Chapter 2

Laws of Motion

In January 1993, the 53rd space shuttle mission crew, in addition to their usual science experiments, brought some toys on board! During the flight, crew members took the toys out and played with them to see how they would work in what NASA calls "microgravity." Many people think astronauts float because there is no gravity in space. Not true! If there were no gravity, the space shuttle would not stay in orbit around Earth. So why do astronauts float?

This chapter will help you explain many aspects of motion as it occurs here on Earth, and even how things like simple toys would act in microgravity. You will be able to use Newton's laws of motion to explain why it's possible to throw a basketball through a hoop. What if that hoop and basketball were on the space shuttle? Would the crew members be able to shoot baskets in a microgravity environment?

Sir Isaac Newton, who lived from 1642-1727, attempted to answer similar questions and soon you will know the answers too!

Key Questions

- ✓ Why do thrown objects fall to Earth instead of flying through the air forever?
- ✓ Is it possible for a feather and a hammer to hit the ground at the same time when dropped?
- ✓ What does a graph of motion look like?

2.1 Newton's First Law

Sir Isaac Newton (1642-1727), an English physicist and mathematician, was one of the most brilliant scientists in history. Before age 30, he had made several important discoveries in physics and had invented a new kind of mathematics called calculus. Newton's three laws of motion are probably the most widely used natural laws in all of science. The laws explain the relationships between the forces acting on an object, the object's mass, and its motion. This section discusses Newton's first law of motion.

Changing an object's motion

Suppose you are playing miniature golf and it is your turn. What action must you take to make the golf ball move toward the hole? Would you yell at the ball to make it move? Of course not! You would have to hit the ball with the golf club to get it rolling. The club applies a force to the ball. This force is what changes the ball from being at rest to being in motion (Figure 2.1).

What is force?

A **force** is a *push* or *pull*, or *any action that has the ability to change motion.* The golf ball will stay at rest until you apply force to set it in motion. Once the ball is moving, it will continue to move in a straight line at a constant speed, unless another force changes its motion. You need force to start things moving and also to make any change to their motion once they are moving. Forces can be used to increase or decrease the speed of an object, or to change the direction in which an object is moving.

How are forces created?

Forces are created in many different ways. For example, your muscles create force when you swing the golf club. Earth's gravity creates forces that pull on everything around you. On a windy day, the movement of air can create forces. Each of these actions can create force because they all can change an object's motion.

Force is required to change motion

Forces create changes in motion, and *there can be no change in motion without the presence of a force.* Anytime there is a change in motion a force must exist, even if you cannot immediately recognize the force. For example, when a rolling ball hits a wall and bounces, its motion changes rapidly. That change in motion is caused by the wall exerting a force that changes the direction of the ball's motion.

Vocabulary

force, Newton's first law, inertia, newton, net force

Objectives

- ✓ Recognize that force is needed to change an object's motion.
- ✓ Explain Newton's first law.
- ✓ Describe how inertia and mass are related.

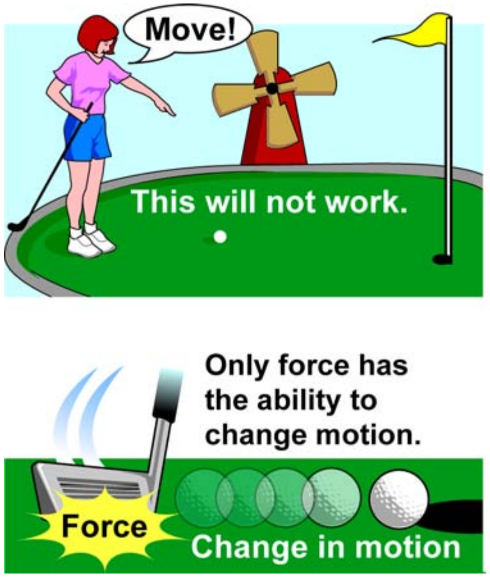

Figure 2.1: *Force is the action that has the ability to change motion. Without force, the motion of an object cannot be started or changed.*

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Forces, mass, and inertia

Stopping a moving object Let's keep playing golf. Once the golf ball is moving, how can you stop it? The only way to stop the ball is to apply a force in a direction opposite its motion. In general, objects want to keep doing what they are already doing. This idea is known as Newton's first law of motion.

Newton's first law **Newton's first law** states that objects tend to continue the motion they already have unless they are acted on by forces. In the absence of forces an object at rest will stay at rest. An object that is moving will keep moving at the same speed and in the same direction. In other words, objects resist changes in their motion.

> An object at rest will stay at rest and an object in motion will continue in motion with the same speed and direction UNLESS acted on by a force.

Inertia Some objects resist changes in motion better than others. **Inertia** is the property of an object that resists changes in its motion. To understand inertia, imagine trying to move a bowling ball and a golf ball. Which requires more force? Of course, the bowling ball needs more force to get it moving at the same speed as the golf ball (assuming the forces act for the same length of time). The bowling ball also requires more force to stop. A bowling ball has more inertia than a golf ball. The greater an object's inertia, the greater the force needed to change its motion. Because inertia is an important idea, Newton's first law is sometimes called the law of inertia.

Mass Inertia comes from mass. Objects with more mass have more inertia and are more resistant to changes in their motion. Mass is measured in kilograms (kg). A golf ball has a mass of 0.05 kilograms, and the average bowling ball has a mass of 5 kilograms (Figure 2.2). A bowling ball is 100 times as massive, so it has 100 times the inertia. For small amounts of mass, the kilogram is too large a unit to be convenient. One gram (g) is one-thousandth of a kilogram. A dollar bill has a mass of about a gram, so 1,000 dollar bills have a mass of approximately 1 kilogram.

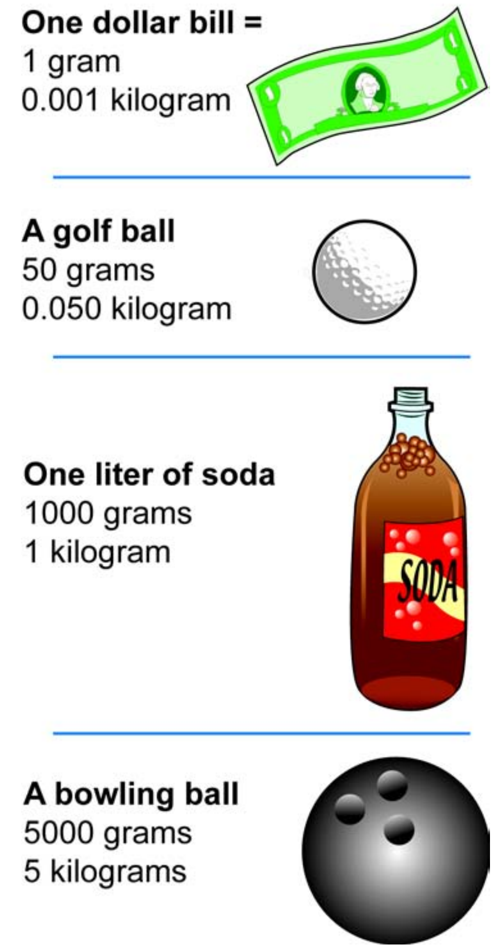


Figure 2.2: *Mass can be measured in grams or kilograms. One kilogram equals 1000 grams.*

Units of force

Pounds

If you are mailing a package at the post office, how does the clerk know how much to charge you? The package is placed on a scale and you are charged based on the package's weight. For example, the scale shows that the package weighs 5 pounds. The pound is a unit of *force* commonly used in the United States. When you measure weight in pounds on a scale, you are measuring the *force of gravity* acting on the object (Figure 2.3).

The origin of the pound

The pound measurement of force is based on the Roman unit *libra*, which means "balance" and is the source for pound's abbreviation, "lb." The word "pound" comes from the Latin word *pondus*, which means "weight." The definition of a pound has varied over time and from country to country.

The newton

Although the pound is commonly used to express force, scientists prefer to use the newton. The **newton (N)** is the metric unit of force. A force of one newton is the exact amount of force needed to cause a mass of one kilogram to speed up by one meter per second each second (Figure 2.3). We call the unit of force the newton because force in the metric system is defined by Newton's laws. The newton is a useful way to measure force because it connects force directly to its effect on mass and speed.

Converting newtons and pounds

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

The force unit of newtons

When physics problems are presented in this book, forces will almost always be expressed in newtons. In the next section, on Newton's second law, you will see that the newton is closely related to the metric units for mass and distance.

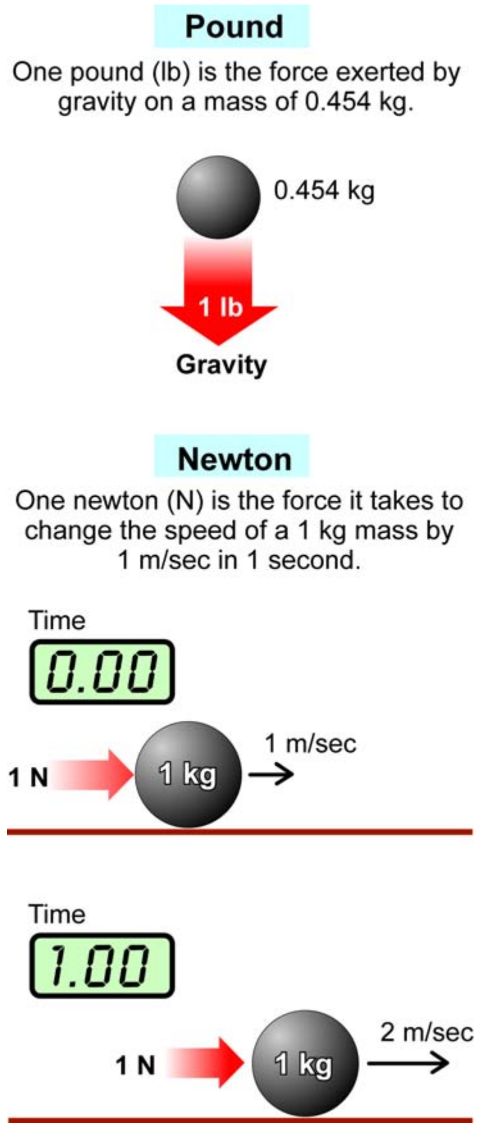


Figure 2.3: *The definition of the pound and the newton.*

The net force

Multiple forces When you hit a golf ball, the force from the club is not the only force that acts. Gravity also exerts a force on the ball. Which force causes the change in the ball's motion: gravity or the force from the golf club? Does gravity stop while the golf club exerts its force?

Forces act together You are right if you are thinking "all forces together." The motion of objects changes in response to the *total force* acting on the object, including gravity and any other force that is present. In fact, it is rare that only one force acts at a time since gravity is always present.

Net force Adding up forces can be different from simply adding numbers because the *directions* of the forces matter. For this reason the term **net force** is used to describe the total of all forces acting on an object. When used this way, the word "net" means *total* but also implies that the direction of the forces has been taken into account when calculating the total.

Forces in the same direction When two forces are in the same direction, the net force is the sum of the two. For example, think about two people pushing a box. If each person pushes with a force of 300 newtons in the same direction, the net force on the box is 600 N (Figure 2.4 top). The box speeds up in the direction of the net force.

Forces in opposite directions What about gravity acting on the box? Gravity exerts a force downward on the box. However, the floor holds the box up. In physics, the term "holds up" means "applies a force." In order to "hold up" the box, the floor exerts a force upward on the box. The net force on the box in the "up-down" direction is *zero* because the force from the floor is opposed to the force of gravity. When equal forces are in the opposite direction they cancel (Figure 2.4 bottom). The motion of the box in the up-down (vertical) direction does not change because the net force in this direction is zero.

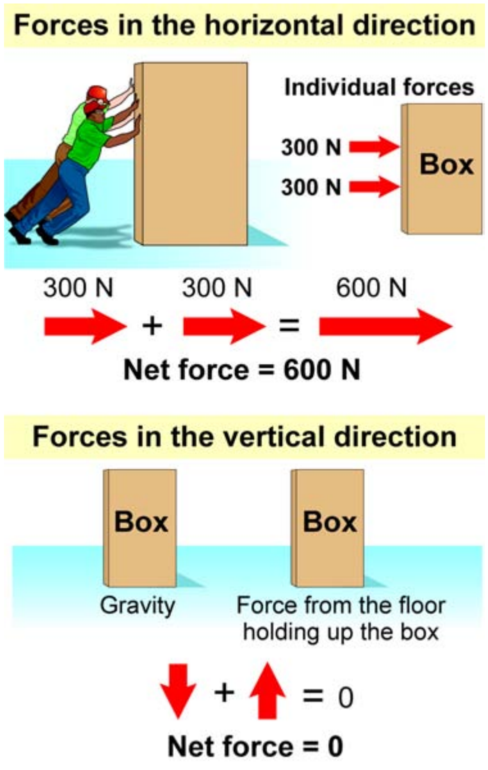


Figure 2.4: *The net force acting on a box being pushed.*

2.1 Section Review

1. State Newton's first law in your own words.
2. How is mass related to inertia?
3. What is the net force and how is it determined?

2.2 Acceleration and Newton's Second Law

Newton's first law says that a force is needed to change an object's motion. But what kind of change happens? The answer is *acceleration*. Acceleration is how motion changes. The amount of acceleration depends on both force and the mass according to Newton's second law. This section is about Newton's second law, which relates force, mass, and acceleration. The second law is probably the most well-used relationship in all of physics.

Vocabulary

acceleration, deceleration, Newton's second law

Objectives

- ✓ Define and calculate acceleration.
- ✓ Explain the relationship between force, mass, and acceleration.
- ✓ Determine mass, acceleration, or force given two of the quantities.

Acceleration

Definition of acceleration What happens if you coast on a bicycle down a long hill without pedaling? At the top of the hill, you move slowly. As you go down the hill, your speed gets faster and faster—you accelerate. **Acceleration** is the rate at which your speed increases. If speed increases by 1 kilometer per hour (km/h) each second, the acceleration is 1 km/h per second.

Time	Speed
0 (start)	0 (start)
1 second	1 km/h
2 seconds	2 km/h
3 seconds	3 km/h
4 seconds	4 km/h
5 seconds	5 km/h

Time	Speed
0 (start)	0 (start)
1 second	2 km/h
2 seconds	4 km/h
3 seconds	6 km/h
4 seconds	8 km/h
5 seconds	10 km/h

Steeper hills Your acceleration depends on the steepness of the hill. If the hill is a gradual incline, you have a small acceleration, such as 1 km/h per second. If the hill is steeper, your acceleration will be greater, perhaps 2 km/h per second. On the gradual hill, your speedometer increases by 1 km/h every second. On the steeper hill, it increases by 2 km/h every second.

Car acceleration Advertisements for sports cars often discuss acceleration. A typical ad might boast that a car can go "from zero to 60 in 10 seconds." This means the car's speed begins at zero and reaches 60 miles per hour (96 km/h) after accelerating for 10 seconds. The car's acceleration is therefore 6 miles per hour per second (Figure 2.5).

Acceleration of the car is 6 mph/sec

Figure 2.5: *It takes 10 seconds for a car to go from zero to 60 mph if it has an acceleration of 6 mph per second. In metric units the car goes from zero to 96 km/h in 10 seconds. The acceleration is 9.6 km/h per second.*

Units of acceleration

Speed units and time units

Acceleration is the rate of change of an object’s speed. To calculate acceleration, you divide the change in speed by the amount of time it takes for the change to happen. In the example of the sports car, acceleration was given in kilometers per hour per second. This unit can be abbreviated as km/h/sec. Notice that two time units are included in the unit for acceleration. One unit of time is part of the speed unit, and the other is the time over which the speed changed.

Metric units

If the change in speed is in meters per second and the time is in seconds, then the unit for acceleration is m/sec/sec or *meters per second per second*. An acceleration of 10 m/sec/sec means that the speed increases by 10 m/sec *every second*. If the acceleration lasts for three seconds, then the speed increases by a total of 30 m/sec (3 seconds × 10 m/sec/sec). This is approximately the acceleration of an object allowed to fall free after being dropped.

What do units of seconds *squared* mean?

An acceleration in m/sec/sec is often written m/sec^2 (meters per second squared). If you apply the rules for simplifying fractions on the units of acceleration (m/sec/sec), the denominator ends up having units of seconds times seconds, or sec^2. Saying *seconds squared* is just a math-shorthand way of talking. It is better to think about acceleration in units of speed change per second (that is, meters per second *per second*).

$$\boxed{\text{Acceleration} = \frac{\text{Change in speed}}{\text{Change in time}}}$$

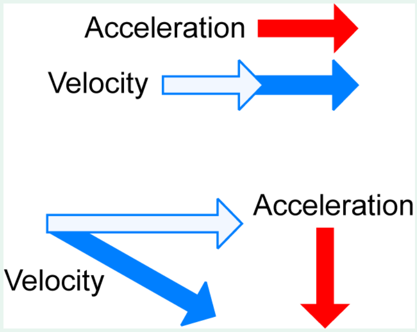
How we get units of m/sec^2

Plug in values		Clear the compound fraction		Final units
$\dfrac{50\,\dfrac{\text{m}}{\text{sec}}}{\text{sec}}$	$=$	$50\,\dfrac{\text{m}}{\text{sec}} \times \dfrac{1}{\text{sec}} = 50\,\dfrac{\text{m}}{\text{sec x sec}}$	$=$	$50\,\dfrac{\text{m}}{\text{sec}^2}$

Acceleration in m/sec^2

Nearly all physics problems will use acceleration in m/sec^2 because these units agree with the units of force (newtons). If you measure speed in centimeters per second, you may have to convert to meters/second before calculating acceleration. This is especially true if you do any calculations using force in newtons.

Acceleration and direction



The velocity of an object includes both its speed and the direction it is moving. A car with a velocity of 20 m/sec north has a speed of 20 m/sec and is moving north.

An object accelerates if its *velocity* changes. This can occur if its *speed* changes or if its *direction* changes (or both). Therefore, a car driving at a constant speed of 40 mph around a bend is actually accelerating. The only way a moving object can have an acceleration of zero is to be moving at constant speed in a straight line.

This chapter covers acceleration that involves only changes in speed. In chapter 6, you will learn about the acceleration of moving objects that change direction as well.

Calculating acceleration

The equation for acceleration

To calculate acceleration, you divide the change in speed by the time over which the speed changed. To find the change in speed, subtract the starting (or initial) speed from the final speed. For example, if a bicycle's speed increases from 2 m/sec to 6 m/sec, its change in speed is 4 m/sec. Because two speeds are involved, subscripts are used to show the difference. The initial speed is v_1, and the final speed is v_2.

ACCELERATION

$$\text{Acceleration (m/sec}^2) \rightarrow a = \frac{\overbrace{v_2 - v_1}^{\text{Change in speed (m/sec)}}}{t \leftarrow \text{Time (sec)}}$$

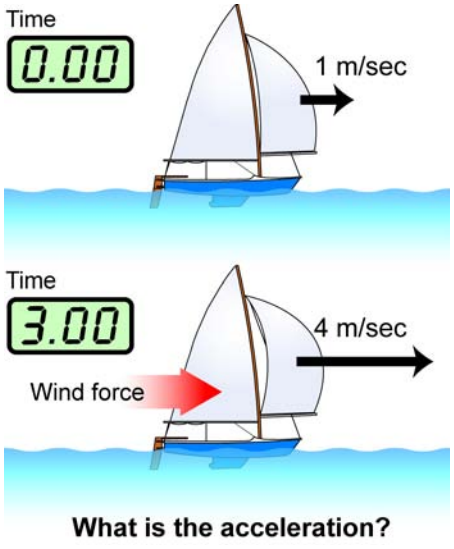


Figure 2.6: *An acceleration example with a sailboat.*

Positive and negative acceleration

If an object *speeds up*, it has a *positive acceleration*. If it *slows down*, it has a *negative acceleration*. In physics, the word acceleration is used to refer to any change in speed, positive or negative. However, people sometimes use the word **deceleration** to describe the motion that is slowing down.

Calculating acceleration (Figure 2.6)

A sailboat moves at 1 m/sec. A strong wind increases its speed to 4 m/sec in 3 seconds (Figure 2.6). Calculate the acceleration.

1. Looking for: You are asked for the acceleration in meters per second.

2. Given: You are given the initial speed in m/sec (v_1), final speed in m/sec (v_2), and the time in seconds.

3. Relationships: Use the formula for acceleration: $a = \frac{v_2 - v_1}{t}$

4. Solution:

$$a = \frac{4\text{ m/sec} - 1\text{ m/sec}}{3\text{ sec}} = \frac{3\text{ m/sec}}{3\text{ sec}} = 1\text{ m/sec}^2$$

Your turn...

a. Calculate the acceleration of an airplane that starts at rest and reaches a speed of 45 m/sec in 9 seconds. **Answer:** 5 m/sec^2

b. Calculate the acceleration of a car that slows from 50 m/sec to 30 m/sec in 10 seconds. **Answer:** -2 m/sec^2

Force, mass, and acceleration

Newton's second law

Newton's second law relates the net force on an object, the mass of the object, and acceleration. It states that the stronger the net force on an object, the greater its acceleration. If twice the net force is applied, the acceleration will be twice as great. The law also says that the greater the mass, the smaller the acceleration for a given net force (Figure 2.7). An object with twice the mass will have half the acceleration if the same force is applied.

Direct and inverse proportions

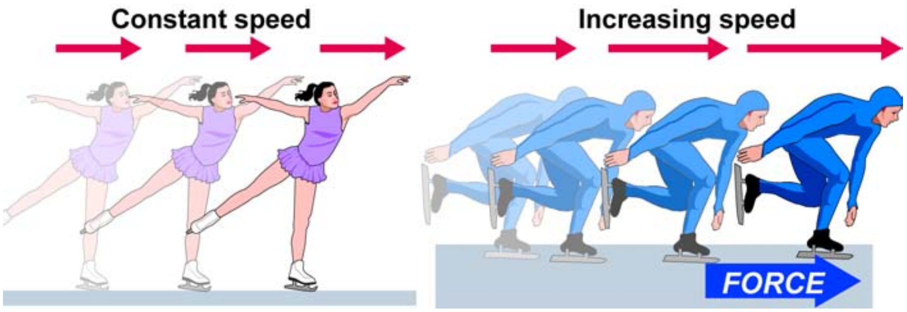
In mathematical terms, the acceleration of an object is directly proportional to the net applied force and inversely proportional to the mass. These two relationships are combined in Newton's second law (below).

NEWTON'S SECOND LAW

Acceleration (m/sec²) → $a = \frac{F}{m}$ ← *Force* (N), ← *Mass* (kg)

Changes in motion involve acceleration

Force is not necessary to keep an object in motion at constant speed. A moving object will keep going at a constant speed in a straight line until a force acts on it. Once a skater is moving, she will coast for a long time without any force to push her along. However, she does need force to speed up, slow down, turn, or stop. Changes in speed or direction always involve acceleration. *Force* causes *acceleration*, and *mass* resists *acceleration.*



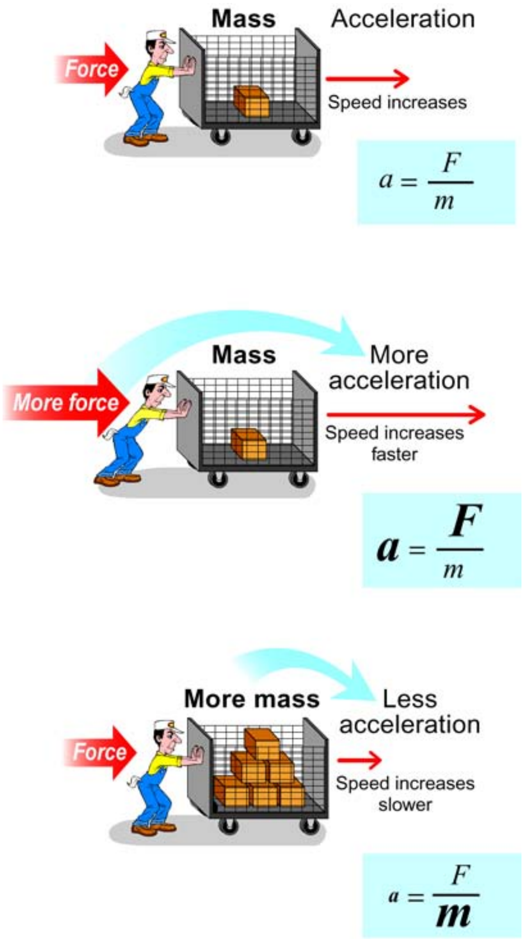


Figure 2.7: *Increasing the force increases the acceleration, and increasing the mass decreases the acceleration.*

Applying the second law

Some guidelines

To use Newton's second law properly, keep the following important ideas in mind. They are a good guideline for how to apply the second law to physics problems.

1. The *net* force is what causes acceleration.
2. If there is *no* acceleration, the net force *must* be zero.
3. If there *is* acceleration, there *must* also be a net force.
4. The force unit of newtons is based on kilograms, meters, and seconds.

Net force

When two forces are in the same direction, the net force is the sum of the two forces. When two forces are in opposite directions the net force is the difference between them. To get the direction right we usually assign positive values to one direction and negative values to the other direction. Figure 2.8 shows how to calculate the net force for different forces.

Examples with and without acceleration

Objects at rest or moving with constant speed have zero acceleration. This means the net force must also be zero. You can calculate unknown forces by using the knowledge that the net force must be zero. The motion of a kicked ball or a car turning a corner are examples where the acceleration is not zero. Both situations have net forces that are not zero.

Using newtons in calculations

The newton is *defined* by the relationship between force, mass, and acceleration. A force of one newton is the exact amount of force needed to cause a mass of one kilogram to accelerate at one m/sec^2 (Figure 2.9). The newton is a useful way to measure force because it connects force directly to its effect on matter and motion. A net force of one newton will always accelerate a 1-kilogram mass at 1 m/sec^2 no matter where you are in the universe. In terms of solving problems, you should always use the following units when using force in newtons:

- mass in kilograms
- distance or position in meters
- time in seconds
- speed in m/sec
- acceleration in m/sec^2

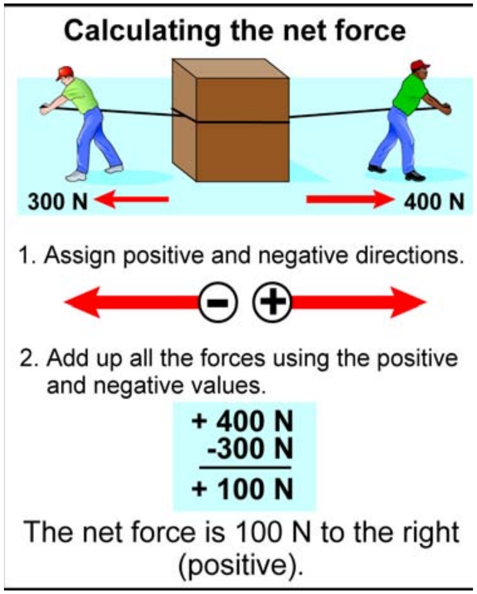


Figure 2.8: *Calculating the net force.*

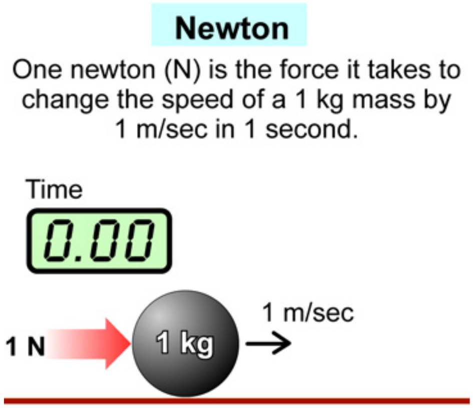


Figure 2.9: *The definition of a newton.*

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Doing calculations with the second law

Writing the second law The formula for the second law of motion uses *F*, *m*, and *a* to represent force, mass, and acceleration. The way you write the formula depends on what you want to know. Three ways to write the law are summarized below.

Table 2.1: ***Three forms of the second law***

Use . . .	. . . if you want to find . . .	. . . and you know . . .
$a=F/m$	acceleration (a)	force (F) and mass (m)
$F=ma$	force (F)	acceleration (a) and mass (m)
$m=F/a$	mass (m)	acceleration (a) and force (F)

Net force Remember, when using the second law, the force that appears is the net force. Consider all the forces that are acting and add them up to find the net force before calculating any accelerations. If you work in the other direction, calculating force from mass and acceleration, it is the net force that you get from the second law. You may have to do additional work if the problem asks for a specific force and there is more than one force acting.

Units and the second law

When using $F = ma$, the units of force (newtons) must equal the units of mass (kilograms) multiplied by the units of acceleration (m/sec^2). How is this possible? The answer is that 1 newton is 1 kg·m/sec^2. The unit “newton” was created to be a shortcut way to write the unit of force. It is much simpler to say 5 N rather than 5 kg·m/sec^2.

Newton’s second law

A car has a mass of 1,000 kg. If a net force of 2,000 N is exerted on the car, what is its acceleration?

1. Looking for: You are asked for the car’s acceleration.

2. Given: You are given its mass in kilograms and the net force in newtons.

3. Relationships:

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

4. Solution:

$$a = \frac{2000\ \text{N}}{1000\ \text{kg}} = \frac{2\text{kg}\bullet\text{m}/\text{sec}^2}{\text{kg}} = 2\ \text{m/sec}^2$$

Your turn...

a. What is the acceleration of a 1,500-kilogram car if a net force of 1,000 N is exerted on it? **Answer:** 1.5 m/sec^2

b. As you coast down the hill on your bicycle, you accelerate at 0.5 m/sec^2. If the total mass of your body and the bicycle is 80 kg, with what force is gravity pulling you down the hill? **Answer:** 40 kg·m/sec^2 or 40 N

c. You push a grocery car with a force of 30 N and it accelerates at 2 m/sec^2. What is its mass? **Answer:** 15 kg

Force and energy

Energy moves through force

Force is the action through which energy moves. This important idea will help you understand why forces occur. Consider a rubber band that is stretched to launch a car. The rubber band has energy because it is stretched. When you let the car go, the energy of the rubber band is transferred to the car. The transfer of energy from the stretched rubber band to the car occurs through the force that the rubber band exerts on the car (Figure 2.10).

Energy differences create force

Forces are created any time there is a difference in energy. A stretched rubber band has more energy than a rubber band lying relaxed. The difference in energy results in a force that the rubber band exerts on whatever is holding it in the stretched shape.

An example of energy difference

Energy differences can be created in many ways. A car at the top of a hill has more energy than when the car is at the bottom. This tells you there must be a force that pulls the car toward the bottom of the hill. You can predict that a downhill force must exist even though you may not know the cause of that force.

An important idea

Suppose there is an energy difference between one arrangement of a system (car at the top) and another arrangement (car at the bottom). Some force will *always* act to bring the system from the higher energy arrangement to the lower energy one. We will find many examples of this important principle throughout the course. The principle is true in all of science, not just physics. It is true in chemistry, earth science, and biology, too.

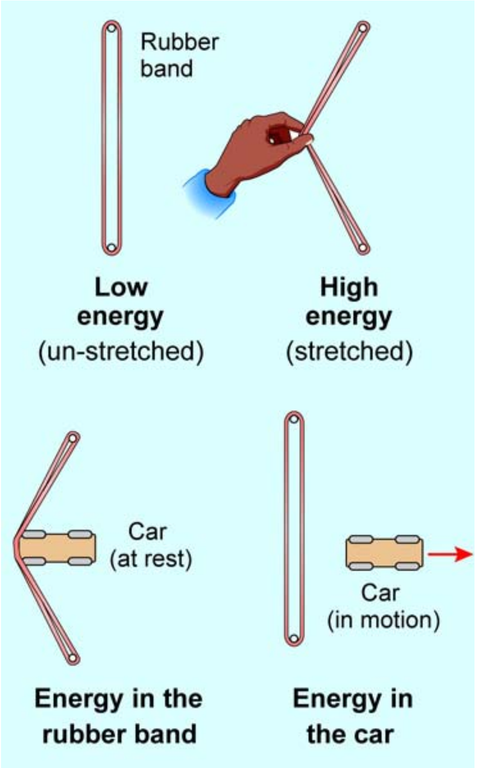

Figure 2.10: *Energy differences cause forces to be created. The forces can transfer energy from one object to another.*

2.2 Section Review

1. List three units in which acceleration can be measured.
2. According to Newton's second law, what causes acceleration? What resists acceleration?
3. An 8,000 kg helicopter's speed increases from 0 m/sec to 25 m/sec in 5 seconds. Calculate its acceleration and the net force acting on it.
4. Define the term "net force."
5. Describe the conceptual relationship between energy and force.

2.3 Gravity and Free Fall

Imagine dropping a baseball out of a second-floor window. What happens? Of course, the ball falls toward the ground. Is the speed constant or does the ball accelerate? If it accelerates, at what rate? Do all objects fall at the same rate? You will learn the answers to these questions in this section.

The acceleration due to gravity

The definition of free fall

An object is in **free fall** if it is accelerating due to the force of gravity and no other forces are acting on it. A dropped baseball is in free fall from the instant it leaves your hand until it reaches the ground. A ball thrown upward is also in free fall after it leaves your hand. Although you might not describe the ball as "falling," it is still in free fall. Birds, helicopters, and airplanes are *not* normally in free fall because forces other than gravity act on them.

The acceleration of gravity

Objects in free fall on Earth accelerate downward at 9.8 m/sec^2, the **acceleration due to gravity**. Because this acceleration is used so frequently in physics, the letter g is used to represent its value. When you see the letter g in a physics question, you can substitute the value 9.8 m/sec^2.

Speed in free fall

If you know the acceleration of an object in free fall, you can predict its speed at any time after it is dropped. The speed of a dropped object will increase by 9.8 m/sec every second (Figure 2.11). If it starts at rest, it will be moving at 9.8 m/sec after one second, 19.6 m/sec after two seconds, 29.4 m/sec after three seconds, and so on. To calculate the object's speed, you multiply the time it falls by the value of g. Because the units of g are m/sec^2, the speed must be in m/sec and the time must be in seconds.

FREE FALL SPEED
(starting at rest)

Acceleration due to gravity (m/sec^2)

Speed (m/sec) → $v = gt$ ← *Time* (sec)

Vocabulary

free fall, acceleration due to gravity, velocity, weight, air resistance, terminal speed

Objectives

- ✓ Describe the motion of an object in free fall.
- ✓ Calculate speed and distance for an object in free fall.
- ✓ Distinguish between mass and weight.
- ✓ Explain how air resistance affects the motion of objects.

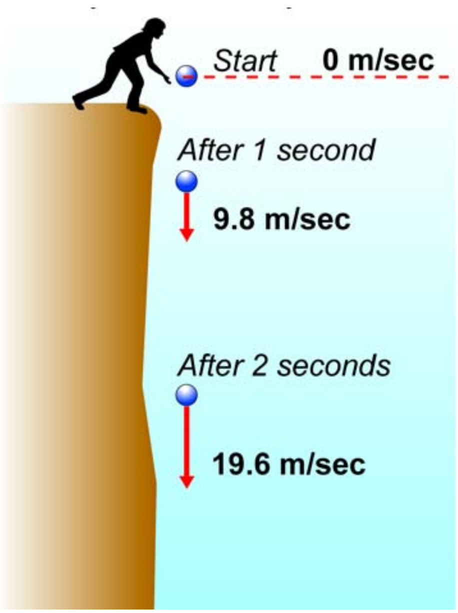

Figure 2.11: *The speed of a ball in free fall increases by 9.8 m/sec every second.*

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Upward launches

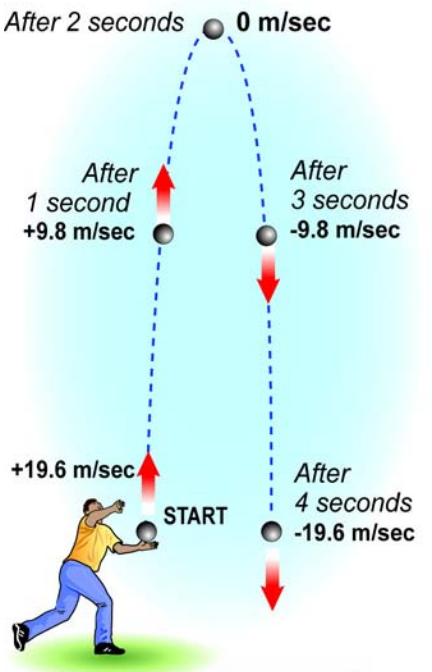
Throwing a ball upward When an object is in free fall, it accelerates *downward* at 9.8 m/sec^2. Gravity causes the acceleration by exerting a downward force. So what happens if you throw a ball *upward*? The ball will slow down as it moves upward, come to a stop for an instant, and then fall back down. As it moves upward, the speed *decreases* by 9.8 m/sec every second until it reaches zero. The ball then reverses direction and starts falling down. As it falls downward, the speed *increases* by 9.8 m/sec every second.

Velocity When an object's direction is important, we use the *velocity* instead of the speed. **Velocity** is speed with direction. In Figure 2.12, the ball's initial velocity is +19.6 m/sec and its velocity four seconds later is -19.6 m/sec. The positive sign means upward and the negative sign means downward.

Speed The acceleration of the ball is -9.8 m/sec^2 (-*g*). That means you subtract 9.8 m/sec from the speed every second. Figure 2.12 shows what happens to a ball launched upward at 19.6 m/sec. The speed decreases for two seconds, reaches zero, and then increases for two seconds. *The acceleration is the same all the time* (-9.8 m/sec^2) even though the ball is slowing down as it goes up and speeding up as it comes back down. The acceleration is the same because the change in speed is the same from one second to the next. The speed always changes by -9.8 m/sec every second.

Stopping for an instant Notice the ball's speed is 0 m/sec at the top of its path. If you watch this motion, the ball looks like it stops, because it is moving so slowly at the top of its path. To your eye it may look like it stops for a second, but a slow-motion camera would show the ball's speed immediately reverses at the top and does not stay zero for any measurable amount of time.

Acceleration You may want to say the acceleration is zero at the top, but only the *speed* is zero at the top. Speed and acceleration are not the same thing, remember — just like 60 miles and 60 miles per hour are not the same thing. The force of gravity causes the ball's acceleration. The force of gravity stays constant; therefore, the acceleration is also constant and cannot be zero while the ball is in the air.



Time (sec)	Velocity (m/sec)
0.0	19.60
1.0	9.80
2.0	0.00
3.0	-9.80
4.0	-19.60

Figure 2.12: *The motion of a ball launched upward at 19.6 m/sec.*

Free fall and distance

Changing speeds In chapter 1, you used $d = vt$ to calculate distance. You cannot calculate distance in the same simple way when speed is not constant, as happens in free fall. An object in free fall increases its speed by 9.8 m/sec each second (or 9.8 m/sec^2), so it moves a greater distance each second.

Average speed One way to calculate distance is to use the *average speed*. In free fall and other situations of *constant* acceleration, the average speed is the average of the starting or initial speed (v_i) and the final speed (v_f). Taking the average accounts for the fact that the speed is not constant. Be careful when doing this calculation. The average speed may *not* be $(v_f + v_i) \div 2$, if the acceleration is not constant.

AVERAGE SPEED

$$\underset{\text{Average speed (m/sec)}}{v_{avg}} = \frac{\overset{\text{Final speed (m/sec)}}{v_f} + \overset{\text{Initial speed (m/sec)}}{v_i}}{2}$$

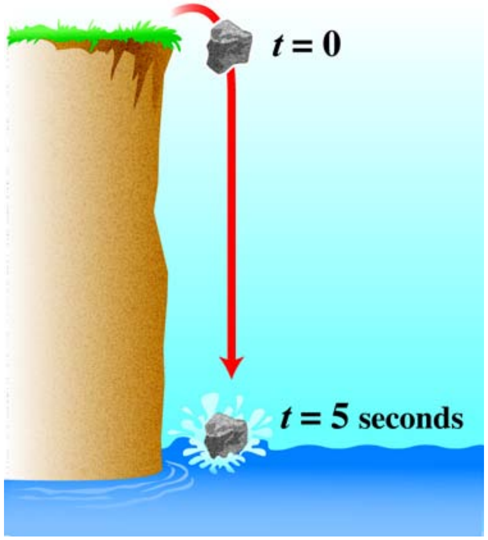


Figure 2.13: *What is the average speed of a rock that falls for 5 seconds?*

Average speed

A rock falls off a cliff and splashes into a river 5 seconds later (Figure 2.13). What was the rock's average speed during its fall?

1. Looking for: You are asked for the average speed in meters per second. You need to find the final speed in meters per second.

2. Given: You may assume zero initial speed and are given the air time in seconds.

3. Relationships: $v_f = gt$ and $v_{avg} = \frac{v_i + v_f}{2}$ where $g = 9.8$ m/sec^2

4. Solution: $v_f = (9.8 \text{ m/sec}^2)(5 \text{ sec}) = 49 \text{ m/sec}$ $\quad v_{avg} = \frac{0 + 49 \text{ m/sec}}{2} = 24.5 \text{ m/sec}$

Your turn...

a. What is the average speed of a baseball dropped from rest that falls for 2 seconds? **Answer:** 9.8 m/sec

b. What is the average speed of a ball with an initial downward speed of 10 m/sec that falls for 2 seconds? **Answer:** 14.8 m/sec

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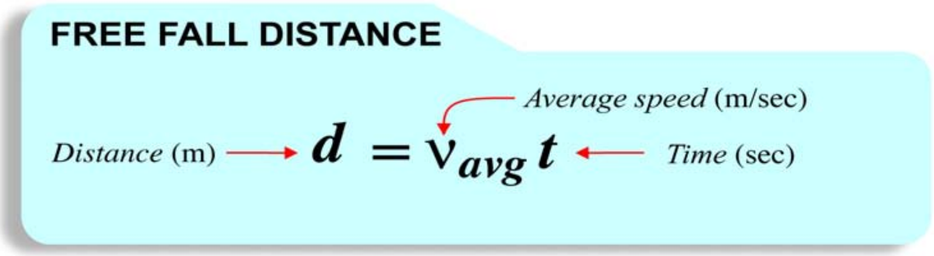
Calculating distance Now that you know how to calculate the average speed for an object in free fall, you can use the average speed to find out the distance it falls.



$$d = v_{avg}\, t$$

Calculating free-fall speed and distance

A skydiver falls for 6 seconds before opening her parachute. Calculate her actual speed at the 6-second mark and the distance she has fallen in this time.

1. Looking for: You are asked to find the final speed and the distance.

2. Given: You may assume zero initial speed and are given the time in seconds.

3. Relationships: $v_f = gt \qquad v_{avg} = \frac{v_i + v_f}{2} \qquad d = v_{avg} t$

4. Solution:

$$v_f = (9.8 \text{ m/sec}^2)(6 \text{ sec}) = 58.8 \text{ m/sec}$$

The speed after 6 seconds is 58.8 m/sec.

$$v_{avg} = \frac{0 + 58.8 \text{ m/sec}}{2} = 29.4 \text{ m/sec}$$

$$d = (29.4 \text{ m/sec})(6 \text{ sec}) = 176.4 \text{ m}$$

The skydiver falls 176.4 meters.

Your turn...

a. Calculate the final speed and distance for a skydiver who waits only 4 seconds to open his parachute. **Answer:** 39.2 m/sec and 78.4 m

b. An apple falls from the top branch of a tree and lands 1 second later. How tall is the tree? **Answer:** 4.9 m

Another way to calculate free-fall distance

Using the average speed to calculate the distance traveled by an object in free fall requires multiple steps. If you are only given the air time, you must first find the final speed, then you must calculate the average speed, and finally you can find the distance.

These three steps can all be combined into one formula. The general version of the formula is more complicated than the scope of this book, but can be simplified if the object starts at rest ($v_i = 0$).

1) If the initial speed is zero and the object falls for *t* seconds, then the final speed is *gt*.

2) The average speed is half the final speed or $\frac{1}{2}gt$.

3) The distance is the average speed multiplied by the time or $\frac{1}{2}gt^2$.

The general formula is therefore:

$$d = \frac{1}{2} g t^2$$

Remember, this formula only works when the object starts at rest and is in free fall.

Gravity and weight

Gravity's force depends on mass

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

Weight and mass

We all tend to use the terms *weight* and *mass* interchangeably. Heavy objects have lots of mass and light objects have little mass. People and things such as food are "weighed" in both kilograms and pounds. If you look on the label of a bag of flour, it lists the "weight" in two units: 5 pounds in the English system and 2.3 kilograms in the metric system. As long as we are on Earth, where g = 9.8 N/kg a 2.3-kilogram object will weigh 5 pounds. But on the moon, g = 1.6 N/kg, so a 2.3 kilogram object will weigh only 0.8 pounds (Figure 2.14).

Weight and the second law

You should recognize that the value of 9.8 N/kg is the same as g (9.8 m/sec^2) but with different units. This is no coincidence. According to the second law, a force of 9.8 newtons acting on one kilogram produces an acceleration of 9.8 m/sec^2. For this reason the value of g can also be used as 9.8 N/kg. Which units you choose depends on whether you want to calculate acceleration or the weight force. Both units are actually identical: 9.8 N/kg = 9.8 m/sec^2.

WEIGHT

$$\text{Weight or force of gravity (N)} \rightarrow F_g = \overset{\text{Mass (kg)}}{m}\,g \leftarrow \text{Strength of gravity (9.8 N/kg)}$$

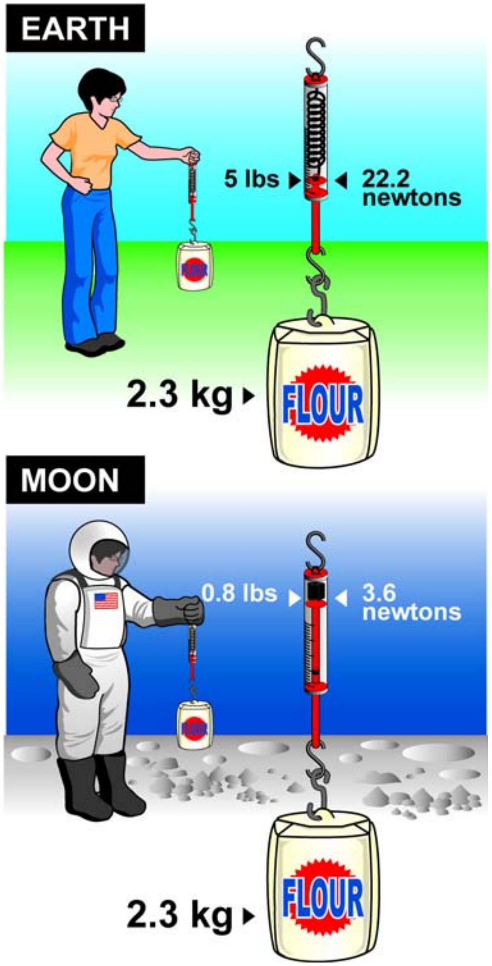


Figure 2.14: *An object that weighs 5 pounds on Earth weighs only 0.8 pounds on the moon. It has the same mass but different weights because gravity is stronger on Earth.*

Mass is fundamental

Although mass and weight are related quantities, always remember the difference when doing physics. Mass is a fundamental property of an object measured in kilograms (kg). Weight is a *force* measured in *newtons (N)* that depends on mass and gravity. A 10-kilogram object has a mass of 10 kilograms no matter where it is in the universe. A 10-kilogram object's weight, however, can vary greatly depending on whether the object is on Earth, on the moon, or in outer space.

Weight and mass

Legend has it that around 1587 Galileo dropped two balls from the Leaning Tower of Pisa to see which would fall faster. Suppose the balls had masses of 1 kilogram and 10 kilograms.

a. Use the equation for weight to calculate the force of gravity on each ball.

b. Use your answers from (a) and Newton's second law to calculate each ball's acceleration.

1. Looking for: You are asked to find the force of gravity (weight) and the acceleration.

2. Given: You are given each ball's mass in kilograms.

3. Relationships: $W=mg$ $a=F/m$

4. Solution: For the 1-kg ball:

a) $W = (1\text{ kg})(9.8\text{ m/sec}^2)$ $W = 9.8\text{ N}$

b) $a = (9.8\text{ N})/(1\text{ kg})$ $a = 9.8\text{ m/sec}^2$

For the 10-kg ball:

a) $W = (10\text{ kg})(9.8\text{ m/sec}^2)$ $W = 98\text{ N}$

b) $a = (98\text{ N})/(10\text{ kg})$ $a = 9.8\text{ m/sec}^2$ Both balls have the same acceleration.

Your turn...

a. Calculate the weight of a 60-kilogram person (in newtons) on Earth and on Mars ($g = 3.7\text{ m/sec}^2$). **Answer:** 588 N, 222 N

b. A 70-kg person travels to a planet where he weighs 1,750 N. What is the value of g on that planet? **Answer:** 25 m/sec^2

Why accelerations are the same

The example problem shows the weight of a 10-kilogram object is 10 times the weight of a 1-kilogram object. However, the heavier weight produces only one-tenth the acceleration because of the larger mass. The increase in force (weight) is exactly compensated by the increase in inertia (mass). As a result, the acceleration of all objects in free fall is the same.

Air resistance

Air resistance We just said the acceleration of all objects in free fall is the same. So why does a feather fall slower than a baseball? The answer is that objects on Earth are not truly in free fall because gravity is *not* the only force acting on falling objects. When something falls through air, the air exerts an additional force. This force, called **air resistance**, acts against the direction of the object's motion.

Factors affecting air resistance The size and shape of an object affect the force of air resistance. A feather has its weight spread out over a comparatively large area, so it must push a lot of air out of the way as it falls. The force of air resistance is large compared with the weight. According to the second law of motion of motion, acceleration is caused by the net force. The net force is the weight minus the force of air resistance. The feather accelerates at much less than 9.8 m/sec^2 because the net force is very small.

Why the baseball falls faster A baseball's shape allows it to move through the air more easily than a feather. The force of air resistance is much smaller relative to the baseball's weight. Since the net force is almost the same as its weight, the baseball accelerates at nearly 9.8 m/sec^2 and falls much more rapidly than the feather.

Terminal speed If you observe a falling feather it stops accelerating after a short distance and then falls at constant speed. That is because air resistance increases with speed. A feather only accelerates until the force of air resistance equals the force of gravity. The net force then becomes zero and the feather falls with a constant speed called the **terminal speed**. The terminal speed depends on the ratio of an object's weight to its air resistance. A tightly crumpled ball of paper has a faster terminal speed than a flat piece of paper because the flat sheet has more air resistance even though the papers' weights are the same.

Skydiving and terminal speed

Parachutes use air resistance to reduce the terminal speed of a skydiver. Without a parachute, the skydiver has a small area and can reach a speed of over 100 mph. The parachute increases the area dramatically and creates greater air resistance. The skydiver's terminal speed is then slow enough to allow for a safe landing.

2.3 Section Review

1. Describe the motion of a freely falling object. Use the words speed, acceleration, and distance in your answer.
2. What is the difference between mass and weight?
3. If you drop a feather and a baseball in a place where there is no air (a vacuum), how will their motions compare? Why?

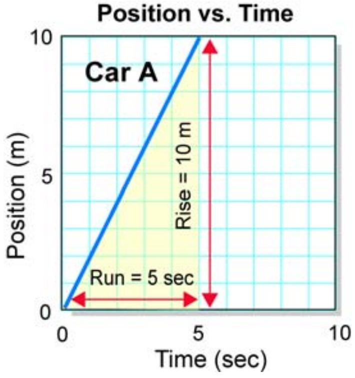
2.4 Graphs of Motion

Motion graphs are an important tool used to show the relationships between distance, speed, acceleration, and time. For example, meteorologists use graphs to show the motion of hurricanes and other storms. Graphs can show the location and speed of a storm at different points in time to help in predicting its path and the time when it will reach a certain location. In this section, you will use graphs of position versus time and speed versus time to represent motion.

The position vs. time graph

Position versus time The position versus time graph in Figure 2.15 shows the constant-speed motion of two cars, A and B. Using the numbers on the graph, you see that both cars move for 5 seconds. Car A moves 10 meters while car B moves only 5 meters. Using the equation $v = d/t$ the speed of car A is 2 m/sec. The speed of car B is 1 m/sec. Notice that line A is steeper than line B. A steeper slope on a position versus time graph means a faster speed.

The definition of slope The **slope** of a line is the ratio of the "rise" (vertical change) to the "run" (horizontal change). The diagram below shows you how to calculate the slope of a line. The rise is equal to the height of the triangle. The run is equal to the length along the base of the triangle. Here, the x-values represent time and the y-values represent distance. The slope of a position versus time graph is therefore a distance divided by a time, which equals speed.



$$\text{Slope} = \frac{\text{rise}}{\text{run}} = \frac{10\ \text{m}}{5\ \text{sec}} = 2\ \text{m/sec}$$

The slope of position vs.time is the **speed.**

Vocabulary

slope

Objectives

- ✓ Describe motion with position versus time and speed versus time graphs.
- ✓ Use a position versus time graph to calculate speed from the slope.
- ✓ Use a speed versus time graph to calculate acceleration and distance traveled.

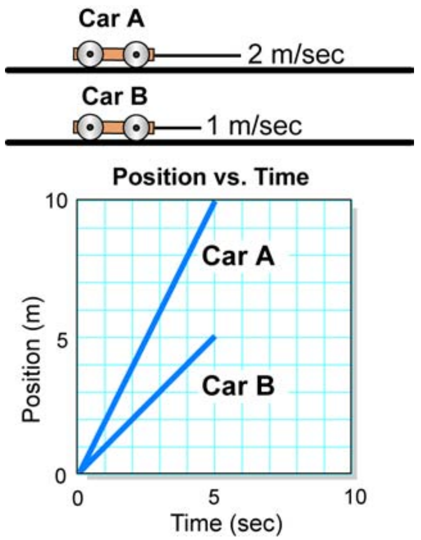
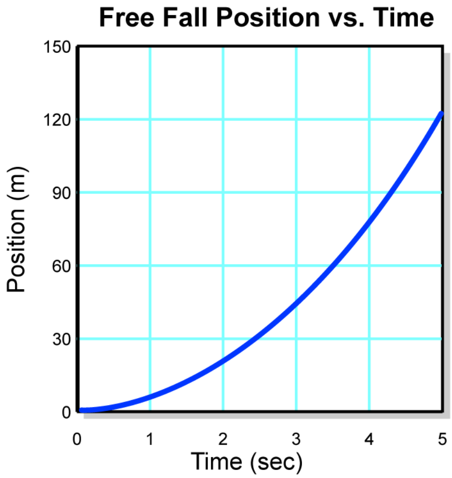


Figure 2.15: *Both cars have constant speed, but Car A is moving faster than Car B.*

Position graphs of accelerated motion

Graphing free fall A position versus time graph can tell you whether an object's speed is constant or changes. If the speed is constant, the graph is a straight line with a constant slope. If the speed is changing, the slope changes, so the graph curves. Consider the speed of an accelerating ball in free fall. As time passes, the ball's speed increases. Because the slope equals the speed, the slope must also become greater with time. The graph is a curve that gets steeper as you move along the *x*-axis (time). A position versus time graph for a ball in free fall is shown below.



Time (sec)	Position (m)
0	0
1	4.9
2	19.6
3	44.1
4	78.4
5	122.5

Slowing down The graph of an object slowing down is also curved. One example might be a car gradually coming to a stop at a red light. As time passes, the car's speed decreases. The slope of the graph must therefore decrease as you trace the line to the right. Figure 2.16 shows the graph of a car coming to a stop.

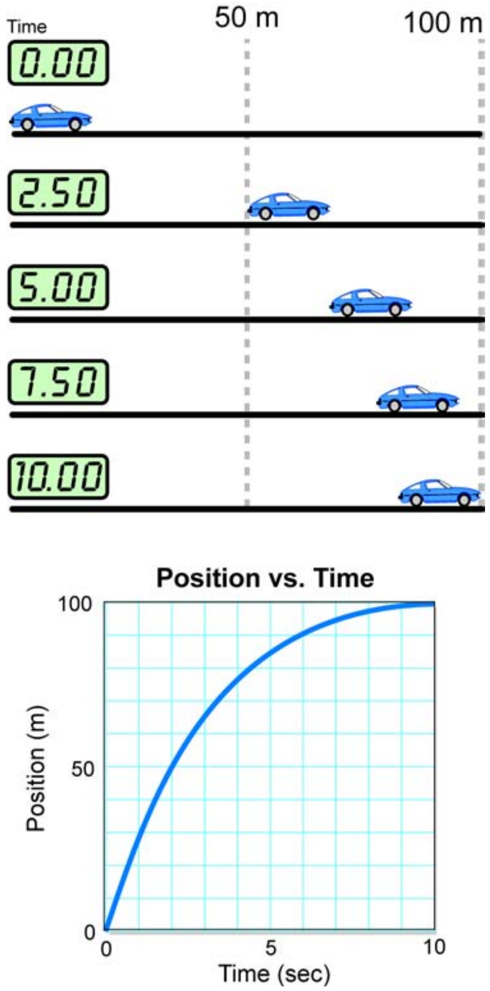
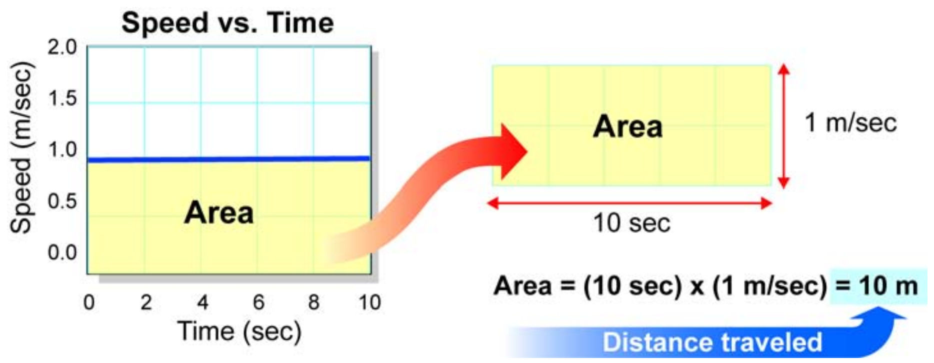


Figure 2.16: *The position versus time graph for a car coming to a gradual stop at a red light.*

The speed vs. time graph for constant speed

The speed versus time graph The speed versus time graph has speed on the *y*-axis and time on the *x*-axis. The graph in Figure 2.17 shows the speed versus time for a ball rolling at constant speed on a level floor. On this graph, constant speed is shown with a straight horizontal line. If you look at the speed on the *y*-axis, you see that the ball is moving at 1 m/sec for the entire 10 seconds. Figure 2.18 is the position versus time graph for the ball. Both of the graphs in the sidebar show the exact same motion. If you calculate the slope of the lower graph, you will find that it is 1 m/sec, the same as the speed in Figure 2.17.

Calculating distance A speed versus time graph also can be used to find the *distance* the object has traveled. Remember, distance is equal to the speed multiplied by the time. Suppose we draw a rectangle on the speed versus time graph between the *x* - axis and the line showing the speed. The area of the rectangle (shown below) is equal to its length times its height. On the graph, the length is equal to the time and the height is equal to the speed. Therefore, the area of the graph is the speed multiplied by the time. This is the distance the ball traveled.



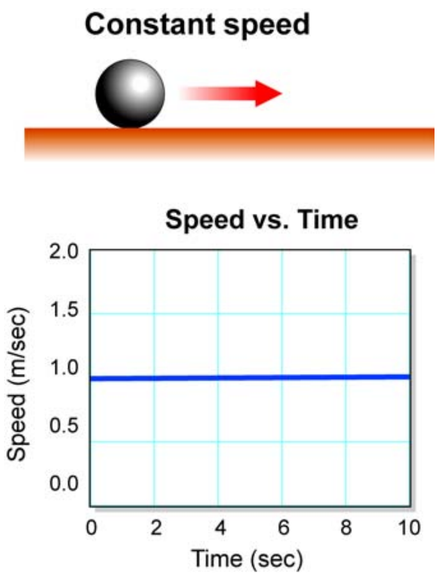


Figure 2.17: *The speed versus time graph for a ball rolling on a level floor at a constant speed of 1 m/sec.*

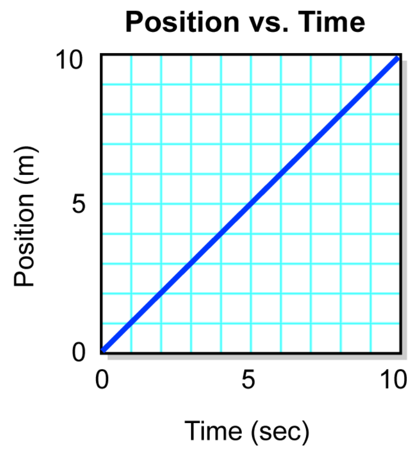


Figure 2.18: *The position versus time graph that shows the exact same motion as the speed versus time graph above.*

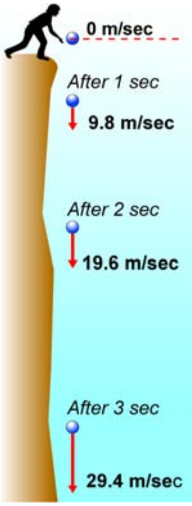
The speed vs. time graph for accelerated motion

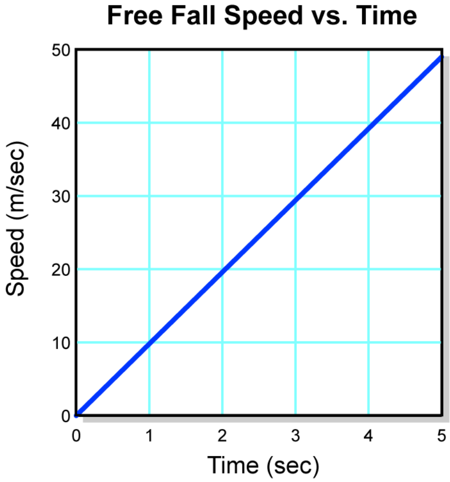
The speed versus time graph

If an object is accelerating it is easier to work with the speed versus time graph instead of the position versus time graph. The speed versus time graph is the best tool for understanding acceleration because it clearly shows how an object's speed changes with time.

Constant acceleration

The speed versus time graph below is for a ball in free fall. Because the graph is a straight line, the speed increases by the same amount each second. This means the ball has a *constant acceleration*. Make sure you do not confuse constant speed with constant acceleration. As long as it is moving in one direction, an object at constant speed has zero acceleration (Figure 2.19, bottom). Constant speed means an object's position changes by the same amount each second. Constant acceleration means an object's *speed* changes by the same amount each second.





Time (sec)	Speed (m/sec)
0	0
1	9.8
2	19.6
3	29.4
4	39.2
5	49.0

Calculating acceleration

The slope of a speed versus time graph represents the object's acceleration. Figure 2.19 shows some examples of graphs with and without acceleration. Note that there is acceleration any time the speed versus time graph is *not perfectly horizontal* (or zero slope). If the graph slopes down, it means the speed is decreasing. If the graph slopes up, the speed is increasing.

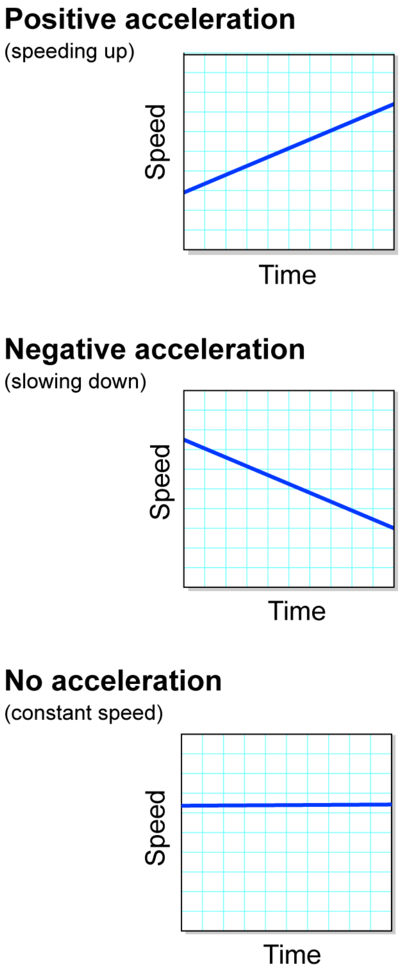


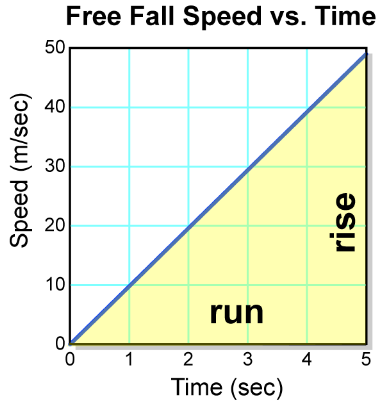
Figure 2.19: *Examples of graphs showing different accelerations.*

Calculating acceleration from the speed vs. time graph

Slope You know that the slope of a graph is equal to the ratio of *rise* to *run*. On the speed versus time graph, the rise and run have special meanings, as they did for the distance versus time graph. The *rise* is the amount the speed changes. The *run* is the amount the time changes.

Acceleration and slope Remember, acceleration is the change in speed over the change in time. This is *exactly the same* as the rise over run for the speed versus time graph. The slope of an object's speed versus time graph is equal to its acceleration. Figure 2.20 shows how to find the acceleration of a ball in free fall from a speed versus time graph.

Make a triangle to get the slope To determine the slope of the speed versus time graph, take the rise (change in speed) and divide by the run (change in time). It is helpful to draw a triangle on the graph to help figure out the rise and run. The rise is the height of the triangle. The run is the length of the base of the triangle. The graph is for a ball in free fall, so you should not be surprised to see that the slope is 9.8 m/sec^2, the acceleration due to gravity.



$$\text{Slope} = \frac{\text{rise}}{\text{run}} = \frac{49\ \text{m/sec}}{5\ \text{sec}} = 9.8\ \text{m/sec}^2$$

Figure 2.20: *The slope of a speed versus time graph equals the acceleration.*

Calculating acceleration

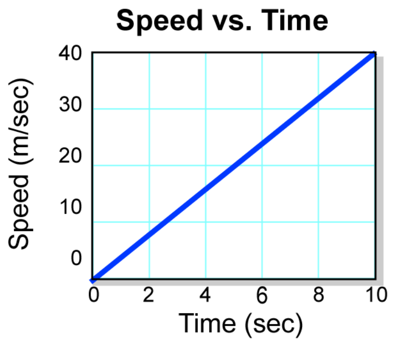
Calculate the acceleration shown by the speed versus time graph at right.

1. Looking for: You are asked for the acceleration in meters per second per second.

2. Given: You are given a graph of speed versus time.

3. Relationships: The acceleration is equal to the slope of the line.

4. Solution: The rise is 40 m/sec, and the run is 10 sec. Dividing the two gives an acceleration of 4 m/sec^2.



Your turn...

a. Calculate the acceleration shown by the graph in Figure 2.21. **Answer:** 1.0 m/sec^2

b. Calculate the acceleration shown by the graph in Figure 2.17. **Answer:** 0 m/sec^2 because the rise is 0 m/sec.

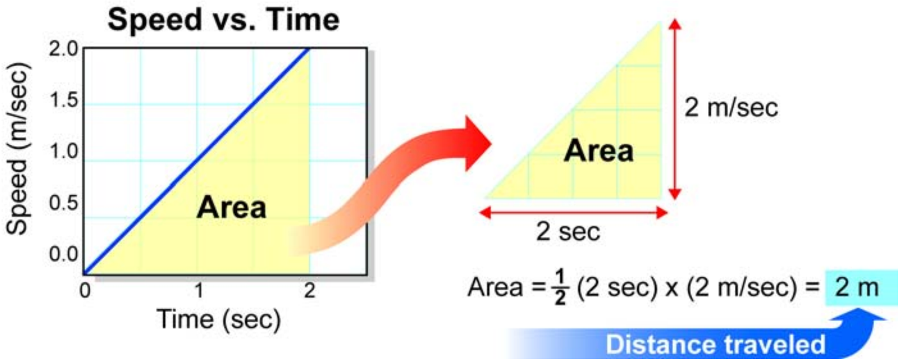
Distance on an accelerated motion graph

A ball rolling downhill

Consider an experiment with a ball rolling downhill. The speed of the ball increases as it rolls downward. The speed versus time graph looks like Figure 2.21. This graph shows a speed that starts at zero. Two seconds later, the speed is two meters per second. A speed versus time graph that shows any slope (like this one does) tells you there is acceleration because the speed is changing over time.

The distance traveled when speed is changing

The speed versus time graph gives us a way to calculate the distance an object moves even when its speed is changing. The distance is equal to the area on the graph, but this time the area is a triangle instead of a rectangle. The area of a triangle is one-half the base times the height. The base is equal to the time, just as before. The height is equal to the speed of the ball at the end of two seconds. For the graph in the example, the ball moves two meters from zero to two seconds.



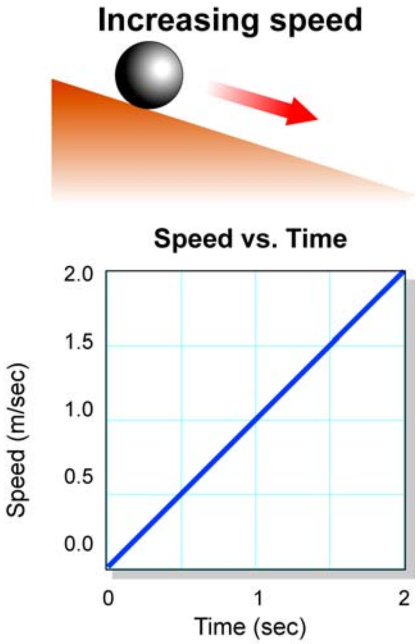


Figure 2.21: *The speed versus time graph for a ball rolling down a hill.*

2.4 Section Review

1. Explain how to calculate the slope of a graph.
2. What does the slope of a position versus time graph represent?
3. Draw the position versus time graph and the speed versus time graph for an object moving at a constant speed of 2 m/sec.
4. How can you use a speed versus time graph to find an object's acceleration?

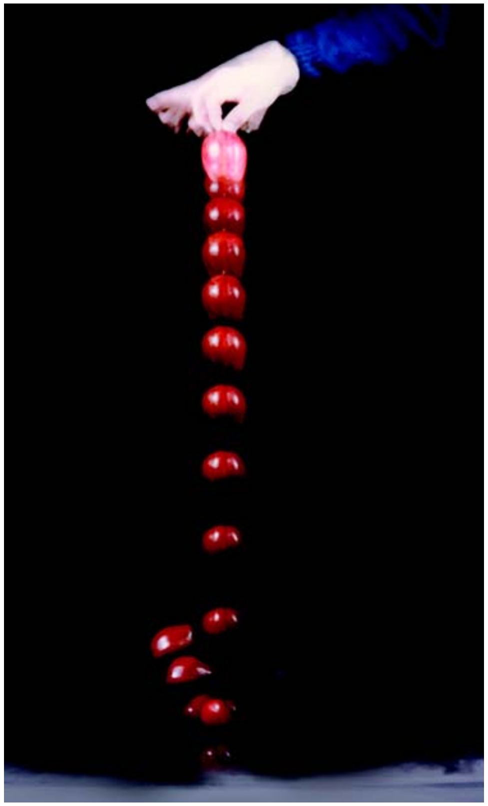
Revealing the secrets of motion

How can a tiny hummingbird fly backward? How does it manage to hover in mid-air as it sips nectar from a flower? For years, answers to these questions eluded naturalists, because a hummingbird's wings beat an average of sixty times per second, so fast that their movement appears blurred to our eyes.

In 1936, a young MIT professor unlocked the secrets of hummingbird flight using a tool he invented to study rotating engines. Harold Edgerton, Ph.D., created a system for taking high-speed photographs of moving objects using a *strobe light* in a darkened room.

Edgerton left his camera shutter open while his strobe light flashed quick, bright pulses of light that lasted only 1/100,000 of a second, with a period of darkness 1/500 of a second between each flash. He invented a device to pull film at a constant speed through his camera, enabling him to take about 540 separate pictures in a single second. The resulting photos revealed that hovering hummingbirds don't beat their wings up and down like other birds. Instead, they move them forward and backward, tracing a figure-eight. This pattern allows them to generate lift during both parts of their wings' beat making hovering possible.

Newton's laws caught on film



"Doc" Edgerton spent a lifetime using his strobe light to illuminate aspects of motion that we aren't normally able to see. His famous photo, *Newton's apple*, is a striking demonstration of acceleration due to gravity. To create this photo, he set his strobe light to flash sixty times per second, and had an assistant drop the apple in a darkened room. By capturing all of the resulting images on a single piece of film, he shows very clearly how the apple accelerates as it falls.

Capturing the moment of impact

Prior to World War II, Edgerton studied another of Newton's laws, an action-reaction pair—the firing of a bullet and the "kickback" of the pistol. Edgerton proved that the pistol's upward "kick" did not affect the bullet's path as was previously thought. Edgerton's photos showed that the gun did not begin its upward motion until after the bullet had left the barrel.

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When U.S. Army officials learned of Edgerton's work, they asked him to assist in testing the effects of various types of shells on armor. They wanted to photograph the exact moment of impact. Edgerton invented a new way to trigger the flash—he placed a microphone in front of the target and connected it to his flash unit. The sound wave from the bullet set off the flash and Edgerton obtained clear photos of the moment the bullet pierced the armor. Edgerton's work helped the Army develop better materials for fighting World War II.

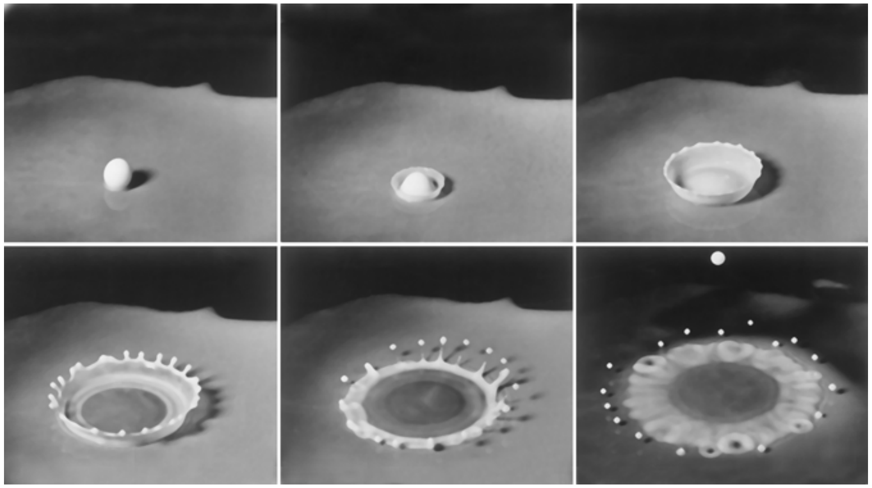
Edgerton also developed a strobe flash that allowed Allied troops to take aerial reconnaissance photos of nighttime movements of enemy troops. His strobes were used in the nights immediately preceding the D-Day invasion of Normandy. In 1946, Edgerton was awarded the Medal of Freedom for this work.

Finding the perfect swing

Edgerton's photographic techniques are also used to analyze motion in sports. In this photograph of a golfer's swing, you can see that the head of the golf club gets faster toward the bottom of the swing because it moves a greater distance between flashes of the strobe. Photographs like these can help an athlete evaluate and improve his or her technique and performance. For example, a high-speed photograph records a player's stance and timing through a swing so that improvements can be made.

An irrepressible curiosity

Although Edgerton is perhaps best remembered as a photographer, he saw himself primarily as a scientist. He wanted to know what could be revealed about motion in all sorts of contexts. Strobe photography was his tool for doing that. His curiosity extended beyond studies of birds, falling apples, ammunition, and sports. In his lifetime, he showed us how red blood cells move through capillaries, how tiny marine animals dart about, and how an atomic bomb explodes. Yet he never lost his appreciation for the beauty of the simplest motions like the splash of a milk drop on a table.



Photos ©Harold & Esther Edgerton Foundation, 2004, courtesy Palm Press, Inc.

Questions:

1. What did Edgerton's photos reveal about hummingbird flight?
2. Describe how Edgerton's photo of an apple's falling motion shows that the apple is accelerating.
3. Make a list of other examples where high-speed photography could be used to better understand what is happening in a situation involving motion.

Chapter 2 Review

Understanding Vocabulary

Select the correct term to complete the sentences.

velocity
Newton's first law
newton
Newton's second law
slope
force
inertia
free fall
weight
acceleration
net force
terminal speed
acceleration due to gravity

Section 2.1

1. A ____ is required to change motion.
2. "Objects want to keep doing the same thing" is a way of stating ____.
3. An object with more mass also has more ____.
4. The total of all the forces acting on an object is called the ____.
5. The ____ is the metric unit of force.

Section 2.2

6. The rate at which speed changes is called ____.
7. ____ relates force, mass, and acceleration in the equation $F = ma$.

Section 2.3

8. A falling object under the influence of only gravity is in ____.
9. The ____ on Earth is equal to 9.8 m/sec^2.
10. Speed with direction is called ____.
11. The force of gravity on an object is its ____.
12. When the force due to gravity equals the force due to air resistance, the speed of a falling object is called its ____.

Section 2.4

13. The ____ of a line is found by dividing the rise by the run.

Reviewing Concepts

Section 2.1

1. Define the term *force* and give three examples of forces
2. Give an example of Newton's first law in everyday life.
3. Explain why Newton's first law is also known as the law of inertia.
4. List two units for measuring mass and two units for measuring force.
5. One newton is the _____ it takes to change the _____ of a _____ mass by _____ in one second.

Section 2.2

6. If an object has an acceleration of 20 cm/sec^2, what do you know about how its speed changes over time?
7. Give two ways the unit "meter per second per second" can be abbreviated.
8. An object accelerates if its speed changes. What is the other way an object can accelerate (without changing speed)?
9. Write the equation for Newton' second law that you would use in each of the following scenarios. Let F = force, m = mass, and a = acceleration:
    a. You know mass and acceleration and want to find the force.
    b. You know mass and force and want to find the acceleration.
    c. You know force and acceleration and want to find the mass.
10. What is the acceleration of a car moving at a steady speed of 50 mph?
11. Give an example of Newton's second law in everyday life.
12. Explain how the unit of 1 newton is defined.

Section 2.3

13. By how much does the speed of an object in free fall change each second?
14. A ball is thrown straight up into the air. As it moves upward, its speed ____ by ____ each second. As it falls back down, its speed ____ by ____ each second.
15. What is the difference between speed and velocity?

16. Can an object have a negative speed? Can it have a negative velocity?
17. Can an object have a speed of zero while it has an acceleration that is not zero? Explain.
18. An astronaut carries a rock from the moon to Earth. Is the rock's mass the same on Earth as on the moon? Is its weight the same? Explain.
19. What is the direction of air resistance on a falling object?
20. Which two forces are equal when an object is at its terminal speed?

Section 2.4

21. Explain how to calculate the slope of a line.
22. The slope of a position vs. time graph is equal to the object's ____.
23. Sam rolls down his driveway on a skateboard while Beth keeps track of his position every second for 15 seconds. When they make a graph of the data, the position vs. time graph is a curve that gets steeper as time increases. What does this tell you about Sam's speed?
24. A graph is made of the speed vs. time of a plane as it flies from San Francisco to the Kahului Airport on Maui. How could the distance traveled by the plane be calculated from the graph?
25. The slope of a speed vs. time graph is equal to the object's ____.
26. Sketch the speed vs. time graph for an object moving at a constant speed of 3 m/sec.

Solving Problems

Section 2.1

1. Order the following mass measurements from smallest to largest: 0.5 kilograms, 1,000 grams, 5 kilograms, 50 grams.
2. Dani and Gina are pushing on a box. Dani pushes with 250 N of force and Gina pushes with 100 N of force.
    a. What is the net force if they both push in the same direction?
    b. What is the net force if they push in opposite directions?

Section 2.2

3. A car accelerates from 0 to 20 m/sec in 10 seconds. Calculate its acceleration.
4. During a race, you speed up from 3 m/sec to 5 m/sec in 4 seconds.
    a. What is your change in speed?
    b. What is your acceleration?
5. Marcus is driving his car at 15 km/hr when he brakes suddenly. He comes to a complete stop in 2 seconds. What was his acceleration in km/hr/sec? Was his acceleration positive, negative, or zero?
6. You start from rest and ski down a hill with an acceleration of 2 m/sec^2. Find your speed at the following times:
    a. 1 second
    b. 2 seconds
    c. 3 seconds
    d. 10 seconds
7. Use your knowledge of Newton's second law to answer the following questions:
    a. What is the net force required to accelerate a 1,000-kg car at 3 m/sec^2?
    b. You pull your little cousin in a wagon. You must pull with a net force of 50 N to accelerate her at 2 m/sec^2. What's her mass?
    c. When a 10-kg object is in free fall, it feels a force of 98 N. What is its acceleration?

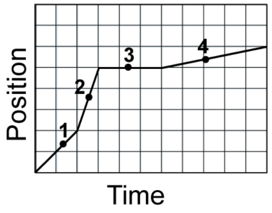
Section 2.3

8. You drop a ball from the edge of a cliff. It lands 4 seconds later.
    a. Make a table showing the ball's speed each second for 4 seconds.
    b. What is the ball's average speed during the first second it is in free fall?
    c. What is the ball's average speed for the whole 4 second?
    d. What distance does the ball fall during the 4 seconds?
9. During a science experiment, your teacher drops a tennis ball out of a window. The ball hits the ground 3 seconds later.
    a. What was the ball's speed when it hit the ground? Ignore air resistance.
    b. What was the ball's average speed during the 3 seconds?
    c. How high is the window?

10. Answer the following questions about mass and weight:
    a. How many newtons does a 5-kg backpack weigh on Earth?
    b. How many newtons does a 5-kg backpack weigh on the moon?
    c. Aya's mass is 45 kg. What is her weight in newtons on Earth?
    d. What is Aya's mass on the moon?
    e. What is Aya's weight in Newtons on the moon?

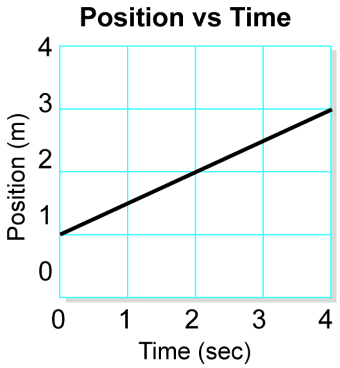
Section 2.4

11. Rank the four points on the position vs. time graph in order from slowest to fastest.



12. Draw the position vs. time graph for a person walking at a constant speed of 1 m/sec for 10 seconds. On the same axes, draw the graph for a person running at a constant speed of 4 m/sec.

13. Calculate speed from the position vs. time graph to the right. Show your work.



14. Draw the position vs. time graph for an object that is not moving.

15. Why is the position vs. time graph for an object in free fall a curve?

16. Draw the speed vs. time graph showing the same motion as the position vs. time graph to the right.

17. Draw a speed vs. time graph for a car that starts at rest and steadily accelerates until it is moving at 40 m/sec after 20 seconds. Then calculate the car's acceleration and the distance it traveled during the 20 seconds.

18. Draw a speed vs. time graph for an object accelerating from rest at 2 m/sec^2.

Applying Your Knowledge

Section 2.1

1. Aristotle, Galileo Galilei, and Sir Isaac Newton all developed their own theories about motion. Research to find out how each scientist changed what people believed about motion. Were all of their theories correct?

2. Write about Newton's three laws of motion, giving examples from your own life. If you have ever ridden in an automobile, taken a bike ride, played a sport, or walked down the street you have experienced Newton's laws. Be sure to describe the effects of all three of Newton's laws on the activities you choose.

Section 2.2

3. Research the accelerations from 0-60 mph for ten different car models and make a table showing: the model of car, the mass of the car, the amount of time to go from 0-60 mph (in seconds), and the acceleration (in mph/sec). Is there any relationship between the masses of the cars and their accelerations? Explain possible reasons.

4. Research the following: What is the fastest acceleration of a human in a sprint race? What is the fastest acceleration of a race horse? Which animal using only its muscles is capable of the fastest acceleration?

Section 2.3

5. A falling object reaches terminal speed when the force of gravity is balanced by the air resistance of the object. Explain this in terms of Newton's first and second laws.

6. Imagine what it would be like if there suddenly were no air resistance. Explain three differences you might notice in the world around you.

Section 2.4

7. As Joseph starts to ride his bike, he accelerates at a constant 1 m/sec^2 from rest to final speed of 10 m/sec.
    a. Make a table of his speed each second from zero to ten seconds. Make a speed vs. time graph from your table.
    b. Make a table of his position each second from zero to ten seconds. Make a position vs. time graph from your table.