 (5th ed)

inertial force: A fictitious force that arises in accelerating (noninertial) reference systems. Examples are the centrifugal and Coriolis forces.

inertial reference system: Any reference system in which the law of inertia (Newton's first law of motion) is valid.

noninertial reference system: Any reference system in which the law of inertia (Newton's first law of motion) is not valid. An accelerating reference system is noninertial.

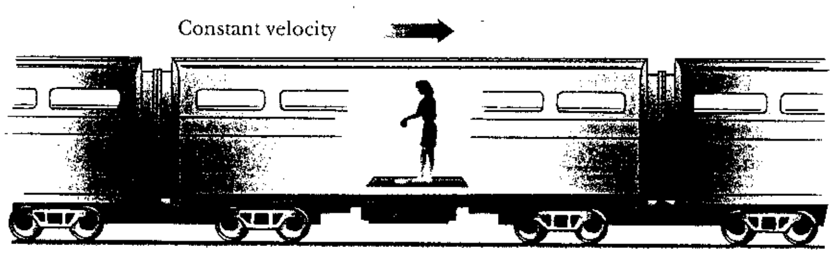
reference system: A collection of objects not moving relative to each other that can be used to describe the motion of other objects. See inertial and noninertial reference systems.

CONCEPTUAL QUESTIONS

1. Newton's first law states: "Every object remains at rest or in motion in a straight line at constant speed unless acted on by an unbalanced force." Is this "law" true in all reference frames? Explain.
2. Newton's third law states: "If an object exerts a force on a second object, the second object exerts an equal force back on the first object." Is this "law" true in all reference frames? Explain.
3. *Alice in Wonderland* begins with Alice falling down a deep, deep rabbit hole. As she falls, she notices that the hole is lined with shelves and grabs a jar of orange marmalade. Upon discovering that the jar is empty, she tries to set it back on a shelf—a difficult task since she is falling. She is afraid to drop the jar for it might hit somebody on the head. What would really happen to the jar if Alice had dropped it? Describe its motion from Alice's reference system and from the reference system of someone sitting on a shelf on the hole's wall.

*4. Imagine riding in a glass-walled elevator that goes up the outside of a tall building at a constant speed of 20 meters per second. As you pass a window washer, he throws a ball upward at a speed of 20 meters per second. Assume, furthermore, that you drop a ball out a window at the same instant.
   a. Describe the motion of each ball from the point of view of the window washer.
   b. Describe the motion of each ball as you perceive it from the reference system of the elevator.

5. You wake up in a windowless room on a train, which rides along particularly smooth tracks. Imagine that you have a collection of objects and measuring devices in your room. What experiment could you do to determine whether the train is stopped at the train station or moving horizontally at a constant velocity?
6. Assume that you are riding in a windowless train on perfectly smooth tracks. Imagine that you have a collection of objects and measuring devices in the train. What experiment could you do to determine whether the train is moving horizontally at a constant velocity or is speeding up?
7. The woman riding the train in the figure drops a ball directly above a white spot on the floor. Where will the ball land relative to the white spot?
8. How would the woman in the figure describe the ball's horizontal velocity while the ball is falling? Would an observer on the ground standing next to the tracks agree?
9. What would the woman in the figure say about the horizontal forces acting on the ball as it falls? Would an observer on the ground standing next to the tracks agree?
10. What value would the woman in the figure obtain for the acceleration of the ball as it falls? Would an observer on the ground standing next to the tracks obtain the same value?
11. Would the woman and the observer on the ground in the figure agree on the ball's kinetic energy just before it leaves her hand? Would they agree on the *change* in kinetic energy of the ball from the moment it leaves her hand until just before it hits the floor? Explain.
12. Would the woman and the observer on the ground in the figure agree on the ball's momentum just before it leaves her hand? Would they agree on the change in momentum of the ball from the moment it leaves her hand until just before it hits the floor? Explain.
13. Gary is riding on a flatbed railway car, which is moving along a straight track at a constant 20 meters per second. By applying a 600-newton force, Gary is trying in vain to push a large block toward the front of the car. His two



Questions 7–12. A train is traveling along a straight, horizontal track at a constant velocity of 50 kilometers per hour. An observer in the train holds a ball directly over a white spot on the floor of the train and drops it.

26. During the time the elevator in Question 25 is moving upward with a constant speed, is the reading on the scale greater than, equal to, or less than 180 pounds? Explain.

27. Assume you are standing on a bathroom scale while an elevator slows down to stop at the top floor. Will the reading on the scale be greater than, equal to, or less than the reading after the elevator stops? Why?

28. The elevator in Question 27 now starts downward to return to the ground floor. Will the reading on the scale be greater than, equal to, or less than the reading with the elevator stopped? Why?

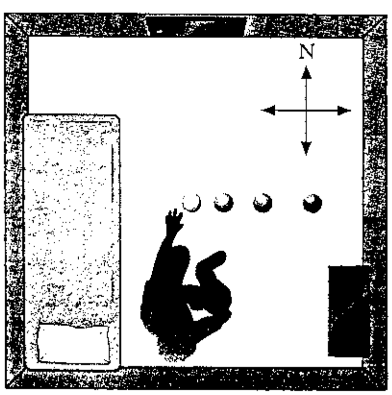
29. If a child weighs 200 newtons standing at rest on Earth, would she weigh more, less, or the same if she were in a spaceship accelerating at 10 (meters per second) per second in a region of space far from any celestial objects? Why?

30. The child in Question 29 enters a circular orbit at constant speed around a distant planet. The spacecraft's centripetal acceleration is 10 (meters per second) per second. Would she weigh less than, equal to, or more than 200 newtons? Why?

*31. Assume that a meter-stick balance is balanced with a 20-gram mass at 40 centimeters from the center and a 40-gram mass at 20 centimeters from the center. Will it remain balanced if it is in an elevator accelerating downward? Explain your reasoning.

*32. Assume that you weigh a book on an equal-arm balance while an elevator is stopped at the ground floor. Would you get the same result if the elevator were accelerating upward? Explain your reasoning.

33. You wake up in a windowless room on a train, traveling along particularly smooth, horizontal tracks. You don't know in which direction the train is moving, but you are carrying a compass. You place a ball in the center of the floor and observe as it rolls east. If the train is moving west, is it speeding up, slowing down, or turning with constant speed? (If turning, state right or left.) What if it is moving east?



34. Consider the train in Question 33. If the train is moving north, is it speeding up, slowing down, or turning with constant speed? (If turning, state right or left.) What if it is moving south?

35. In an inertial reference system, we define *up* as the direction opposite the gravitational force. In a noninertial reference system, *up* is defined as the direction opposite the vector sum of the gravitational force and any inertial forces. Which direction is up in each of the following cases?

a. An elevator accelerates downward with an acceleration smaller than that of free fall.
b. An elevator accelerates upward with an acceleration larger than that of free fall.
c. An elevator accelerates downward with an acceleration larger than that of free fall.

*36. Using the definition of *up* in Question 35, which direction is up for each of the following situations?

a. A child rides near the outer edge of a merry-go-round.
b. A dining car going around a curve turns to the right.
c. A skier skies down a hill with virtually no friction.

37. Which direction is up for astronauts orbiting Earth in the space shuttle?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38. A spacecraft in deep space uses its engines to guide it along a circular path of constant radius 6700 kilometers at a constant speed of 27,800 kilometers per hour. This is identical to the trajectory of the space shuttle. Which direction is up for astronauts in this spacecraft?

39. You and a friend are rolling marbles across a horizontal table in the back of a moving van traveling along a straight section of an interstate highway. You roll the marbles toward the side of the van. What can you say about the velocity and acceleration of the van if you observe the marbles (a) head straight for the wall? (b) Curve toward the front of the truck?

40. A ball is thrown vertically upward from the center of a moving railroad flatcar. Where, relative to the center of the car, does the ball land in each of the following cases?

a. The flatcar moves at a constant velocity.
b. The velocity of the flatcar increases.
c. The velocity of the flatcar decreases.
d. The flatcar travels to the right in a circle at constant speed.

41. You fill a bucket half full of water and swing it in a vertical circle. When the bucket is at the top of its arc, the bucket is upside down but the water does not spill on your head. What direction is up for the water?

42. Would it be possible to take a drink at the top of a loop-the-loop on a roller coaster? Explain.

43. For a science project, a student plants some bean seeds in water and lets them grow in containers fastened near the outer edge of a merry-go-round that is continually turning. Draw a side view of the experiment showing the direction the plants will grow.

44. A student carries a ball on a string onto the rotating cylinder ride shown in Figure 9-9. With the ride in operation, she holds her hand straight in front of her and lets the ball hang by the string. Using a side view, draw a free-body diagram for the ball from the student's reference frame. For each force on the diagram, state, if possible, the object responsible for the force.

45. Why does the mud fly off the tires of a pickup traveling down the interstate?

46. The Red Cross uses centrifuges to separate the various components of donated blood. The centrifugal force causes the denser component (the red blood cells) to go to the bottom of the test tube. If there were a dial on the wall of the lab that allowed the "local gravity" to be increased to any value, would the centrifuge still be required? Why or why not?

***47.** Copernicus had difficulty convincing his peers of the validity of his heliocentric model because if Earth were moving around the Sun, stellar parallax should have been observed, which it wasn't. If Earth's orbital radius about the Sun were magically doubled, would this make stellar parallax easier or harder to observe? Explain.

48. What evidence do you have to support the belief that Earth rotates on its axis?

49. Would a Foucault pendulum rotate at the equator? Explain your reasoning.

50. If you were to set up a Foucault pendulum at the South Pole, would it appear to rotate clockwise or counterclockwise when viewed from above? Why?

51. Why are there no hurricanes on the equator?

52. In preparation for hunting season, you practice at a shooting range in which the targets are located straight to the south. You find that you must aim slightly to the right of the target to account for the Coriolis force. Are you in the Northern or the Southern Hemisphere? If you are out hunting and shoot to the north, do you have to aim slightly to the right or slightly to the left to ensure a direct hit?

***53.** It is known that Earth is bigger around the equator than around the poles. How does this equatorial bulge support the idea that Earth is rotating?

EXERCISES

1. A spring gun fires a ball horizontally at 15 m/s. It is mounted on a flatcar moving in a straight line at 25 m/s. Relative to the ground, what is the horizontal speed of the ball when the gun is aimed (a) forward? (b) backward?

2. An aircraft carrier is moving to the north at a constant 25 mph on a windless day. A plane requires a speed relative to the air of 125 mph to take off. How fast must the plane be traveling relative to the deck of the aircraft carrier to take off if the plane is headed (a) north? (b) south?

3. A child can throw a ball at a speed of 50 mph. If the child is riding in a bus traveling at 20 mph, what is the speed of the ball relative to the ground if the ball is thrown (a) forward? (b) backward?

4. A transport plane with a large rear-facing cargo door flies at a constant horizontal speed of 400 mph. A major-league baseball pitcher hurls his best fastball, which he throws at 95 mph, out the rear door of the plane. Describe what the motion of the baseball would look like to an observer on the ground.

5. What would an observer measure for the magnitude and direction of the free-fall acceleration in an elevator near the surface of Earth if the elevator (a) accelerates downward at 6 m/s^2? (b) accelerates downward at 16 m/s^2?

6. An observer measures the free-fall acceleration in an elevator near the surface of Earth. What would the value and direction be if the elevator (a) accelerates upward at 4 m/s^2? (b) travels upward with a constant speed of 4 m/s?

7. A person riding a train at a constant speed of 30 m/s drops a 2-kg suitcase from a height of 1.25 m. The fall requires half a second and the suitcase acquires a vertical velocity of 5 m/s. Find the initial kinetic energy, the final kinetic energy, and the change in kinetic energy from the reference system of an observer on the train.

***8.** Consider the falling suitcase described in Exercise 7 from the reference system of an observer standing along the side of the track. Find the initial kinetic energy, the final kinetic energy, and the change in kinetic energy. How does the change in kinetic energy compare to the answer in previous exercise?

9. What is the maximum total force exerted on a 50-kg astronaut by her seat during the launch of a space shuttle?

10. What would be the maximum total force exerted on a 90-kg fighter pilot when ejecting from an aircraft?

11. A child weighs 300 N standing on Earth. What is the weight of the child in an elevator accelerating upward at 0.3 g?

12. An elevator is moving downward and slowing down with an acceleration equal to one-quarter that of gravity. If a person who weighs 800 N when at rest on Earth steps on a bathroom scale in this elevator, what will the scale read?

13. An 8-kg monkey rides on a bathroom scale in an elevator that is accelerating upward at $\frac{1}{4}$ g. What does the scale read?

14. What does the scale read if a 5-kg cat lies on a bathroom scale in an elevator accelerating downward at 0.2 g?

15. A room is being accelerated through space at 3 m/s^2 relative to the "fixed stars." It is far away from any massive objects. If a man weighs 800 N when he is at rest on Earth, how much will he weigh in the room?

16. A woman with a weight of 700 N on Earth is in a spacecraft accelerating through space a long way from any massive objects. If the acceleration is 4 m/s^2, what is her weight in the ship?

17. A 400-N child is seated in a plane cruising at constant horizontal speed. The plane begins to speed up rapidly, at which point the child's weight increases to 500 N. What is the magnitude of the inertial force while the plane is accelerating?

18. A 600-N person is riding in the rotating cylinder ride shown in Figure 9-9. The cylinder rotates fast enough to create an 800-N centrifugal force. What is the magnitude of the person's weight in the rotating reference frame?

***19.** A cylindrical space station with a 40-m radius is rotating so that points on the walls have speeds of 20 m/s. What is the acceleration due to this artificial gravity at the walls?

***20.** What is the centrifugal acceleration on the equator of Mars given that it has a radius of 3400 km and a rotational period of 24.6 h? How does this compare to the acceleration due to gravity on Mars of 3.7 m/s^2?

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