Gravity

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Printed: March 23, 2014

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CHAPTER 1 Gravity

Lesson Objectives

- Define gravity.
- State Newton's law of universal gravitation.
- Explain how gravity affects the motion of objects.

Lesson Vocabulary

- gravity
- law of universal gravitation
- orbit
- projectile motion

Introduction

Long, long ago, when the universe was still young, an incredible force caused dust and gas particles to pull together to form the objects in our solar system (see **Figure** 1.1). From the smallest moon to our enormous sun, this force created not only our solar system, but all the solar systems in all the galaxies of the universe. The force is gravity.

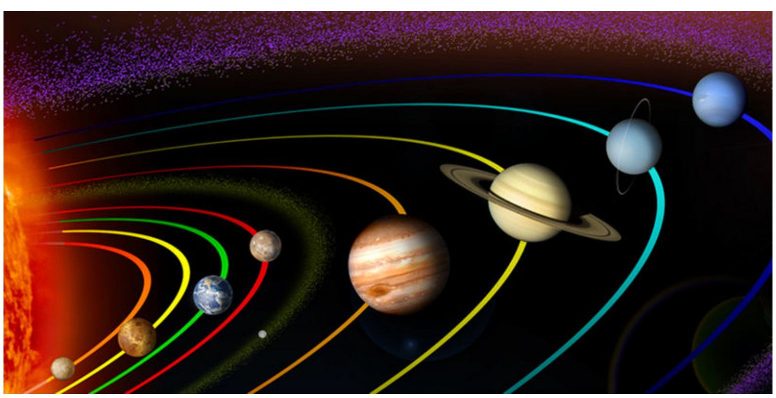

FIGURE 1.1
Gravity helped to form our solar system and all the other solar systems in the universe.

Defining Gravity

Gravity has traditionally been defined as a force of attraction between two masses. According to this conception of gravity, anything that has mass, no matter how small, exerts gravity on other matter. The effect of gravity is that objects exert a pull on other objects. Unlike friction, which acts only between objects that are touching, gravity also acts between objects that are not touching. In fact, gravity can act over very long distances.

Earth's Gravity

You are already very familiar with Earth's gravity. It constantly pulls you toward the center of the planet. It prevents you and everything else on Earth from being flung out into space as the planet spins on its axis. It also pulls objects above the surface, from meteors to skydivers, down to the ground. Gravity between Earth and the moon and between Earth and artificial satellites keeps all these objects circling around Earth. Gravity also keeps Earth moving around the sun.

Gravity and Weight

Weight measures the force of gravity pulling on an object. Because weight measures force, the SI unit for weight is the **newton (N)**. On Earth, a mass of 1 kilogram has a weight of about 10 newtons because of the pull of Earth's gravity On the moon, which has less gravity, the same mass would weigh less. Weight is measured with a scale, like the spring scale in **Figure** 1.2. The scale measures the force with which gravity pulls an object downward.

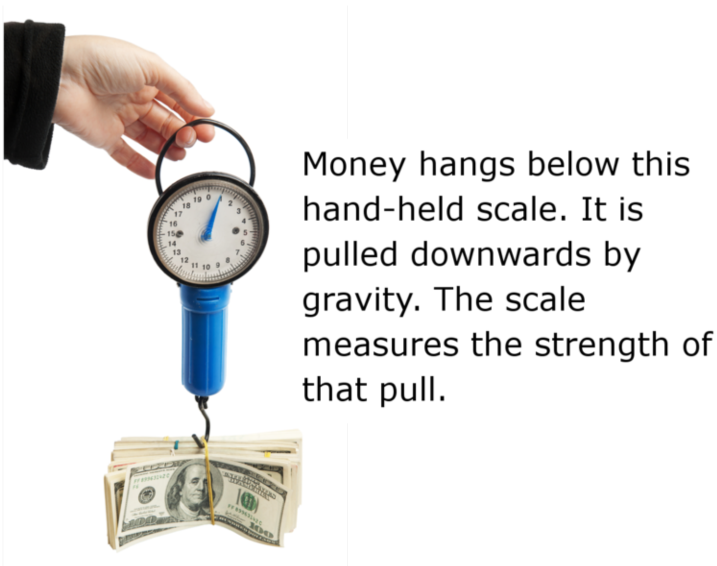

FIGURE 1.2
A scale measures the pull of gravity on an object.

Law of Gravity

People have known about gravity for thousands of years. After all, they constantly experienced gravity in their daily lives. They knew that things always fall toward the ground. However, it wasn't until Sir Isaac Newton developed his law of gravity in the late 1600s that people really began to understand gravity. Newton is pictured in **Figure** 1.3.

Newton's Law of Universal Gravitation

Newton was the first one to suggest that gravity is universal and affects all objects in the universe. That's why his law of gravity is called the **law of universal gravitation**. Universal gravitation means that the force that causes

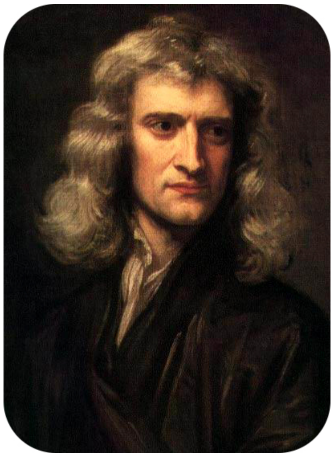

FIGURE 1.3
Sir Isaac Newton discovered that gravity is universal.

an apple to fall from a tree to the ground is the same force that causes the moon to keep moving around Earth. Universal gravitation also means that while Earth exerts a pull on you, you exert a pull on Earth. In fact, there is gravity between you and every mass around you —your desk, your book, your pen. Even tiny molecules of gas are attracted to one another by the force of gravity.

Newton's law had a huge impact on how people thought about the universe. It explains the motion of objects not only on Earth but in outer space as well. You can learn more about Newton's law of gravity in the video at this URL: http://www.youtube.com/watch?v=O-p8yZYxNGc .

Factors that Influence the Strength of Gravity

Newton's law also states that the strength of gravity between any two objects depends on two factors: the masses of the objects and the distance between them.

- Objects with greater mass have a stronger force of gravity. For example, because Earth is so massive, it attracts you and your desk more strongly than you and your desk attract each other. That's why you and the desk remain in place on the floor rather than moving toward one another.
- Objects that are closer together have a stronger force of gravity. For example, the moon is closer to Earth than it is to the more massive sun, so the force of gravity is greater between the moon and Earth than between the moon and the sun. That's why the moon circles around Earth rather than the sun. This is illustrated in **Figure** 1.4.

You can apply these relationships among mass, distance, and gravity by designing your own roller coaster at this URL: http://www.learner.org/interactives/parkphysics/coaster/ .

Einstein's Theory of Gravity

Newton's idea of gravity can predict the motion of most but not all objects. In the early 1900s, Albert Einstein came up with a theory of gravity that is better at predicting how all objects move. Einstein showed mathematically that gravity is not really a force in the sense that Newton thought. Instead, gravity is a result of the warping, or curving, of space and time. Imagine a bowling ball pressing down on a trampoline. The surface of the trampoline would curve downward instead of being flat. Einstein theorized that Earth and other very massive bodies affect space and time around them in a similar way. This idea is represented in **Figure** 1.5. According to Einstein, objects curve toward one another because of the curves in space and time, not because they are pulling on each other with a force

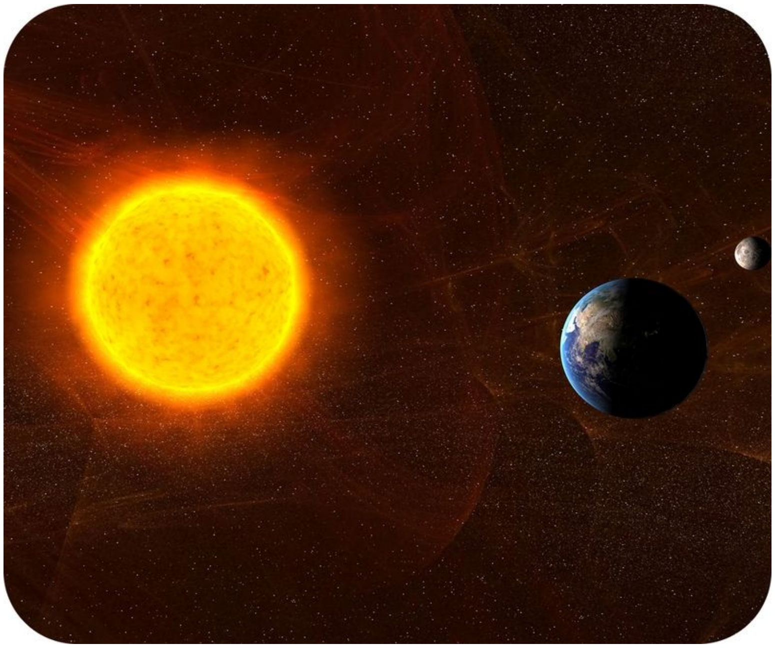

FIGURE 1.4
The moon keeps moving around Earth rather than the sun because it is much closer to Earth.

of attraction as Newton thought. You can see an animation of Einstein's theory of gravity at this URL: http://einstein.stanford.edu/Media/Einsteins_Universe_Anima-Flash.html . To learn about recent research that supports Einstein's theory of gravity, go to this URL: http://www.universetoday.com/85401/gravity-probe-b-confirms-two-of-einsteins-space-time-theories/ .

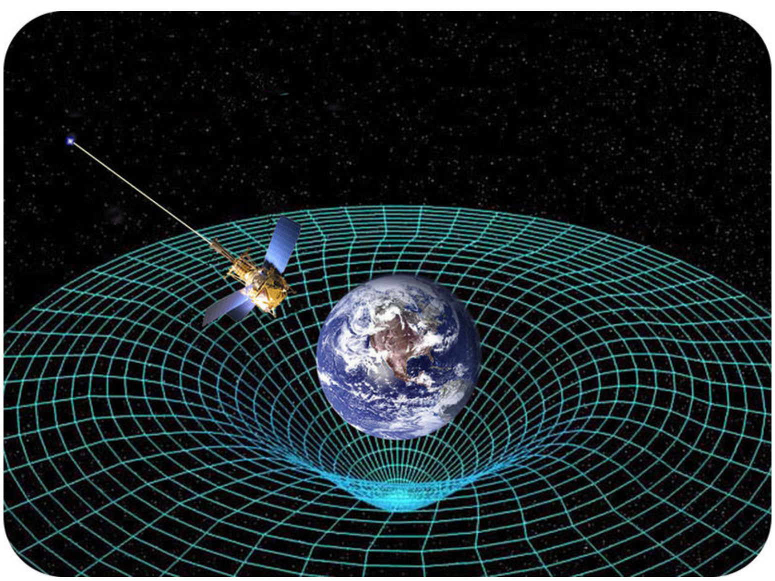

FIGURE 1.5
Einstein thought that gravity is the effect of curves in space and time around massive objects such as Earth. He proposed that the curves in space and time cause nearby objects to follow a curved path. How does this differ from Newton's idea of gravity?

Gravity and Motion

Regardless of what gravity is —a force between masses or the result of curves in space and time —the effects of gravity on motion are well known. You already know that gravity causes objects to fall down to the ground. Gravity affects the motion of objects in other ways as well.

Acceleration Due to Gravity

When gravity pulls objects toward the ground, it causes them to accelerate. Acceleration due to gravity equals 9.8 m/s^2. In other words, the velocity at which an object falls toward Earth increases each second by 9.8 m/s. Therefore, after 1 second, an object is falling at a velocity of 9.8 m/s. After 2 seconds, it is falling at a velocity of 19.6 m/s (9.8 m/s $\times$ 2), and so on. This is illustrated in **Figure** 1.6. You can compare the acceleration due to gravity on Earth, the moon, and Mars with the interactive animation called "Freefall" at this URL: http://jersey.uoregon.edu/vlab/ .

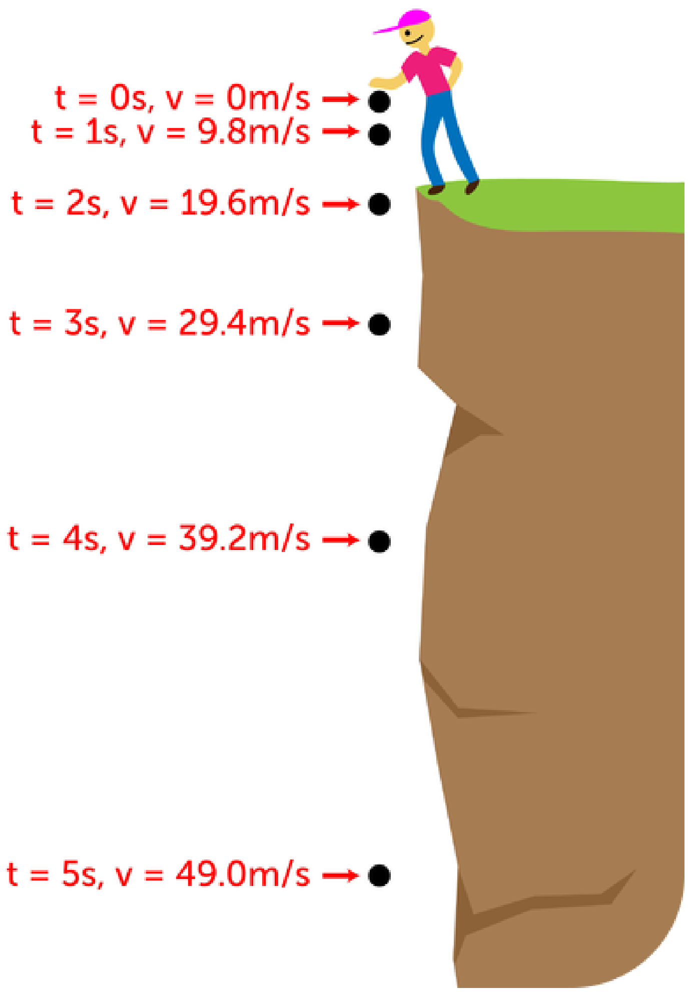

FIGURE 1.6
A boy drops an object at time t = 0 s. At time t = 1 s, the object is falling at a velocity of 9.8 m/s. What is its velocity by time t = 5 ?

You might think that an object with greater mass would accelerate faster than an object with less mass. After all, its greater mass means that it is pulled by a stronger force of gravity. However, a more massive object accelerates at the same rate as a less massive object. The reason? The more massive object is harder to move because of its greater mass. As a result, it ends up moving at the same acceleration as the less massive object.

Consider a bowling ball and a basketball. The bowling ball has greater mass than the basketball. However, if you were to drop both balls at the same time from the same distance above the ground, they would reach the ground together. This is true of all falling objects, unless air resistance affects one object more than another. For example, a falling leaf is slowed down by air resistance more than a falling acorn because of the leaf's greater surface area. However, if the leaf and acorn were to fall in the absence of air (that is, in a vacuum), they would reach the ground at the same time.

Projectile Motion

Earth's gravity also affects the acceleration of objects that start out moving horizontally, or parallel to the ground. Look at **Figure** 1.7. A cannon shoots a cannon ball straight ahead, giving the ball horizontal motion. At the same time, gravity pulls the ball down toward the ground. Both forces acting together cause the ball to move in a curved path. This is called **projectile motion**.

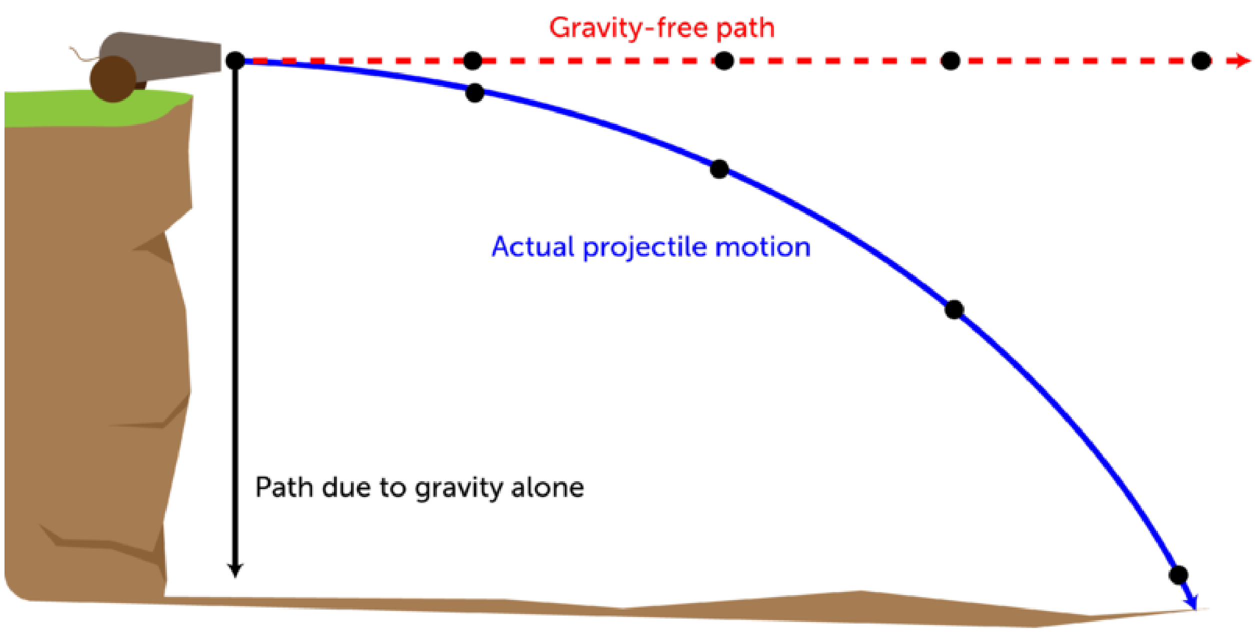

FIGURE 1.7
The cannon ball moves in a curved path because of the combined horizontal and downward forces.

Projectile motion also applies to other moving objects, such as arrows shot from a bow. To hit the bull's eye of a target with an arrow, you actually have to aim for a spot above the bull's eye. That's because by the time the arrow reaches the target, it has started to curve downward toward the ground. **Figure** 1.8 shows what happens if you aim at the bull's eye instead of above it. You can access interactive animations of projectile motion at these URLs:

- http://phet.colorado.edu/en/simulation/projectile-motion
- http://jersey.uoregon.edu/vlab/ *(Select the applet entitled "Cannon.")*

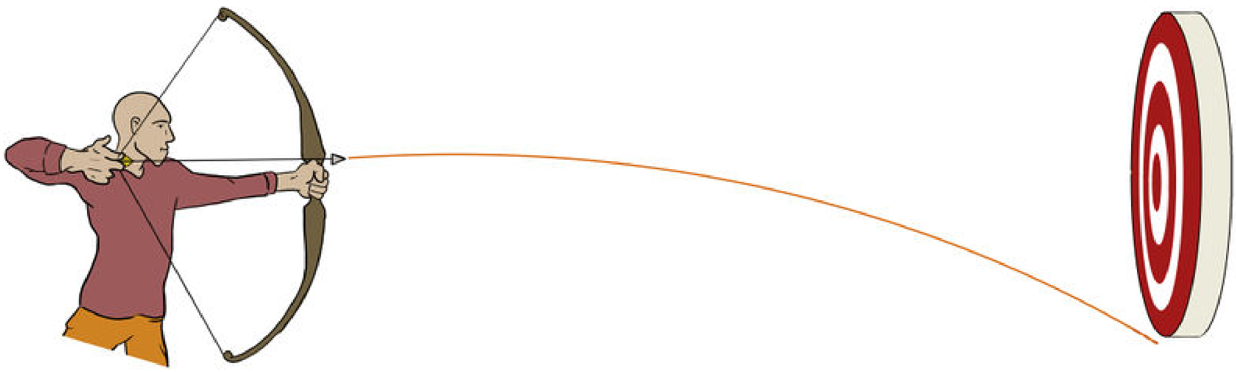

FIGURE 1.8

Aiming at the center of a target is likely to result in a hit below the bull's eye.

Orbital Motion

The moon moves around Earth in a circular path called an **orbit**. Why doesn't Earth's gravity pull the moon down to the ground instead? The moon has enough forward velocity to partly counter the force of Earth's gravity. It constantly falls toward Earth, but it stays far enough away from Earth so that it actually falls around the planet. As a result, the moon keeps orbiting Earth and never crashes into it. The diagram in **Figure** 1.9 shows how this happens. You can explore gravity and orbital motion in depth with the animation at this URL: http://phet.colorado.edu/en/simulation/gravity-and-orbits .

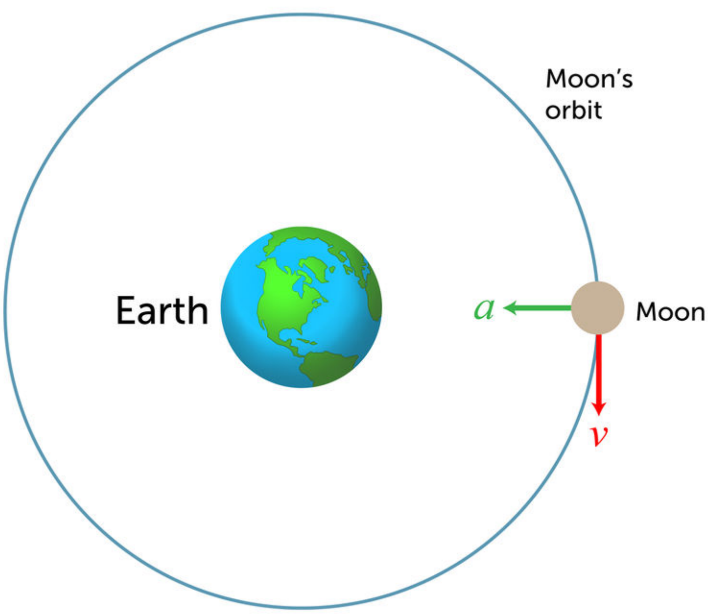

FIGURE 1.9

In this diagram, "v" represents the forward velocity of the moon, and "a" represents the acceleration due to gravity. The line encircling Earth shows the moon's actual orbit, which results from the combination of "v" and "a."

You can see an animated version of this diagram at: http://en.wikipedia.org/wiki/File:Orbital_motion.gif .

Lesson Summary

- Gravity is traditionally defined as a force of attraction between two masses. Weight measures the force of gravity and is expressed in newtons (N).
- According to Newton's law of universal gravitation, gravity is a force of attraction between all objects in the universe, and the strength of gravity depends on the masses of the objects and the distance between them. Einstein's theory of gravity states that gravity is an effect of curves in space and time around massive objects such as Earth.
- Gravity causes falling objects to accelerate at 9.8 m/s^2. Gravity also causes projectile motion and orbital motion.

Lesson Review Questions

Recall

1. What is the traditional definition of gravity?
2. How is weight related to gravity?
3. Summarize Newton's law of universal gravitation.
4. Describe Einstein's idea of gravity.

Apply Concepts

5. Create a poster to illustrate the concept of projectile motion.

Think Critically

6. In the absence of air, why does an object with greater mass fall toward Earth at the same acceleration as an object with less mass?
7. Explain why the moon keeps orbiting Earth.

Points to Consider

The scale you saw in **Figure** 1.2 contains a spring. When an object hangs from the scale, the spring exerts an upward force that partly counters the downward force of gravity. The type of force exerted by a spring is called elastic force, which is the topic of the next lesson.

- Besides springs, what other objects do you think might exert elastic force?
- What other ways might you use elastic force?

References

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