26.1 Classical Relativity and the Michelson–Morley Experiment

1. **MC** An object free of all forces exhibits a changing velocity in a certain reference frame. It follows that (a) the frame is inertial, (b) $\vec{\mathbf{F}} = m\vec{\mathbf{a}}$ applies in this frame, (c) the laws of mechanics are the same in this reference frame as in all inertial frames, (d) none of the preceding. (d)

2. **MC** Car A is traveling eastward at 85 km/h Car B is traveling westward with a speed of 65 km/h. The velocity of car B as measured by the driver of car A is (a) 150 km/h eastward (b) 20 km/h westward (c) 150 km/h westward (d) 20 km/h eastward (c)

3. **MC** A space probe is moving rapidly away from the Sun at 0.2*c*. As it passes the probe, the speed of the sunlight measured by the probe has what value? (a) 1.2*c* (b) exactly *c* (c) 0.8*c* (b)

7. ● A person 1.20 km away from you fires a gun, and you observe the flash from the muzzle. A wind of 10.0 m/s is blowing. How long will the sound of gunfire take to reach you if the wind is (a) toward you and (b) toward the person who fired the gun? (Take the speed of sound to be 345 m/s.) (a) 3.38 s (b) 3.58 s

8. ● A small airplane has an airspeed (speed with respect to air) of 200 km/h. Find the airplane's ground speed if there is (a) a headwind of 35 km/h and (b) a tailwind of 25 km/h. (a) 165 km/h (b) 225 km/h

10. **IE** ●● A boat can make a round trip between two locations, A and B, on the same side of a river in a time *t* if there is no current in the river. (a) If there is a constant current in the river, the time the boat takes to make the same round trip will be (1) longer, (2) the same, (3) shorter. Why? (b) If the boat can travel with a speed of 20 m/s in still water, the speed of the river current is 5.0 m/s, and the distance between points A and B is 1.0 km, calculate the times when there is no current and when there is current. (a) (1) longer (b) 1.7 min and 1.8 min

26.2 The Postulates of Special Relativity and the Relativity of Simultaneity

12. **MC** Events that are simultaneous in one inertial reference frame are (a) always simultaneous in other inertial reference frames, (b) never simultaneous in other inertial reference frames, (c) sometimes simultaneous in other inertial reference frames, (d) none of the preceding. (c)

13. **MC** An object is at rest in an inertial reference frame. What will be the same about the object as measured by an inertial observer moving relative to the object: (a) its free-body diagram, (b) its velocity, (c) its kinetic energy, or (d) none of the preceding? (a)

14. **MC** An object is moving in an inertial reference frame. What will be the same about the object as measured by an inertial observer moving relative to the object? (a) its velocity, (b) its speed, (c) its kinetic energy, (d) its acceleration, or (e) none of the preceding? (d)

17. **CQ** In the *gedanken* experiment shown in ▼Fig. 26.17, two events in the same inertial reference frame *O* are related by cause and effect: (1) A gun at the origin fires a bullet along the *x*-axis with a speed of 300 m/s. (Assume that there are no gravitational or frictional forces.) (2) The bullet hits a target at $x = +300 \text{ m}$. Show, using qualitative arguments, that the two events cannot be viewed simultaneously by any inertial observer. (*Note:* This shows that special relativity preserves the time *sequence* of two events if they are related as cause and effect. In this situation, this means that all observers agree that the gun fires before the bullet hits the target.)

26.3 The Relativity of Length and Time: Time Dilation and Length Contraction

19. **MC** An observer sees a friend passing her in a rocket ship that has a uniform velocity of 0.90 *c*. The observer knows her friend to be 1.45 m tall, and he is standing such that his length is perpendicular to their relative velocity. To the observer, her friend will appear (a) taller than 1.45 m, (b) shorter than 1.45 m, (c) exactly 1.45 m tall. (c)

20. **MC** An observer sees a friend passing her in a rocket ship that has a uniform velocity of 0.90 *c*. Her friend claims that exactly 10 seconds have elapsed on his clock. How will the observer's identical clock measure the same time interval? The observer's clock will read (a) less than 10 seconds, (b) greater than 10 seconds, (c) exactly 10 seconds. (b)

21. **MC** A speedboat completes one straight leg of a lap that the race organizers have carefully laid out to be exactly 2.55 km long. Which observer(s) measures the leg's proper length: (a) the organizers, (b) the driver of the speedboat, (c) they both do, or (d) neither does? (a)

23. **CQ** A farm boy wants to store a 5-m-long pole in a shed that is only 4 m long (it does have both front and rear doors). He claims that if he runs through the shed sufficiently fast, according to an observer at rest, the pole will fit in the shed (both doors closed at least for an instant) as a result of length contraction. Can this be true? Show that from the boy's reference frame the pole could not possibly fit into the shed.

29. ●● The proper lifetime of a muon is $2.20\ \mu\text{s}$. If the muon has a lifetime of $34.8\ \mu\text{s}$ according to an observer on Earth, what is the muon's speed, as a fraction of *c*, relative to the observer? 0.998 *c*

31. **IE** ●● Alpha Centauri, a binary star close to our solar system, is about 4.3 light-years away. Suppose a spaceship traveled this distance with a constant speed of 0.60 *c* relative to Earth. (a) Compared with a clock on the spaceship, an Earth-based clock will measure (1) a longer time, (2) an equal time, (3) a shorter time. Why? (b) How much time would elapse on an Earth-based clock and on a clock on the spaceship? (a) (1) a longer time (b) 7.2 years and 5.7 years

36. ●● The distance to Planet X is 1.00 light-year. How long does it take a spaceship to reach X, according to the pilot of the spaceship, if the speed of the ship is 0.700 *c* relative to X? 1.02 years

26.4 Relativistic Kinetic Energy, Momentum, Total Energy, and Mass–Energy Equivalence

40. **MC** How does an object's relativistically correct kinetic energy compare to its kinetic energy calculated from the Newtonian expression? (a) The relativistic result is always larger, (b) the Newtonian result is always larger, (c) they are the same, or (d) one can be larger or smaller than the other depending upon the object's speed. (a)

41. **MC** The total energy *E* of a free-moving particle of mass *m* with speed v is given by which of the following: (a) mv^2, (b) γmc^2, (c) $1/2\ mc^2$, or (d) $K + \gamma mc^2$. (b)

42. **MC** How does an object's relativistically correct linear momentum (magnitude) compare to its momentum calculated from the Newtonian expression? (a) The relativistic result is always less, (b) the Newtonian result is always less, (c) they are the same, or (d) one can be larger or smaller than the other, depending on the object's velocity. (b)

59. ●● A beam of electrons is accelerated from rest to a speed of 0.950 *c* in a particle accelerator. In MeV, what are the (a) kinetic energy and (b) total energy of the electrons? (a) 1.13 MeV (b) 1.64 MeV

26.5 The General Theory of Relativity

63. **MC** General relativity (a) provides a theoretical basis for explaining the gravitational force, (b) applies only to rotating systems, (c) applies only to inertial systems. (a)

64. **MC** One of the predictions of general relativity is (a) the mass–energy equivalence, (b) time dilation, (c) the twin paradox, (d) the bending of light in a gravitational field. (d)

65. **MC** Black hole A has three times the mass of black hole B. How do their Schwarzschild radii *R* compare? (a) $R_A = R_B$, (b) $R_B = 3R_A$, (c) $R_A = 3R_B$, (d) $R_A = 9R_B$. (c)

69. ●● If the Sun became a black hole, what would be its average density? (See Example 26.8.) $1.8\times10^{19}\ \mathrm{kg/m^3}$

*26.6 Relativistic Velocity Addition

71. ● After jettisoning a stage, a rocket has a velocity of $+0.20c$ relative to the jettisoned stage. An observer on Earth sees the jettisoned stage moving with a velocity of $+7.5\times10^7\ \mathrm{m/s}$, relative to her, in the same direction as the rocket. What is the velocity of the rocket relative to the Earth observer? 0.43 *c*

Comprehensive Exercises

76. **IE** A spaceship containing an astronaut travels at a speed of 0.60*c* relative to a second inertial observer. (a) Which measures proper time intervals in the ship and the proper length of the ship: (1) the astronaut in the ship, (2) the second observer, (3) neither? (b) How much time does a clock onboard the spaceship appear to lose in a day, according to the second observer? (c) If the second observer measures a length of 110 m for the ship, what is its "proper" length"? (a) (1) the astronaut in the ship (b) 4.8 h (c) 138 m