## CONCEPTUAL QUESTIONS

1. If you were located in a spaceship traveling with a constant velocity somewhere in the Galaxy, could you devise experiments to determine your speed? If so, what kinds of experiments?

2. If you were on the starship *Enterprise* in a room with no windows, could you devise experiments to determine your acceleration? If so, what kinds of experiments?

3. Einstein's theory of special relativity is often interpreted as saying, "Everything is relative and there are no absolutes." Is this interpretation consistent wih the fundamental postulates of the theory?

4. If Michelson and Morley had detected an ether in their experiment, what implications would it have had for the first postulate of special relativity?

5. Your friend is driving her 1964 Thunderbird convertible straight toward you at 40 mph. She stands up and throws a baseball forward at 30 mph. How fast do you see the ball approaching you?

6. Your friend from Question 5 finds that hanging "fuzzy dice" from the rearview mirror allows the car to travel up to 98% of the speed of light. She is driving straight toward you when she turns on her headlights. How fast do you see the light approaching you?

7. An observer in the train in the figure stands in the back of the car. He turns on a light and measures the time it takes for the light to get to the front of the car, bounce off a mirror, and return to him. (Assume that the light is traveling in a vacuum.) Knowing the length of the car, he is able to calculate the speed of light. Will he obtain a speed less than, greater than, or equal to $c$? Explain.

8. If an observer on the ground uses her own instruments to measure the speed of the light in Question 7, will she obtain a value less than, greater than, or equal to $c$? Explain.

9. According to the special theory of relativity, a twin who makes a long trip at a high speed can return to Earth at a younger age than the twin who remains at home. Is it possible for one twin to return before the other is born? Explain.

10. Suppose that in the situation depicted in Figure 10-3 the observer on the ground saw the rear paint can explode before the front one. For the observer in the van, is it possible that the two explosions occurred (a) simultaneously, (b) in the order as observed from the ground, or (c) in the reverse order as observed from the ground? Explain.

*11. A particularly fortunate astronomer observes light from two supernovae (exploding stars) at exactly the same time. One supernova is in the nearby Andromeda Galaxy while the other is in the more distant Whirlpool Galaxy. Were the two explosions simultaneous?

12. Two lighthouses are located 4 miles apart. An observer in the middle sees flashes from the two lighthouses at exactly the same time and concludes that the flashing events are simultaneous. A second observer, located 1 mile from one lighthouse and 3 miles from the other, does not receive the flashes at the same time. Does this observer disagree with the first one about whether the events were simultaneous? Explain.

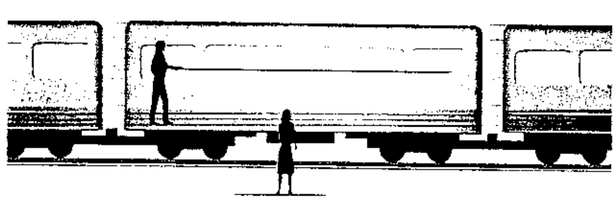
13. An observer on the ground reports that, as the midpoint of the train in the figure passes her, simultaneous flashes occurred in the engine and caboose. What would an observer in the train say about this?

14. An observer in the train in the figure determines that firecrackers go off simultaneously in the engine and in the caboose. What will an observer on the ground say about this?

15. As a friend passes you at a very high speed to the right, he explodes a firecracker at each end of his skateboard. These explode simultaneously from his point of view. Which one explodes first from your point of view? How must a third person be moving for her to have observed the other firecracker explode first?

16. Two lights on lampposts flash simultaneously as seen by an observer on the ground. How would you have to be moving in order to see (a) the right-hand light flash first? (b) the left-hand light flash first?

17. It is possible for observers moving relative to one another to disagree on the order of two events. However, the theory of special relativity preserves cause and effect. If one event caused, or could have caused, the other, then the order of the two events must be preserved for all observers. Two light sources, A and B, are located 186,000 miles apart (the distance light travels in 1 second). An observer at the midpoint between the sources receives a light



**Questions 7, 8, 13, and 14** A train is traveling along a straight, horizontal track at a constant speed that is only slightly less than that of light.

signal from source A $\frac{1}{2}$ second before receiving a signal from B. Is it possible that the light from source A caused source B to flash? Could another observer have seen B flash before A?

**18.** If the signal from source B in Question 17 was received 2 seconds after the signal from source A, is it possible that the light from source A caused source B to flash? Could another observer have seen B flash before A?

**19.** Space travelers on the way to colonize a planet orbiting a distant star decide to cook a "three-minute egg." Would a clock on Earth record the cooking time as less than, equal to, or greater than 3 minutes? Why?

**20.** Skip Parsec ventured into space without taking his watch. Wishing to cook a perfect "three-minute egg" on board his fast-moving spaceship, Skip is forced to rely on a clock on Earth. Because Skip missed the day that special relativity was taught at training camp, he cooks his egg for 3 minutes according to the Earth clock. Is his egg undercooked or overcooked?

**21.** If a musician plays middle C on a clarinet while traveling at 85% of the speed of light in a spaceship, will passengers in the ship hear a lower note, a higher note, or the same note? Why?

**22.** Superman wants to travel back to his native Krypton for a visit, a distance of 3,000,000,000 kilometers. (It takes light 10,000 seconds to travel this distance.) Superman can hold his breath for only 1000 seconds, but he can travel at any speed less than that of light. Can he make it?

**23.** In an experiment to measure the lifetime of muons moving through the laboratory, scientists obtained an average value of 8 microseconds before a muon decayed into an electron and two neutrinos. If the muons were at rest in the laboratory, would they have a longer, a shorter, or the same average life? Why?

**24.** On average, an isolated neutron at rest lives for 17 minutes before it decays. If neutrons are moving relative to you, will you observe that they have a longer, a shorter, or the same average life? Explain.

**25.** A warning light in the engine of a fast-moving train flashes once each second according to a clock on the train. Will an observer on the ground measure the time between flashes to be greater than, less than, or equal to 1 second? Explain.

**26.** A warning light on the ground flashes once each second. Will an observer in a fast-moving train measure the time between flashes to be greater than, less than, or equal to 1 second? Why?

**27.** Peter volunteers to serve on the first mission to visit Alpha Centauri. Even traveling at 80% of the speed of light, the round-trip will take a minimum of 10 years. When Peter returns from the trip, how will his biological age compare with that of his twin brother Paul, who will remain on Earth?

**28.** Is it physically possible for a 30-year-old college professor to be the natural parent of a 40-year-old student? Would this imply that the child was conceived before the professor was born?

**29.** What does the special theory of relativity say about the possibility of the event described in the following limerick?

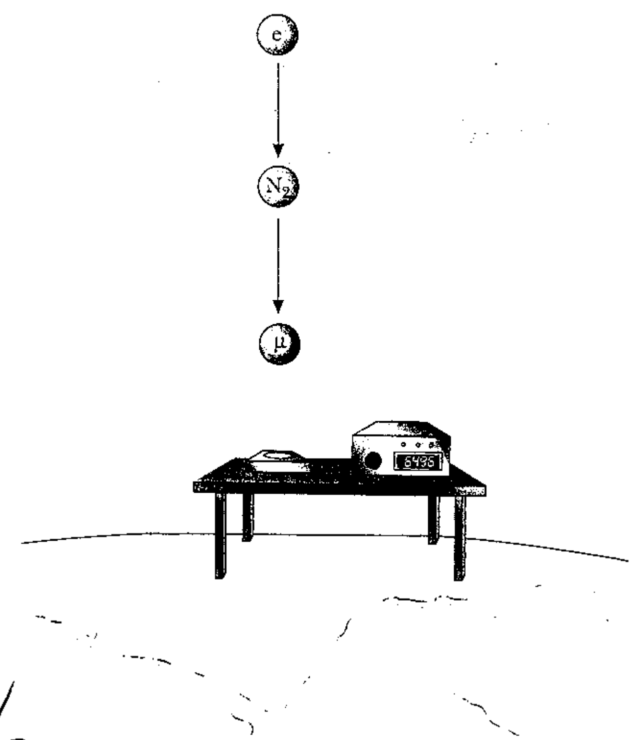
> There was a young lady named Bright
> Who could travel much faster than light.
> She went away one day
> In a relative way
> And returned on the previous night.

**30.** In *A Connecticut Yankee in King Arthur's Court,* Mark Twain chronicles the adventures of a New England craftsman who in 1879 is suddenly transported back in time to Camelot in the year 528. What does the special theory of relativity say about this possibility? What effect would such a trip have on our beliefs about cause and effect?

**31.** Suppose a meter stick zips by you at a speed only slightly less than the speed of light. If you measure the length of the meter stick as it goes by, would you determine it to be longer than, shorter than, or equal to 1 meter long? Why?

**32.** Is it possible for length contraction to occur without time dilation? Explain.

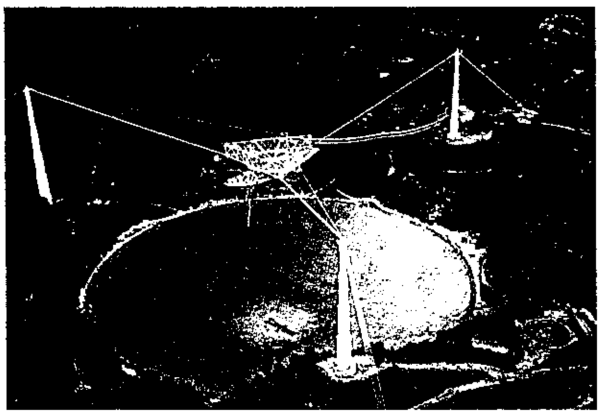
**33.** Muons are created in the upper atmosphere, thousands of meters above sea level. A muon at rest has an average lifetime of only 2.2 microseconds, which would allow it to travel a maximum distance of 660 meters before disintegrating. However, most muons created in the upper atmosphere survive to strike Earth. This effect is often explained in terms of time dilation. In this explanation, is the observer in the reference system of Earth or the reference system of the muon? Explain.




**34.** An alternative explanation for the survival of muons as described in Question 33 invokes length contraction. In this explanation is the observer in the reference system of Earth or the reference system of the muon? Explain.

## EXERCISES

1. The Moon shines by reflecting light from the Sun. The distance from Earth to the Moon is $3.84 \times 10^8$ m, and the distance from Earth to the Sun is $1.5 \times 10^{11}$ m.
   a. How long does it take for light to reach Earth from the Sun?
   b. How long does it take for light to reach Earth from the Moon?
2. If it takes light 4.4 years to reach Earth from the nearest star system, how far is it to the star system?
3. When Venus is closest to Earth, it is approximately 45 million km away. If the radio telescope at Arecibo, Puerto Rico, bounces a radio signal from Venus's surface, how long will it take the radio signal to make the round-trip?



Dr. Seth Shostak/Science Photo Library/Photo Researchers, Inc.

4. How long would it take a radio signal to reach a space probe in orbit about Saturn when Saturn is $1.5 \times 10^{12}$ m from Earth?
5. What is the size of the adjustment factor for a speed of $0.4c$?
6. What is the size of the adjustment factor for a speed of 25% that of light?
7. The average lifetime of a pion moving at 99% the speed of light is measured to be 2.69 nanoseconds (1 ns = $10^{-9}$ s). What would be the average lifetime of a pion at rest in the laboratory?
8. The average lifetime of isolated neutrons measured at rest relative to the lab is 920 s. What is the average lifetime of neutrons traveling at 80% of the speed of light?
9. An astronaut traveling at 99% of the speed of light waits 4 h (on his watch) after breakfast before eating lunch. To an observer on Earth, how long did the astronaut wait between meals?
10. The ground-based mission doctor for the astronaut in Exercise 9 is concerned that the astronaut is getting out of shape and requires him to exercise. The doctor tells the astronaut to begin pedaling the stationary bicycle and continue until she tells him to stop. She waits for 1 h on her clock. How long does the astronaut have to exercise according to his watch?
11. A ground-based observer measures a rocket ship to have a length of 60 m. If the rocket was traveling at 50% of the speed of light when the measurement was made, what length would the rocket have if brought to rest?
12. A rocket ship is 80 m long when measured at rest. What is its length as measured by an observer who sees the rocket moving past at 99% of the speed of light?
13. The conductor of a high-speed train uses a meter stick to measure the length of her train at 200 m while the train is stopped at the station. The train then travels at 80% of the speed of light (this is the supersupersonic train!). If she repeats the measurement on the moving train, what answer will she get?
14. An observer standing beside the tracks in Exercise 13 measures the length of the moving train as it goes by. What value does he get?
15. What is the distance to the nearest star system measured by an observer in a rocket ship traveling to the star system with a speed of $0.95c$? (The distance is 42 trillion km as measured by an observer on Earth.)
16. The pilot of an interstellar spaceship traveling at $0.98c$ determines the diameter of our Milky Way Galaxy to be about $1.2 \times 10^{14}$ km. What value would an Earth-based observer calculate for the Galaxy's diameter?
17. According to the classical form of Newton's second law, $F\Delta t = \Delta p$, it would require a force of 9.5 N acting for a year to accelerate a 1-kg mass to a speed of $0.9999c$. Using the relativistic form of Newton's second law, what force is required?
18. Calculate the impulse ($F\Delta t$) needed to accelerate a 1-kg mass to 80% of the speed of light, using both the classical and relativist forms of Newton's second law of motion.
19. A spaceship in deep space has a velocity of 200 km/s and an acceleration in the forward direction of 5 m/s$^2$. What is the acceleration of a ball relative to the spaceship after it is released in this spaceship?
20. Two spaceships, one red and one blue, are traveling through deep space. The red spaceship has a velocity of 20 m/s and an acceleration of 40 m/s$^2$, and the blue spaceship has a velocity of 40 m/s and an acceleration of 20 m/s$^2$. In which spaceship do the astronauts experience the greater effective gravitational force?
21. A spacecraft is descending to land on planet Y and slows by 4 m/s every second. The strength of the planet's gravitational field is 7 N/kg. If the passengers in the spacecraft account for the forces they feel in terms of a single gravitational field, how strong would this field have to be?