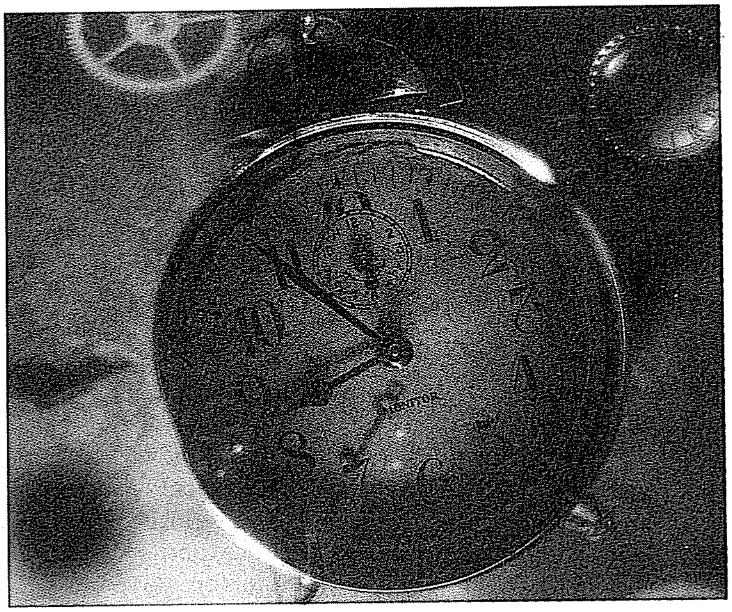
15 Special Relativity—Space and Time



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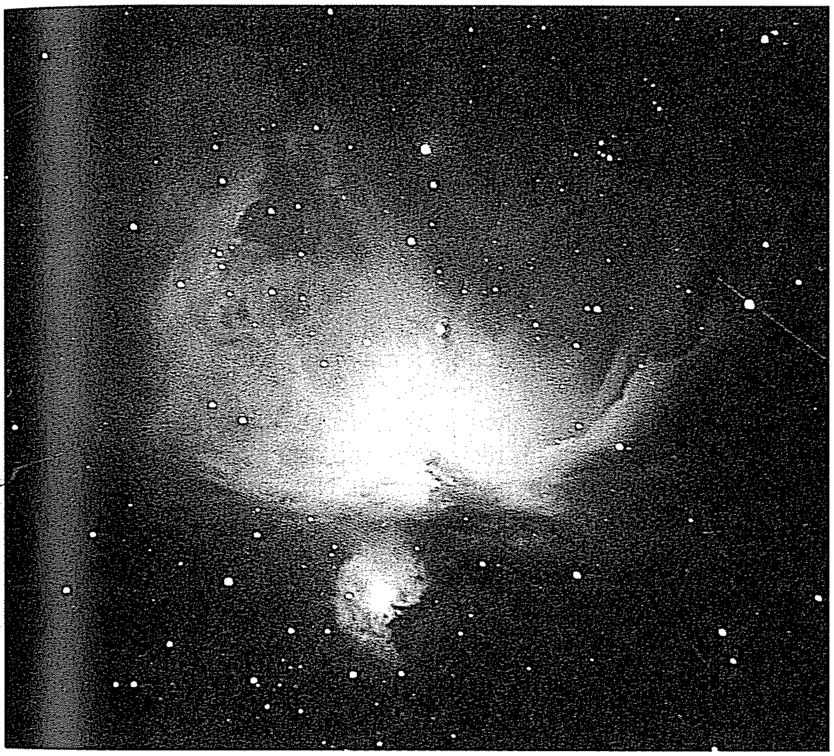
* The concerns of Albert Einstein (1879–1955) were not limited to physics. As a German citizen in Nazi Germany he spoke out against Hitler's racial and political policies, which prompted his resignation from the University of Berlin. He fled Germany in 1933 and became an American citizen in 1940.

15.1 Space-Time

Newton and other investigators before Einstein thought of space as an infinite expanse in which all things exist. We are in space, and we move about in space. It was never clear whether the universe exists in space, or space exists within the universe. Is there space outside the universe? Or is space only within the universe? The same question could be raised for time. Does the universe exist in time, or does time exist only within the universe? Was there time before the universe came to be? Will there be time if and when the universe ceases to exist? Einstein's answer to these questions is that both space and time exist only within the universe. There is no time or space "outside."



◀ **Figure 15.1**
The universe does not exist in a certain part of infinite space, nor does it exist during a certain era in time. It is the other way around: space and time exist within the universe.

Einstein reasoned that space and time are two parts of one whole called **space-time.** To begin to understand this, consider your present knowledge that you are moving through time at the rate of 24 hours per day. This is only half the story. To get the other half, convert your thinking from "moving through time" to "moving through space-time." From the viewpoint of special relativity, you travel through a combination of space and time. You travel through space-time. When you stand still, then all your traveling is through time. When you move a bit, then some of your travel is through space and most of it is still through time. If you were somehow able to travel through space at the speed of light, what changes would 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.**

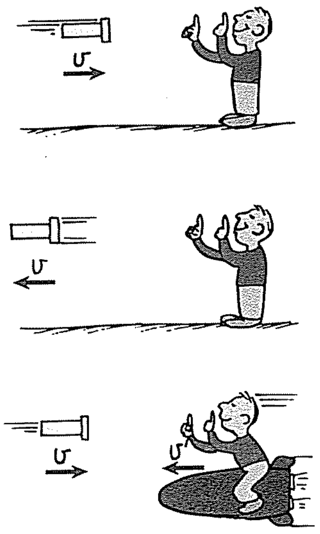


Figure 15.6 ▲
The speed of light is found to be the same in all frames of reference.

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 the 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 the earth was moving and slower when it was going opposite to the direction the 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.

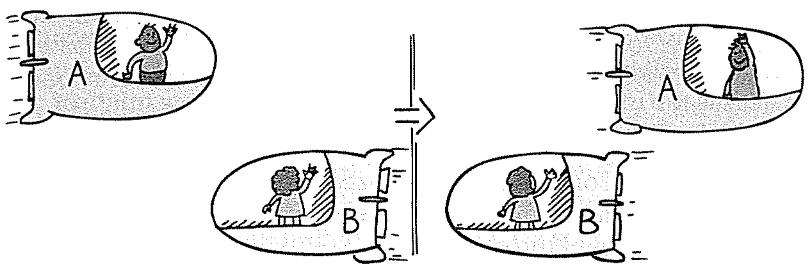


Figure 15.7 ▲
Spaceman A considers himself at rest and sees spacewoman B pass by. But spacewoman B considers herself at rest and sees spaceman A pass by. Who is moving and who is at rest?

This is a familiar experience to a passenger in a car at rest waiting for the traffic light to change. If you look out the window and see the car in the next lane begin moving backward, you may be surprised to find that the car you're observing is really at rest—your car is moving forward. If you could not see out the windows, there would be no way to determine whether your car was moving with constant velocity or was at rest.

In a high-speed jetliner we flip a coin and catch it just as we would if the plane were at rest. Coffee pours from the flight attendant's coffee pot as it does when the plane is standing on the runway. If we swing a pendulum, it will move no differently when the plane is moving uniformly (constant velocity) than when not moving at all. There is no physical experiment we can perform to determine our state of uniform motion. Of course, we can look outside and see the earth whizzing by, or send a radar signal out. However, no experiment confined within the cabin itself can determine whether or not there is uniform motion. The laws of physics within the uniformly moving cabin are the same as those in a stationary laboratory.

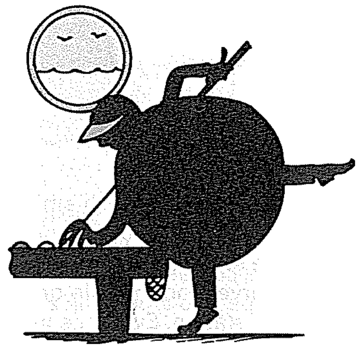


Figure 15.8 ▲
A person playing pool on a smooth and fast-moving ocean liner does not have to make adjustments to compensate for the speed of the ship. The laws of physics are the same for the ship whether it is moving uniformly or is at rest.

These examples illustrate one of the two building blocks of special relativity. It is Einstein's **first postulate of special relativity:**

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

Any number of experiments can be devised to detect *accelerated* motion, but none can be devised, according to Einstein, to detect the state of uniform motion.

15.5 The Second Postulate of Special Relativity

One of the questions that Einstein as a youth asked his schoolteacher was, "What would a light beam look like *if* you traveled along beside it?" According to classical physics, the beam would be at rest to such an observer. The more Einstein thought about this, the more 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*.

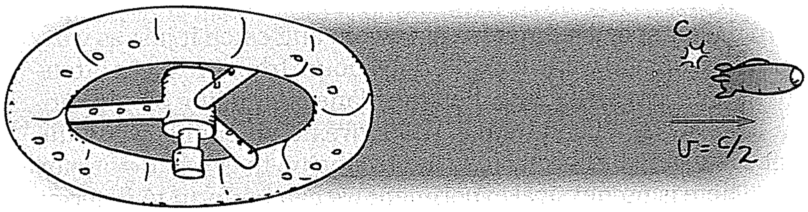


Figure 15.9 ▶
The speed of a light flash emitted by either the spaceship or the space station is measured as *c* by observers on the ship or the space station. Everyone who measures the speed of light will get the same value *c*.

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 frozen! So if your spaceship is not moving, you will see the hometown clock move into the future at the rate of 60 seconds per minute; if you could move at the speed of light, you'd see seconds on the clock taking infinite time. These are the two extremes. What's in between? How would the time readings appear to you moving at less than the speed of light? A little thought will show that the clock will be seen to run somewhere between the rate 60 seconds per minute and 60 seconds per an infinity of time if your speed is between zero and the speed of light. From your high-speed (but less than *c*) moving frame of reference, the clock and all events in the reference frame of the clock will be seen in slow motion. Time will be stretched. How much depends on speed. This is *time dilation.*

Special relativity turns around some of our conceptions about the world. We agree that speed is relative, that it depends on the speeds of the source and the observer. Yet, one speed, the speed of light, is absolute—independent of the speeds of the source or observer. Time, on the other hand, is usually thought of as absolute. It seems to pass at the same rate regardless of what is happening. Yet, our imaginary spaceship experience shows this is not true. Einstein proposed that time depends on the motion between the observer and the events being observed.

We measure time with a clock. A clock can be any device that measures periodic intervals, such as the swings of a pendulum, the oscillations of a balance wheel, or the vibrations of a quartz crystal. We are going to consider a "light clock," a rather impractical device, but one that will help to describe time dilation.

Imagine an empty tube with a mirror at each end (Figure 15.11). A flash of light bounces back and forth between the parallel mirrors. The mirrors are perfect reflectors, so the flash bounces indefinitely. If the tube is 300 000 km in length, each bounce will take 1 s in the frame of reference of the light clock. If the tube is 3 km long, each bounce will take 0.00001 s.

Suppose we view the light clock as it whizzes past us in a high-speed spaceship (Figure 15.12). We see the light flash bouncing up and down along a longer diagonal path.

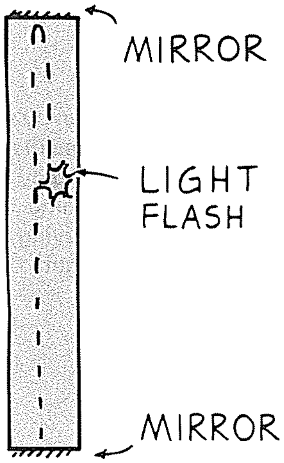


Figure 15.11 ▲
A stationary light clock. Light bounces between parallel mirrors and "ticks off" equal intervals of time.

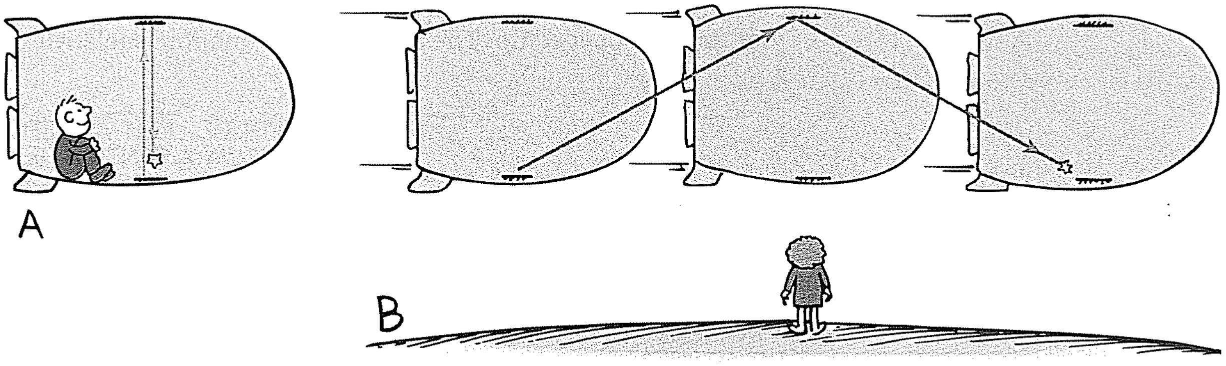
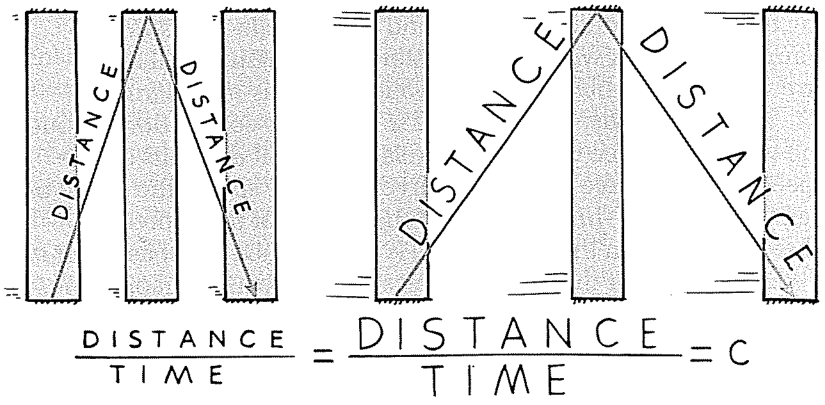


Figure 15.12 ▲
(a) An observer moving with the spaceship observes the light flash moving vertically between the mirrors of the light clock. (b) An observer who is passed by the moving ship observes the flash moving along a diagonal path.

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

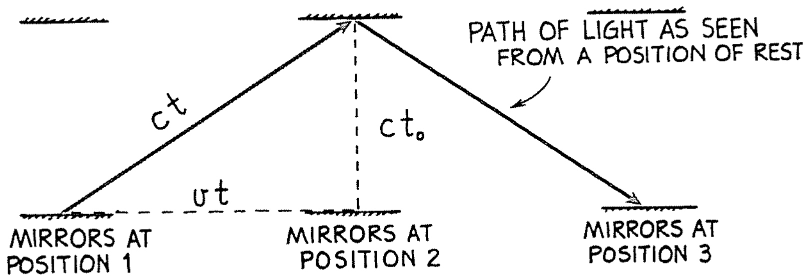


Figure 15.14 ▲
Mathematical detail of Figure 15.13.

The Time Dilation Equation*

Figure 15.14 shows three successive positions of the light clock as it moves to the right at constant speed v. The diagonal lines represent the path of the light flash as it starts from the lower mirror at position 1, moves to the upper mirror at position 2, and then back to the lower mirror at position 3.

The symbol t_0 represents the time it takes for the flash to move between the mirrors as measured from a frame of reference fixed to the light clock. This is the time for straight up or down motion. Since the speed of light is always c, the light flash is observed to move a vertical distance ct_0 in the frame of reference of the light clock. This is the distance between mirrors and is at right angles to the horizontal motion of the light clock. This vertical distance is the same in both reference frames.

The symbol t represents the time it takes the flash to move from one mirror to the other as measured from a frame of reference in which the light clock moves to the right with speed v. Since the speed of the flash is c and the time to go from position 1 to position 2 is t, the diagonal distance traveled is ct. During this time t, the clock (which travels horizontally at speed v) moves a horizontal distance vt from position 1 to position 2.

These three distances make up a right triangle in the figure, in which ct is the hypotenuse, and ct_0 and vt are legs. A well-known theorem of geometry (the Pythagorean theorem) states that the square of the hypotenuse is equal to the sum of the squares of the other two sides. If we apply this to the figure, we obtain:

$$\begin{aligned}
(ct)^2 &= (ct_0)^2 + (vt)^2 \\
(ct)^2 - (vt)^2 &= (ct_0)^2 \\
t^2[1 - (v^2/c^2)] &= t_0^2 \\
t^2 &= \frac{t_0^2}{1 - (v^2/c^2)} \\
t &= \frac{t_0}{\sqrt{1 - (v^2/c^2)}}
\end{aligned}$$

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* The mathematical derivation of this equation for time dilation is included here mainly to show that it involves only a bit of geometry and elementary algebra. It is not expected that you master it! (If you take a follow-up physics course, you can master it then.)

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 the 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 0.5c relative to the 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.

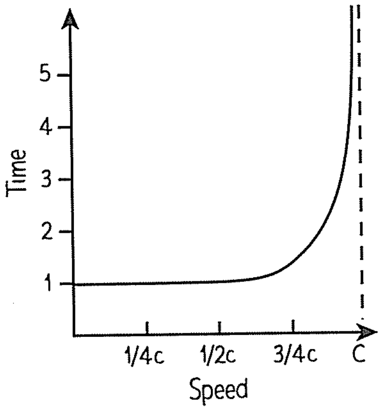

Figure 15.15 ▲
The graph shows how 1 second on a stationary clock is stretched out, as measured on a moving clock. Note that the stretching becomes significant only at speeds near the speed of light.

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 they will each see events on Earth in the same slow motion.

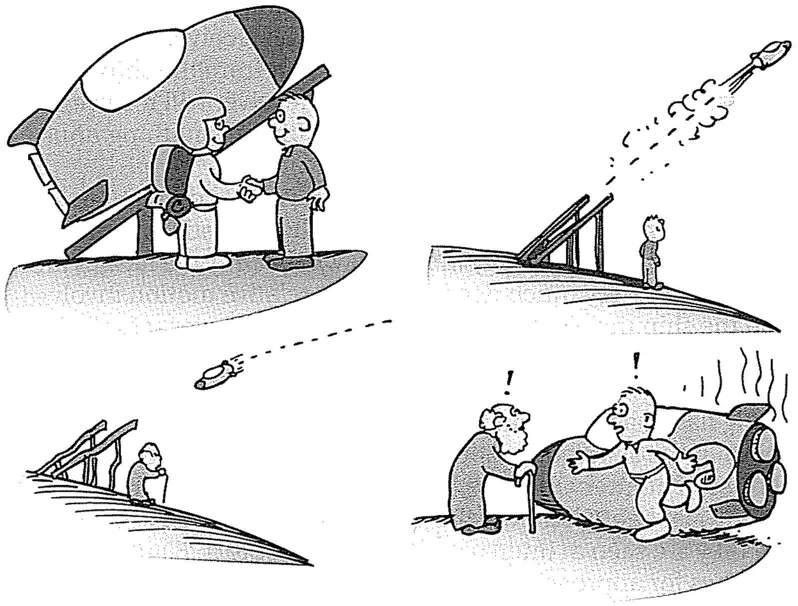

Figure 15.16
The traveling twin does not age as fast as the stay-at-home twin.

10 earth years would pass in one spaceship year. At this speed the traveling twin would age a single year while the stay-at-home twin ages 10 years.

The question arises, since motion is relative, why isn't it just as well the other way around—why wouldn't the traveling twin return to find his stay-at-home twin younger than himself? We will show that from the frames of reference of both the earthbound twin and the traveling twin, it is the earthbound twin who ages more.

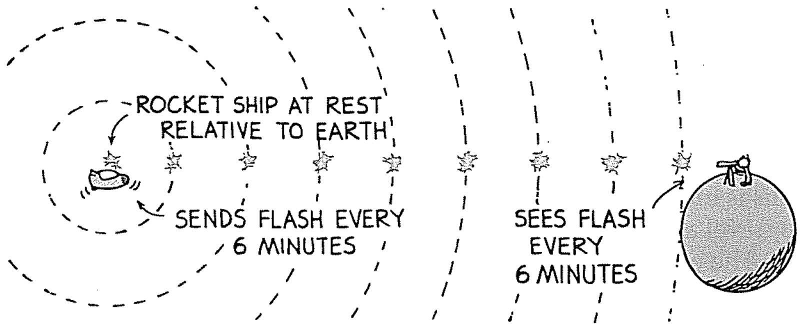

Figure 15.17
When no motion is involved, the light flashes are received as frequently as the spaceship sends them.

First, consider a spaceship hovering at rest relative to a distant planet. Suppose the spaceship sends regularly spaced brief flashes of light to the planet (Figure 15.17). Some time will elapse before the flashes get to the planet, just as 8 minutes elapses before sunlight gets to the earth. The light flashes will encounter the receiver on the 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.

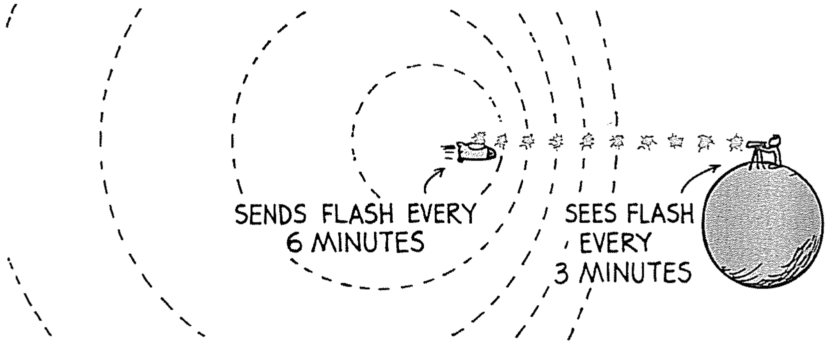

Figure 15.18 ▶ When the sender moves toward the receiver, the flashes are seen more frequently.

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.

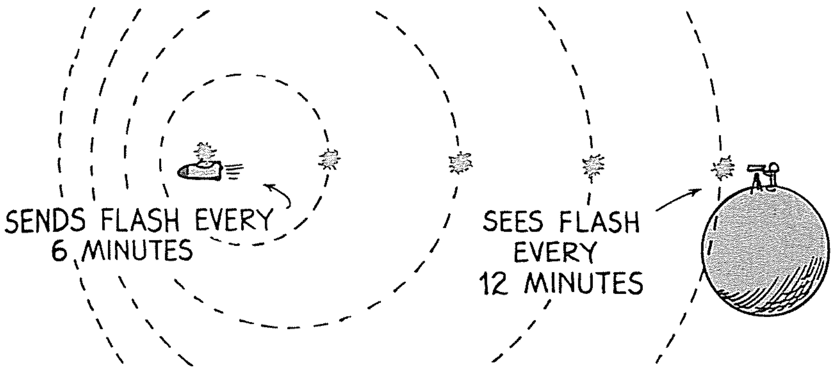

Figure 15.19
When the sender moves away from the receiver, the flashes are spaced farther apart and are seen less frequently.

The light flashes make up a light clock, or timer. In the frame of reference of the receiver, something like taking a bath or cooking pancakes that takes 6 min in the spaceship, is seen to take 12 min when the spaceship recedes, and only 3 min when the ship is approaching.

Questions

1. Here's a simple arithmetic question: If a spaceship travels for one hour and emits a flash every 6 min, how many flashes will be emitted?
2. A spaceship sends equally spaced flashes while approaching a receiver at constant speed. Will the flashes be equally spaced when they encounter the receiver?
3. A spaceship emits flashes every 6 min for one hour. If the receiver sees these flashes at 3-min intervals, how much time will occur between the first and the last flash (in the frame of reference of the receiver)?

Let's apply this doubling and halving of flash intervals to the twins. Suppose the traveling twin recedes from the earthbound twin at the same high speed for one hour, then quickly turns around and returns in one hour. The traveling twin takes a round trip of two hours, according to all clocks aboard the spaceship. This trip will *not* be seen to take two hours from the earth frame of reference,

Answers

1. Ten flashes, since (60 min)/(6 min/flash) = 10 flashes.
2. Yes, as long as the ship moves at constant speed, the equally spaced flashes will be seen equally spaced but more frequently. (If the ship accelerated while sending flashes, then they would not be seen at equally spaced intervals.)
3. All 10 flashes will be seen in 30 min [(10 flashes) × (3 min/flash) = 30 min].

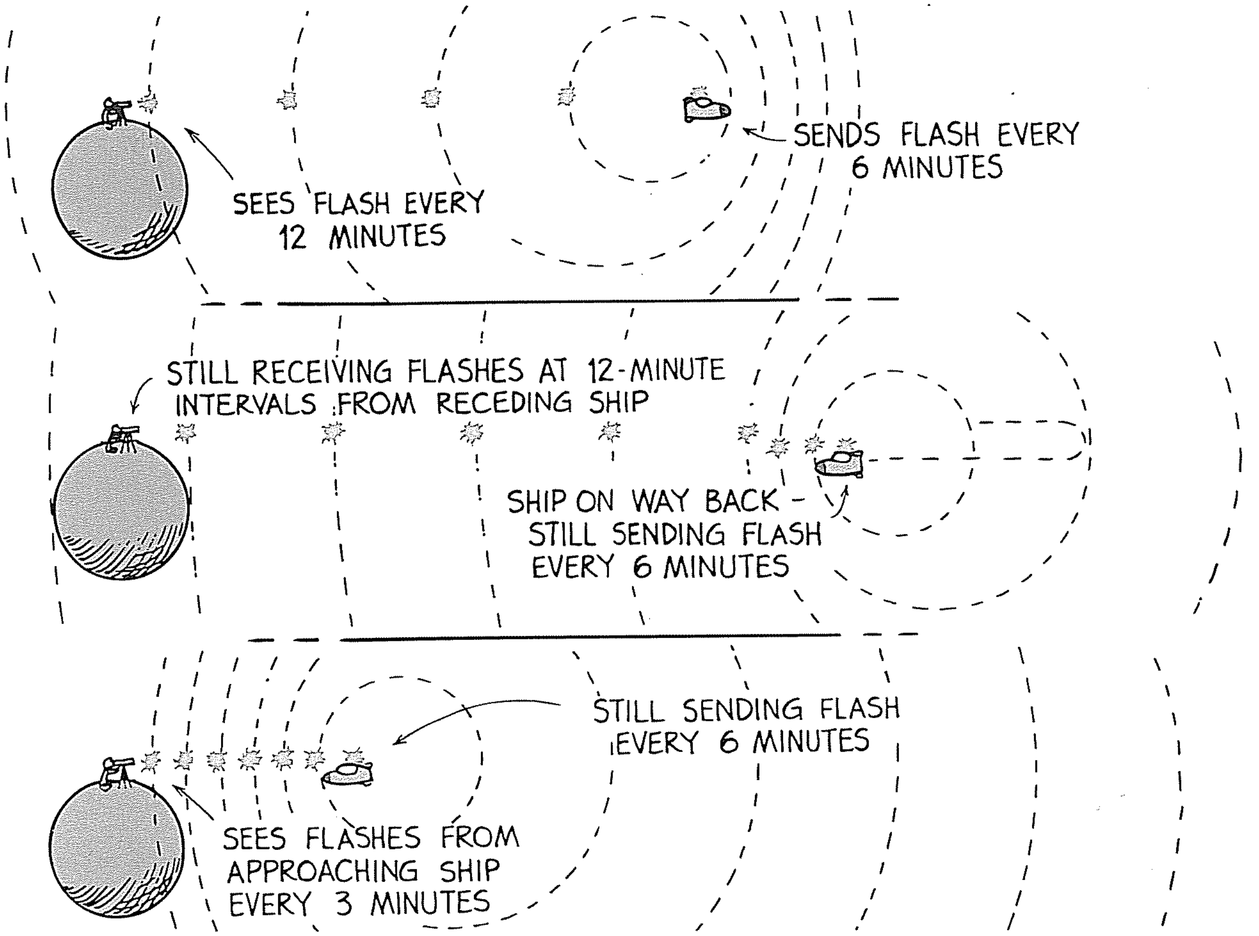

Figure 15.20 ▲
The spaceship emits flashes each 6 minutes during a two-hour trip. During the first hour, it recedes from the earth. During the second hour, it approaches the earth.

however. We can see this with the help of the flashes from the ship's light clock.

As the ship recedes from the 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 the earth, a total of 10 flashes are emitted. If the ship departs from the 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 the earth? The answer is 2 p.m. Why? Because the time it takes the 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!

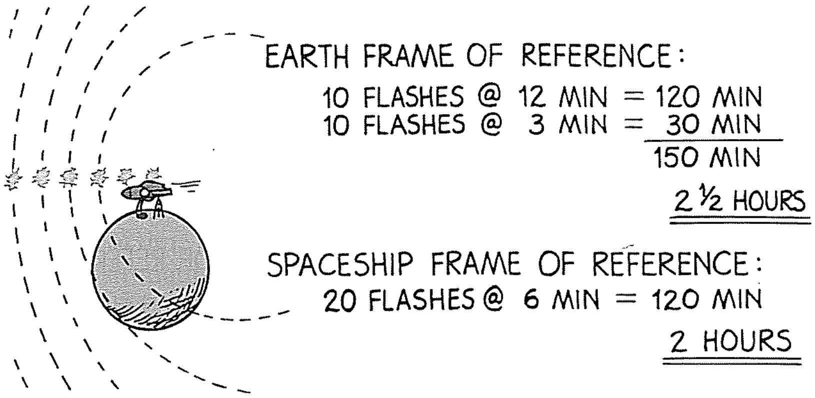

Figure 15.21
The trip that takes 2 hours in the frame of reference of the spaceship takes 2.5 hours in the earth's frame of reference.

The result is the same from either frame of reference. Consider the same trip again, only this time with flashes emitted *from the earth* at regularly spaced 6-min intervals in earth time. From the frame of reference of the receding spaceship, these flashes are received at 12-min intervals (Figure 15.22a). This means that 5 flashes are seen by the spaceship during the hour of receding from the earth. During the spaceship's hour of approaching, the light flashes are seen at 3-min intervals (Figure 15.22b), so 20 flashes will be seen.

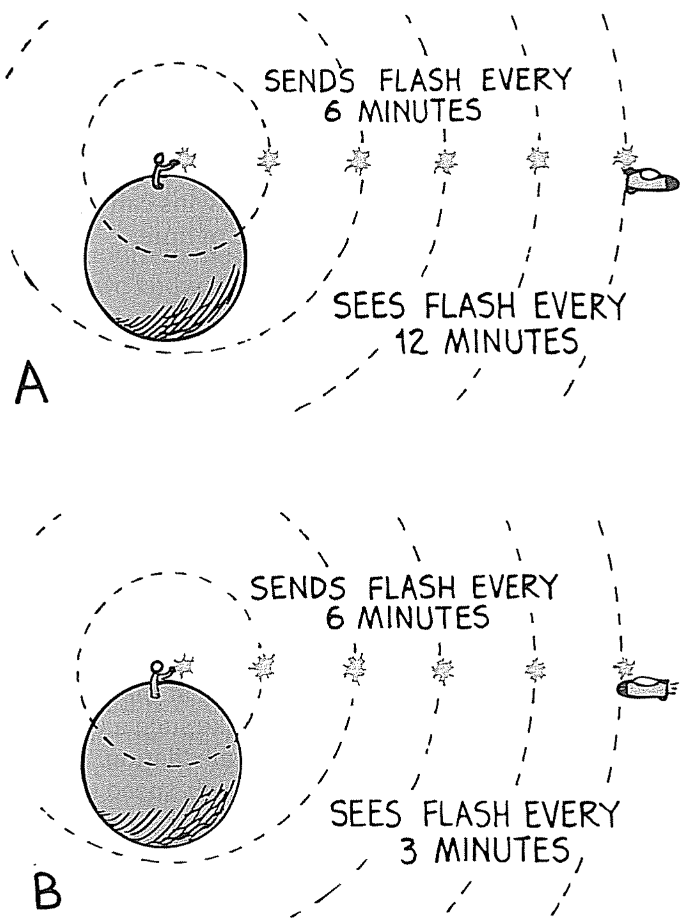

Figure 15.22
Flashes sent from Earth at 6-min intervals are seen at 12-min intervals by the ship when it recedes, and at 3-min intervals when it approaches.

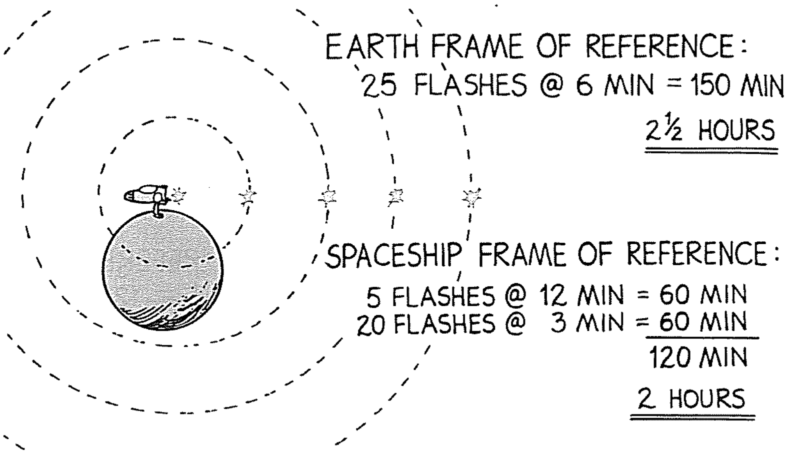

Figure 15.23 ▲
A time interval of 2.5 hours on Earth is seen to be 2 hours in the spaceship's frame of reference.

Hence, the spaceship receives a total of 25 flashes during its two-hour trip. According to clocks on the 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 the 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

Relativistic Clocks

In 1971 atomic clocks were carried around the earth in jet planes. Upon landing, the traveling clocks were a few billionths of a second "younger" than twin clocks that stayed behind. Atomic clocks now cruise overhead at even greater speeds in the 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. So 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).

A person's heart beats to the rhythm of the realm of time it is in. One realm of time seems the same as any other realm of time to the person, but not to an observer who is located outside the person's frame of reference—for she sees the difference. As an example, astronauts traveling at 99% the speed of light could go to the star Procyon (11.4 light-years distant) and back in 23.0 years in earth time. It would take light itself 22.8 years in earth time to make the same round-trip. Because of time dilation, it would seem that only 3 years had gone by for the astronauts. All their clocks would indicate this, and biologically they would be only 3 years older. It would be the space officials greeting them on their return who would be 23 years older.

At higher speeds the results are even more impressive. At a speed of 99.99% the speed of light, travelers could travel slightly more than 70 light-years in a single year of their own time. At 99.999% the speed of light, this distance would be pushed appreciably further than 200 years. A 5-year trip for them would take them farther than light travels in 1000 earth-time years.

Such journeys seem impossible to us today. The amounts of energy involved to propel spaceships to such relativistic speeds are billions of times the energy used to put the space shuttles into orbit. The problems of shielding radiation induced by these high speeds seems formidable. The practicalities of such space journeys are prohibitive, so far.

If and when these problems are overcome and space travel becomes routine, people will have the option of taking a trip and returning in future centuries of their choosing. For example, one might depart from Earth in a high-speed ship in the year 2150, travel for 5 years or so, and return in the year 2500. One might live among earthlings of that period for a while and depart again to try out the year 3000 for style. People could keep jumping into the future with some expense of their own time, but they could not trip into the past. They could never return to the same era on Earth that they bid farewell to.

Time, as we know it, travels only one way—forward. Here on Earth we constantly move into the future at the steady rate of 24 hours per day. An astronaut leaving on a deep-space voyage must live with the fact that, upon her return, much more time will have elapsed on Earth than she has experienced on her voyage. Star travelers will not bid "so long, see you later" to those they leave behind but, rather, a permanent "good-bye."

We can see into the past, but we cannot go into the past. When we look at stars in the night skies, the starlight we see left those stars dozens, hundreds, even millions of years ago. What we see is the stars as they were long ago. We are thus eyewitnesses to ancient history. We can only speculate about what may have happened to the stars since then.

When we think of time and the universe, we may wonder what went on before the universe began. We wonder what will happen if the universe ceases to exist in time. But the concept of time applies to events within the universe. Time is "in" the universe; the universe is not "in" time. Without the universe, there is no time; no before, no after. Likewise, space is "in" the universe; the universe is not "in" a region of space. There is no space "outside" the universe. We see that space-time exists within the universe. Think about that!

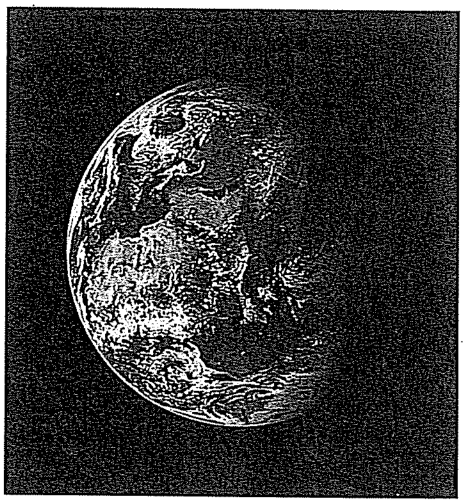

Figure 15.24
From the earth frame of reference, light takes 30 000 years to travel from the center of the Milky Way galaxy to our solar system. From the frame of reference of a high-speed spaceship, the trip takes less time. From the frame of reference of light itself, the trip takes no time. There is no time in a speed-of-light frame of reference.