Read to Learn

Main Idea **We are pulled to the ground by the same force that keeps the Moon orbiting Earth, and the planets orbiting the Sun.**

Why Would Air Make a Difference?

The student in the diagram has just dropped a solid rubber ball and a feather from the same height at the same time. The ball has covered a greater distance than the feather in the same amount of time. This means that the ball has fallen at a greater rate. Should we conclude that heavier objects fall faster than lighter objects?

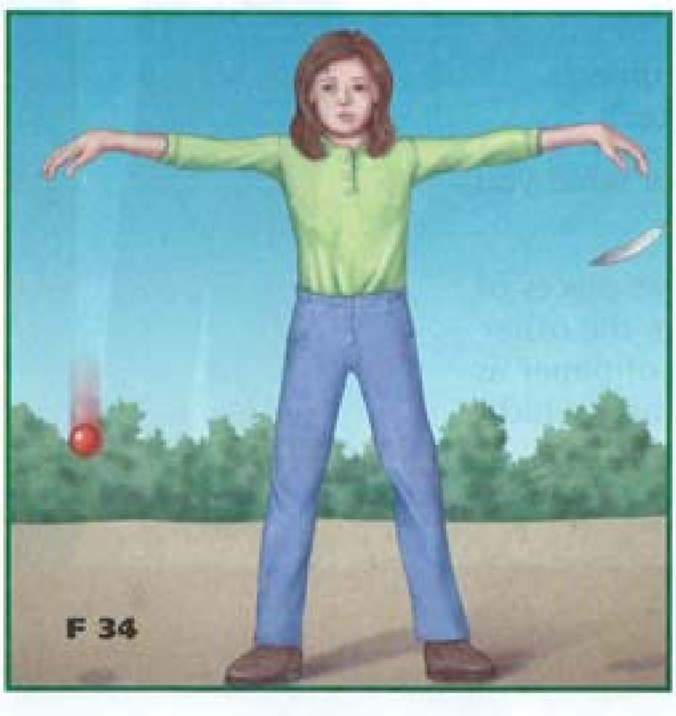
It is important to realize that when the ball and feather are falling, they both must pass through air. Air offers resistance to the motion of objects through it. In the case of the ball and feather, air resistance acts against the feather's motion more than it does against the ball's motion. As a result, the air slows the feather more than it does the ball, and the ball falls farther during the same amount of time.

What would happen, though, if the air were removed so that air resistance disappeared? There is no air on the Moon. If you were to drop a hammer and a feather at the same time on the Moon, would they still fall at different rates? No. Since there is no air resistance, the ball and the feather would fall at the same rate!

Scientists have learned that when the effects of air resistance are removed, objects of different weights do, indeed, fall at the same rate. In addition, air resistance may be too small to matter for objects that are fairly compact. Over short distances such objects fall at the same rate even in air.

How does air affect how a feather falls to the ground?

Do the ball and feather fall at the same rate on Earth as they do on the Moon? Explain.



Before the parachutes open, these skydivers are in *free fall*—falling toward Earth with the acceleration caused by gravity.

What Makes Objects Fall at the Same Rate?

Aristotle was a philosopher who lived in ancient Greece nearly 2,400 years ago. He believed that heavy things fall faster than lighter things. Aristotle's teachings were accepted for nearly 2,000 years after his death.

In the early 1600s, however, Galileo challenged Aristotle's ideas. Galileo reasoned that objects fall at the same rate (ignoring air resistance). To test his ideas about falling objects, Galileo carried out experiments that involved rolling marbles down ramps. He also talked about dropping two objects with different weights off a tall tower to show that they would hit the ground at the same time. Galileo concluded that objects accelerate steadily as they fall and that an object's weight (or mass) does not affect how fast it accelerates when falling.

We know today that Galileo was right. An object is pulled to Earth by gravity, an attraction between the mass of Earth and the mass of the object. Objects with a large mass are pulled on by gravity with more force, but they also have more inertia. (Remember that an object's inertia is its resistance to a change in motion.) This extra resistance to motion exactly offsets the greater pull of gravity on them. Therefore, objects with greater mass fall with the same acceleration as less massive objects!

What force pulls falling objects toward the ground at the same rate?

The 2-kg object is pulled on by twice the force, but its mass is also twice as great, so it has the same acceleration as the 1-kg object.

What Is the Acceleration of Falling Objects?

There is a story that says that a falling apple may have set Isaac Newton to thinking about gravity. In the late 1660s, there was a plague (very bad illness that spread very easily) in Cambridge, England, where Newton had gone to college. To avoid the plague, he went home to the countryside. The legend says Newton was sitting under an apple tree one day when an apple hit him on the head. The legend may or may not be true. However, an idea did hit Newton. That idea was that the force that pulls an apple to the ground is the same force that keeps the Moon in its orbit around Earth.

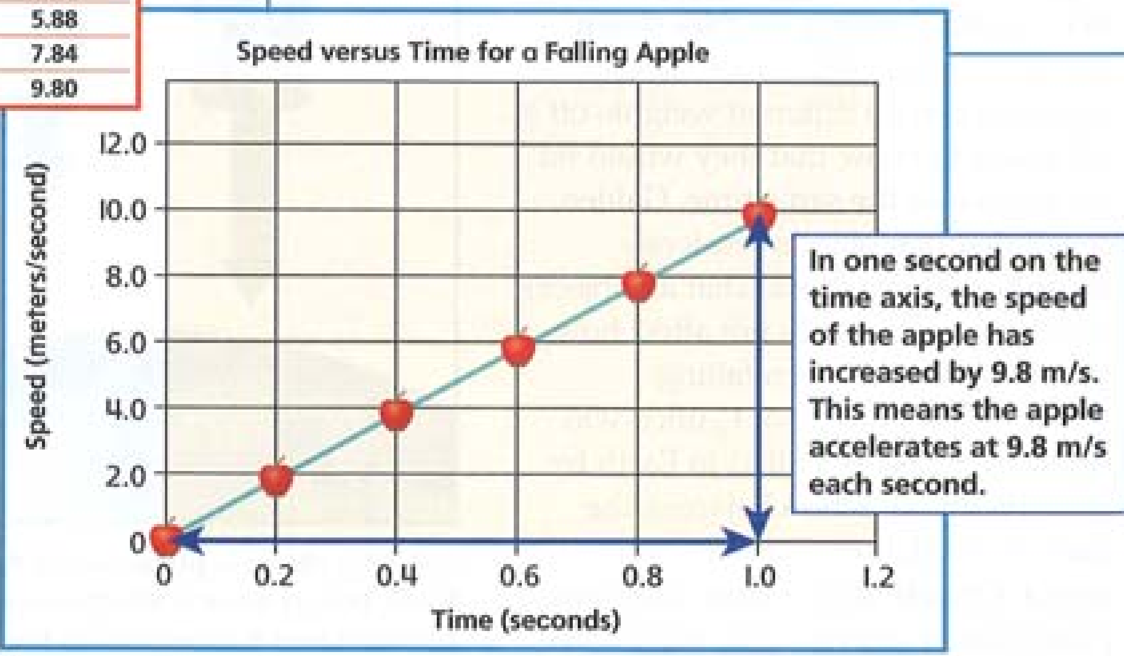
The graph shows how an apple's speed changes as it falls from a tree. Since the apple's speed changes, it must be accelerating. This, in turn, means that it is acted on by an unbalanced force. The force acting on the falling apple is gravity. We give the force of gravity on any object a special name—**weight**. It is the weight of the apple that makes it accelerate to the ground. You can find

Speed Versus Time for a Falling Apple

Time (s)	Speed (m/s)
0.0	0.00
0.2	1.96
0.4	3.92
0.6	5.88
0.8	7.84
1.0	9.80

READING Graphs

What if the apple fell for a full two seconds? Ignoring air resistance, what speed would it reach?



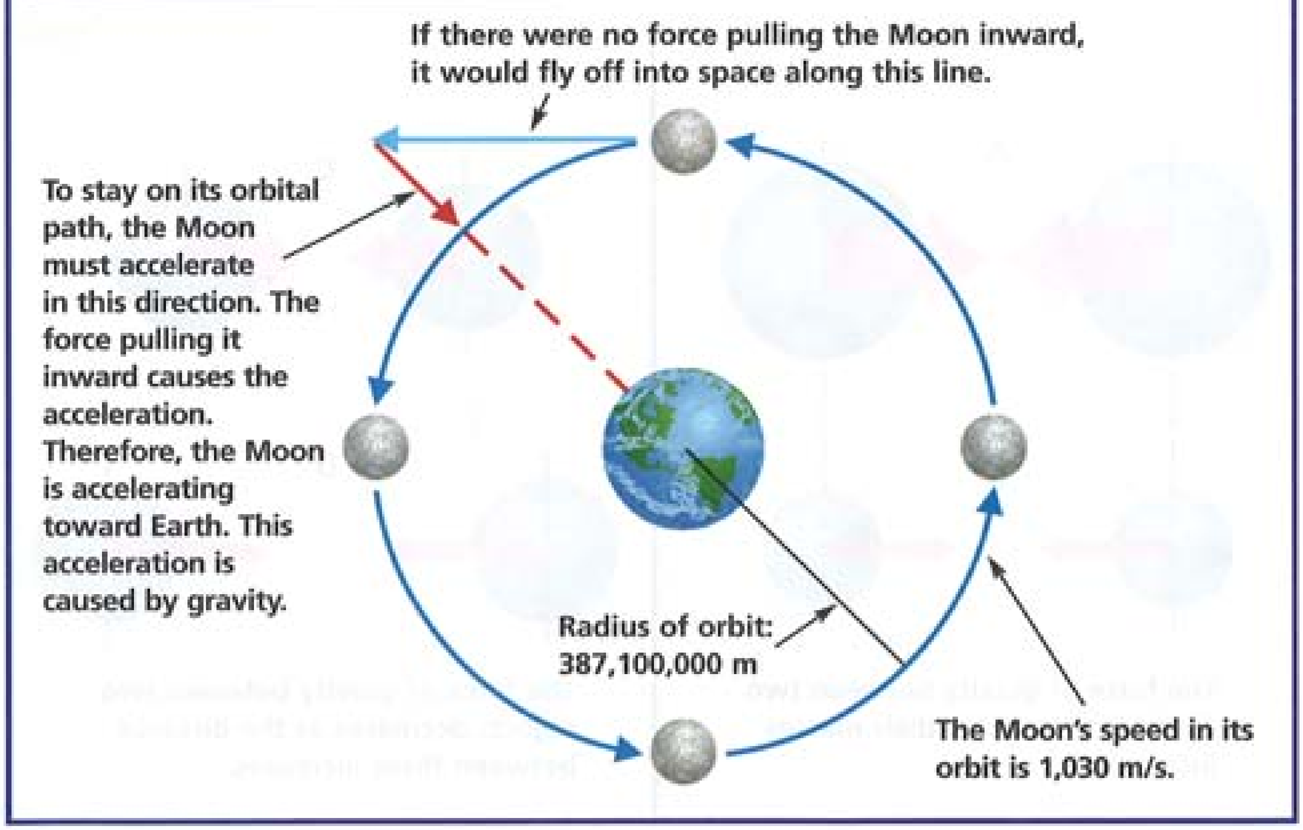
the weight in newtons of any object by multiplying its mass in kilograms by 9.8. If the apple has a mass of 0.4 kg for example, its weight is 0.4 x 9.8 = 3.92 N.

The weight or mass of an object does not affect how fast it accelerates when falling (if we ignore air resistance). This means that all objects accelerate to the ground at 9.8 meters per second each second. Put another way, the speed of any object falling to the ground increases by 9.8 meters per second each second. However, as you will soon learn, this value is only true for objects falling near the surface of Earth.

Isaac Newton once wrote, "I began to think of gravity extending to the orb [orbit] of the Moon." He wondered if the gravity of Earth could be the force that holds the Moon in its orbit. Just as there is a force between an apple and Earth, there is a force between the Moon and Earth. The force is stronger if the objects are more massive, but it is weaker the farther they are apart. The Moon is much more massive than an apple. However, the Moon is also much farther from Earth's surface than an apple hanging on a tree is. Even so, the same force that pulls the apple to the ground keeps the Moon from flying off into outer space. A combination of the Moon's inertia and the force of gravity between Earth and Moon keeps the Moon orbiting Earth.

How fast do falling objects on Earth fall toward the ground?

The Moon's Acceleration



How Can Gravity Be Universal?

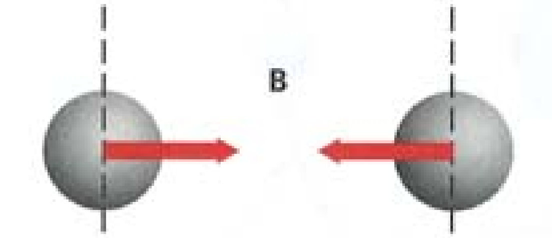
When Isaac Newton discovered that Earth's gravity held the Moon in orbit, he next applied his ideas to the planets in the solar system. Could the Sun's gravity hold the planets in their orbits? First, Newton had to work out how the strength of the force depends on the mass of the Sun and each planet.

Newton decided that as mass increases, the force of gravity also increases. From his third law of motion, he knew that two objects pull on each other due to gravity. Then he reasoned that increasing the mass of either object will increase the force of gravity.

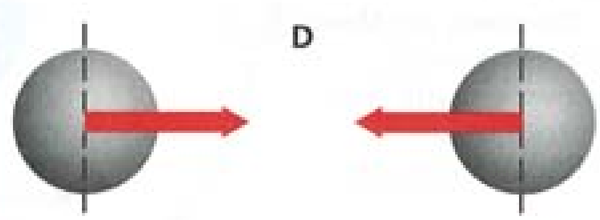
In thinking about the Moon, Newton had already inferred how gravity would change with distance. Putting all of his ideas together, he arrived at another law. This is *Newton's law of universal gravitation:* The force of gravity between two objects increases with the mass of the objects and decreases with the distance between them squared.

Newton's law of gravity is "universal" because it applies to any objects, not just moons, planets, and stars. We could find, for example, the force of gravity between two cars in a parking lot. For light objects the force of gravity is quite weak—it will not pull two parked cars together. For massive objects like moons, planets, and stars, though, the masses are so large that the force of gravity becomes very large also.

What does it mean to say that the law of gravity is universal?



The force of gravity between two objects increases as their masses increase.



The force of gravity between two objects decreases as the distance between them increases.

Inquiry Skill BUILDER

SKILL Use Numbers

What Do I Weigh on Other Worlds?

The Sun, planets, and moons in the solar system have different masses and radii. This causes the force of gravity at their surfaces to vary from world to world (for a gaseous planet, the "surface" is the top of its atmosphere). As the mass of any world increases, surface gravity tends to be stronger. However, as the radius increases, surface gravity tends to weaken. How would your weight change from one world to the next?

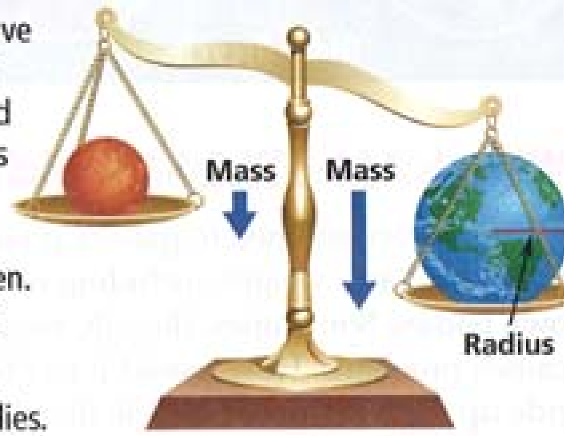


Table 1 lists gravity multipliers for solar system bodies. These values show the combined effect of the objects' different masses and radii on surface gravity compared with Earth. You can use the gravity multipliers to find your weight on other worlds. Just multiply your weight on Earth by the gravity multiplier for the new world. On Neptune, for example, your weight would be your weight on Earth multiplied by 1.1.

Table 1

Object	Gravity (Earth = 1)
Sun	28
Moon	0.16
Mars	0.38
Jupiter	2.6
Saturn	1.07
Neptune	1.1
Venus	0.91
Mercury	0.38
Uranus	0.91

Procedure

1. **Analyze** Study Tables 1 and 2. Look carefully to see how numbers were used in the examples in Table 2.
2. **Use Numbers** Copy and complete Table 2.

Table 2

World	Weight of a 250-Pound Astronaut	Your Weight in Pounds
Sun	7,000 lb	
Moon		
Mars	95 lb	
Jupiter		
Saturn		
Neptune		
Venus		
Mercury		
Uranus	227.5 lb	

Drawing Conclusions

1. **Predict** A student who weighs 95 pounds on Earth has a mass of about 43 kg. What would the student's mass be on each world above?
2. **Infer** Saturn has much more mass than Earth, but your weight on Saturn is about the same as on Earth. How is this possible?

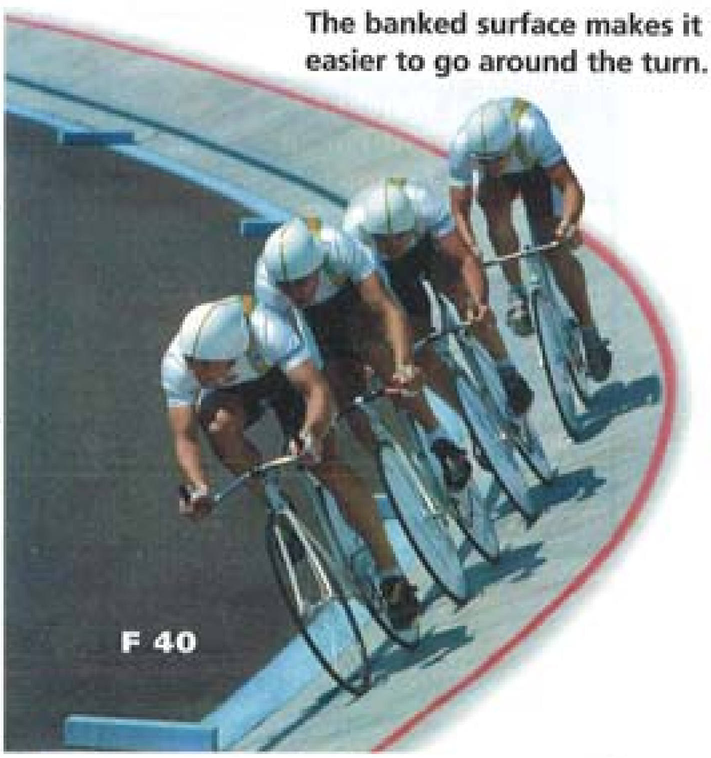
When Is Added Weight Helpful?

We are accustomed to gravity giving things on Earth weight, including our own bodies. Sometimes, though, weight causes problems. How would it feel to ride up a hill on an old bicycle like the one on the left? Compared with the newer one on the right, the older bike is so much more massive that it would take a lot more force to accelerate it. Which would you rather ride?

Older bicycles were made with steel frames. While steel is strong, it is also very heavy. Some modern bicycle frames are made with steel alloys, titanium, aluminum, or carbon fiber. These materials are a great deal lighter than plain steel, and bikes made with them are much easier to pedal. Of course, the lightweight materials are also much more expensive than steel!

In cycling, weight does offer certain advantages. The weight of the rider and bicycle presses the tires against the ground. This downward force creates increased friction between the tires and the road, giving the tires traction. If it were not for the friction, the tires could not push on the road surface to drive the rider forward.

Bicycle racers often travel on a circular path at high speed. There must be a force acting inward on them to change their direction of travel. The banked track they are riding on uses their weight to help provide this force. The weight of each bike and rider presses into the track through the tires. The track, in turn, pushes back through the tires on each bike and rider. Due to the tilt of the track surface, some of this return push is directed inward and can act as the force that changes each bike's direction of travel.



The banked surface makes it easier to go around the turn.

READING **Draw Conclusions**
How is added weight helpful in cycling?

Lesson Review

L·I·N·K·S

MATH LINK

Solve this problem. Look at the tables on page F39. How much would the astronaut weigh on a planet with 1.5 times as much gravity as Neptune?

WRITING LINK

Writing a Story You are a passenger on a space-shuttle flight. You're in orbit. For the first time, you cannot feel your weight. Write a story describing what it feels like to be weightless. Include dialogue with a friend on the ground. Turn your story into a play to perform.

MUSIC LINK

Write a song. Think about what it might be like to live on a world where you weigh half as much as you do now. Write a song describing your experiences.

TECHNOLOGY LINK

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Why It Matters

On a flat road, the only force available for making cars go around a turn is the friction between the tires and the road surface. In wet or icy weather, the friction may not be strong enough, and the cars can slide off and crash on the turn. If the road is banked like the bicycle race track, though, the inward push of the road surface helps cars to make the turn. The same sort of banking is also done when making auto racetracks.

e-Journal Visit our Web site **www.science.mmhschool.com** to do a research project on gravity.

Think and Write

1. What causes objects to fall?
2. Ignoring air resistance, why do objects with different masses fall at the same rate?
3. A rubber ball is dropped off a tall tower. After one second, how fast will it be traveling?
4. INQUIRY SKILL **Use Numbers** Two planets in a distant solar system have the same radius but different masses. On which world would you weigh more? Why?
5. **Critical Thinking** How could you carry out a demonstration on Earth of a feather falling at the same rate as a bowling ball?