Hawthorne Academy
Physics
Period ~~3 and 4~~ 4+6
Ms. Davis

Physics Chapter Lesson 13, 14, and 15

Objective: Students will be able to maximize his or her personal experiences in the everyday world and their everyday language through the conceptual understanding of physics.

Core Standards: Motion and Forces 1. Newton's laws predict the motion of most objects. As a basis for understanding this concept.

Tuesday-Friday (3/17-3/20/20)

1. **Read Chapter 13 and 14: Do Key Terms and Review Questions for both Chapters**

Monday-Wednesday (3/23-3/24/20)

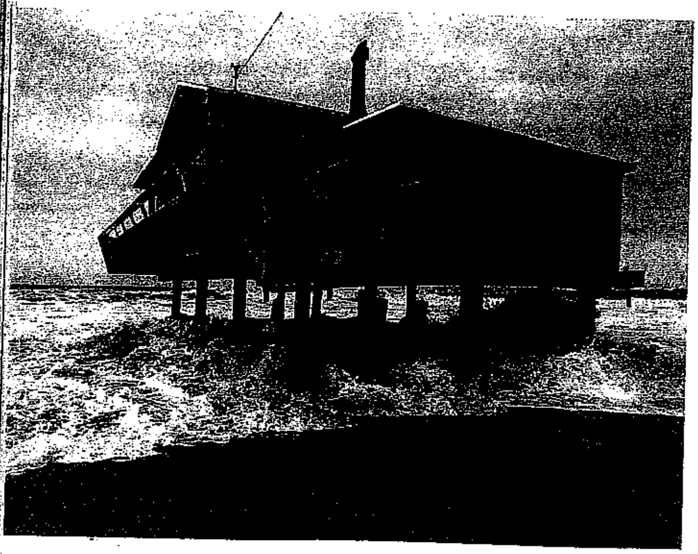
1. **Read Chapter 15: Do Key Terms and Review Questions**

Thursday- Friday (3/26-3/27/20)

1. **Write out all Concept Summaries for Chapters 13, 14, and 15**

Chapter 13

Gravitational Interactions



All matter is under the influence of gravity.

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 both Earth and the moon are similarly held in orbit around the sun. And the sun revolves as part of a cluster of other stars around the center of our galaxy, the Milky Way. Newton discovered that all objects in the universe attract each other. This was discussed in the previous chapter. In this chapter we'll investigate the role of gravity at, below, and above Earth's surface. We will see how gravity affects Earth's oceans and its atmosphere, and then we will look at gravity at its extreme—in stellar objects called black holes. We begin with the concept of the gravitational field.

13.1 Gravitational Fields

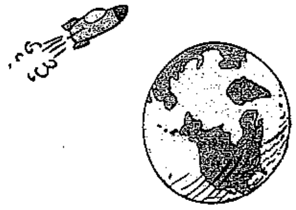


Figure 13.1 ▲
We can say that the rocket is attracted to Earth, or that it is interacting with the gravitational field of Earth. Both are correct.

If you have ever played with iron filings and a magnet, you're familiar with magnetic fields. A magnetic field is a **force field** that surrounds a magnet. A force field exerts a force on objects in its vicinity. A magnetic field exerts a magnetic force on magnetic substances. You can look ahead to Figure 36.4 and see how the iron filings around a magnet reveal the shape of its force field. 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. Later we will learn about similar electric force fields that surround electric charges. But now we will investigate the kind of force field that surrounds massive objects—the **gravitational field.**

know the mass and radius of any planet, you can calculate the acceleration due to gravity at the surface of that planet.

The strength of Earth's gravitational field, like the strength of its force on objects, follows the inverse-square law outside Earth. So **g** weakens with increasing distance from Earth.

1 Explore **2 Develop** **3 Apply**

1 **Laboratory Manual** *36, 37*
1 **Probeware Lab Manual** *9*
2 **Concept-Development Practice Book** *13-1, 13-2*

■ Questions

1. Why do all freely falling objects have the same acceleration?
2. The acceleration of objects on the surface of the moon is only 1/6 of 9.8 m/s^2. From this fact, is it correct to say that the mass of the moon is therefore 1/6 the mass of Earth?
3. How does **g** at the surface of Jupiter compare with **g** at the surface of Earth? Data: Jupiter's mass is about 300 times that of Earth, and its radius is about 10 times greater than the radius of Earth.

13.2 Gravitational Field Inside a Planet

The gravitational field of Earth exists inside Earth as well as outside. To investigate the gravitational field beneath the surface, imagine a hole drilled completely through 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, and then overshoot and lose speed all the way to the South Pole. You'd gain speed moving toward the center, and lose speed moving away from the

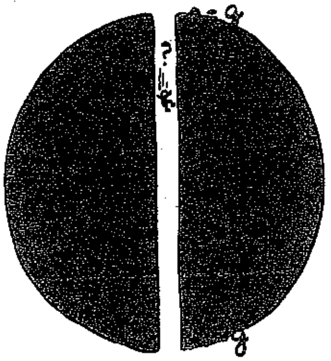


Figure 13.4 ▲
As you fall faster and faster into a hole bored through Earth, your acceleration diminishes because the pull of the mass above you partly cancels the pull below. At Earth's center the pulls cancel to zero and your acceleration is zero. Momentum carries you against a growing acceleration past the center to the opposite side where it is again **g**.

■ Answers

1. When we studied Newton's second law in Chapter 5, we learned that $a = F/m$. In free fall, the ratio F/m (weight/mass) is the same for all masses, so acceleration is the same. In this chapter we say the same thing from another point of view—the concept of the gravitational field **g**, which also equals F/m. From Newton's equation for the force of gravity, we see that F/m at Earth's surface equals 9.8 m/s^2. In the same gravitational field **g**, all freely falling objects have the same acceleration g.
2. No. We could conclude that the mass of the moon is 1/6 that of Earth's *only* if both the moon and Earth had the same radius. The radius of the moon (1.74×10^6 m) is in fact less than one third of Earth's radius, and its mass (7.36×10^{22} kg) is about 1/80 the mass of Earth.
3. For Earth, $\mathbf{g} = GM/R^2$. The value of **g** on Jupiter's surface is $G(300M)/(10R)^2 = 300\ GM/(100R^2) = 3\ GM/R^2$, or 3 times Earth's **g**. (More precisely, Jupiter's $\mathbf{g} \approx 2.44$ times Earth's **g** because its radius is nearly 11 times that of Earth.)

[illegible] ducts experiments during spaceflights. Astronauts understand how the force of gravity will change throughout their trip. They apply physics to control the direction of a spacecraft, conduct experiments in space, and move outside the spacecraft. Astronauts usually have flight experience along with degrees in scientific disciplines such as physics or chemistry. The United States astronaut program is managed by the National Aeronautics and Space Administration (NASA).

13.3 Weight and Weightlessness

The force of gravity, like any force, causes acceleration. Objects under the influence of gravity are pulled toward each other and accelerate (as long as nothing prevents the acceleration). We are almost always in contact with Earth. For this reason, we think of gravity primarily as something that presses us against Earth rather than as something that accelerates us. The pressing against 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 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 repeated 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 accelerated upward, the bathroom scale and floor would push harder against your feet, and the springs inside the scale would be compressed even more. The scale would show an increase in your weight.

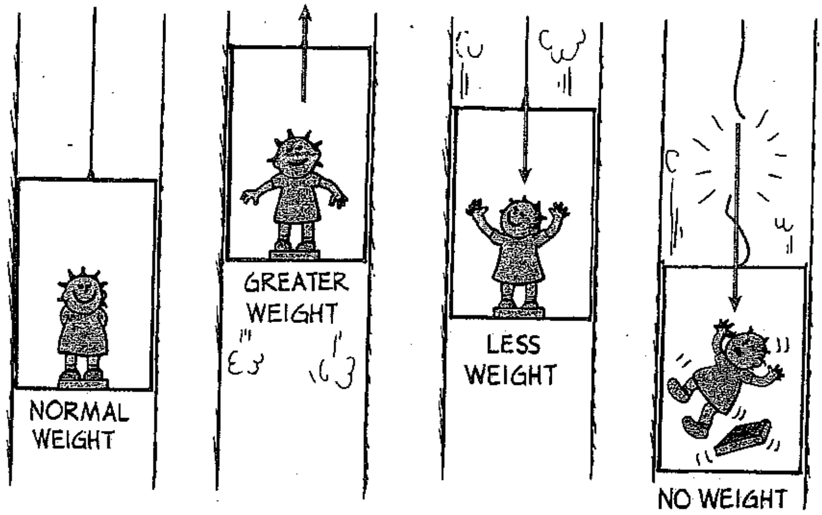


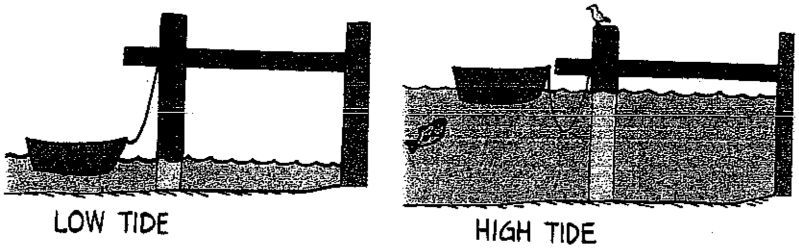
Figure 13.6 ▶
The sensation of weight is equal to the force that you exert against the supporting floor. When the floor accelerates up or down, your weight seems to vary. You feel weightless when you lose your support in free fall.

If the elevator accelerated downward, the scale would show a decrease in your weight. The support force of the floor would now be less. If the elevator cable broke and the elevator fell freely, the scale reading would register zero. According to the scale, you would be weightless. And you would feel weightless, for your insides would no longer be supported by your legs and pelvic region. Your organs would respond as though gravity were absent. But gravity is not absent, so would you really be weightless? The answer to this question depends on your definition of weight.

1 Explore **2 Develop** **3 Apply**

1 **Laboratory Manual** *38*

Figure 13.9 ▶
Twice a day, every point along the ocean shore has a high tide. In between the high tides is a low tide.



Why isn't there one tide every day instead of two tides every day? There would be only one tide *if* Earth were "nailed down" in one place and held stationary except for its daily rotation. But Earth is not nailed down; it is in orbit around the moon, just as the moon is in orbit around Earth. Actually, both are circling about their combined center of mass, a point inside Earth about three-quarters of the way from Earth's center to its surface (Figure 13.10).

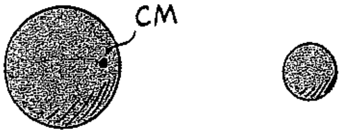


Figure 13.10 ▲
Both Earth and the moon orbit about a common point—the center of mass of the Earth–moon system.

What then happens is that the ocean nearest the moon is pulled upward toward the moon, while the main body of Earth is pulled toward the moon also—away from the ocean on the far side. This is because Earth as a whole is closer to the moon than the far-side ocean is. So Earth's waters get slightly elongated—at both ends. A crude model of this elongation is shown in Figure 13.11. If a ball of taffy is swung on the end of a string, it deforms, with "tidal bulges" on the inner and outer sides. Although the actual Earth–moon interaction differs from this simplified model, the result is similar. Both the taffy and Earth are elongated. Earth's elongation is evident in the pair of ocean bulges on opposite sides of Earth.*

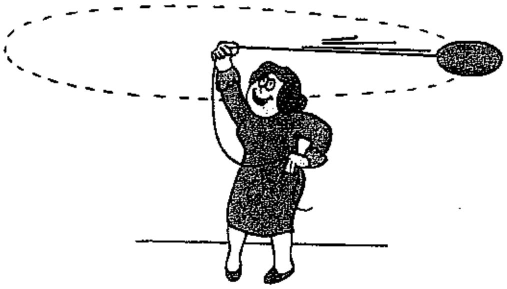
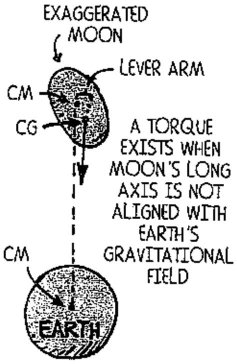


Figure 13.11 ▲
An initially spherical ball of gooey taffy will be elongated when it is spun in a circular path.



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* Earth likewise causes tides on the moon, which means the solid moon is slightly football shaped. Its deviation from a sphere is enough that its center of gravity is slightly displaced from its center of mass. Both lie along the moon's long axis. Whenever the moon's long axis is not lined up toward Earth (see sketch), Earth exerts a small torque on the moon. This tends to twist the moon toward aligning with Earth's gravitational field, like the torque that aligns a compass needle with a magnetic field. So we see there is a reason why the moon always shows us its same face! Interestingly enough, this "tidal lock" is also working on Earth. Our days are getting longer at the rate of 2 milliseconds per century. In a few billion years our day will be as long as a month and Earth will always show the same face to the moon. How about that?

Newton deduced that the difference in pulls decreases as the *cube* of the distance between the centers of the bodies—twice as far away produces 1/8 the tide; three times as far, only 1/27 the tide, and so on. Only relatively close distances result in appreciable tides, and so the nearby moon "out-tides" the enormously more massive but farther-away sun. The size of the tide also depends on the size of the body having tides. Although the moon produces a considerable tide in Earth's oceans, which are thousands of kilometers apart, it produces scarcely any in a lake. That's because no part of the lake is significantly closer to the moon than any other part of the lake, so there is no significant *difference* in the moon's pull on the lake. The same is true for the fluids in your body. Any tides in the fluids of your body caused by the moon are negligible. You're not tall enough compared with the moon's distance for tides. The microtides produced by a 1-kilogram book held 1 meter over your head are far greater than any microtides produced in your body by the moon.

■ Question

We know that both the moon and the sun produce our ocean tides. And we know the moon plays the greater role because it is closer. Does its closeness mean it pulls with more gravitational force than the sun on Earth's oceans?

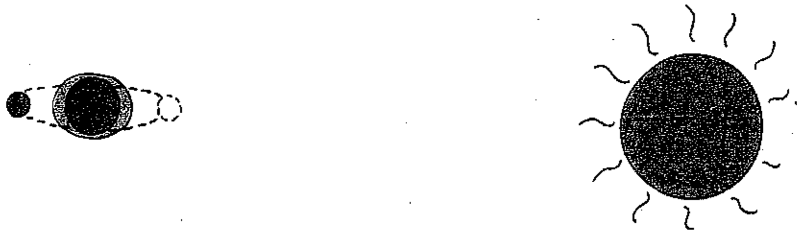


Figure 13.14 ▶
When the sun, the moon, and Earth are aligned, spring tides occur.

When the sun, Earth, and the moon are all lined up, the tides due to the sun and the moon coincide. We then have higher-than-average high tides and lower-than-average low tides. These are called **spring tides** (Figure 13.14). (Spring tides have nothing to do with the spring season.)

■ Answer

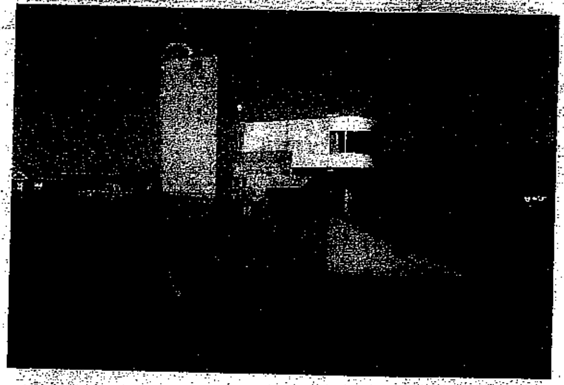
No, the sun's pull is much stronger. Gravitational pull weakens with the square of the distance to the body that pulls. But the *difference* in pulls across Earth's oceans weakens with the distance cubed. When the distance to the sun is squared, gravitation from the sun is still stronger than gravitation from the closer moon—because of the sun's enormous mass. But when the distance to the sun is cubed, as is the case for tidal forces, the sun's influence is less than the moon's. Distance is the key to tidal forces. If the moon were closer to Earth, the tides on both Earth and the moon would increase with the inverse cube of this closer distance—which could be catastrophic, as the planetary rings of other planets suggest.

SCIENCE, TECHNOLOGY, AND SOCIETY

Power Production

In 1984, the first modern tidal power plant in North America began operating in Nova Scotia, Canada. A dam across an estuary gets its power from the rising and falling of the daily ocean tide. First the water is higher on one side of the dam, and is maintained at about 1.6 meters higher than the lower side. Water then flows through a series of gates to the lower side, turning a huge turbine in the process. When the tide changes, the flow of water is in the reverse direction, again turning the turbine. The dam produces more than 20 MW of power—enough to meet the electricity needs for 4500 homes.

Critical Thinking What are the advantages of using ocean tides to produce electricity?



Another factor affecting tides is the tilt of Earth's axis (Figure 13.17). Even though the opposite tidal bulges are equal, Earth's tilt causes the two daily high tides experienced in most parts of the ocean to be unequal most of the time.

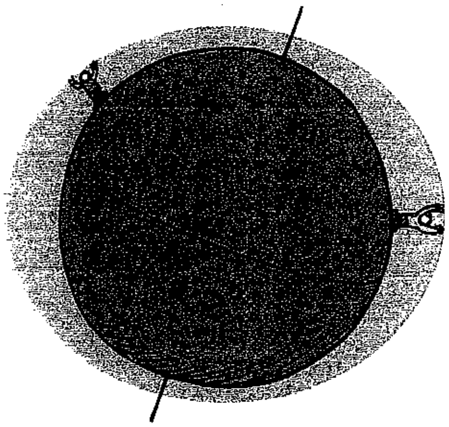


Figure 13.17 ▶ Earth's tilt causes the two daily high tides in the same place to be unequal.

Our treatment of tides is quite simplified here. We have ignored such complications as interfering land masses, tidal inertia, and friction with the ocean bottom, all of which result in a wide range of tides in different parts of the world. Although worldwide average tides are about 1 meter above and below the ocean's normal level, in some places the tides are much greater than this. In the Bay of Fundy in Nova Scotia and in some Alaskan fjords, for example, tides sometimes exceed 15 meters. This is largely due to the ocean floor, which funnels shoreward in a V-shape. The tide often comes in faster than a person can run. Don't dig clams near the water's edge at low tide in the Bay of Fundy!

1 Explore | 2 Develop | 3 Apply

2 **Concept-Development Practice Book** *13-3*

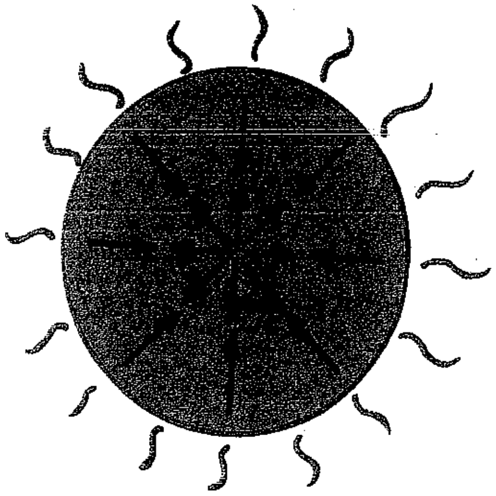


Figure 13.18 ▲
The size of the sun is the result of a "tug-of-war" between two opposing processes: nuclear fusion, which tends to blow it up (blue arrows), and gravitational contraction, which tends to crunch it together (black arrows).

swallow Earth. Fortunately, this won't take place until some 5 billion years from now. When the helium is all "burned," 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 a heavy star, one that is at least two to three times more massive than our sun,* once the flame of thermonuclear fusion is extinguished, gravitational collapse takes over—and it doesn't stop! The star not only caves in on itself, but the atoms that compose the stellar material also cave in on themselves until there are no empty spaces. According to theory, the collapse never stops and the density becomes literally infinite. Gravitation near 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.**

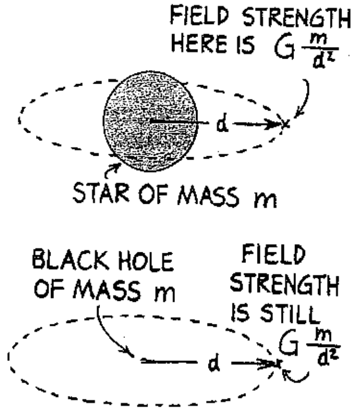


Figure 13.19 ▲
The gravitational field strength near a giant star that collapses to become a black hole is the same before collapse (top) and after collapse (bottom).

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 13.19). 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.

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 13.20. Astronauts could enter the fringes of this warp and, with a powerful spaceship, still escape. After a certain distance, however, they could

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* Astrophysicists don't yet have an exact number for the least massive star that will inevitably become a black hole. They believe it to be at least two solar masses.

16. Distinguish between *spring* tides and *neap* tides. (13.4)

17. Do the sun and moon produce atmospheric tides on Earth? (13.5)

18. What two major factors determine the size of a star? (13.6)

19. Distinguish between a stellar black *dwarf* and a black *hole*. (13.6)

20. Why would Earth not be sucked into the sun if it became a black hole? (13.6)

Plug and Chug *Use Equations*

Problems 21–24 all relate to the following information.

A kilogram of water on the side of Earth nearest the moon is gravitationally attracted to the moon with a greater force than a kilogram of water on the side of Earth farthest from the moon. The difference in force per mass, the tidal force, is approximated by

$$F_T = \frac{4GMR}{d^3}$$

where G is the gravitational constant, M is the mass of the moon, R is the radius of Earth, and d is the distance between the centers of the moon and Earth.

21. Calculate F_T of the moon on Earth in units N/kg. ($M = 7.35 \times 10^{22}$ kg, $R = 6.4 \times 10^6$ m, and $d = 3.85 \times 10^8$ m)

22. If you stand on Earth directly under the moon, the moon's tidal pull will slightly stretch you, pulling harder on your head than on your feet. Your head and feet are not far apart like Earth's oceans are, so R in the tidal force equation is only about half your height rather than half Earth's diameter. Approximate the F_T of the moon on you.

23. Earth under your feet also stretches you ever so slightly by pulling harder on your feet than on your head. What is Earth's F_T on you? (Now R is half your height and d is the distance from the center of Earth to you, 6.4×10^6 m. M will be Earth's mass, 6.0×10^{24} kg.) How does Earth's tidal force on you compare with the moon's?

24. Even a 1-kg melon held above your head exerts a tidal force on you. The above equation, however, is a good approximation only when d is much larger than R—certainly true for the previous cases, but not for the melon. The distance d between the center of the melon and your center is only about twice R. So the general tidal force equation (the source of the above equation) must be used, which is $F_T = (4GMdR)/(d^2 - R^2)^2$. Use this to calculate the melon's F_T on you. Here $M = 1$ kg, and if you're 2 m tall, $R = 1$ m, and $d = 2$ m. How does this compare with the tidal force of the moon on you?

Think and Explain *Think Critically*

25. The gravitational field strength at Earth's surface is 9.8 N/kg. What is the field strength at the center of Earth? At a distance one Earth radius beyond the surface?

26. If Earth were the same size but twice as massive, how would the value of G change, if at all? How would the value of $\mathbf{g}$ change, if at all? (Why are your answers different? In this and the following question, let the equation $\mathbf{g} = GM/R^2$ guide your thinking.)

27. How would the gravitational field at Earth's surface be affected if Earth shrank in size without any change in mass? What would be its relative strength at the new surface if Earth shrank to half size? To one-tenth size?

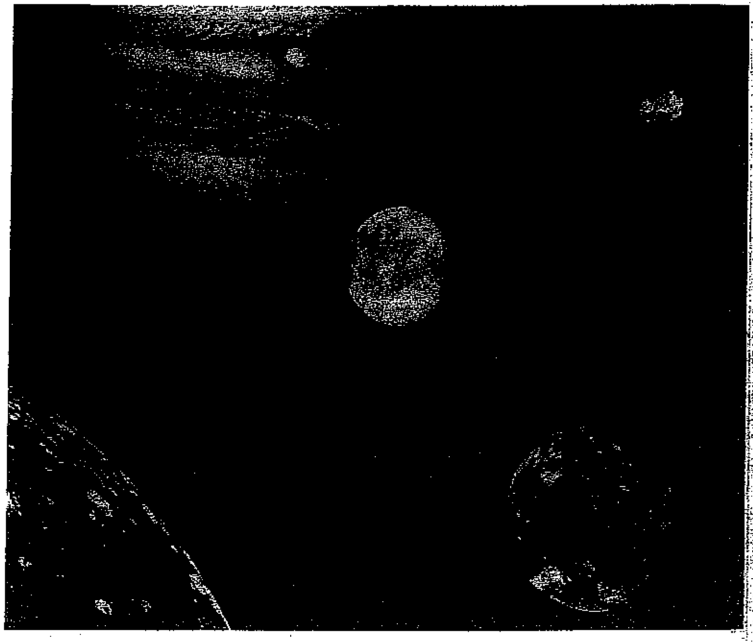
28. If the radius of Earth somehow shrank by half without any change in Earth's mass, what would be the value of $\mathbf{g}$ at the new surface? What would be the value of $\mathbf{g}$ above the new surface at a distance equal to the present radius?

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

30. A friend proposes an idea for launching space probes that consists of boring a hole completely through Earth. Your friend reasons that a probe dropped into such a hole would accelerate all the way through and shoot like a projectile out the other side. Defend or oppose the reasoning of your friend.

Chapter 14

Satellite Motion



All bodies in space are falling around other bodies.

If you drop a stone, it will fall in a straight-line path to the ground below. If you move your hand horizontally as you drop the stone, it will follow a curved path to the ground. If you move your hand faster, the stone will land farther away and the curvature of the path will be less pronounced. What would happen if the curvature of the path matched the curvature of Earth? The answer is simple enough: Without air resistance, you'd have an Earth satellite!

Figure 14.1 ▲
The greater the stone's horizontal motion when released, the wider the arc of its curved path.

14.1 Earth Satellites

Simply put, an Earth satellite is a projectile that falls *around* Earth rather than *into* it. Imagine yourself on a planet that is smaller than Earth (Figure 14.2). Because of the planet's small size and low mass, you would not have to throw the stone very fast to make its curved path match the surface curvature of the planet. If you threw the stone just right, it would follow a circular orbit.

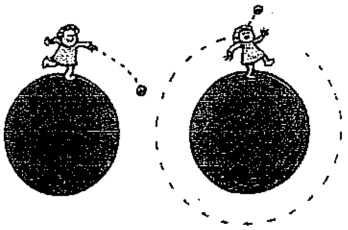
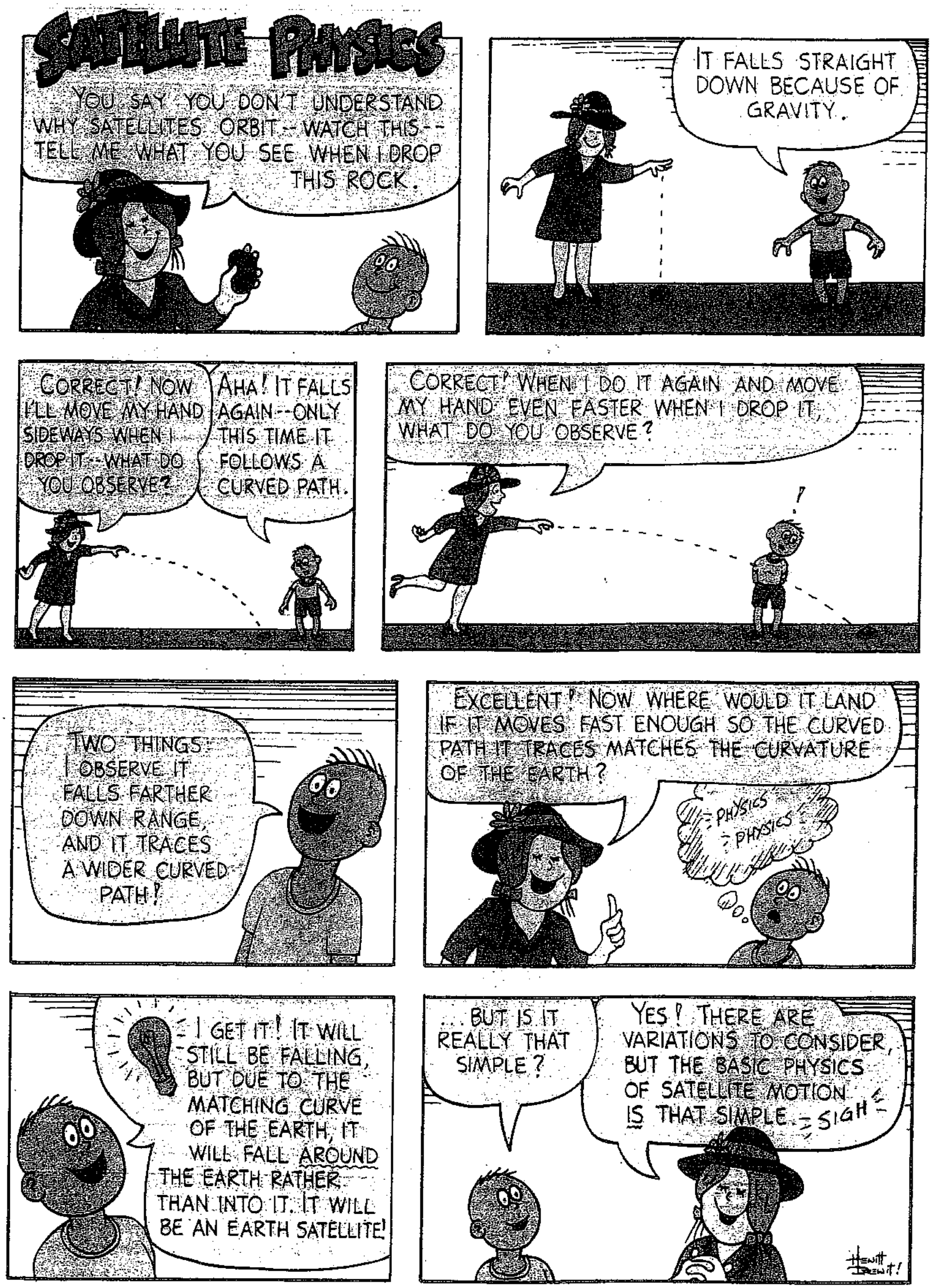


Figure 14.2 ▲
If you toss the stone horizontally with the proper speed, its path will match the surface curvature of the asteroid.


SATELLITE PHYSICS
YOU SAY YOU DON'T UNDERSTAND WHY SATELLITES ORBIT -- WATCH THIS -- TELL ME WHAT YOU SEE WHEN I DROP THIS ROCK.
IT FALLS STRAIGHT DOWN BECAUSE OF GRAVITY.
CORRECT! NOW I'LL MOVE MY HAND SIDEWAYS WHEN I DROP IT -- WHAT DO YOU OBSERVE?
AHA! IT FALLS AGAIN -- ONLY THIS TIME IT FOLLOWS A CURVED PATH.
CORRECT! WHEN I DO IT AGAIN AND MOVE MY HAND EVEN FASTER WHEN I DROP IT, WHAT DO YOU OBSERVE?
!
TWO THINGS: I OBSERVE IT FALLS FARTHER DOWN RANGE, AND IT TRACES A WIDER CURVED PATH!
EXCELLENT! NOW WHERE WOULD IT LAND IF IT MOVES FAST ENOUGH SO THE CURVED PATH IT TRACES MATCHES THE CURVATURE OF THE EARTH?
PHYSICS PHYSICS
I GET IT! IT WILL STILL BE FALLING, BUT DUE TO THE MATCHING CURVE OF THE EARTH, IT WILL FALL AROUND THE EARTH RATHER THAN INTO IT. IT WILL BE AN EARTH SATELLITE!
... BUT IS IT REALLY THAT SIMPLE?
YES! THERE ARE VARIATIONS TO CONSIDER, BUT THE BASIC PHYSICS OF SATELLITE MOTION IS THAT SIMPLE. SIGH
Hewitt Drewit!

Questions

1. There are usually alternate explanations for things. Is the following explanation valid? Satellites remain in orbit instead of falling to Earth because they are beyond the main pull of Earth's gravity.
2. Satellites in close circular orbit fall about 5 m during each second of orbit. How can this be if the satellite does not get closer to Earth?

Recall from Chapter 12 that Isaac Newton understood satellite motion from his investigation of the moon's motion. He foresaw the launching of artificial satellites, for he reasoned that without air resistance, a cannonball could circle Earth and coast indefinitely if it had sufficient speed. He calculated this speed to be the same as 8 km/s. Since such speed was impossible then, he was not optimistic about people launching satellites. What Newton did not consider was multistage rockets—the idea of rockets carried piggyback style on other rockets to reach orbital speed by a succession of rocket firings.

14.3 Elliptical Orbits

A projectile just above the atmosphere at a horizontal speed somewhat more than 8 km/s will overshoot a circular path and trace an oval-shaped path—an **ellipse.**

An ellipse is a specific curve: the closed path taken by a point that moves in such a way that the sum of its distances from two fixed points (called **foci**) is constant. For a satellite orbiting a planet, the center of the planet is at one focus and the other focus could be inside or outside the planet. An ellipse can be easily constructed by using a pair of tacks, one at each focus, a loop of string, and a pencil, as shown in Figure 14.7. The closer the tacks, the closer the ellipse is to a circle. When the foci are together, the ellipse *is* a circle. A circle is a special case of an ellipse.

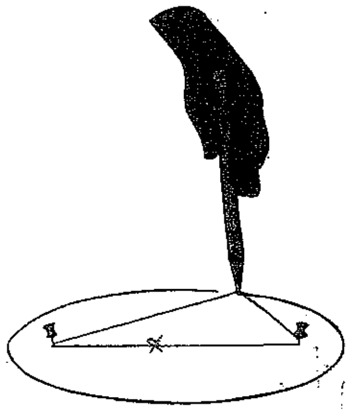


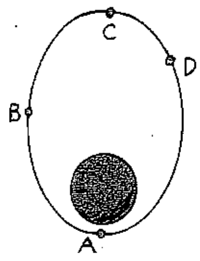
Figure 14.7 ▲
A simple method of constructing an ellipse.

Answers

1. No, no, a thousand times no! No mass can be beyond the pull of gravity. If any moving object were, it would move in a straight line and would not curve around Earth. Satellites remain in orbit because they *are* being pulled by gravity, not because they are beyond it.
2. In each second, the satellite falls about 5 m below the straight-line tangent it would have taken if there were no gravity. Earth's surface curves 5 m below an 8-km straight-line tangent. Since the satellite moves at 8 km/s, it "falls" at the same rate Earth "curves."

Question

The orbit of a satellite is shown in the sketch. In which of the positions *A* through *D* does the satellite have the greatest speed? Least speed?



14.4 Energy Conservation and Satellite Motion

Recall from Chapter 8 that moving objects have kinetic energy (KE). An object above Earth's surface has potential energy (PE) due to its position. Everywhere in its orbit, a satellite has both KE and PE. The sum of the KE and PE everywhere is constant.

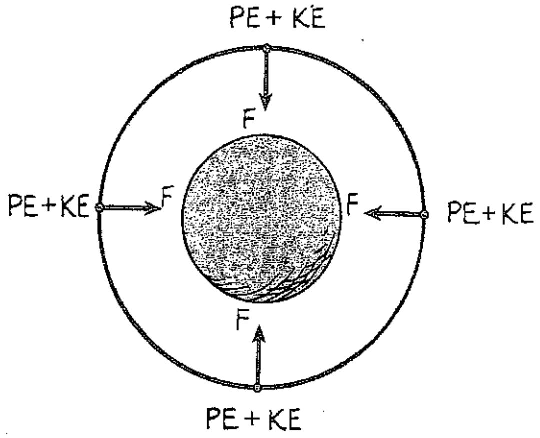


Figure 14.10 ▲
The force of gravity on the satellite is always toward the center of the body it orbits. For a satellite in circular orbit, no component of force acts along the direction of motion. The speed, and thus the KE, cannot change.

Answer

The satellite has its greatest speed as it whips around *A*. It has its least speed at *C*. Beyond *C*, it gains speed as it falls back to *A* to repeat its cycle.

Satellite Design Engineer

Satellites play an important role in conducting scientific research, obtaining environmental data, and providing communications services. Satellite design engineers are employed by the United States government through NASA and by commercial communications companies. The goal of a satellite design engineer is to design satellites that will orbit at specific distances from Earth, carry the necessary equipment, and withstand the conditions to which they will be exposed—all of this within a controlled monetary budget.

14.5 Escape Speed

When a payload is put into Earth-orbit by a rocket, the speed and direction of the rocket are very important. For example, what would happen if the rocket were launched vertically and quickly achieved a speed of 8 km/s? Everyone had better get out of the way, because it would soon come crashing back at 8 km/s. To achieve orbit, the payload must be launched *horizontally* at 8 km/s once above air resistance. Launched vertically, the old saying "What goes up must come down" becomes a sad fact of life.

But isn't there some vertical speed that is sufficient to ensure that what goes up will escape and not come down? The answer is yes. Neglecting air resistance, fire anything at any speed greater than 11.2 km/s, and it will leave Earth, going more and more slowly, but never stopping.* Let's look at this from an energy point of view.

How much work is required to move a payload against the force of Earth's gravity to a distance very, very far ("infinitely far") away? We might think that the PE would be infinite because the distance is infinite. But gravity diminishes rapidly with distance via the inverse-square law. The force of gravity is strong only when close to Earth. Most of the work done in launching a rocket, for example, occurs near Earth. It turns out that the value of PE for a 1-kilogram mass infinitely far away is 62 million joules (MJ). So to put a payload infinitely far from Earth's surface requires at least 62 MJ of energy per kilogram of load. We won't go through the calculation here, but a KE per unit mass of 62 MJ/kg corresponds to a speed of 11.2 km/s. This is the value of the **escape speed** from the surface of Earth.**

If we give a payload any more energy than 62 MJ/kg at the surface of Earth or, equivalently, any greater speed than 11.2 km/s, then, neglecting air resistance, the payload will escape from Earth never to return. As it continues outward, its PE increases and its KE decreases. Its speed becomes less and less, though it is never reduced to zero. The payload outruns the gravity of Earth. It escapes.

The escape speeds of various bodies in the solar system are shown in Table 14.1. Note that the escape speed from the sun is 620 km/s at the surface of the sun. Even at a distance equaling that of Earth's orbit, the escape speed from the sun is 42.2 km/s. The escape speed values in the table ignore the forces exerted by other bodies. A projectile fired from Earth at 11.2 km/s, for example, escapes Earth but not necessarily the moon, and certainly not the sun. Rather than recede forever, it will take up an orbit around the sun.

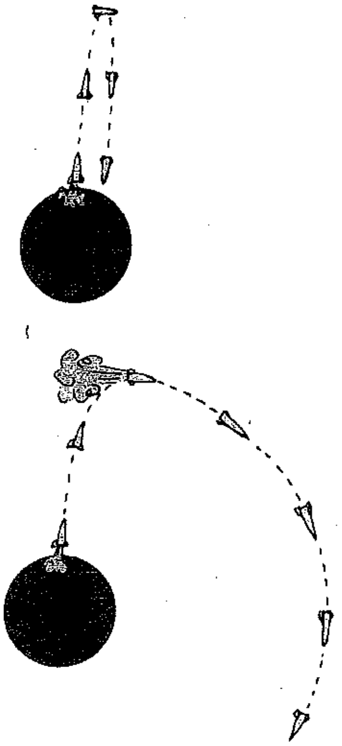


Figure 14.13 ▲
The initial thrust of the rocket lifts it vertically. Another thrust tips it from its vertical course. When it is moving horizontally, it is boosted to the required speed for orbit.

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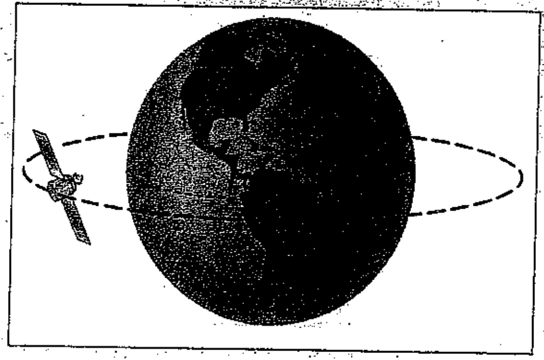
* In later physics courses you will learn how the value of escape speed *v*, from any planet or any body, is given by $v = \sqrt{2GM/d}$, where *G* is the universal gravitational constant, *M* is the mass of the attracting body, and *d* is the distance from its center. (At the surface of the body *d* would simply be the radius of the body.)

** Interestingly enough, this might well be called the *maximum falling speed.* Any object, however far from Earth, released and allowed to fall to Earth only under the influence of Earth's gravity would not exceed 11.2 km/s. (With air friction, it would be less.)

SCIENCE, TECHNOLOGY, AND SOCIETY

Communications Satellites

The electromagnetic signals that are broadcast into space to carry television programs or telephone conversations travel in straight lines. In times past these straight-line (often called line-of-sight) communications required tall receiving antenna towers and signal-boosting relay stations on high buildings or mountains. Today many television and telephone signals bounce to us from satellites. These communications satellites are in equatorial orbits with 24-hour periods. Because they revolve once each time Earth rotates once, they appear stationary when we look up at them.



Dish-shaped antennas almost anywhere on Earth are on a line of sight from one or more communications satellites. Because communications satellites are in equatorial orbit, dish antennas on the equator may tilt east or west, but they don't tilt north or south. An equatorial dish right under a communications satellite is looking straight up. If it held water, it would resemble a birdbath filled to the brim. Antennas north of the equator must be tilted to the south (and perhaps east or west, too). Those south of the equator must be tilted to the north, and likely east or west as well. Unless you live on the equator, all of the antennas that you see look like partly emptied bowls. In Antarctica or near the North Pole, a dish antenna is tipped so far over that it could hold no water at all.

Critical Thinking Explain why it is not possible for a single communications satellite to serve all parts of Earth.

rocket is going to a destination such as the moon. If the rocket engines burn out while still close to Earth, the rocket will need a minimum speed of 11.2 km/s. But if the rocket engines can be sustained for long periods of time, the rocket could go to the moon without ever attaining 11.2 km/s.

It is interesting to note that the accuracy with which an unpiloted rocket reaches its destination is accomplished not by staying on a preplanned path, or by getting back on that path if it strays off course. No attempt is made to return the rocket to its planned path. Instead, by communication with the control center, the rocket in effect asks, "Where am I now, and where do I want to go? What is the best way to get there from here, given my present situation?" With the aid of high-speed computers, the answers to these questions are used to find a *new* path. Corrective thrusters put the rocket on this new path. This process is repeated continuously along the way until the rocket reaches its destination.

Is there a lesson to be learned here? Suppose you find that you are "off course." You may, like the rocket, find it more fruitful to take a course that leads to your goal as best plotted from your present position and circumstances, rather than try to get back on the course you plotted from a previous position and in, perhaps, different circumstances.

1 Explore *2 Develop* *3 Apply*

3 **Problem-Solving Exercises in Physics** *7-3*

Think and Explain *Think Critically*

15. A satellite can orbit at 5 km above the moon, but not at 5 km above Earth. Why?

16. Does the speed of a satellite around Earth depend on its mass? Its distance from Earth? The mass of Earth?

17. If a cannonball is fired from a tall mountain, gravity changes its speed all along its trajectory. But if it is fired fast enough to go into circular orbit, gravity does not change its speed at all. Why?

18. Does gravity do any *net* work on a satellite in an elliptical orbit during one full orbit? Explain your answer.

19. If you stopped an Earth satellite dead in its tracks, it would simply crash into Earth. Why, then, don't the communications satellites that "hover motionless" above the same spot on Earth crash into Earth?

20. Would you expect the speed of a satellite in close circular orbit about the moon to be less than, equal to, or greater than 8 km/s? Why?

21. Why do you suppose that sites close to the equator are preferred for launching satellites? (*Hint:* Look at the spinning Earth from above either pole and compare it to a spinning turntable.)

22. Why do you suppose that a space shuttle is sent into orbit by firing it in an easterly direction (the direction in which Earth spins)?

23. If an astronaut in an orbiting space shuttle wished to drop something to Earth, how could this be accomplished?

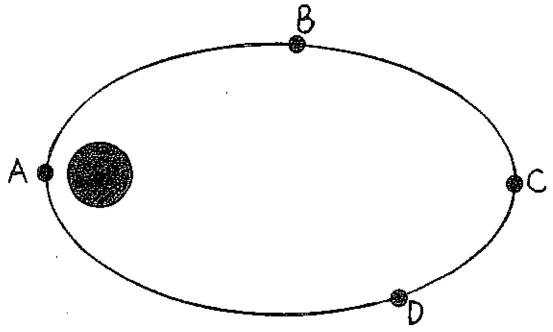
24. Why does most of the work done in launching a rocket take place when the rocket is still close to Earth's surface?

25. What is the maximum possible speed of impact upon Earth's surface for a far-away object initially at rest that falls to Earth due only to Earth's gravity?

26. If Pluto were somehow stopped short in its orbit, it would fall into the sun rather than around it. About how fast would it be moving when it hit the sun?

27. If Earth somehow acquired more mass, with no change in its radius, would escape speed be less than, equal to, or more than 11.2 km/s? Why?

28. This question reviews several concepts of mechanics. A satellite travels the elliptical path shown below. At which of the indicated positions *A* through *D* does the satellite experience the maximum (a) gravitational force? (b) speed? (c) velocity? (d) momentum? (e) kinetic energy? (f) gravitational potential energy? (g) total energy? (h) acceleration? (i) angular momentum?



Think and Solve
Develop Problem-Solving Skills

29. Calculate the speed in m/s at which Earth revolves around the sun. Note: The orbit is nearly circular.

30. Calculate the speed in m/s at which the moon revolves around Earth. Note: The orbit is nearly circular.

31. Escape speed at a distance *d* from the center of a body of mass *M* is

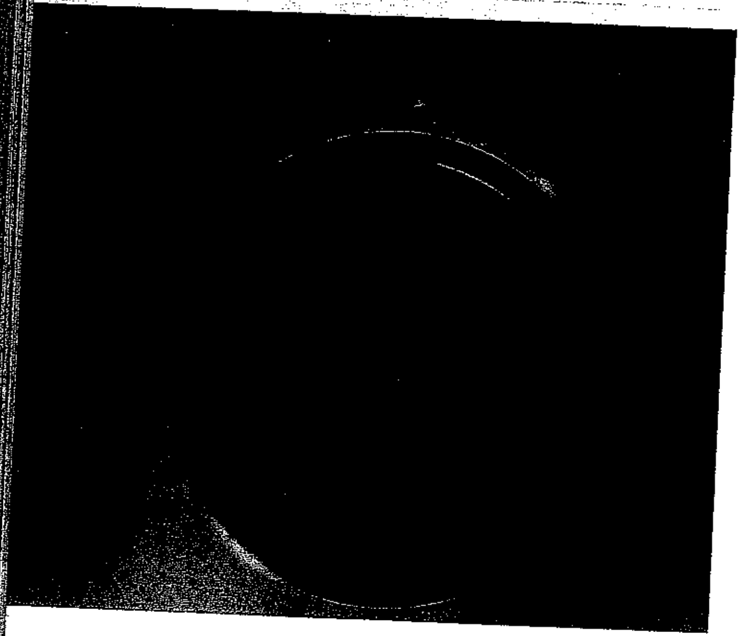
$$v_{\text{escape}} = \sqrt{\frac{2GM}{d}}$$

Calculate the escape speed from the moon's surface (moon radius = 1.74×10^6 m, moon mass = 7.35×10^{22} kg). Check your answer with Table 14.1.

More Problem-Solving Practice
Appendix F

Chapter

Special Relativity—Space and Time



Space and time are related.

Everyone knows that we move in time, at the rate of 24 hours per day. And everyone knows that we can move through space, at rates ranging from a snail's pace to those of supersonic aircraft and space shuttles. But relatively few people know that motion through space is related to motion in time.

The first person to understand the relationship between space and time was Albert Einstein.* Einstein went beyond common sense when he stated in 1905 that in moving through space we also change our rate of proceeding into the future—time itself is altered. This view was introduced to the world in his **special theory of relativity.** This theory describes how time is affected by motion in space at constant velocity, and how mass and energy are related. Ten years later Einstein announced a similar theory, called the *general theory of relativity,* which encompasses accelerated motion as well. These theories have enormously changed the way scientists view the workings of the universe. This book discusses only the special theory and leaves the general theory for follow-up study later in your education.

This chapter will serve merely to acquaint you with the basic ideas of special relativity as they relate to space and time. Chapter 16 will continue with the relationship between mass and energy. These ideas, for the most part, are not common to your everyday experience. As a result, they don't agree with common sense. So please be patient with yourself if you find that you do not understand them. Perhaps your children or grandchildren will find them very much a part of their everyday experience. If so, they should find an understanding of relativity considerably less difficult.

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* The concerns of Albert Einstein (1879–1955) were not limited to physics. As a German citizen in Nazi Germany he spoke out against Hitler's racial and political policies, which prompted his resignation from the University of Berlin. He fled Germany in 1933 and became an American citizen in 1940.

you experience in time? The answer is that all your traveling would be through space, with no travel through time! You would be as ageless as light, for light travels through space only (not time) and is timeless. From the frame of reference of a photon traveling from one part of the universe to another, the journey takes no time at all!

Motion in space affects motion in time. Whenever we move through space, we to some degree alter our rate of moving into the future. This is **time dilation,** a stretching of time that occurs ever so slightly for everyday speeds, but significantly for speeds approaching the speed of light. If spacecraft of the future reach sufficient speed, people will be able to travel noticeably in time. They will be able to jump centuries ahead, just as today people can jump from Earth to the moon. To understand time dilation and how this can be, you first need to understand several ideas: the relativity of motion and the fundamental assumptions (postulates) of special relativity.

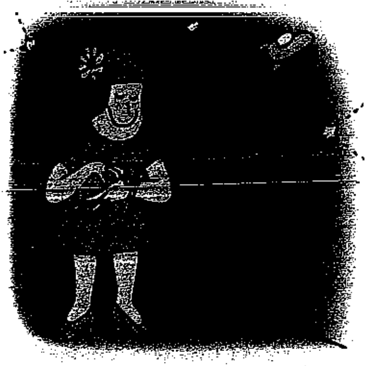

Figure 15.2 ▲
When you stand still, you are traveling at the maximum rate in time: 24 hours per day. If you traveled at the maximum rate through space (the speed of light), time would stand still.

15.2 Motion Is Relative

Recall from Chapter 2 that whenever we discuss motion, we must specify the position from which the motion is being observed and measured. For example, you may walk along the aisle of a moving bus at a speed of 1 km/h relative to your seat, but at 100 km/h relative to the road outside. Speed is a relative quantity. Its value depends upon the place—the frame of reference—where it is observed and measured. An object may have different speeds relative to different frames of reference.

Suppose your friend always pitches a baseball at the same speed of 60 km/h. Neglecting air resistance and other small effects, the ball is moving at 60 km/h when you catch it. Now suppose your friend pitches the ball to you from the flatbed of a truck that moves toward you at 40 km/h. How fast does the ball meet you? You'll have to be sure to wear a catcher's mitt, because the speed of the ball will be 100 km/h (the 60 km/h relative to the truck plus the 40 km/h relative to the ground). Speed is relative.

Figure 15.3 ▲
The bag of groceries has an appreciable speed in the frame of reference of the building, but in the frame of reference of the freely falling elevator it has no speed at all.

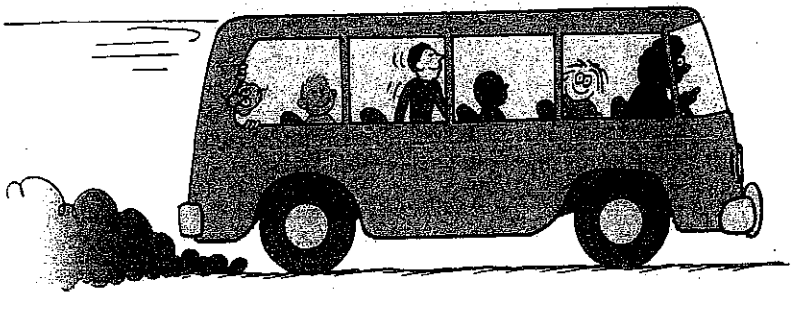

Figure 15.4 ▲
Your speed is 1 km/h relative to your seat, and 100 km/h relative to the road.

same value of 300 000 km/s, regardless of the speed of the source or the speed of the receiver.* We do not ordinarily notice this because light travels so incredibly fast.

The fact that light has only one speed in empty space was discovered at the end of the last century.** Light from an approaching source reaches an observer at the same speed as light from a receding source. And the speed of light is the same whether we move toward or away from a light source. How did the physics community regard this finding? They were as perplexed as you would be if you caught baseballs at only one speed no matter how they were thrown. Experiments were done and redone, and always the results were the same. Nothing could vary the speed of light. Various interpretations were proposed, but none were satisfactory. The foundations of physics were on shaky ground.

Albert Einstein looked at the speed of light in terms of the definition of speed. What is speed? It is the amount of *space* traveled compared to the *time* of travel. Einstein recognized that the classical ideas of space and time were suspect. He concluded that space and time were a part of a single entity—space-time. The constancy of the speed of light, Einstein reasoned, unifies space and time.

The special theory of relativity that Einstein developed rests on two fundamental assumptions, or **postulates.**

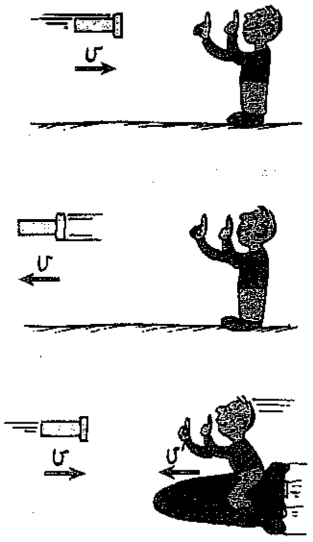

Figure 15.6 ▲
The speed of light is found to be the same in all frames of reference.

15.4 The First Postulate of Special Relativity

Einstein reasoned that there is no stationary hitching post in the universe relative to which motion should be measured. Instead, all motion is relative and all frames of reference are arbitrary. A spaceship cannot measure its speed relative to empty space, but only relative to other objects. If, for example, spaceship A drifts past spaceship B in empty space, spaceman A and spacewoman B will each observe only the relative motion. From this observation each will be unable to determine who is moving and who is at rest, if either.

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* The presently accepted value for the speed of light is 299 792 km/s, which we round off to 300 000 km/s. This corresponds to 186 000 mi/s.

** In 1887 two American physicists, A. A. Michelson and E. W. Morley, performed an experiment to determine differences in the speed of light in different directions. They thought that the motion of Earth in its orbit about the sun would cause shifts in the speed of light. They thought that the speed of light should have been faster when it was going in the direction Earth was moving and slower when it was going opposite to the direction Earth was moving. Using a device called an *interferometer,* they found that the speed seemed to be the same in all directions. For Michelson's many experiments on the speed of light, he was the first American honored with a Nobel Prize.

convinced he became of its impossibility. He came to the conclusion that *if* an observer could travel *close* to the speed of light, he would measure the light as moving away from him at 300 000 km/s.

This is the idea that makes up Einstein's **second postulate of special relativity:**

> The speed of light in empty space will always have the same value regardless of the motion of the source or the motion of the observer.

The speed of light in all reference frames is always the same. Consider, for example, a spaceship departing from the space station shown in Figure 15.9. A flash of light is emitted from the station at 300 000 km/s—a speed we'll simply call *c*. No matter what the speed of the spaceship relative to the space station is, an observer on the spaceship will measure the speed of the flash of light passing her as *c*. If she sends a flash of her own to the space station, observers on the station will measure the speed of these flashes as *c*. The speed of the flashes will be no different if the spaceship stops or turns around and approaches. All observers who measure the speed of light will find it has the same value, *c*.

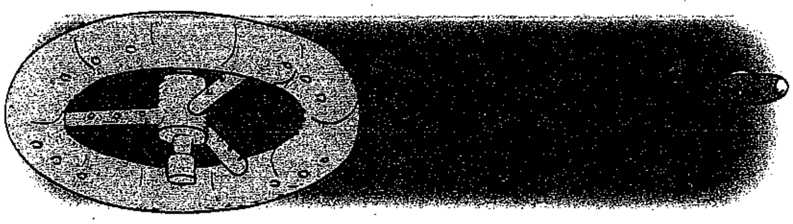


Figure 15.9 ▶
The speed of a light flash emitted by either the spaceship or the space station is measured as *c* by observers on the ship or the space station. Everyone who measures the speed of light will get the same value *c*.

The constancy of the speed of light is what unifies space and time. And for any observation of motion through space, there is a corresponding passage of time. The ratio of space to time for light is the same for all who measure it. The speed of light is a constant.

$$\frac{\text{SPACE}}{\text{TIME}} = \frac{\text{SPACE}}{\text{TIME}} = c$$

Figure 15.10 ▲
All space and time measurements of light are unified by *c*.

15.6 Time Dilation

Pretend you are in a spaceship at rest in a part of your "hometown" where a large public clock is displayed. Suppose the clock reads "12 noon." To say it reads "12 noon" is to say that light reflects from the clock and carries the information "12 noon" toward you in the direction of your line of sight. If you suddenly move your head to the side, instead of meeting your eye, the light carrying the information will continue past, presumably out into space. Out there an observer who *later* receives the light could say, "Oh, it's 12 noon on Earth now." But from your point of view it isn't. You and the distant observer will see 12 noon at different times. Now suppose your spaceship is moving as fast as the speed of light (just pretending). Then you'd keep up with the clock's information that says "12 noon." Traveling at the speed of light, then, tells you its always 12 noon back home. Time at home is

But remember the second postulate of relativity: The speed will be measured by *any* observer as c. Since the speed of light will not increase, we must measure more time between bounces! For us, looking in from the outside, one tick of the light clock takes longer than it takes for occupants of the spaceship. The spaceship's clock, according to our observations, has slowed down—although, for occupants of the spaceship, it has not slowed at all!

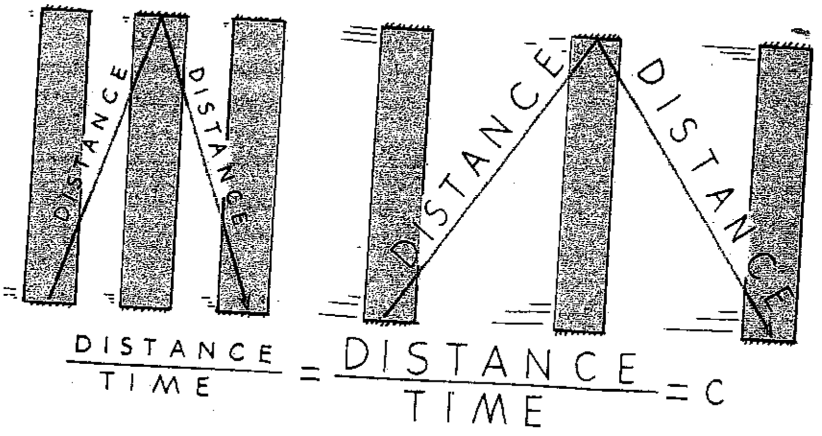


Figure 15.13 ▶
The longer distance taken by the light flash in following the diagonal path must be divided by a correspondingly longer time interval to yield an unvarying value for the speed of light.

The slowing of time is not peculiar to the light clock. It is time itself in the moving frame of reference, as viewed from our frame of reference, that slows. The heartbeats of the spaceship occupants will have a slower rhythm. All events on the moving ship will be observed by us as slower. We say that time is "dilated."

How do the occupants on the spaceship view their own time? Do they perceive themselves moving in slow motion? Do they experience longer lives as a result of time dilation? As it turns out, they notice none of these things. Time for them is the same as when they do not appear to us to be moving at all. Recall Einstein's first postulate: All laws of nature are the same in all uniformly moving frames of reference. There is no way the spaceship occupants can tell uniform motion from rest. They have no clues that events on board are seen to be dilated when viewed from other frames of reference.

How do occupants on the spaceship view *our* time? Do they see our time as speeded up? The answer is no—motion is relative, and

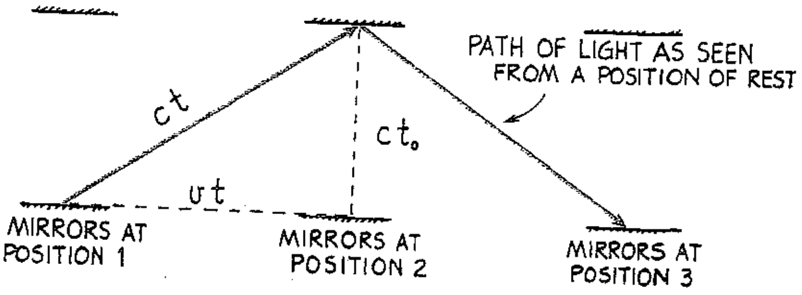


Figure 15.14 ▲
Mathematical detail of Figure 15.13.

1 Explore **2 Develop** **3 Apply**

Problem-Solving Exercises in Physics *8-1*

Questions

1. Does time dilation mean that time *really* passes more slowly in moving systems or that it only *seems* to pass more slowly?
2. If you were moving in a spaceship at a high speed relative to Earth, would you notice a difference in your pulse rate? In the pulse rate of the people back on Earth?
3. Will observers A and B agree on measurements of time if A moves at half the speed of light relative to B? If both A and B move together at 0.5*c* relative to Earth?

from *their* frame of reference it appears that *we* are the ones who are moving. They see our time running slow, just as we see their time running slow. Is there a contradiction here? Not at all. It is physically impossible for observers in different frames of reference to refer to one and the same realm of space-time. The measurements in one frame of reference need not agree with the measurements made in another reference frame. There is only one measurement they will always agree on: the speed of light.

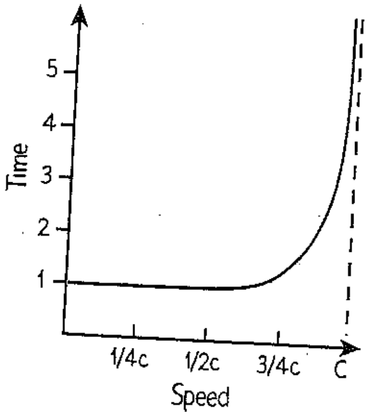


Figure 15.15 ▲
The graph shows how 1 second on a stationary clock is stretched out, as measured on a moving clock. Note that the stretching becomes significant only at speeds near the speed of light.

15.7 The Twin Trip

A dramatic illustration of time dilation is afforded by identical twins, one an astronaut who takes a high-speed round-trip journey while the other stays home on Earth. When the traveling twin returns, he is younger than the stay-at-home twin. How much younger depends on the relative speeds involved. If the traveling twin maintains a speed of 50% the speed of light for one year (according to clocks aboard the spaceship), 1.15 years will have elapsed on Earth. If the traveling twin maintains a speed of 87% the speed of light for a year, then 2 years will have elapsed on Earth. At 99.5% the speed of light,

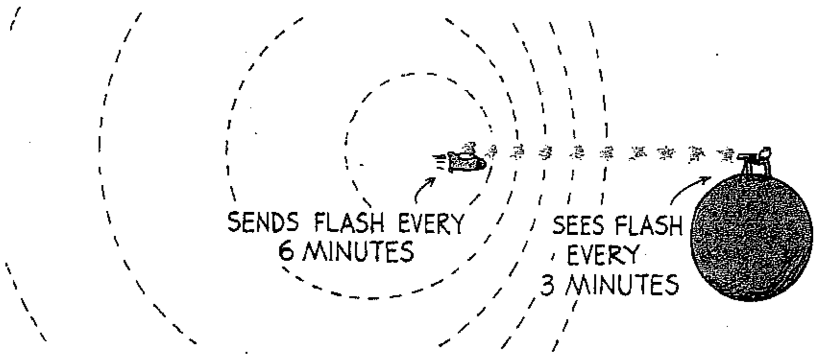
Answers

1. The slowing of time in moving systems is not merely an illusion resulting from motion. Time really does pass more slowly in a moving system compared with one at relative rest, as we shall see in the next section. Read on!
2. There would be no relative speed between you and your own pulse, so no relativistic effects would be noticed. There would be a relativistic effect between you and people back on Earth. You would find their pulse rate slower than normal (and they would find your pulse rate slower than normal). Relativity effects are always attributed to "the other guy."
3. When A and B have different motions relative to each other, each will observe a slowing of time in the frame of reference of the other. So they will not agree on measurements of time. When they are moving in unison, they share the same frame of reference and will agree on measurements of time. They will see each other's time as passing normally, and each one will see events on Earth in the same slow motion.

planet at speed c. Since there is no relative motion between the sender and receiver, successive flashes will be received as frequently as they are sent. For example, if a flash is sent from the ship every 6 minutes, then after some initial delay, the receiver will receive a flash every 6 minutes. With no motion involved, there is nothing unusual about this.

When motion is involved, the situation is quite different. It is important to note that the *speed* of the flashes will still be c, no matter how the ship or receiver may move. How *frequently* the flashes are seen, however, very much depends on the relative motion involved. When the ship travels *toward* the receiver, the receiver sees the flashes more often—that is, more frequently. This happens not only because time is altered due to motion, but mainly because each succeeding flash has less distance to travel as the ship gets closer to the receiver. If the spaceship emits a flash every 6 minutes, the flashes will be seen at intervals of less than 6 minutes. Suppose the ship is traveling fast enough for the flashes to be seen twice as frequently. Then they are seen at intervals of 3 minutes. Note in Figure 15.18 that the flashes for approach are closer together and equally spaced.

Figure 15.18 ▶
When the sender moves toward the receiver, the flashes are seen more frequently.



If the ship *recedes* from the receiver at the same speed and still emits flashes at 6-min intervals, these flashes will be seen half as frequently by the receiver, that is, at 12-min intervals (Figure 15.19). This is mainly because each succeeding flash has a longer distance to travel as the ship gets farther away from the receiver.

The effect of moving away is just the opposite of moving closer to the receiver. So if the flashes are received twice as frequently when the spaceship is approaching (6-min flash intervals are seen every 3 min), they are received half as frequently when it is receding (6-min flash intervals are seen every 12 min).*

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* The frequencies for approach and for recession are *reciprocals* of each other. That is, flashes that are seen 2 times as frequently for approach are seen $\frac{1}{2}$ as frequently for recession. If seen 3 times as frequently for approach, the flashes are seen $\frac{1}{3}$ as frequently for recession, and so on for higher speeds. This reciprocal relationship does not hold for waves that require a medium. In the case of sound waves, for example, a speed that results in a doubling of emitting frequency for approach produces the emitting frequency for recession.

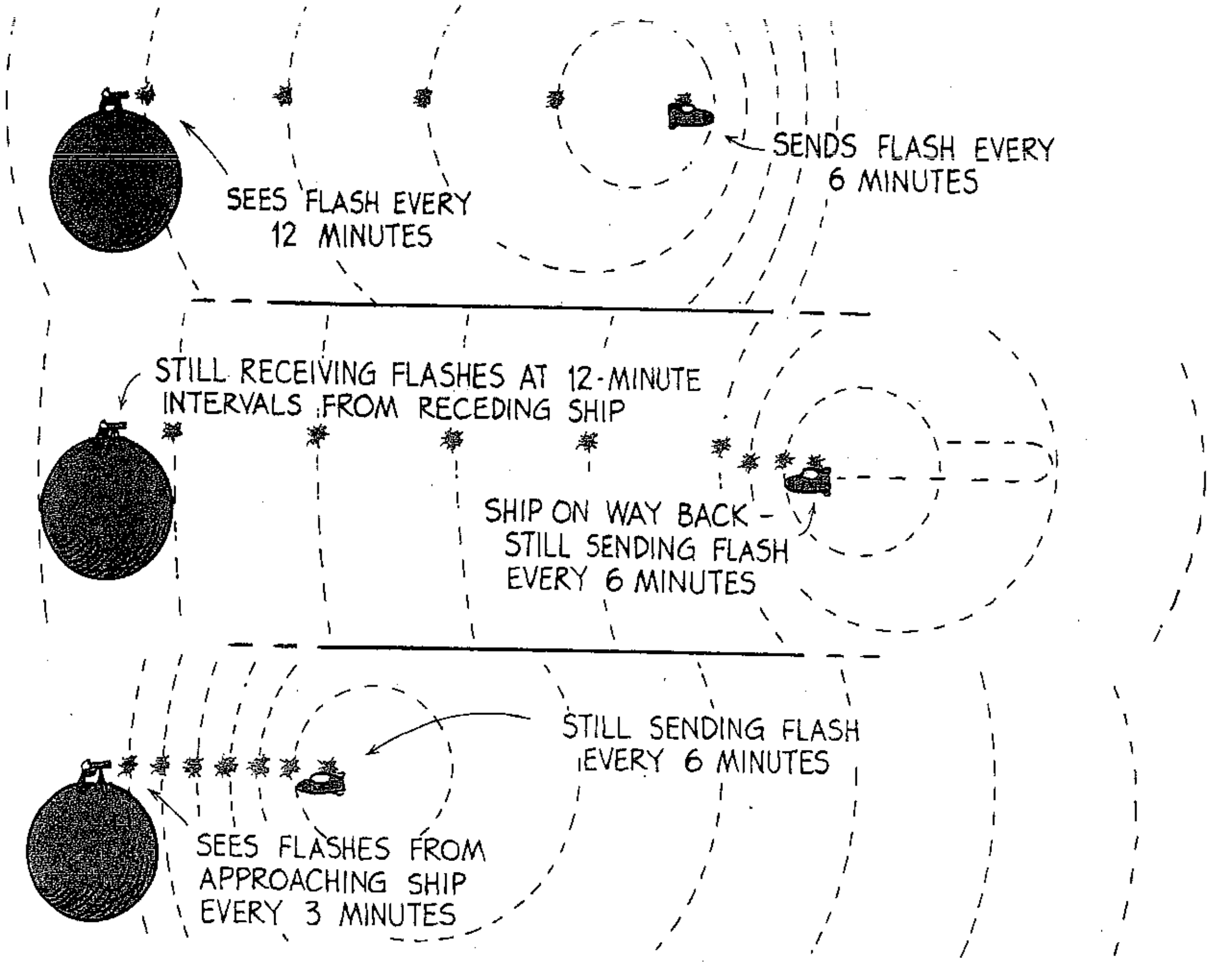

Figure 15.20 ▲
The spaceship emits flashes each 6 minutes during a two-hour trip. During the first hour, it recedes from Earth. During the second hour, it approaches Earth.

As the ship recedes from Earth, it emits a flash of light every 6 min. These flashes are received on Earth every 12 min. During the hour of going away from Earth, a total of 10 flashes are emitted. If the ship departs from Earth at noon, clocks aboard the ship will read 1 p.m. when the tenth flash is emitted. What time will it be on Earth when this tenth flash reaches Earth? The answer is 2 p.m. Why? Because the time it takes Earth to receive 10 flashes at 12-min intervals is (10 flashes) × (12 min/flash), or 120 min (= 2 h).

Suppose the spaceship is somehow able to suddenly turn around in a negligibly short time and return at the same high speed. During the hour of return it emits 10 more flashes at 6-min intervals. These flashes are received every 3 min on Earth, so all 10 come in 30 min. A clock on Earth will read 2:30 p.m. when the spaceship completes its two-hour trip. We see that the Earthbound twin has aged a half hour more than the twin aboard the spaceship!

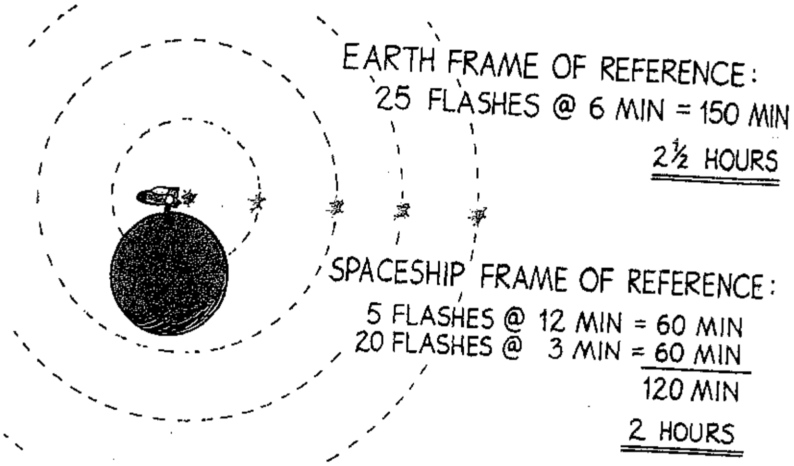

Figure 15.23 ▲
A time interval of 2.5 hours on Earth is seen to be 2 hours in the spaceship's frame of reference.

Hence, the spaceship receives a total of 25 flashes during its two-hour trip. According to clocks on Earth, however, the time it took to emit the 25 flashes at 6-min intervals was (25 flashes) × (6 min/flash), or 150 min (= 2.5 h). This is shown in Figure 15.23.

So both twins agree on the same results, with no dispute as to who ages more than the other. While the stay-at-home twin remains in a single reference frame, the traveling twin has experienced two different frames of reference, separated by the acceleration of the spaceship in turning around. The spaceship has in effect experienced two different realms of time, while Earth has experienced a still different but single realm of time. The twins can meet again at the same place in space only at the expense of time.

LINK TO TECHNOLOGY

[illegible] satellites that are part of the global positioning system (GPS). In designing this system, which can pinpoint positions on Earth to within meters, scientists and engineers had to accommodate for relativistic time dilation. If they didn't, GPS could not precisely locate positions on Earth. Time dilation is a fact of everyday life to scientists and engineers—especially those who design equipment for global navigation work.

15.8 Space and Time Travel

Before the theory of special relativity was introduced, it was argued that humans would never be able to venture to the stars. It was thought that our life span is too short to cover such great distances—at least for the distant stars. Alpha Centauri is the nearest star to Earth, after the sun, and it is 4 light-years away.* It was therefore thought that a round-trip even at the speed of light would require 8 years. The center of our galaxy is some 30 000 light-years away, so it was reasoned that a person traveling even at the speed of light would have to survive for 30 000 years to make such a voyage! But these arguments fail to take into account time dilation. Time for a person on Earth and time for a person in a high-speed spaceship are not the same.

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* A light-year is the distance that light travels in one year (9.46 × 10^{12} km).

Chapter Assessment

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Concept Summary

According to Einstein's special theory of relativity, time is affected by motion in space at constant velocity.

- Time appears to pass more slowly in a frame of reference that is moving relative to the observer.

All the laws of nature are the same in all uniformly moving frames of reference.

- No experiment can be devised to detect whether the observer is moving at constant velocity.

The speed of light in empty space is the same in all frames of reference.

- The speed of light has the same value regardless of the motion of the source or the motion of the observer.

Key Terms

first postulate of special relativity (15.4)
postulate (15.3)
second postulate of special relativity (15.5)
space-time (15.1)
special theory of relativity (15.0)
time dilation (15.1)

Review Questions *Check Concepts*

1. What is space-time? (15.1)
2. Can you travel while remaining in one place in space? Explain. (15.1)
3. Does light travel through space? Through time? Through both space and time? (15.1)
4. What is time dilation? (15.1)
5. What does it mean to say that motion is relative? (15.2)
6. The speed of a ball you catch that is thrown from a moving truck depends on the speed and direction of the truck. Does the speed of light caught from a moving source similarly depend on the speed and direction of the source? Explain. (15.3)
7. What does it mean to say that the speed of light is a constant? (15.3)
8. What is the first postulate of special relativity? (15.4)
9. What is the second postulate of special relativity? (15.5)
10. The ratio of velocity gain to time for a freely falling body is g. Similarly, what is the ratio of distance to time for light waves? (15.5)
11. The path of light in a vertical "light clock" in a high-speed spaceship is seen to be longer when viewed from a stationary frame of reference. Why, then, does the light not appear to be moving faster? (15.6)
12. If we view a passing spaceship and see that the inhabitants' time is running slow, how do they see our time running? (15.6)
13. When a flashing light source approaches you, does the speed of light, or the frequency of arrival of light flashes, or both, increase? (15.7)
14. **a.** How many frames of reference does the stay-at-home twin experience in the twin trip?

    b. How many frames of reference does the traveling twin experience? (15.7)
15. Is it possible for a person with a 70-year life span to travel farther than light travels in 70 years? Explain. (15.8)