11 Gravitational Interactions

Everyone knows that objects fall because of gravity. Even people before the time of Isaac Newton knew this. Contrary to popular belief, Newton did not discover gravity. What Newton discovered was that gravity is *universal*—that the same force that pulls an apple off a tree holds the moon in orbit, and that the earth and moon are similarly held in orbit about the sun. And the sun revolves as part of a cluster of other stars about the center of the galaxy, the Milky Way. Newton discovered that all objects in the universe attract each other. This was discussed in the last chapter. In this chapter we shall investigate the role of gravity at, below, and above the earth's surface; in the earth's oceans and its atmosphere; and in stellar objects called black holes. We begin with the simple case of free fall.

11.1 Acceleration Due to Gravity

Recall from earlier chapters that an object in free fall (that is, falling with only the force of gravity acting on it) accelerates downward at the rate of 9.8 m/s^2. This acceleration is known as g, the acceleration due to gravity. Some people get mixed up between little g and big G. Big G is not acceleration, but is the universal gravitational constant in the equation for the gravitational force between any two objects:

$$F = G\frac{m_1 m_2}{d^2}$$

Thus g and G are quite different quantities that represent quite different things. Nevertheless, there is an interesting relationship between the two. The value of little g was found from measurements of falling objects. But why should it be 9.8m/s² and not some other value? We can find the answer from the equation for gravity.

The weight of any object is the gravitational force of attraction between that object and the earth. This force depends on the mass of the object, m, and the mass of the earth, which we will call M. At the surface of the earth the distance between their centers is simply the radius of the earth, which we will call R. If we make these substitutions ($m_1 = m$, $m_2 = M$, $d = R$) in the law of gravity, we get an equation for the weight of an object at the earth's surface:

$$\text{weight} = \frac{GmM}{R^2}$$

From Newton's second law, $F = ma$, the weight of an object is mg. Substituting mg for weight in the preceding equation, we get

$$mg = \frac{GmM}{R^2}$$

Notice that m, the mass of the object, appears on both sides. We can divide it out, which leaves

$$g = \frac{GM}{R^2}$$

Suppose you use a calculator to evaluate g, using the following values for G, M, and R:

$$G = 6.67 \times 10^{-11}\ \text{N·m}^2/\text{kg}^2$$
$$M = 5.98 \times 10^{24}\ \text{kg}$$
$$R = 6.37 \times 10^{6}\ \text{m}$$

Multiply the first two numbers and divide two times by the third. Rounded off to two digits, your answer will be 9.8 N/kg. And, since 1 N equals 1 kg·m/s², the combination unit N/kg is the same as m/s².

Thus, you can see that the numerical value of g depends on the mass of the earth and its radius. If the earth had a different mass or radius, g would have a different value. If you know the mass and radius of any planet, you can calculate the value of g for that planet.

Interestingly enough, the mass of the earth was itself found from this equation after the value of G was experimentally determined in 1798 by an English scientist named Henry Cavendish. In fact, his procedure for determining G with heavy lead weights was called the "weighing-the-earth experiment." You can see that if g, G, and R are known, then the mass of the earth M is easily found. So the combined mass of all the rock, oceans,

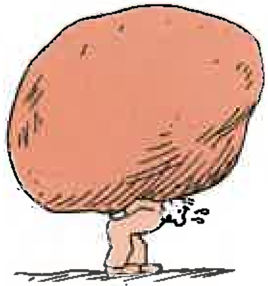

Fig. 11-1 The weight of the load is the gravitational force of attraction between the load and the earth.

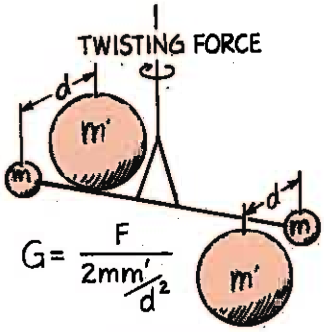

Fig. 11-2 Cavendish determined G by measuring the force of gravity between lead masses. Once he had the value of the force, the masses, and their distances apart, can you see how he determined G?

mountains, trees, sticks, and twigs that make up the planet earth can be easily calculated. The power of a little algebra is enormous!

> ▸ **Questions**
>
> 1. The acceleration of objects on the surface of the moon due to universal gravity is only $\frac{1}{6}$ of 9.8 m/s². From this fact, is it correct to say that the mass of the moon is therefore $\frac{1}{6}$ the mass of the earth?
>
> 2. Estimate "g" on the surface of the planet Jupiter by comparing its mass and size with that of the earth. First, it is about 300 times more massive than the earth. (This means that if it had the same radius, "g" for Jupiter would be 300 earth g.) But the radius of Jupiter is about 10 times greater than the radius of earth, so an object at its surface is 10 times farther from Jupiter's center than it would be on earth. So about how much greater is "g" on Jupiter compared to earth g?

11.2 Gravitational Fields

The earth pulls on the moon. We regard this as *action at a distance,* because the earth and moon interact with each other even though they are not in contact. Or we can look at this in a different way: we can regard the moon as interacting with the **gravitational field** of the earth. The properties of the space surrounding any mass can be considered to be altered in such a way that another mass introduced to this region will experience a force. This alteration of space is the gravitational field. It is common to think of distant rockets and space probes as interacting with gravitational fields rather than with the masses of the earth and other planets or stars that are the sources of these fields. The field concept plays an in-between role in our thinking about the forces between different masses.

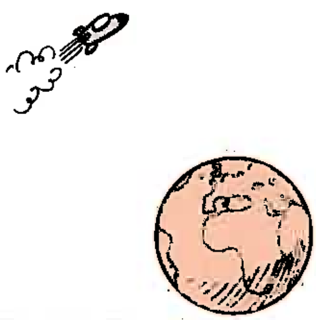

Fig. 11-3 We can say that the rocket is attracted to the earth, or that it is interacting with the gravitational field of the earth. Both points of view are equivalent.

▸ **Answers**

1. No. We could assume the mass of the moon to be $\frac{1}{6}$ that of earth only if both moon and earth had the same radius. The radius of the moon (1.74×10^6 m) is in fact less than one third the earth's radius, and its mass (7.36×10^{22} kg) is about $\frac{1}{80}$ the mass of the earth.
2. The value of "g" on Jupiter's surface is $G(300M)/(10R)^2 = 300GM/(100R^2) = 3GM/R^2 = 3g$.

A gravitational field is an example of a **force field**, for something in the space experiences a force due to the field. Another force field you may be familiar with is a magnetic field. You have probably seen iron filings lined up in patterns around a magnet. (Look ahead to Figure 36-4 on page 541, for example.) The pattern of the filings shows the strength and direction of the magnetic field at different points in the space around the magnet. Where the filings are closest together, the field is strongest. The direction of the filings shows the direction of the field at each point.

The pattern of the earth's gravitational field can be represented by field lines (Figure 11-4). Like the iron filings around a magnet, the field lines are closer together where the gravitational field is stronger. At each point on a field line, the direction of the field at that point is along the line. Arrows show the field direction. A particle, astronaut, spaceship, or any mass in the vicinity of the earth will be accelerated in the direction of the field line at that location.

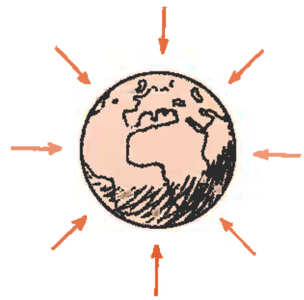

Fig. 11-4 Field lines represent the gravitational field about the earth. Where the field lines are closer together, the field is stronger. Farther away, where the field lines are farther apart, the field is weaker.

The strength of the earth's gravitational field, like the strength of its force on objects, follows the inverse-square law.* It is strongest near the earth's surface, and weakens with increasing distance from the earth.

The gravitational field of the earth exists inside the earth as well as outside. To investigate the field beneath the surface, imagine a hole drilled completely through the earth, say from the North Pole to the South Pole. Forget about impracticalities such as lava and high temperatures, and consider the kind of motion you would undergo if you fell into such a hole. If you started at the North Pole end, you'd fall and gain speed all the way down to the center, then overshoot and lose speed all the way "up" to the South Pole. You'd gain speed moving toward the center, and lose speed moving away from the center. Without air drag, the one-way trip would take nearly 45 minutes. If you failed to grab the edge, you'd fall back toward the center, overshoot, and return to the North Pole in the same time.

Repeat this trip with an accelerometer of some kind. Your acceleration at the beginning of fall is g, but you'd find it progressively less as you continue toward the center of the earth. Why? Because as you are being pulled "downward" toward the earth's center, you are also being pulled "upward" by the part of the earth that is "above" you. In fact, when you get to the center of the earth, the pull "down" is balanced by the pull "up." You

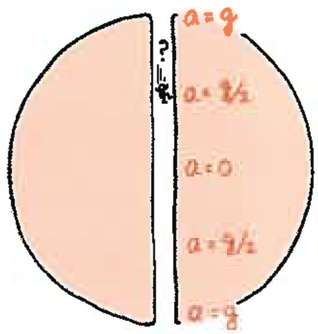

Fig. 11-5 As you fall faster and faster in a hole bored completely through the earth, your acceleration diminishes because the mass you leave behind retards it. At the earth's center your acceleration is zero. Momentum carries you against a growing acceleration past the center to the opposite end of the tunnel where it is again g.

* The strength of the gravitational field at any point is measured by the force on a unit mass placed there. If a force F is exerted on a mass m, the field strength is F/m, and its units are newtons per kilogram (N/kg).

are pulled in every direction equally, so the net force on you is zero. There is no acceleration as you whiz with maximum speed past the center of the earth. The gravitational field of the earth at its center is zero!

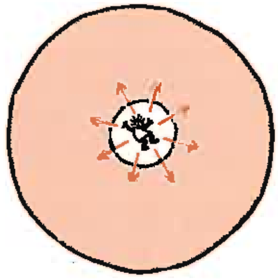

Fig. 11-6 In a cavity at the center of the earth your weight would be zero because you are pulled equally by gravity in all directions. The gravitational field at the earth's center is zero.

Interestingly enough, you'd gain acceleration during the first few kilometers beneath the earth's surface, because the density of surface material is much less than the condensed center. The mass of earth "above you" exerts a small backward pull compared to the disproportionally greater pull of the denser core material. This means you'd weigh slightly more for the first few kilometers beneath the earth's surface. Further in, your weight would decrease and would diminish to zero at the earth's center.

► **Questions**

1. If you stepped into a hole through the center of the earth and made no attempt to grab the edges at either end, what kind of motion would you experience?
2. Halfway to the center of the earth, would you weigh more or weigh less than you weigh at the surface of the earth?

► **Answers**

1. You would oscillate back and forth, in what is called *simple harmonic motion.* Each round trip would take nearly 90 minutes. Interestingly enough, we will see in the next chapter that an earth satellite in close orbit about the earth also takes the same 90 minutes to make a complete round trip. (This is no coincidence, for if you study physics further, you'll learn about an interesting relationship between simple harmonic motion and circular motion at constant speed.)
2. You would weigh less, because the part of the earth's mass that pulls you "down" is counteracted by mass above you that pulls you "up." If the earth were of uniform density, halfway to the center your weight would be exactly half your surface weight. But since the earth's core is so dense (about 7 times the density of surface rock) your weight would be somewhat more than half surface weight. Exactly how much depends on how the earth's density varies with depth, information that is not known today.

11.3 Weight and Weightlessness

The force of gravity, like any force, causes acceleration. Objects under the influence of gravity accelerate toward each other. We are almost always in contact with the earth. For this reason, we think of gravity primarily as something that presses us against the earth rather than as something that accelerates us. The pressing against the earth is the sensation we interpret as weight.

Stand on a bathroom scale that is supported on a stationary floor. The gravitational force between you and the earth pulls you against the supporting floor and scale. By Newton's third law, the floor and scale in turn push upward on you. Located in between you and the supporting floor are springs inside the bathroom scale. The springs are compressed by this pair of forces. The weight reading on the scale is linked to the amount of compression of the springs.

If you repeat this weighing procedure in a moving elevator, you would find your weight reading would vary—not during steady motion, but during accelerated motion. If the elevator accelerates upward, the bathroom scale and floor push harder against your feet, and the springs inside the scale are compressed even more. The scale shows an increase in your weight.

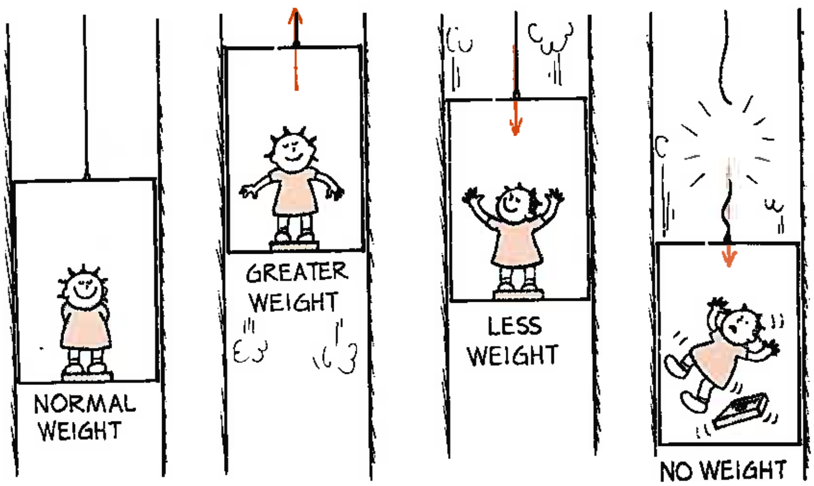

Fig. 11-7 The sensation of weight is equal to the force that you exert against the supporting floor. If the floor accelerates up or down, your weight seems to vary. You feel weightless when you lose your support in free fall.

If the elevator accelerates downward, the scale shows a decrease in your weight. The support force of the floor is now less. If the elevator cable breaks and the elevator falls freely, the scale reading would register zero. According to the scale, you are weightless. Would you really be weightless? The answer to this question depends on your definition of weight.

If you define weight as gravitational force acting on an object, then you still have weight whether or not you are freely falling. Astronauts in earth orbit who float freely inside their capsules are still being pulled by gravity and therefore have weight. But you in the falling elevator and the astronauts in the "falling" satellites don't feel the usual effects of weight. You feel weightless. That is, your insides are no longer supported by your legs and pelvic region. Your organs respond as though gravity were absent. You are in a state of **apparent weightlessness**.

Fig. 11-8 The astronaut is in a state of apparent weightlessness all the time in orbit.

To be truly weightless, you would have to be far out in space—well away from the earth and other attracting stars and planets—where gravitational forces are negligible. In this truly weightless condition, you would drift in a straight-line path rather than in the curved path of an orbit.

In a more practical sense, we define the weight of an object as the force it exerts against a supporting floor (or weighing scales). According to this definition, you are as heavy as you feel. The condition of weightlessness is then not the absence of gravity, but the absence of a support force. That queasy feeling you get when you are in a car that seems to leave the road momentarily when it goes over a hump, or worse, off a cliff, is not the absence of gravity. It is the absence of a support force. Astronauts in orbit are without a support force and are in a sustained state of weightlessness. That causes "spacesickness" until they get used to it.

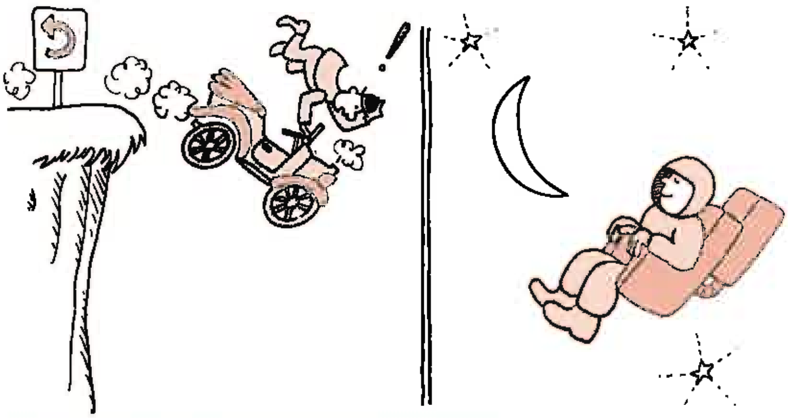

Fig. 11-9 Both people experience weightlessness.

11.4 Ocean Tides

Seafaring people have always known there was a connection between the ocean tides and the moon, but no one could offer a satisfactory theory to explain the two high tides per day. Newton showed that the ocean tides are caused by *differences* in the gravitational pull between the moon and the earth on opposite sides of the earth. The gravitational force of the moon on the earth is stronger on the side of the earth nearer to the moon, and weaker on the side of the earth farther from the moon. This is simply because the gravitational force is weaker with increased distance.

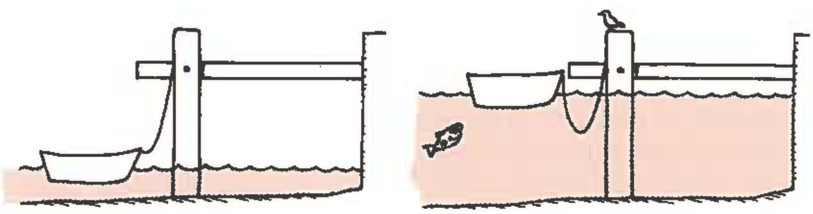

Fig. 11-10 Twice a day, every point along the ocean shore has a high tide. In between the high tides is a low tide.

Consider a big spherical ball of gooey taffy. If you exert the same force on every part of the ball, it would remain spherical as it accelerates. But if you pulled harder on one side than the other, its shape would become elongated. Imagine that you attach a rope to the ball of taffy and swing it in a circle around you (Figure 11-11). The ball will bulge outward in two places. One bulge will be toward the center of the circular path. The other bulge will be on the opposite side, on the faster-moving outer part that is "thrown" outward. For an initially spherical ball of uniform taffy, these oppositely facing bulges would be of equal size.

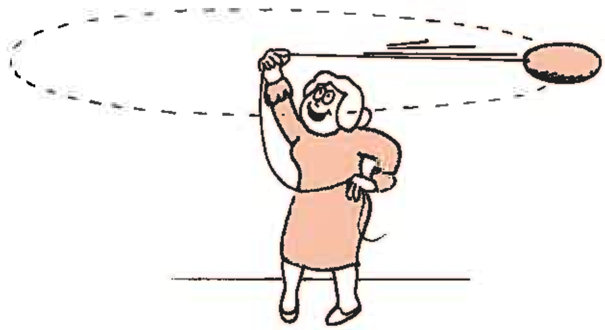

Fig. 11-11 An initially spherical ball of gooey taffy will be elongated when it is spun in a circular path.

This is what happens to this big ball we're living on. You might tend to think of the earth at rest and the moon circling around us. But if you lived on the moon, you'd likely say that the moon is at rest and the earth circles about the moon. It turns out that both the earth and the moon orbit about a common point—their earth-moon center of mass. So the water covering the circling earth is distorted and will bulge like the circling taffy in Figure 11-11.

The earth makes one complete spin per day beneath these ocean bulges. This produces two sets of ocean tides per day. Any part of the earth that passes beneath one of the bulges has a high tide. On a world average, a high tide is about 1 m above the average surface level of the ocean. When the earth makes a quarter turn, 6 hours later, the water level at the same part of the ocean is about 1 m below the average sea level. This is low tide. The water that "isn't there" is under the bulges that make up the high tides. A second high tidal bulge is experienced when the earth makes another quarter turn. So we have two high tides and two low tides daily. It turns out that while the earth spins, the moon moves in its orbit and appears at the same position in our sky every 24 hours and 50 minutes, so the two-high-tide cycle is actually at 24-hour-and-50-minute intervals. That is why tides do not occur at the same time every day.

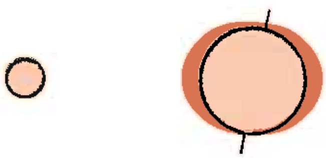

Fig. 11-12 Two tidal bulges remain relatively fixed with respect to the moon while the earth spins daily beneath them.

The sun also contributes to ocean tides, although it is less than half as effective as the moon in raising tides. This may seem puzzling when it is realized that the pull between the sun and earth is about 180 times stronger than the pull between the moon and earth. Why, then, does the sun not cause tides 180 times greater than lunar tides? The answer has to do with a key word: *difference*. Because of the sun's great distance from the earth, there is not much difference in the distances from the sun to the near part of the earth and the far part. This means there is not much difference in the gravitational pull of the sun on the part of the ocean nearest it and on the part farthest from it. The relatively small difference in pulls on opposite sides of the earth only slightly elongates the earth's shape and produces tidal bulges less than half those produced by the moon.*

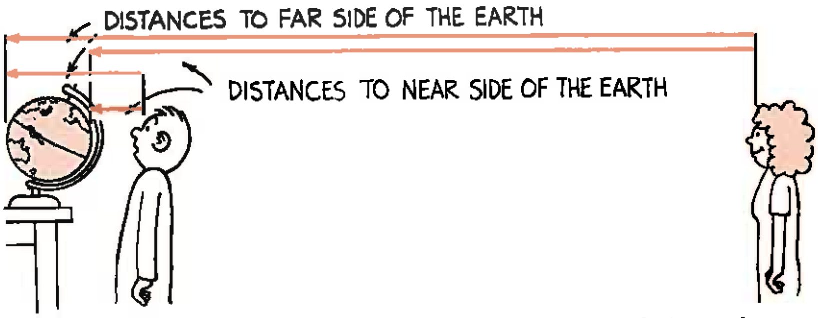

Fig. 11-13 If you stand close to the globe (as the moon is in relation to the earth), the closest part of the globe is noticeably nearer to you than the farthest part. If you stand far away (as the sun is in relation to the earth), the difference in distance between the closest and farthest part of the globe is less significant.

When the sun, earth, and moon are all lined up, the tides due to the sun and the moon coincide. Then we have higher-than-average high tides and lower-than-average low tides. These are called **spring tides** (Figure 11-14). (Spring tides have nothing to do with the spring season.)

Fig. 11-14 When the attractions of the sun and the moon are lined up with each other, spring tides occur.

* The relative differences in distance is only hinted at in Figure 11-13, which is way off scale. The actual distance between the earth and the sun is nearly 12 000 earth diameters. So for an ordinary globe of $\frac{1}{3}$ meter in diameter, to judge the relative difference between closest and farthest parts of the globe from the moon, you'd have to stand 10 meters away; and from the sun's position, you'd have to stand "across town," 4 kilometers away!

If the alignment is *perfect*, we have an eclipse. A **lunar eclipse** is produced when the earth is directly between the sun and moon (Figure 11-15a). A **solar eclipse** is produced if the moon is directly between the sun and earth (Figure 11-15c). The alignment is usually not perfect. Instead, we have a full moon when the earth is in the middle, and a new moon when the moon is in the middle. So spring tides occur at the times of a new or full moon.

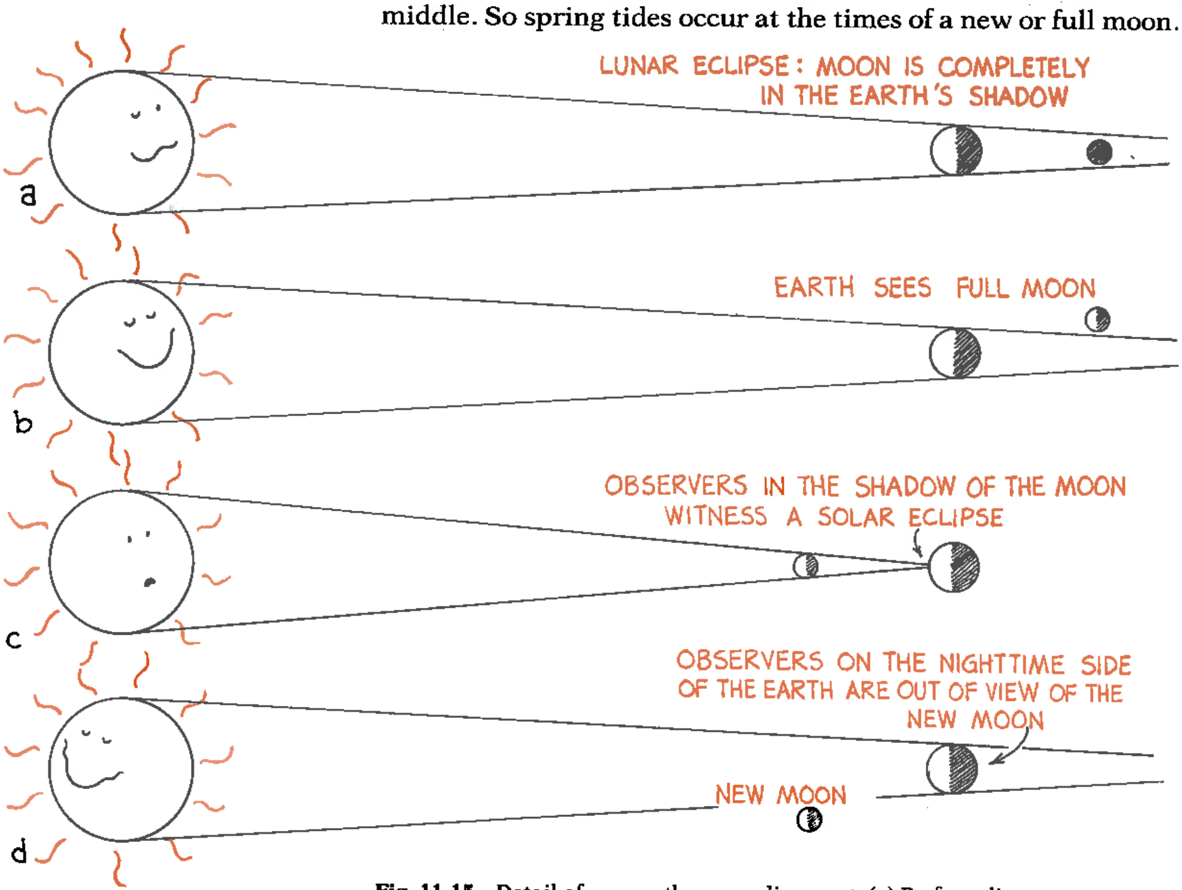

Fig. 11-15 Detail of sun-earth-moon alignment. (a) Perfect alignment produces a lunar eclipse. (b) Non-perfect alignment produces a full moon. (c) Perfect alignment produces a solar eclipse. (d) Non-perfect alignment produces a new moon. Can you see that from the daytime side of the world, the new moon cannot be seen because the dark side faces the earth, and from the nighttime side of the world, the moon is out of view altogether?

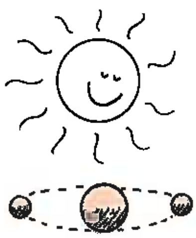

Fig. 11-16 When the attractions of the sun and the moon are at right angles to one another (at the time of a half moon), neap tides occur.

When the moon is half way between a new moon and a full moon, in either direction (Figure 11-16), the tides due to the sun and the moon partly cancel each other. Then, the high tides are lower than average and the low tides are not as low as average low tides. These are called **neap tides**.

Another factor that affects the tides is the tilt of the earth's axis (Figure 11-17). Even though the opposite tidal bulges are equal, the earth's tilt causes the two daily high tides experienced in most parts of the ocean to be unequal most of the time.

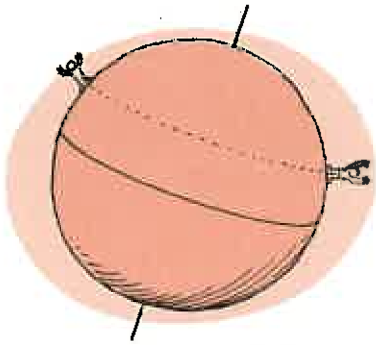

Fig. 11-17 The earth's tilt causes the two daily high tides in the same place to be unequal.

11.5 Tides in the Earth and Atmosphere

The earth is not a rigid solid but, for the most part, is molten liquid covered by a thin solid and pliable crust. As a result, the moon-sun tidal forces produce earth tides as well as ocean tides. Twice each day the solid surface of the earth rises and falls by as much as 25 cm! As a result, earthquakes and volcanic eruptions have a slightly higher probability of occurring when the earth is experiencing an earth spring tide—that is, near a full or new moon.

We live at the bottom of an ocean of air that also experiences tides. Because of the low mass of the atmosphere, the atmospheric tides are very small. In the upper part of the atmosphere is the ionosphere, so named because it is made up of ions, electrically charged atoms that are the result of intense cosmic ray bombardment. Tidal effects in the ionosphere produce electric currents that alter the magnetic field that surrounds the earth. These are magnetic tides. They in turn regulate the degree to which cosmic rays penetrate into the lower atmosphere. The cosmic ray penetration affects the ionic composition of our atmosphere, which in turn, is evident in subtle changes in the behaviors of living things. The highs and lows of magnetic tides are greatest when the atmosphere is having its spring tides—again, near the full and new moon.*

* This may be why some of your friends seem a bit weird at the time of a full moon!

11.6 Black Holes

There are two main processes that are going on all the time in stars such as our sun. One is gravitation, which tends to crunch all solar material toward the center. The other process is nuclear fusion. The core of the sun is continuously undergoing hydrogen-bomb-like explosions that tend to blow its material out from the center. The two processes balance each other, and the result is the sun of a given size.

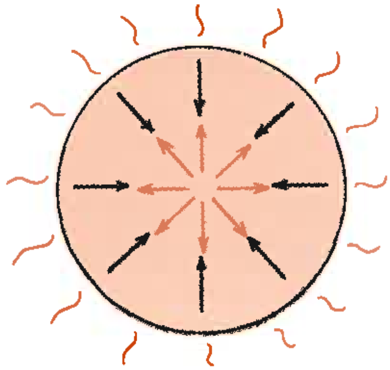

Fig. 11-18 The size of the sun is the result of a "tug-of-war" between two opposing processes: nuclear fusion, which tends to blow it up (colored arrows), and gravitational contraction, which tends to crunch it together (black arrows).

If the fusion rate increases, the sun gets bigger; if the fusion rate decreases, the sun gets smaller. What happens when the sun runs out of fusion fuel (hydrogen)? The answer is, gravitation dominates and the sun collapses. For our sun, this collapse will ignite the nuclear ashes of fusion (helium) and fuse them into carbon. During this fusion process, the sun will expand to become the type of star known as a *red giant*. It will be so big that it will extend beyond the earth's orbit and swallow the earth. Fortunately, this won't take place until 5 billion years from now. When the helium is all fused, the red giant will collapse and die out. It will no longer give off heat and light. It will then be the type of star called a *black dwarf*—a cool cinder among billions of others.

The story is a bit different for stars more massive than the sun. For stars of more than four solar masses, once gravitational collapse takes place—fusion or no fusion—it doesn't stop! The stars not only cave in on themselves, but the atoms that compose the stellar material also cave in on themselves until there are no empty spaces. What is left is compressed to unimaginable densities. Gravitation near the surfaces of these shrunken configurations is so enormous that nothing can get back out. Even light cannot escape. They have crushed themselves out of visible existence. They are called **black holes**.

Interestingly enough, a black hole is no more massive than the star from which it collapsed. The gravitational field near the black hole may be enormous, but the field beyond the original radius of the star is no different after collapse than before (Figure 11-19). The amount of mass has not changed, so there is no change in the field at any point beyond this distance. Black holes will be formidable only to future astronauts who venture too close.

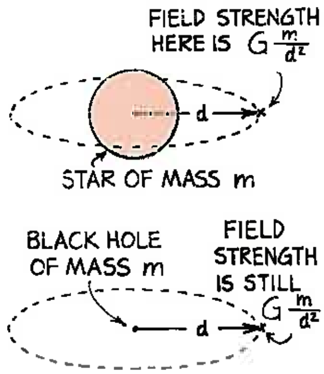

Fig. 11-19 The gravitational field strength near a giant star that collapses to become a black hole is the same (top) before collapse and (bottom) after collapse.

> ▶ **Question**
> If the sun were to collapse from its present size and become a black hole, would the earth be drawn into it?

The configuration of the gravitational field about a black hole represents the collapse of space itself. The field is usually represented as a warped two-dimensional surface, as shown in Figure 11-20. Astronauts could enter the fringes of this warp and, with a powerful spaceship, still escape. After a certain distance, however, they could not, and they would disappear from the observable universe. Don't go too close to a black hole!

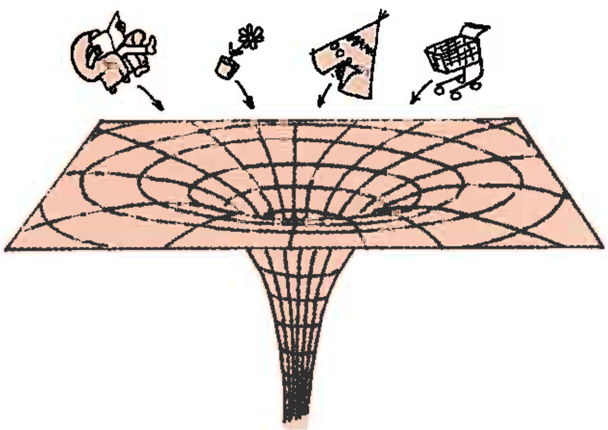

Fig. 11-20 A two-dimensional representation of the gravitational field around a black hole. Anything that falls into the central warp disappears from the observable universe.

▶ **Answer**
No, the gravitational force between the solar black hole and the earth would not change. The earth and other planets would continue in their orbits. Observers outside the solar system would see the planets orbiting about "nothing" and likely deduce the presence of a black hole. Observations of astronomical bodies that orbit unseen partners indicate the presence of black holes.

11 Chapter Review

Concept Summary

The acceleration due to gravity at the earth's surface can be derived from the law of universal gravitation.

The earth can be thought of as being surrounded by a gravitational field that interacts with objects and causes them to experience gravitational forces.

Objects in orbit around the earth have a gravitational force acting on them even though they may appear to be weightless.

Ocean tides (and even tides in the solid earth and in the atmosphere) are caused by differences in the gravitational pull of the moon on the earth on opposite sides of the earth.

When a star runs out of fuel for fusion, it collapses under gravitational forces.

Important Terms

apparent weightlessness (11.3)
black hole (11.6)
force field (11.2)
gravitational field (11.2)
lunar eclipse (11.4)
neap tide (11.4)
solar eclipse (11.4)
spring tide (11.4)

Review Questions

1. Distinguish between g and G. Which is a variable (that is, something that can vary in value)? (11.1)
2. Upon what quantities does the acceleration of gravity on the surfaces of various planets depend? (11.1)
3. Why was Henry Cavendish's experiment to determine the value of G called the "weighing-the-earth experiment"? (11.1)
4. Which is more correct—to say that a distant rocket interacts with the mass of the earth or to say that it interacts with the gravitational field of the earth? Explain. (11.2)
5. How does the gravitational field strength about the planet earth vary with increasing distance? (11.2)
6. If you fell into a hole that was bored completely through the earth, would you accelerate all the way through and shoot like a projectile out the other side? Why or why not? (11.2)
7. What is the value of the gravitational field of the earth at its center? (11.2)
8. Where is your weight greatest—at the surface of the earth, slightly below the surface, or above the surface? (11.2)
9. Does your apparent weight change when you ride an elevator at constant speed, or only while it is accelerating? Explain. (11.2)
10. Distinguish between apparent weightlessness and true weightlessness. (11.3)
11. Why is *difference* a key word in explaining tides? (11.4)
12. If the gravitational pull between the moon and the earth were the same over all parts of the earth, would there be any tides? Defend your answer. (11.4)
13. Which force-pair is greater—that between the moon and earth, or that between the sun and earth? (11.4)

14. Which is more effective in raising ocean tides—the moon or the sun? (11.4)

15. Why are tides greater at the times of the full and new moons and at the times of lunar and solar eclipses? (11.4)

16. Distinguish between *spring* tides and *neap* tides. (11.4)

17. Why are ocean tides greater than atmospheric tides? (11.5)

18. What two major processes determine the size of a star? (11.6)

19. Distinguish between a stellar black *dwarf* and a black *hole*. (11.6)

20. Why would the earth not be sucked into the sun if it evolved to become a black hole? (11.6)

Think and Explain

1. If the earth were the same size but twice as massive, what would be the value of G? What would be the value of g? (Why are your answers different? In this and the following question, let the equation $g = GM/R^2$ guide your thinking.)

2. If the earth somehow shrunk to half size without any change in its mass, what would be the value of g at the new surface? What would be the value of g above the new surface at a distance equal to the present radius?

3. A man named Philipp von Jolly suspended a spherical vessel of mercury of known mass on one arm of a very sensitive balance that he put in equilibrium with counterweights, as shown in Figure A. He rolled a 6-ton lead sphere beneath the mercury and had to readjust the balance. Why? And how did this enable him to calculate the value of G?

4. We can think of a force field as a kind of extended aura that surrounds a body, spreading its influence to affect things. As later chapters will show, an electric field affects electric charges, and a magnetic field affects magnetic poles. What does a gravitational field affect?

5. The weight of an apple near the surface of the earth is 1 N. What is the weight of the earth in the gravitational field of the apple?

6. If you stand on a shrinking planet, so that in effect you get closer to its center, your weight increases. But if you instead burrow into the planet and get closer to its center, your weight decreases. Explain.

7. If you were unfortunate enough to be in a freely-falling elevator, you might notice the bag of groceries you were carrying hovering in front of you, apparently weightless. Are the groceries falling? Defend your answer.

8. When would the moon be its fullest—just before a solar eclipse or just before a lunar eclipse? Defend your answer.

9. The human body is about 80% water. Is it likely that the moon's gravitational pull causes biological tides—cyclic changes in water flow among the fluid compartments of the body? (*Hint*: Is any part of your body appreciably closer to the moon than any other part? Is there a *difference* in lunar pulls?)

10. A black hole is no more massive than the star from which it collapsed. Why then, is gravitation so intense near a black hole?

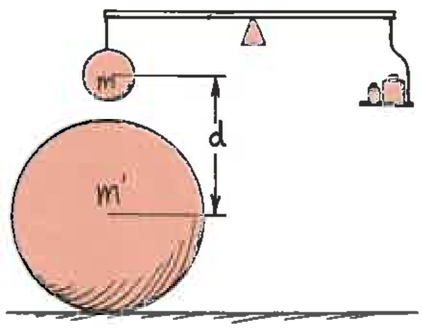

Fig. A