did see the connection, revealed in his second law of motion. Explain with the second law why heavy and light objects in free fall gain the same speed in the same time. In this letter, it's okay to use an equation or two, making it clear that you see equations as a shorthand notation of explanations.

More Problem-Solving Practice
Appendix F