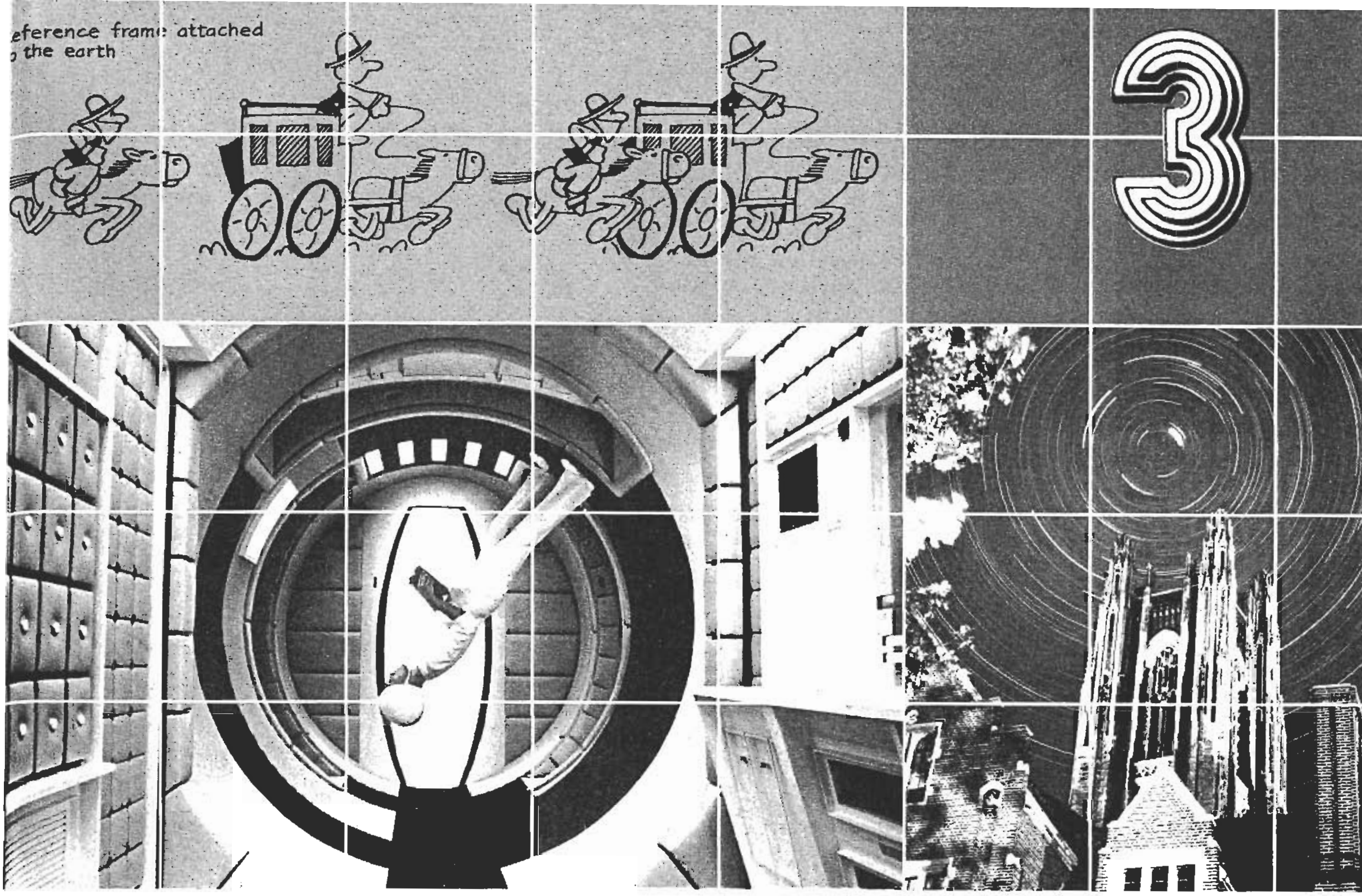
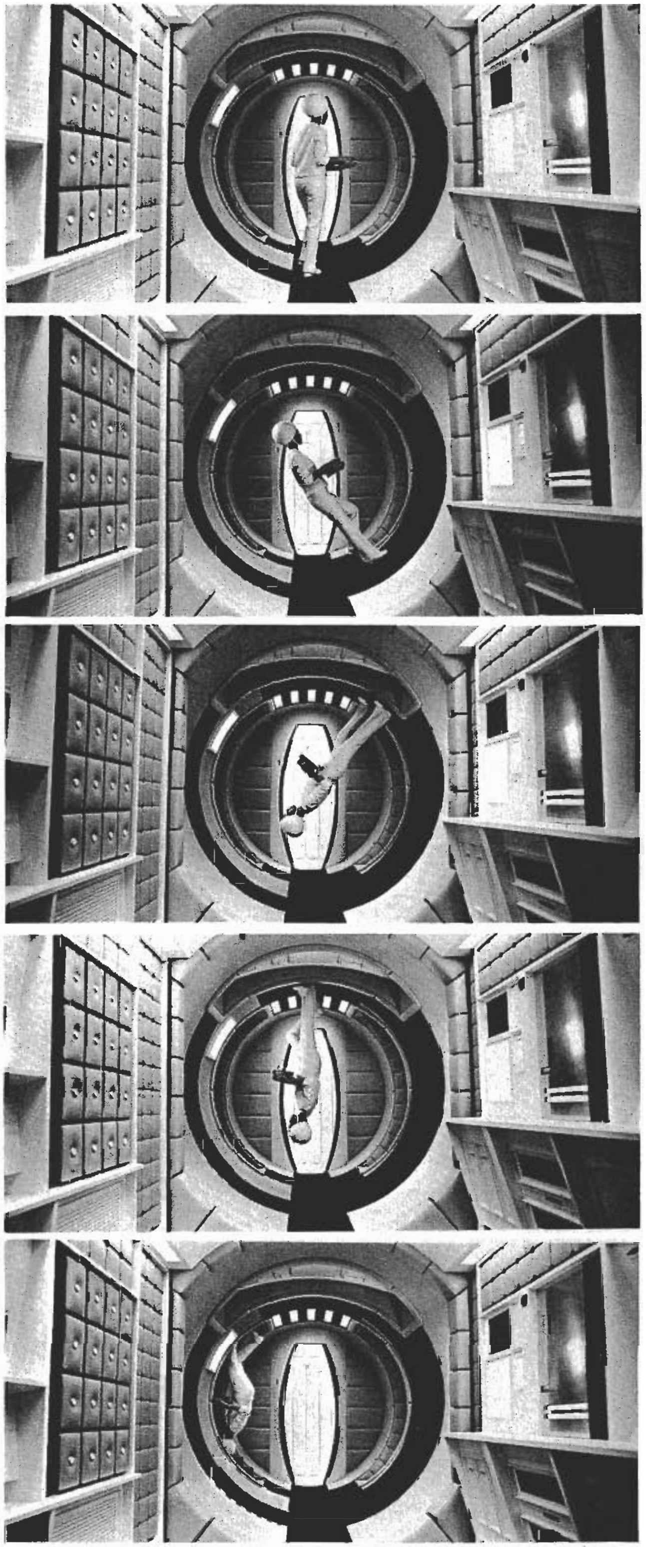


Relative Motion at Low Speeds

Ever walked on walls—or even on ceilings? Taken from *2001: A Space Odyssey,* the scene in Figure 3-1 depicts a flight attendant walking in the weightless environment of space. It was, of course, filmed right here on earth. This scene and a variety of other special effects are created by changing the reference frame from which we view motion.

The last chapter dealt with motion only within stationary reference frames. However, motion also occurs in moving reference frames. You can walk around on an airplane as it transports you from one city to another. This chapter examines motion in coordinate systems that are moving at a constant velocity relative to each other. We will restrict ourselves to low speeds, that is, speeds that are far less than the speed of light. Reference frames moving at speeds near the speed of light will be discussed in the next chapter. We will see that the motion of the reference frame changes our description of the velocity of an individual object but not the *relative velocity* between two objects. This tells us that some quantities remain constant regardless of the

Figure 3-1



motion of the reference frame. For reference frames moving at constant velocity relative to each other, the *principle of relativity* states that events in any reference frame are the same.

MOVING REFERENCE FRAMES

Until as late as the eighteenth century, controversy raged over the earth-centered and sun-centered views of the universe. Religious teaching caught up in the conflict made the controversy extraordinarily complex. At face value, however, it was simply a disagreement about how to interpret the daily motion of the sun across the sky. Does the earth stand still and the sun move across the sky? Or, does the sun stand still and the earth rotate beneath it, creating the apparent motion of the sun? While mountains of evidence have piled up to convince us that the sun-centered model is the better one, our naked-eye observations alone do not enable us to decide between the two points of view.

Different points of view can arise when we use the same reference frame but make different statements about the motion of that reference frame. In saying that the sun moves, we imagine a stationary reference frame, the earth. In saying the earth moves, we imagine a moving reference frame, the rotating earth. In order to agree on descriptions of motion, we must specify both the reference frame and its state of motion.

Motion of the Reference Frame is Often Ignored

Our language reveals an assumption that the earth is stationary. We say that the sun rises and sets, that it moves across the sky, and that it is lower in winter than in summer. These statements arise not from ignorance about the motion of the earth but from the fact that the earth's motion is irrelevant in our everyday conversations about the sun.

To pursue this idea further, suppose you travel by bicycle from Denver, Colorado, to Washington, D.C.—a distance of 2500 kilometers (km). Such a trip would take about 35 days. During that time interval, the earth moves in its orbit around the sun, traveling a distance of about 94,000,000 km. Would you tell your friends that you traveled 94,002,500 km? If you did, you would receive rather strange looks! You ignore the motion of the earth because it is not relevant to your trip. In fact, you ignore a lot of motion—the earth rotating on its axis, the earth revolving around the sun, the solar system moving through the galaxy, and the galaxy moving through the universe. None of these motions, even though they occur continuously, are needed to describe a trip from Denver to Washington.

All Reference Frames are Valid

Although it seems absurd to include the motion of the earth in describing a trip from Denver to San Francisco, it would still be valid, particularly in a

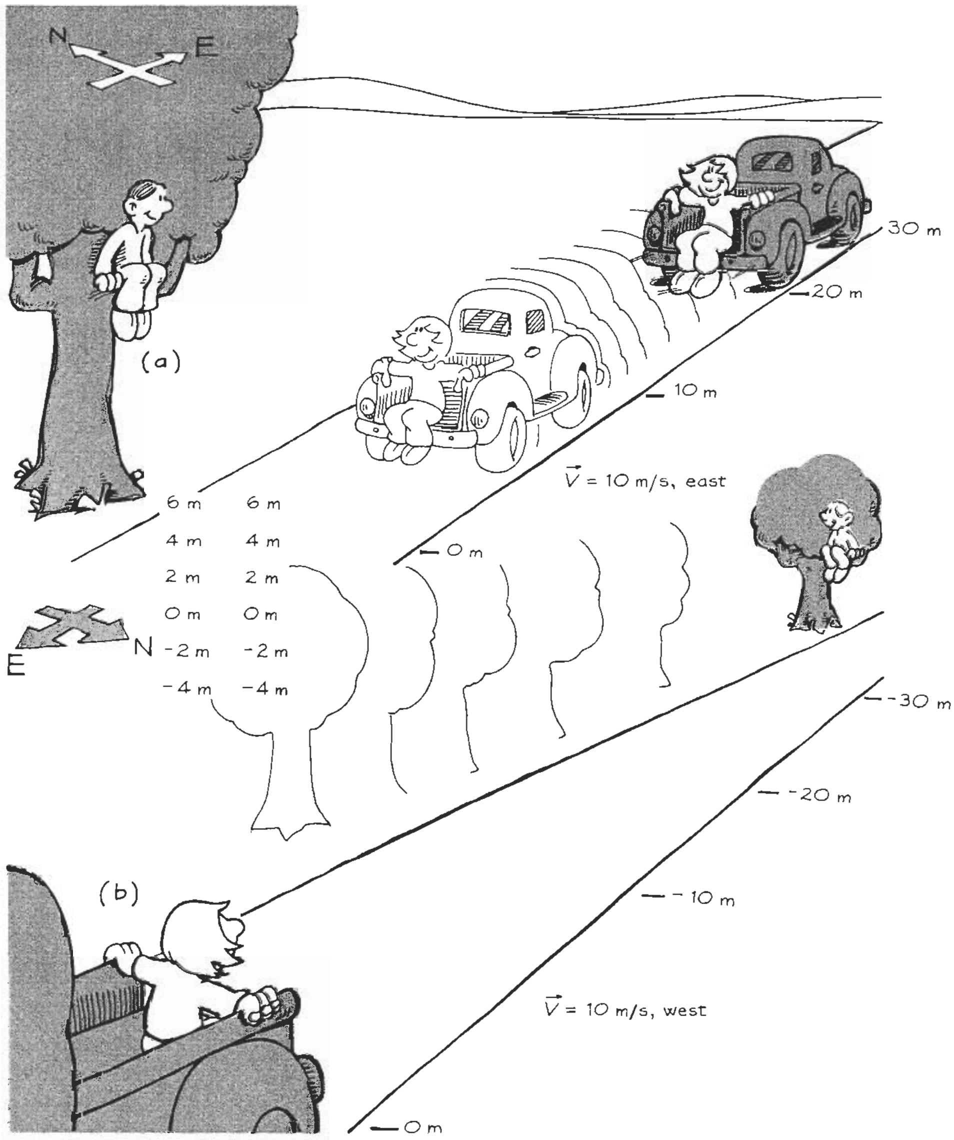


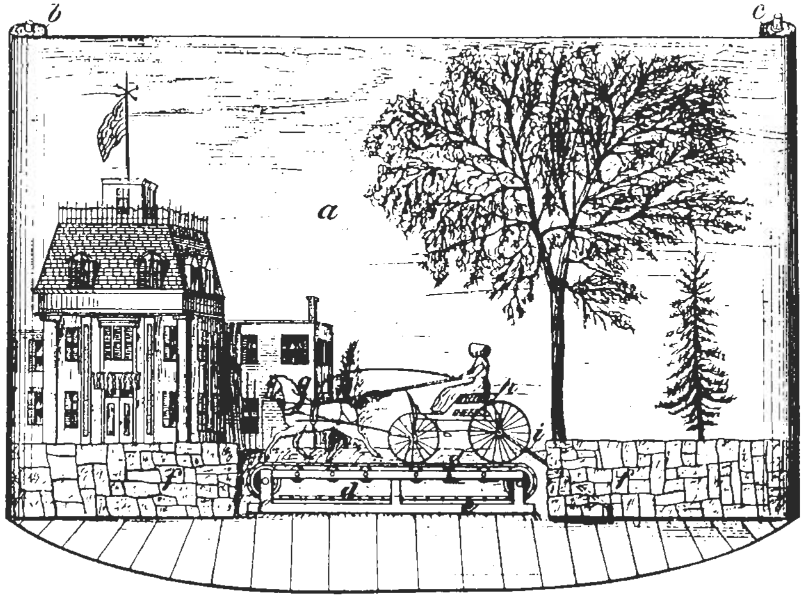
Figure 3-2

Your description of what moves depends on the reference frame.
(a) In a reference frame attached to the tree, the truck moves past at a velocity of 10 m/s, east.
(b) In a reference frame attached to the truck, the tree moves past at a velocity of 10 m/s, west.

reference frame outside our solar system. In fact, in such a reference frame the motion from Denver to San Francisco would seem minute compared to the motion of the earth itself.

Motion can be described from a variety of reference frames. To illustrate this, let's examine a simple, everyday event like a truck moving past a tree. We can describe this event from two different reference frames—one attached to the tree and a second attached to the truck itself (Figure 3-2). In the reference frame attached to the tree, Figure 3-2(a), the truck is moving relative to a stationary tree. We could even estimate its velocity—10 meters/second (m/s), east. In the reference frame attached to the truck, Figure 3-2(b), the tree moves relative to the truck. Its velocity is 10 m/s, west.

ROLLING RIGHT ALONG



James William Knell took advantage of the ideas of relative motion when, in 1882, he invented and patented the "Apparatus for Producing Illusory Dramatic Effects." Mr. Knell wished to enable stage directors to present the illusion of motion during a play. His apparatus consists of a large painted canvas (*a*) which moves from left to right on two rollers (*b* and *c*). At the center of the stage in front of this canvas is a horse and carriage (*i*), which are placed on a treadmill (*d*). As the horse trots, but does not move relative to the stage, the canvas is rolled past. The relative motion between the horse and buggy and the background presents the illusion of motion.

Your immediate response might well be: "What do you mean, the tree moves? Trees don't move. Trucks move!" Your reaction reflects our tendency to choose the earth (including its hills, trees, and general land features) to be a motionless reference frame. However, descriptions of motion depend on the reference frame. When we change to a reference frame attached to the truck, all parts of the truck are stationary relative to itself. Objects not attached to the truck can move; consequently, we say that the tree moved relative to the truck.

Both reference frames, the one attached to the tree and the one attached to the truck, are equally valid in describing the event. "Move the truck 10 meters farther from the tree" seems more direct than "Drive until the tree has moved 10 meters farther behind the truck." Likewise, "The sun rises at 6:30 A.M." is easier to say than "At 6:30 A.M. the earth will have rotated to a position in which the sun will become visible." However, both statements describe the same event. The truck and the tree become separated by a larger distance. Dawn occurs. The difference is not in the event itself but in our description of it based upon our choice of reference frames.

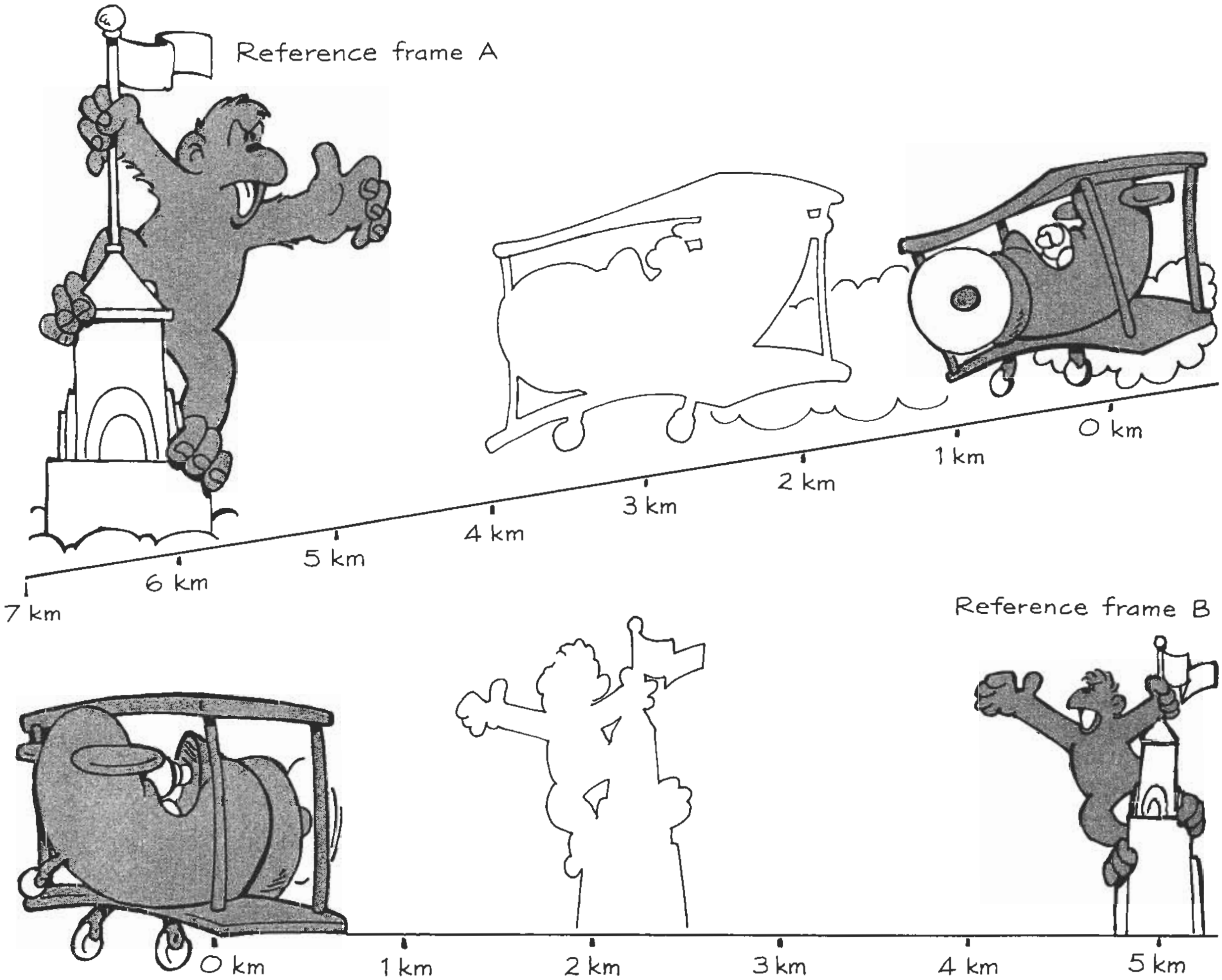


Figure 3-3

SELF-CHECK 3A

Figure 3-3 shows an event in two different reference frames. In each, identify the reference frame and describe the event in that reference frame.

Illusions of Motion

Many illusions in motion pictures take advantage of our natural tendency to assume that objects attached to the earth do not move. Animators cause their characters to move across a landscape, even though the body of the character

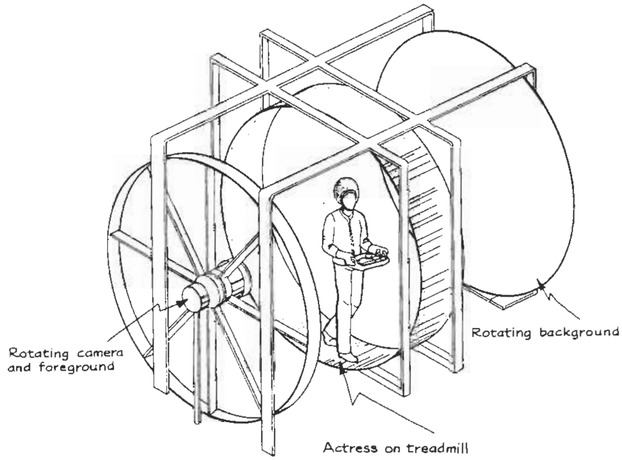


Figure 3-4
The motion in Figure 3-1 was created by rotating a camera, background, and foreground. The actress walked on a treadmill in a separate room.

and the camera are motionless in the studio. The character remains stationary relative to the camera and the background is pulled along behind it. Because we naturally assume that the earth and its scenery are not moving, we interpret the movement as the character walking. This technique is extended to nonanimated films, from the famous old-time cowboy "chase scenes" to spaceships moving through a background of stars. In *Return of the Jedi,* Luke Skywalker and Princess Leia were filmed while sitting on Imperial speeders that were essentially stationary. A second film was recorded by a camera mounted on a truck that drove through the forest. The two films were then superimposed to provide a breathtaking chase scene.

The more complex motion of the flight attendant in space that opened the chapter was filmed by a rotating camera. As shown in Figure 3-4, the actress remained fixed on the floor of the film studio, walking along a treadmill. As she walked, the camera and background were rotated. When the camera was upside down relative to the earth, it photographed the actress as being on the ceiling. This technique is effective photographically because we automatically use the room as a motionless reference frame.

Another common illusion occurs when you are stopped at a traffic light and a car on your right or left begins to move forward. With no other reference object to check your perception, you may think you are rolling backward and instinctively step on the brake. The impression created by our assumption that the other car is stationary can be so strong that many actually feel physical sensations of motion.

RELATIVE SPEED AND VELOCITY

All reference frames are equally valid. In one reference frame, trucks move; in another, trees move. If we calculated velocities, they would be different in the different reference frames. Most of us are uneasy with all these possibilities. We might wish we could find some absolute reference frame against which "true" motion could be described. Since we do not believe that such a

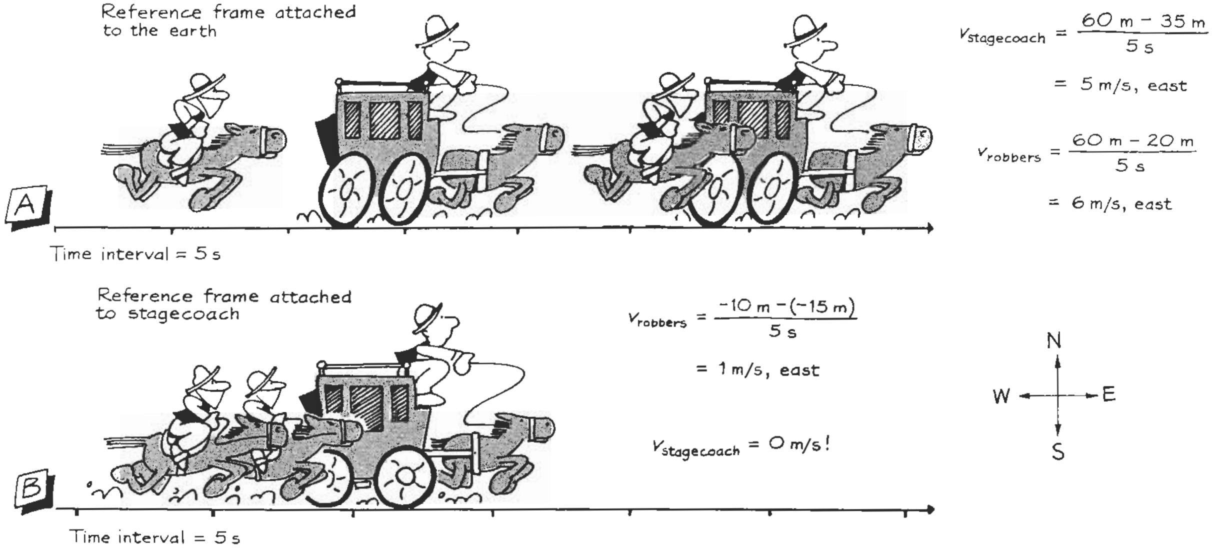


Figure 3-5
(a) In a reference frame attached to the earth, the stagecoach moves at a velocity of 5 m/s, E, and the robbers at 6 m/s, E.
(b) In a reference frame attached to the stagecoach, the stagecoach is stationary and the robbers move at a velocity of 1 m/s, E.

reference frame exists, we look instead for some quantity that does not change from one reference frame to another. For reference frames moving at a constant velocity relative to one another, relative speeds and relative velocities provide us with such a concept.

Velocity of One Object Relative to Another

Let's consider a familiar scene from old western movies. The stagecoach driver, who is being chased by the bad guys, looks behind him and says, "They're gaining on us!" The driver chose a reference frame attached to himself. The bad guys would still be gaining on him if he had chosen another reference frame—for instance, one attached to the earth. The rate at which the robbers catch up to the stagecoach remains constant regardless of the reference frame we choose.

We can convince ourselves of this by comparing the velocity of the robbers with the velocity of the stagecoach in two different reference frames. In Figure 3-5(a) the reference frame chosen is one attached to the earth. The velocity of the stagecoach is 5 m/s, east. The robbers are moving faster, at a velocity of 6 m/s, east. Using a coordinate system attached to the moving stagecoach, Figure 3-5(b), the robbers are moving at a velocity of 1 m/s, east. Relative to itself, however, the stagecoach is stationary. Its speed is 0 m/s.

As expected, the velocities of the stagecoach and robbers are different in the two reference frames. The stagecoach moves at a velocity of 5 m/s, east, in a reference frame attached to the earth and 0 m/s in a reference frame attached to itself. The robbers move at a velocity of 6 m/s, east, in a reference frame attached to the earth and 1 m/s, east, in a reference frame attached to the stagecoach. As we have already seen, the velocity of an object depends upon the motion of the reference frame chosen.

Now, compare the motion of the robbers to the motion of the stagecoach. In a reference frame attached to the earth, the stagecoach is moving at a velocity of 5 m/s, east, while the robbers are moving faster, at a velocity of 6 m/s, east. The robbers are gaining on the stagecoach at a rate of 1 m/s. When we change to a reference frame attached to the stagecoach, we find the same result: The robbers are moving at a velocity of 1 m/s, east, relative to the stationary stagecoach. If we were to choose yet another reference frame, we would find the same result. The robbers are always gaining on the stagecoach. The motion of one object relative to another remains constant when we change reference frames.

Relative Velocity Remains Constant

The realization that the velocity of the robbers relative to the stagecoach is the same regardless of the reference frame we choose makes this quantity more useful to us in describing the motion among objects. Consequently, we introduce the concept of relative velocity to describe the motion of one object relative to another. The **relative velocity** between two objects is the velocity of one object in a reference frame in which the second object is stationary. **Relative speed** is defined in the same manner, except that speeds are substituted for velocities. When we chose a reference frame attached to the stagecoach, Figure 3-5(b), the stagecoach became the reference object. Its velocity was 0 m/s. Consequently, the velocity of the robbers in this reference frame was their velocity relative to the stagecoach. When we chose the reference frame attached to the earth, we introduced a third object, the earth. The relative velocity must be determined from the velocity of each object relative to the earth.

A general rule for determining the relative velocity between two objects, A and B, given their velocities relative to the earth is:

$$\textbf{Velocity}\text{ of A relative to B} = \textbf{Velocity}\text{ of A relative to Earth} - \textbf{Velocity}\text{ of B relative to Earth}$$

Velocity of *A* relative to *B*

Velocity of *B* relative to Earth

$$\mathbf{V}_{AB} = \mathbf{V}_A - \mathbf{V}_B$$

Velocity of *A* relative to Earth

Velocity is a vector quantity, so we must keep track of direction as well as magnitude. Let's apply this general rule for determining relative velocities between two objects to the robbers and the stagecoach.

As shown in Figure 3-6(a), the velocity of the robbers (A) is 6 m/s, east. The velocity of the stagecoach (B) relative to the earth is 5 m/s, east. According to our rule, the velocity of the robbers (A) relative to the stagecoach (B) is the difference between the two velocities relative to the earth. Since the stagecoach and robbers are both moving in the same direction, we can subtract the two magnitudes. (You could also apply vector subtraction, as shown in Figure 3-6(a).) The relative velocity between the robbers and the stagecoach is 6 m/s, east, minus 5 m/s, east, which equals 1 m/s, east. The robbers are gaining on the stagecoach at a speed of 1 m/s.

Suppose the movie script requires that the robbers come toward the stagecoach rather than chasing it from behind. Let's assume that the velocity of the robbers (A) relative to the earth is 6 m/s, west, and the velocity of the

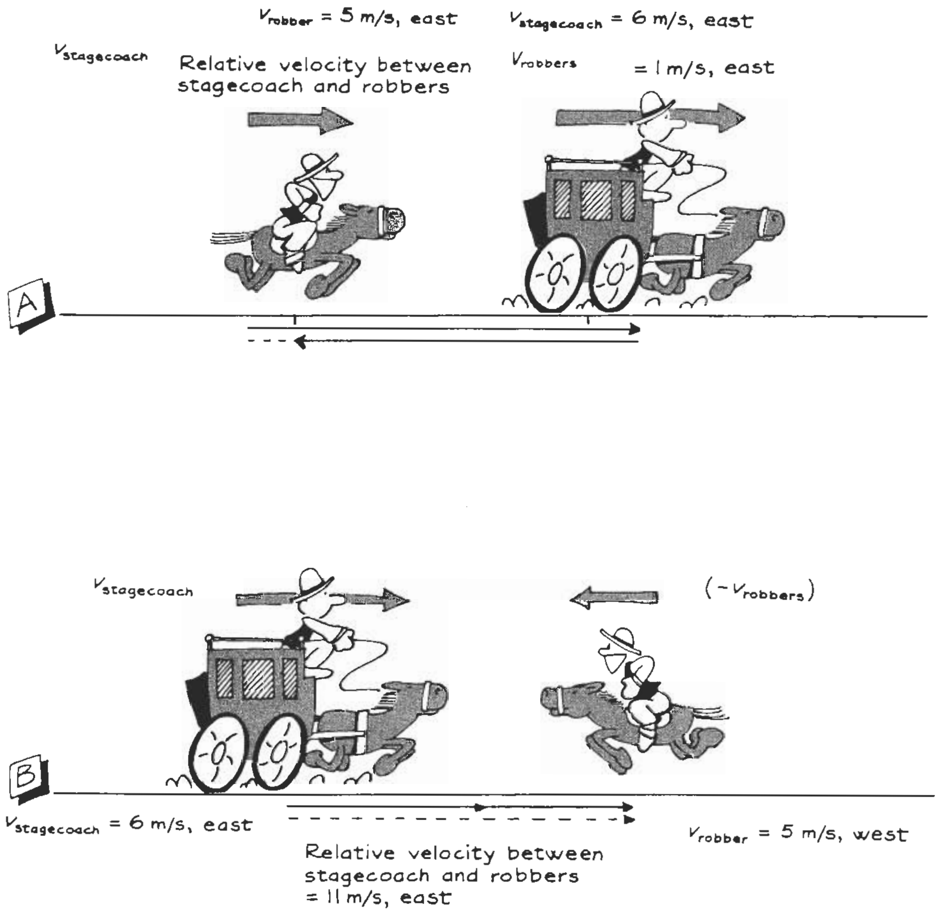


Figure 3-6 (a) In a reference frame attached to the earth, the stagecoach moves at a velocity of 5 m/s, E, and the robbers at 6 m/s, E. The relative velocity between the robbers and the stagecoach is 1 m/s, E.
(b) In a reference frame attached to the earth, the stagecoach moves at a velocity of 5 m/s, E, while the robbers move at a velocity of 6 m/s, W. The relative velocity between the robbers and the stagecoach is 11 m/s, W.

stagecoach (B) relative to the earth is still 5 m/s, east. Now the stagecoach and robbers are moving in opposite directions. Figure 3-6(b) illustrates the tail-to-tip method for subtracting the two vectors. A velocity of 6 m/s, west, minus a velocity of 5 m/s, east, equals a velocity of 11 m/s, west. The robbers are approaching the stagecoach at a speed of 11 m/s.

The fact that we are adding vectors makes the rule a little more complex, since the direction in which the two objects move must be taken into account. Many people find it easier to remember the general rule in terms of simply adding or subtracting the magnitudes of the velocities. When two objects are moving in the same direction, the magnitude of their relative velocity is the difference between the magnitudes of the velocities relative to the earth. When the two objects are moving in opposite directions, the magnitude of their relative velocity is simply the sum of the magnitudes of their velocities relative to the earth. That is,

$$v_{AB} = v_A - v_B \quad \text{A and B in same direction}$$

$$v_{AB} = v_A + v_B \quad \text{A and B in opposite directions}$$

The direction of the relative velocity is the direction in which object A is moving relative to the earth. These two expressions can be applied only to those cases where the two objects are moving along the same line, in the same direction or in opposite directions. If the two objects move toward one another at an angle, then the tail-to-tip method for subtracting vectors provides the simplest way of determining the relative velocity between the two objects.

We have described the process by which we can determine the relative velocity between two objects, given their velocities relative to the earth. Our rule can be extended to reference frames other than the earth. If we know the velocity of both objects (A and B) relative to some third object, then our rule can be applied to these situations as well. We substitute the third object, whatever it might be, for the earth in our expressions.

SELF-CHECK 3B

Traveling along the interstate highway, you pass a truck. Your velocity is 80 kilometers/hour (km/h), east, relative to the ground. The truck's velocity is 60 km/h, east, relative to the ground. What is your velocity relative to the truck? What would your velocity relative to the truck be if its velocity were 60 km/h, west, relative to the ground and yours were 80 km/h, east, relative to the ground?

When the robbers were chasing the stagecoach, the only velocity that mattered to the stagecoach driver was how fast the robbers were gaining on him. While the velocities of the stagecoach and robbers changed as we changed reference frames, the relative velocity between them remained constant. Relative velocity is, in fact, the velocity we perceive in everyday situations. When you see a friend walking away, you run to catch up. If you walked at the same velocity relative to the earth as your friend, your velocity relative to the friend would be zero. You would not catch up. You use the relative velocity between you and your friend to judge how fast you must run. The relative velocity between two objects is the same in any coordinate system moving at a constant velocity relative to any other coordinate system.

THE PRINCIPLE OF RELATIVITY

Careful observation over several centuries has confirmed the idea that relative velocity is the same in different reference frames, as long as the reference

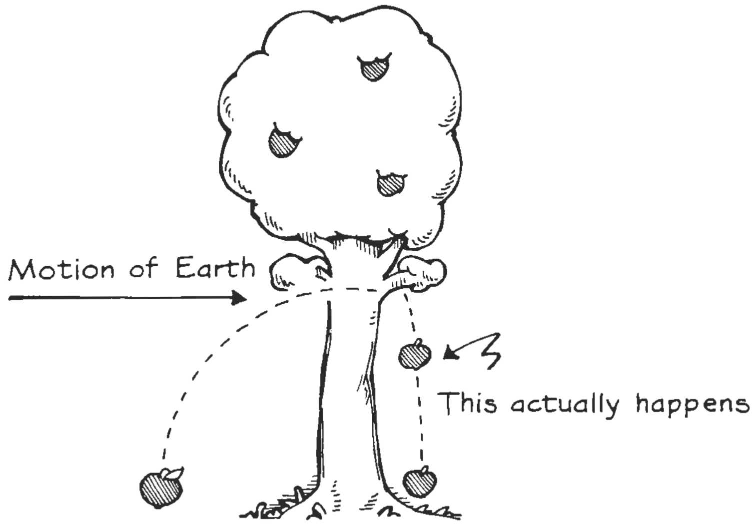


Figure 3-7
Those who believed that the earth was stationary argued that a moving earth would cause apples to land west of, rather than beneath, the tree. In truth, apples land beneath the tree in either a stationary earth or an earth moving at a constant velocity.

frames move at constant velocity relative to one another. Though this may have seemed quite obvious in our examples, it is not always obvious in everyday life. If you stand still and drop a rock, you know that the rock will fall in a straight line and land at your feet. Using yourself as a stationary reference frame, you expect objects to fall straight down. Many people suppose, however, that if they drop a rock while walking at a constant speed, the rock will land behind them. They expect the motion of the reference frame to affect the way in which the rock falls.

At the time of the controversy between the earth- and sun-centered views of the universe, some who held the earth-centered view argued that an apple that fell from a moving tree would land west of the tree rather than beneath it (Figure 3-7). Since the apple does in fact land beneath the tree, they reasoned, the earth does not move. In actuality, the apple always falls from the tree in exactly the same manner on a stationary earth or on an earth moving at a constant velocity, just as the rock always lands at your feet regardless of whether you are walking or stationary.

The observation that events occur in the same manner independently of the velocity of the reference frame led Galileo and others to suspect that the fundamental principles of physics do not depend upon the constant motion of the reference frame from which they are observed. Called the **principle of relativity,** this conclusion is: The laws of physics are the same in all reference frames moving at constant velocities relative to one another. The principle of relativity has been important as we have stepped beyond our own earth-centered reference frame into space. First stated by Galileo more than 300 years ago, this principle correctly guided our exploration into space—first into earth-centered orbits and later to the moon and back. It governs all events—those at everyday speeds and those at speeds near the speed of light. At speeds near the speed of light, however, our fundamental concepts of space and time have had to be altered in order to preserve our belief in the principle of relativity. These modifications are the subject of the next chapter.

CHAPTER SUMMARY

Motion, like position, must be described in terms of a reference frame. The velocity of an object is usually described in terms of a reference frame that is assumed to be stationary. The earth is rotating on its axis and revolving around the sun, yet we describe motion on the surface of the earth relative to a stationary earth. Two people who use reference frames that are moving at constant velocities relative to one another will describe the motion of an object differently. Both descriptions are equally valid, but one may be more useful than another in a given situation.

The velocity of an object will be described differently in reference frames moving at different—but constant—velocities relative to one another. But, the relative velocity between any two objects remains constant. The *relative velocity* between objects A and B is defined as the velocity of one object in a reference frame in which the second object is stationary. When the velocity of both objects is given relative to the earth, the relative velocity between the two objects is the vector difference between the velocity of each object relative to the earth. The relative velocity between two automobiles, for example, is the difference between their velocities relative to the ground. Relative velocity remains constant in all reference frames moving at a constant velocity relative to one another. More generally, the principles of physics in any reference frame are the same as those in any other reference frame moving at constant velocity relative to it. This is called the *principle of relativity.*

ANSWERS TO SELF-CHECKS

3A. In reference frame A, the airplane moves from (1 km) to (4 km). The coordinate system is stationary relative to the earth. In reference frame B, the top of the building moves from (5 km) to (2 km). The coordinate system is stationary relative to the airplane.

3B. 20 km/h, east; 140 km/h, east.

PROBLEMS AND QUESTIONS

A. Review of Chapter Material

A1. Under what circumstances will two people describe the motion of the same object differently?

A2. Give two examples that show how we ignore the motion of reference frames in describing events in everyday life.

A3. Is one reference frame better than another in describing motion? How do we choose which reference frame to use?

A4. What velocity remains unchanged as we change from one reference frame to another which is moving at a constant velocity relative to the first?

A5. Suppose you are given the velocities of objects X and Y relative to the earth. Describe how you could determine the velocity of X relative to Y.

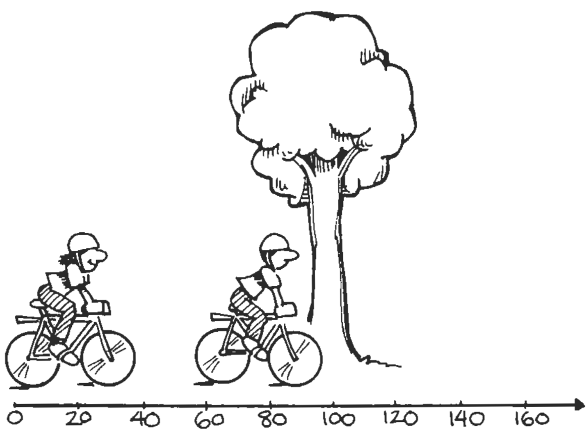
A6. State the principle of relativity.

B. Using the Chapter Material

B1. While riding on a bus, you drop a book.
  a. How would you normally describe the motion of the book?
  b. What reference frame did you use in your description? Was the reference frame moving or stationary relative to the earth?
  c. What motion have you ignored in your description in (a)?
  d. Describe the motion of the book from a reference frame that is stationary relative to the earth.
  e. Do your descriptions in (a) and (d) agree? Why or why not?

B2. The photograph of the pole vaulter in Figure 2-9 was taken by a camera stationary relative to the earth. In this reference frame, the cross bar is stationary and the pole vaulter is moving.
  a. Describe how a photograph would look had the camera been attached to the pole vaulter.
  b. Which reference frame, the one attached to the earth or the one attached to the pole vaulter, would be most helpful to the coach in examining the pole vaulter's technique. Why?

B3. Figure 3-B3 is a strobelike drawing of a bicyclist moving in a reference frame attached to the earth.
  a. Describe the motion of the tree and the bicycle in a reference frame attached to the tree.



  b. Describe the same motion in a reference frame attached to the bicycle.
  c. Which reference frame is more valid?

B4. The time interval between the two images in Figure 3-B3 is 8 s.
  a. What is the velocity of the bicyclist relative to the tree?
  b. What is the velocity of the tree relative to the bicyclist?
  c. Why are the magnitudes of these two velocities equal?

B5. An airplane which has a velocity of 400 km/h, east, relative to the ground is flying in a wind with a velocity relative to the ground of 50 km/h, east. What is the speed of the airplane relative to the wind? (This speed is called the *airspeed* of the airplane.)

B6. A police officer, motionless relative to the earth, measures the relative speed between the police car and another car as 100 km/h. What would the relative speed be if the police officer measured the speed while driving at a constant speed of 50 km/h in a direction opposite to that of the other car?

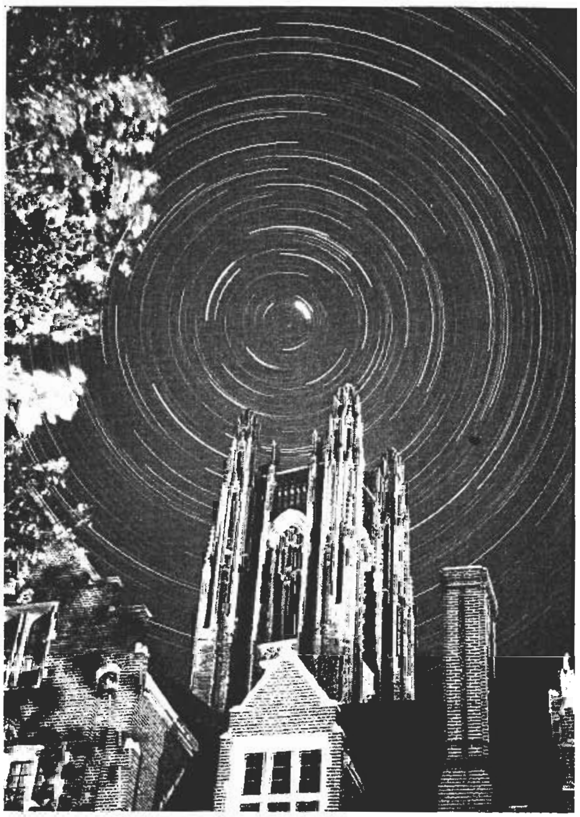
B7. Maria is jogging at a velocity of 4 m/s, east. David is 12 m behind her, running at a velocity of 3 m/s, east. (Both velocities are relative to the earth.) What is David's velocity relative to Maria? Can David ever catch up with Maria? Why or why not?

B8. Kim and Kevin are rushing through an airport. Their velocities relative to the earth are 6 m/s, east, and 6 m/s, west, respectively.
  a. What is Kim's speed relative to Kevin?
  b. Kim and Kevin eventually bump into each other. Is it possible to change to a reference frame in which they do not bump into each other? If yes, describe the origin and motion of the reference frame. If no, explain why not.

B9. A police car is pursuing an automobile that has violated the speed limit. What velocity does the police officer use to judge how fast he must travel to overtake the automobile? Under what circumstances will the police officer radio ahead to another officer rather than pursue the automobile himself?

C. Extensions to New Situations

C1. The photograph in Figure 3-C1 was taken by aiming a camera toward the North Star and opening the shutter. The streaks are made by the light emitted from stars.
 a. How would you describe the motion of the church tower?
 b. How would you describe the motion of the stars?
 c. Describe the reference frame used in (a) and (b). What have you assumed about that reference frame?
 d. Someone else reports that the earth rotates beneath the stars. The stars are, in fact, stationary. What reference frame did this person use?
 e. What is different about the two reference frames used?
 f. Which reference frame, (c) or (d), is more valid?



C2. In coordinate system A, a ball moved from (0 m, 2 m) to (0 m, 10 m) in 4 s. Measured in a different coordinate system, system B, the ball moved from (2 m, 10 m) to (2 m, 18 m) in the same 4 s.
 a. What was the ball's velocity in coordinate system A?
 b. What was the ball's velocity in coordinate system B?
 c. Compare your answers in (a) and (b). What can you say about coordinate systems A and B? If they are moving relative to one another, find their relative velocity.

C3. Problem 2-C8 asked you to analyze the horizontal and vertical motions of an object thrown upward and outward near the surface of the earth. (See Figure 2-C8.)
 a. Describe the reference frame from which the photograph was taken.
 b. Sketch the motion of the object had the camera been moving horizontally at the same velocity as the object.
 c. In a reference frame fixed relative to the earth, how would you throw the object to make its motion appear as your description in (b)?
 d. Use the results in (a), (b), and (c) to explain why an object dropped from the top of a building lands immediately below where it was dropped rather than behind where it was dropped. (Since the building is attached to the rotating earth, it moves eastward during the time that the object falls to the ground.)

C4. Police radar systems determine a car's speed by measuring its speed relative to the police car. From this relative speed and the speed of the police car relative to the ground, a small computer determines your speed relative to the highway.
 a. Suppose you are traveling at 80 km/h, north, relative to the road and a police car is traveling at 70 km/h, south, relative to the road. Radar measures the speed of your car relative to the police car. What is the speed measured by the radar?
 b. A radar unit is moving at 50 km/h relative to the road. It measures the relative speed of an oncoming car to be 150

km/h. What is the speed of the oncoming car relative to the road?

c. A radar unit traveling at 90 km/h relative to the road measures a relative speed of 0 km/h for a car traveling in the same direction. What is the speed of the car relative to the road?

C5. The earth rotates from west to east. If relative speeds were the only factor, which would be faster: a trip by air from New York to San Francisco or one from San Francisco to New York?

C6. A bicyclist is traveling at a constant velocity of 10 km/h, east, relative to the road.

a. What is her velocity relative to a wind blowing 10 km/h, east, relative to the earth?

b. What is her velocity relative to a wind blowing 10 km/h, west, relative to the earth?

c. In which situation, (a) or (b), will the bicyclist feel a wind moving past her?

d. Evaporation of sweat by the wind is an important factor in making a bicyclist feel cool on a hot day. Why will riding with the wind make the bicyclist less comfortable than riding against the wind?

C7. In this chapter we discussed the relative motion of two objects moving toward or away from one another. Another situation in which relative motion is important is when one object moves inside of another moving object. For example, you are on a bus moving forward 30 m/s relative to the earth and are walking toward the back of the bus at a speed of 2 m/s relative to the bus.

a. In 1 s how far does the bus move forward?

b. In 1 s how far do you move backward?

c. What is your total displacement relative to the earth in 1 s?

d. What is your velocity relative to the earth?

e. Can you state a general rule for calculating relative velocities when one object is moving inside another?

C8. Test the rule you stated in Problem C7 on a new example. In still water you can paddle a canoe 2 m/s. That is your speed relative to water that is not moving. Suppose you continue to paddle in exactly the same manner; however, now you are floating on a river that flows at a rate of 1 m/s.

a. If you paddle in the same direction as the current, what is your velocity relative to the earth?

b. If you paddle against the current, what is your velocity relative to the earth?

C9. A lion pursues an antelope. Relative to the earth, the lion moves at a velocity of 23 m/s, west, while the antelope runs at a velocity of 15 m/s, west.

a. What is the relative velocity between the lion and the antelope? Will the lion catch the antelope?

b. In reference frame A, the lion's velocity is measured to be 100 m/s, west, and the antelope's velocity is 88 m/s, west. What do we know about reference frame A relative to the reference frame attached to the earth?

c. If we compared our value of the relative velocity between the lion and the antelope with that measured in reference frame A, would there be any way that we could determine that reference frame A is moving relative to the earth?

C10. Police radar must accurately measure two relative speeds: the speed of the suspect speeder relative to the police car and the speed of the police car relative to the highway. With these two speeds, the radar system's computer can compute the speed of the suspect relative to the highway. To determine these two relative speeds, moving police radar uses two radar signals. One bounces off the road and measures the speed of the highway relative to the police car. The second bounces off the suspect's car and measures its speed relative to the police car. Recently some of the radar measurements have been questioned because of possible error. If the radar used to determine the police car's speed hits a large object on the side of the road rather than the road itself, the speed of the car relative to the road will be measured to be less than it really was. (This malfunction is named after a mathematical function and is called *cosine error*.) However, the speed of the alleged speeder's car relative to the police car will be accurate. To investigate this situation, suppose a police car is actually traveling at 70 km/h, but its radar reports its speed to be 60 km/h.

a. The radar measures the speed of car A moving in the same direction as the police car as 30 km/h. What is the actual speed of car A relative to the highway?
b. What speed relative to the highway does the radar calculate for car A?
c. Car B is traveling toward the police car. Its speed relative to the police car is measured to be 160 km/h. What is car B's actual speed relative to the highway?
d. What speed relative to the highway does the radar calculate for car B?
e. The speed limit on the interstate is 90 km/h. Which car—A or B—is actually speeding? Which driver will receive a speeding ticket?
f. If you wish to use the cosine error as a defense in court, which way relative to the police car must you have been traveling?

D. Activities

D1. Have you ever been in a situation where you were confused about what was moving? If so, describe the situation.

D2. Select special effects from current movies and analyze how they might have been filmed using the concepts of relative motion.

D3. As a fair-weather jogger, you enjoy getting your exercise indoors. But, you want to jog at least 2 km per day. Design a device which will move 2 km relative to your feet while your body is fixed relative to your house.