For Thought and Discussion

1. Under what conditions is the magnitude of the vector sum $\vec{A} + \vec{B}$ equal to the sum of the magnitudes of the two vectors?
2. Can two vectors of equal magnitude sum to zero? Can two vectors of unequal magnitude sum to zero?
3. Repeat Question 2 for three vectors.
4. Three vectors sum to zero. If they are placed head to tail, what geometric figure must they form? Explain.
5. Is it meaningful to talk about vectors without mentioning coordinate systems or components?
6. Can an object have a southward acceleration while moving northward? A westward acceleration while moving northward?
7. Is there any way to negotiate a curved path without accelerating?
8. A satellite glides through space at a steady 29,000 km/h in a circular orbit around Earth. Is the satellite accelerating? If so, in what direction? If not, why not?
9. You're moving northward when you accelerate briefly toward the east. Is your subsequent motion strictly eastward? Explain.
10. In what sense is Equation 3.8 really two (or three) equations?
11. Is the speed of a projectile constant throughout its parabolic trajectory?
12. What is the vertical component of a projectile's velocity at the peak of its trajectory?
13. Is there any point on a projectile's trajectory where the velocity and acceleration are perpendicular?
14. Projectiles launched at 30° and 60° have the same range. Does this mean they stay in the air the same amount of time?
15. A friend who's not taking physics insists that you can't be accelerating when you drive around a curve since the speedometer reading remains steady. Refute this argument.
16. How is it possible for an object to be moving in one direction but accelerating in another?

Exercises and Problems

Exercises

Section 3.1 Vectors

17. You walk west 220 m and then north 150 m. What are the magnitude and direction of your displacement vector?
18. An ion in a mass spectrometer (a device that sorts atomic-size particles) follows a semicircular path of radius 15.2 cm. What are (a) the distance it travels and (b) the magnitude of its displacement?
19. A migrating whale follows the west coast of Mexico and North America toward its summer home in Alaska. It first travels 360 km due northwest to just off the coast of northern California and then turns due north and travels 400 km toward its destination. Determine graphically the magnitude and direction of its displacement vector.
20. A city's streets are laid out with its north-south blocks twice as long as its east-west blocks. You walk 8 blocks east and 3 blocks north. Determine (a) the total distance you've walked and (b) the magnitude of your displacement vector. Express answers in units of east-west blocks.
21. Vector $\vec{A}$ has magnitude 3.0 m and points to the right; vector $\vec{B}$ has magnitude 4.0 m and points vertically upward. Find the magnitude and direction of a vector $\vec{C}$ such that $\vec{A}+\vec{B}+\vec{C}=\vec{0}$.
22. Vector $\vec{V}$ represents a displacement of 120 km at 29° counterclockwise from the x axis. Write $\vec{V}$ in unit vector notation.
23. Find the magnitude of the vector $34\hat{\imath}+13\hat{\jmath}$ m and determine the angle it makes with the x axis.
24. (a) What is the magnitude of $\hat{\imath}+\hat{\jmath}$? (b) What angle does it make with the x axis?

Section 3.2 Velocity and Acceleration Vectors

25. An asteroid is discovered heading straight toward Earth at 15 km/s. An international team manages to attach a giant rocket engine to the asteroid. The rocket fires for 10 min, after which the asteroid is moving at 28° to its original path at a speed of 19 km/s. Find its average acceleration.
26. An object is moving at 18 m/s at an angle of 220° counterclockwise from the x axis. What are the x and y components of its velocity?
27. A car drives north at 40 mi/h for 10 min and then turns east and goes 5.0 mi at 60 mi/h. Finally, it goes southwest at 30 mi/h for 6.0 min. Draw a vector diagram and determine (a) the car's displacement and (b) its average velocity for this trip.
28. The minute hand of a clock is 5.5 cm long. What is the average velocity vector for the tip of the hand during the interval from the hour to 20 minutes past the hour, expressed in a coordinate system with the y axis toward noon and the x axis toward 3:00?
29. A car, initially going eastward, rounds a 90° curve and ends up heading southward. If the speedometer reading remains constant, what is the direction of the car's average acceleration vector?
30. What are (a) the average velocity and (b) the average acceleration of the tip of the 2.4-cm-long hour hand of a clock in the interval from 12 PM to 6 PM? Express the answers in unit vector notation, with the x axis pointing toward 3 PM and the y axis toward 12 PM.
31. A skater is gliding along the ice at 2.4 m/s, when she undergoes an acceleration of magnitude 1.1 m/s² for 3.0 s. At the end of that time she is moving at 5.7 m/s. What must be the angle between the acceleration vector and the initial velocity vector?
32. An object is moving in the x direction at 1.3 m/s when it is subjected to an acceleration given by $\vec{a}=0.52\hat{\jmath}$ m/s². What is its velocity vector after 4.4 s of acceleration?

Section 3.3 Relative Motion

33. A jetliner with an airspeed of 1000 km/h sets out on a 1500-km flight due south. To maintain a southward direction, however, the plane must be pointed 15° west of south. If the flight takes 100 min, what is the wind velocity?
34. You wish to row straight across a 63-m-wide river. You can row at a steady 1.3 m/s relative to the water, and the river flows at 0.57 m/s. (a) In what direction should you head? (b) How long will it take you to cross the river?
35. An airplane with airspeed of 370 km/h flies perpendicularly across the jet stream. To achieve this flight, the plane must be pointed into the jet stream at an angle of 32° from the perpendicular direction of its flight. What is the speed of the jet stream?
36. A flock of geese is attempting to migrate due south, but the wind is blowing from the west at 5.1 m/s. If the birds can fly at 7.5 m/s relative to the air, in what direction should they head?

Section 3.4 Constant Acceleration

37. The position of an object as a function of time is given by $\vec{r}=(3.2t+1.8t^2)\hat{\imath}+(1.7t-2.4t^2)\hat{\jmath}$ m, where t is the time in seconds. What are the magnitude and direction of the acceleration?
38. A sailboard is sailing at 6.5 m/s when a gust of wind hits, causing it to accelerate at 0.48 m/s² at a 35° angle to its original direction of motion. If the acceleration lasts 6.3 s, what is the board's net displacement during the wind gust?

Section 3.5 Projectile Motion

39. You toss an apple horizontally at 8.7 m/s from a height of 2.6 m. Simultaneously, you drop a peach from the same height. How long does each take to reach the ground?
40. A carpenter tosses a shingle off an 8.8-m-high roof, giving it an initially horizontal velocity of 11 m/s. (a) How long does it take the shingle to reach the ground? (b) How far does it move horizontally in this time?
41. An arrow fired horizontally at 41 m/s travels 23 m horizontally before it hits the ground. From what height was it fired?
42. Ink droplets in an ink-jet printer are ejected horizontally at 12 m/s and travel a horizontal distance of 1.0 mm to the paper. How far do they fall in this interval?
43. Protons in a particle accelerator drop 1.2 μm over the 1.7-km length of the accelerator. What is their approximate average speed?
44. If you can hit a golf ball 180 m on Earth, how far can you hit it on the Moon? (Your answer is an underestimate because the distance on Earth is restricted by air resistance as well as by a larger g.)

Section 3.6 Uniform Circular Motion

45. How fast would a car have to round a turn with a radius of 75 m for its acceleration to be numerically equal to that of gravity?
46. Estimate the acceleration of the Moon, which completes a nearly circular orbit of 385,000 km radius in 27 days.
47. Global Positioning System satellites are at altitudes of approximately 20,000 km, where the acceleration of gravity is only 5.8% of its surface value. To the nearest hour, what's the orbital period of the GPS satellites?

Problems

48. Two vectors $\vec{A}$ and $\vec{B}$ have the same magnitude A and are at right angles. Find the magnitude of the vectors (a) $\vec{A}+2\vec{B}$ and (b) $3\vec{A}-\vec{B}$.
49. Vector $\vec{A}$ has magnitude 1.0 m and points at 35° clockwise from the x axis. Vector $\vec{B}$ has magnitude 1.8 m. What angle should $\vec{B}$ make with the x axis so that $\vec{A}+\vec{B}$ is purely vertical?
50. Let $\vec{A}=15\hat{\imath}-40\hat{\jmath}$ and $\vec{B}=31\hat{\jmath}+18\hat{k}$. Find a vector $\vec{C}$ such that $\vec{A}+\vec{B}+\vec{C}=\vec{0}$.
51. A biologist studying the motion of bacteria notes a bacterium at position $\vec{r}_1=2.2\hat{\imath}+3.7\hat{\jmath}-1.2\hat{k}$ μm (1 μm $=10^{-6}$ m). After 6.2 s the bacterium is at $\vec{r}_2=4.6\hat{\imath}+1.9\hat{k}$ μm. What is its average velocity? Express the answer in unit vector notation, and calculate the magnitude.
52. An object's position as a function of time is given by $\vec{r}=12t\hat{\imath}+(15t-5.0t^2)\hat{\jmath}$ m, where t is time in seconds. (a) What is the object's position at $t=2.0$ s? (b) What is its average velocity in the interval from $t=0$ to $t=2.0$ s? (c) What is its instantaneous velocity at $t=2.0$ s?
53. Attempting to stop on a slippery road, a car moving at 80 km/h skids across the road at a 30° angle to its initial motion, coming to a stop in 3.9 s. Determine the average acceleration in m/s², using a coordinate system with the x axis in the direction of the car's original motion and the y axis toward the side of the road to which the car skids.
54. An object undergoes acceleration of $2.3\hat{\imath}+3.6\hat{\jmath}$ m/s² over a 10-s interval. At the end of this time, its velocity is $33\hat{\imath}+15\hat{\jmath}$ m/s. (a) What was its velocity at the beginning of the 10-s interval? (b) By how much did its speed change? (c) By how much did its direction change? (d) Show that the speed change is *not* given by the magnitude of the acceleration multiplied by the time. Why not?
55. The sweep-second hand of a clock is 3.1 cm long. What are the magnitude of (a) the average velocity and (b) the average acceleration of the hand's tip over a 5.0-s interval? (c) What is the angle between the average velocity and acceleration vectors?
56. A ferryboat sails between two towns directly opposite each other on a river. If the boat sails at 15 km/h relative to the water, and if the current flows at 6.3 km/h, at what angle should the boat head?
57. The sum, $\vec{A}+\vec{B}$, of two vectors is perpendicular to the difference, $\vec{A}-\vec{B}$. How do the magnitudes of the two vectors compare?
58. Write an expression for a unit vector that lies at 45° between the positive x and y axes.
59. An object is moving initially in the x direction at 4.5 m/s, when an acceleration is applied in the y direction for a period of 18 s. If the object moves equal distances in the x and y directions during this time, what is the magnitude of its acceleration?
60. A particle leaves the origin with initial velocity $\vec{v}_0=11\hat{\imath}+14\hat{\jmath}$ m/s. It undergoes a constant acceleration given by $\vec{a}=-1.2\hat{\imath}+0.26\hat{\jmath}$ m/s². (a) When does the particle cross the y axis? (b) What is its y coordinate at the time? (c) How fast is it moving, and in what direction, at that time?
61. A kid fires water horizontally from a squirt gun held 1.6 m above the ground. It hits another kid 2.1 m away square in the back, at a point 0.93 m above the ground. What was the initial speed of the water?
62. In a chase scene, a movie stuntman is supposed to run right off the flat roof of one city building and land on another roof 1.9 m lower. If the gap between the buildings is 4.5 m wide, how fast must he run?
63. Standing on the ground 3.0 m from the wall of a building, you want to throw a package from your 1.5-m shoulder level to someone in a second-floor window 4.2 m above the ground. At what speed and angle should you throw the package so it just barely reaches the window?
64. Derive a general formula for the horizontal distance covered by a projectile launched horizontally at speed v_0 from height h.
65. Compare the travel times for the projectiles launched at 30° and 60° in Fig. 3.19, both of which have the same starting and ending points.
66. You toss a chocolate bar to your hiking companion located 8.6 m up a 39° slope, as shown in Fig. 3.23. Determine the initial velocity vector so that the chocolate bar will reach your friend moving horizontally.

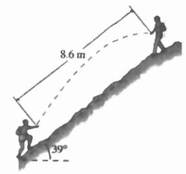


FIGURE 3.23 Problem 66

67. Prove that a projectile launched on level ground reaches its maximum height midway along its trajectory.
68. A projectile launched at an angle θ to the horizontal reaches a maximum height h. Show that its horizontal range is $4h/\tan\theta$.
69. A motorcyclist driving in a 60 km/h zone hits a stopped car on a level road. The cyclist is thrown from his bike and lands 39 m down the road. Was the cyclist speeding? To answer, find the minimum speed he could have been going just before the accident.
70. Show that, for a given initial speed, the horizontal range of a projectile is the same for launch angles $45°+\alpha$ and $45°-\alpha$, where α is between 0° and 45°.

3e/

4-41. 71. A basketball player is 15 ft horizontally from the center of the basket, which is 10 ft off the ground. At what angle should the player aim the ball if it is thrown from a height of 8.2 ft with a speed of 26 ft/s?

4-47. 72. A jet is diving vertically downward at 1200 km/h. If the pilot can withstand a maximum acceleration of $5g$ (i.e., 5 times Earth's gravitational acceleration) before losing consciousness, at what height must the plane start a quarter turn to pull out of the dive? Assume the speed remains constant.

4-55. 73. An alpine rescue team is using a slingshot to send an emergency medical packet to climbers stranded on a ledge, as shown in Fig. 3.24. What should be the launch speed from the slingshot?

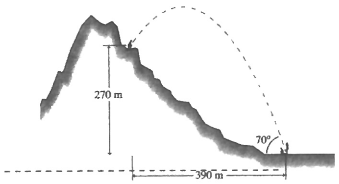


FIGURE 3.24 Problem 73

4-57. 74. If you can throw a stone straight up to a height of 16 m, how far could you throw it horizontally over level ground? Assume the same throwing speed and optimum launch angle.

4-58. 75. In a conversion from military to peacetime use, a missile with a maximum horizontal range of 180 km is being adapted for studying the upper atmosphere. What is the maximum altitude it can achieve if launched vertically?

4-59. 76. I can kick a soccer ball 28 m on level ground, giving it an initial velocity at 40° to the horizontal. At the same initial speed and angle to the horizontal, what horizontal distance can I kick the ball on a 15° upward slope?

4-71. 77. A diver leaves a 3-m board on a trajectory that takes her 2.5 m above the board and then into the water a horizontal distance of 2.8 m from the end of the board. At what speed and angle did she leave the board?

4-72. 78. In your calculus class, you may have learned that you can find the maximum or minimum of a function by differentiating and setting the result to zero. Do this for Equation 3.15, differentiating with respect to θ, and thus verify that the maximum range occurs for $\theta = 45°$.

4-75. 79. A well-engineered ski jump is less dangerous than it looks because skiers hit the ground with very small velocity components perpendicular to the ground. Skiers leave the Olympic ski jump in Lake Placid, New York, at 28 m/s at an angle of 9.5° below the horizontal. Their landing zone is a horizontal distance of 55 m from the end of the jump. The ground at that point is contoured so skiers' trajectories make an angle of only 3.0° with the ground on landing, as suggested in Fig. 3.25. What is the slope of the ground in the landing zone?

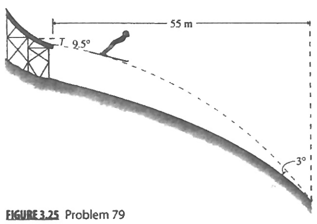


FIGURE 3.25 Problem 79

✓ 80. Differentiate the trajectory Equation 3.14 to find its slope, $\tan\theta = dy/dx$, and show that the slope is in the direction of the projectile's velocity, as given by Equations 3.10 and 3.11.

✓ 81. A projectile has horizontal range R and maximum height h. Find an expression for its initial speed.

✓ 82. (a) Show that the position of a particle on a circle of radius R with center at the origin $(x=0, y=0)$ is given in unit vectors by $\hat{r} = \cos\theta\hat{\imath} + \sin\theta\hat{\jmath}$, where θ is the angle of the position vector with the x axis. (b) If the particle moves with constant speed v and period T, starting on the x axis at $t=0$, find an expression for θ in terms of the time and T. (c) Differentiate the position vector twice with respect to time to find the acceleration, and show that it is the centripetal acceleration, whose magnitude is given by Equation 3.16 and whose direction is toward the center of the circle. (Note that the unit vectors $\hat{\imath}$ and $\hat{\jmath}$ are constants, independent of time.)

83. A friend is writing a science fiction screenplay about an asteroid on a collision course with Earth. Despite your admonitions about other films with the same plot, she asks you to calculate some numbers so her scenario will be correct. Astronauts will attach a rocket engine to the asteroid in an attempt to divert it. The asteroid is moving at 21 km/s. The rocket will provide an acceleration of 0.035 km/s^2 at a right angle to the original motion. This will change the direction of the asteroid's motion by 22.6° and displace it 5.36×10^3 km, enough to miss Earth and save civilization. Your friend asks you whether a rocket firing lasting 4 min will be enough to give these results. How do you advise her?

84. An archery coach at your college wishes to know the approximate speed with which arrows are fired. She tells you the archer fires an arrow horizontally from a height of 1.54 m. The arrow hits the ground 23 m downrange from the archer. Ignoring air resistance, what speed do you report to the coach?

85. Using your textbook as a guide to projectile motion, search the Internet for information on the range of baseballs and golf balls. What factors affect the range? The theoretical best launch angle for maximum range is 45°, but in reality this is not the case. What angle gives the greatest range for a baseball or a golf ball? Why is the potential range of a baseball greater in Denver than in Minneapolis?

Answers to Chapter Questions

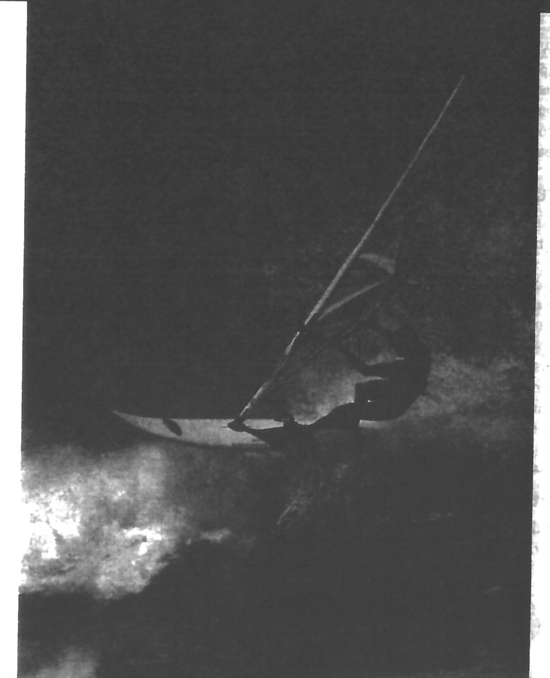
Answer to Chapter Opening Question

Assuming negligible air resistance, the penguin should leave the water at a 45° angle.

Answers to GOT IT? Questions

3.1 (c).
3.2 (d) only.
3.3 (c) gives the greatest change in speed; (b) gives the greatest change in direction.
3.4 $a_2 > a_3 > a_4 > a_1$.

4 Force and Motion



What forces govern the motion of the sailboard?

▶ To Learn

By the end of this chapter you should be able to

- Explain the concept of force and its role in causing *change* in motion (4.1).
- Describe the fundamental forces of physics (4.3).
- State Newton's three laws of motion (4.2, 4.6).
- Explain the force of gravity and the distinction between mass and weight (4.4).
- Apply Newton's laws to one-dimensional motion (4.5, 4.6).

◀ To Know

- Newton's laws relate force and acceleration. Therefore you need a solid understanding of acceleration, here based on the one-dimensional analysis of Chapter 2 (2.3).

An interplanetary spacecraft moves effortlessly, yet its engines shut down years ago. Why does it keep moving? A baseball heads toward the batter. The batter swings, and suddenly the ball is heading toward left field. Why did its motion change?

Questions about the "why" of motion are the subject of **dynamics**. Here we develop the basic laws that answer those questions. Isaac Newton first stated these laws more than 300 years ago, yet they remain a vital part of physics and engineering today, helping us guide spacecraft to distant planets, develop better cars, and manipulate the components of individual cells.

4.1 The Wrong Question

We began this chapter with two questions: one about why a spacecraft *moved* and the other about why a baseball's motion *changed*. For nearly 2000 years following the work of Aristotle (384–322 BCE), the first question—Why do things move?—was the crucial one.

For Thought and Discussion

1. Distinguish between the Aristotelian and Galilean/Newtonian view of the natural state of motion.
2. A ball bounces off a wall with the same speed it had before it hit the wall. Has its momentum changed? Has a force acted on the ball? Has a force acted on the wall? Relate your answers to Newton's laws of motion.
3. We often use the term "inertia" to describe human sluggishness. How is this usage related to the meaning of "inertia" in physics?
4. My high school physics teacher defined mass as "inverse pushability aroundness." Comment.
5. Does a body necessarily move in the direction of the net force acting on it?
6. A truck crashes into a stalled car. A student trying to explain the physics of this event claims that no forces are involved; the car was just "in the way" so it got hit. Comment.
7. A barefoot astronaut kicks a ball across the recreation area of a space station. Does the ball's apparent weightlessness mean the astronaut's toes don't get hurt? Explain.
8. The surface gravity of Jupiter's moon Io is one-fifth that of Earth. What would happen to your weight and to your mass if you were to travel to Io?
9. In paddling a canoe, you push water backward with your paddle. What force actually propels the canoe forward?
10. Is it possible for a nonzero net force to act on an object without the object's speed changing? Explain.
11. As your plane accelerates down the runway, you take your keys from your pocket and suspend them by a thread. Do they hang vertically? Explain.
12. I tell passengers in my car to buckle their seatbelts, explaining that I believe in the law of inertia. What's that got to do with seatbelts?

Exercises and Problems

Exercises

Section 4.2 Newton's First and Second Laws

13. A subway train has a mass of 1.5×10^6 kg. What force is required to accelerate the train at 2.5 m/s²?
14. A railroad locomotive with a mass of 6.1×10^4 kg can exert a force of 1.2×10^5 N. At what rate can it accelerate (a) by itself and (b) when pulling a 1.4×10^6-kg train?
15. A small plane starts down the runway with acceleration 7.2 m/s². If the force provided by its engine is 1.1×10^4 N, what is the plane's mass?
16. A car leaves the road traveling at 110 km/h and hits a tree, coming to a complete stop in 0.14 s. What average force does a seatbelt exert on a 60-kg passenger during this collision?
17. By how much does the force required to stop a car increase if the initial speed is doubled and the stopping distance remains the same?
18. A 3800-kg jet touches down at 240 km/h on the deck of an aircraft carrier and immediately deploys a parachute to slow itself down. If the plane comes to a stop in 170 m, what is the average force of air on the parachute? Assume the parachute provides essentially all the stopping force.
19. Starting from rest, a 940-kg racing car covers 400 m in 4.95 s. What is the average force acting on the car?
20. In an egg-dropping contest, a student encases an 85-g egg in a styrofoam block. If the force on the egg is not to exceed 1.5 N, and if the block hits the ground at 1.2 m/s, by how much must the styrofoam crush?
21. In a front-end collision, a 1300-kg car with shock-absorbing bumpers can withstand a maximum force of 65 kN before damage occurs. If the maximum speed for a nondamaging collision is 10 km/h, by how much must the bumper be able to move relative to the car?

Section 4.4 The Force of Gravity

22. Show that the units of acceleration can be written as N/kg. Why does it make sense to give g as 9.8 N/kg when talking about mass and weight?
23. My spaceship crashes on one of the Sun's nine planets. Fortunately, the ship's scales are intact and show that my weight is 532 N. If I know my mass is 60 kg, where am I? *Hint:* Consult Appendix E.
24. If I can barely lift a 35-kg concrete block on Earth, how massive a block can I lift on the Moon?
25. A cereal box says "net weight 340 grams." What is the actual weight (a) in SI units and (b) in ounces?
26. A bridge specifies a maximum load of 10 tons. What is the maximum mass, in kilograms, that the bridge can carry?
27. The gravitational acceleration at a typical space-shuttle altitude is about 93% of its surface value. What is the weight of a 68-kg astronaut in a shuttle at this altitude?

Section 4.5 Using Newton's Second Law

28. A 50-kg parachute jumper descends at a steady 40 km/h. What is the force of air on the parachute?
29. A 930-kg motorboat accelerates away from a dock at 2.3 m/s². Its propeller provides a thrust force of 3.9 kN. What drag force is exerted by the water on the boat?
30. An elevator accelerates downward at 2.4 m/s². What force does the floor of the elevator exert on a 52-kg passenger?
31. What is the vertical lifting force on a 747 jetliner when the plane is (a) flying at constant altitude and (b) accelerating upward at 1.1 m/s²? The aircraft's mass is 4.5×10^5 kg.
32. At liftoff, a space shuttle with 2.0×10^6-kg total mass undergoes an upward acceleration of $0.60g$. (a) What is the total thrust force developed by its engines? (b) What force does the seat exert on a 60-kg astronaut during liftoff?
33. You step into an elevator, and it accelerates to a downward speed of 9.2 m/s in 2.1 s. How does your apparent weight during this acceleration time compare with your actual weight?

Section 4.6 Newton's Third Law

34. What upward gravitational force does a 5600-kg elephant exert on Earth?
35. I have a mass of 65 kg. If I jump off a 120-cm-high table, how far toward me does Earth move during the time I fall?
36. What force is necessary to stretch a spring 48 cm, if the spring constant is 270 N/m?
37. A 35-N force is applied to a spring with spring constant $k = 220$ N/m. How much does the spring stretch?
38. A spring with spring constant $k = 340$ N/m is used to weigh a 6.7-kg fish. How far does the spring stretch?

Problems

39. A 1.25-kg object is moving in the x direction at 17.4 m/s. Just 3.41 s later, it is moving at 26.8 m/s at 34.0° to the x axis. What are the magnitude and direction of the force applied during this time?
40. An airplane encounters sudden turbulence, and you feel momentarily lighter. If your apparent weight seems to be about 70% of your normal weight, what are the magnitude and direction of the plane's acceleration?
41. A 74-kg tree surgeon rides a "cherry picker" lift to reach the upper branches of a tree. What force does the bucket of the lift exert on the surgeon when the bucket is (a) at rest; (b) moving upward at a steady 2.4 m/s; (c) moving downward at a steady 2.4 m/s; (d) accelerating upward at 1.7 m/s²; (e) accelerating downward at 1.7 m/s²?
42. A ballet dancer executes a vertical jump during which the floor pushes up on his feet with a force 50% greater than his weight. What is his upward acceleration?
43. An elevator moves upward at 5.2 m/s. What is the minimum stopping time it can have if the passengers are to remain on the floor?
44. A 2.50-kg object is moving along the x axis at 1.60 m/s. As it passes the origin, two forces $\vec{F}_1$ and $\vec{F}_2$ are applied, both in the y direction (plus or minus); $\vec{F}_1 = 15\hat{j}$ N. The forces are applied for 3.00 s, after which the object is at the point $x = 4.80$ m, $y = 10.8$ m. Find $\vec{F}_2$.
45. Blocks of 1.0, 2.0, and 3.0 kg are lined up on a table, as shown in Fig. 4.21. A rightward-pointing 12-N force is applied to the leftmost block. What force does the middle block exert on the rightmost one?

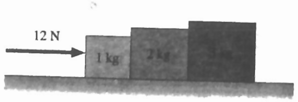


FIGURE 4.21 Problem 45

46. A child pulls an 11-kg wagon with a horizontal handle whose mass is 1.8 kg, giving the wagon and handle an acceleration of 2.3 m/s². (a) The tension at each end of the handle is different. Why? (b) Find the tension at each end of the handle.
47. A 2200-kg airplane is pulling two gliders, the first of mass 310 kg and the second of mass 260 kg, down the runway with an acceleration of 1.9 m/s² (Fig. 4.22). Neglecting the mass of the two ropes and any frictional forces, determine (a) the horizontal thrust of the plane's propeller; (b) the tension force in the first rope; (c) the tension force in the second rope; and (d) the net force on the first glider.

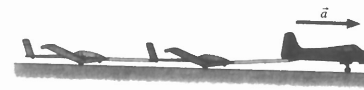


FIGURE 4.22 Problem 47

48. In a tractor pulling contest, a 2300-kg tractor pulls a 4900-kg sledge with an acceleration of 0.61 m/s². If the tractor exerts a horizontal force of 7700 N on the ground, determine the magnitudes of (a) the force of the tractor on the sledge; (b) the force of the sledge on the tractor; and (c) the frictional force exerted on the sledge by the ground.
49. A biologist is studying the growth of rats in an orbiting space station. To determine a rat's mass, she puts it in a 320-g cage, attaches a spring scale, and pulls so that the scale reads 0.46 N. If the resulting acceleration of the rat and cage is 0.40 m/s², what is the rat's mass?
50. An elastic tow rope has a spring constant of 1300 N/m. It is connected between a truck and a 1900-kg car. As the truck tows the car, the rope stretches 55 cm. Starting from rest, how far do the truck and the car move in 1 min? Assume the car experiences negligible friction.
51. A 2.0-kg mass and a 3.0-kg mass are on a horizontal frictionless surface, connected by a massless spring with spring constant $k = 140$ N/m. A 15-N force is applied to the larger mass, as shown in Fig. 4.23. How much does the spring stretch from its equilibrium length?

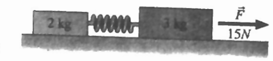


FIGURE 4.23 Problem 51

52. Two large crates, with masses 640 kg and 490 kg, are connected by a stiff, massless spring ($k = 8.1$ kN/m) and propelled along an essentially frictionless, level factory floor by a force applied horizontally to the more massive crate. If the spring compresses 5.1 cm from its equilibrium length, what is the applied force?
53. What downward force is exerted on the air by the blades of a 4300-kg helicopter when it is (a) hovering at constant altitude; (b) dropping at 21 m/s with speed decreasing at 3.2 m/s²; (c) rising at 17 m/s with speed increasing at 3.2 m/s²; (d) rising at a steady 15 m/s; (e) rising at 15 m/s with speed decreasing at 3.2 m/s²?
54. What engine thrust (force) is needed to accelerate a rocket of mass m (a) downward at $1.40g$ near Earth's surface; (b) upward at $1.40g$ near Earth's surface; (c) at $1.40g$ in interstellar space far from any star or planet?
55. An elevator cable can withstand a maximum tension of 19,500 N before breaking. The elevator has a mass of 490 kg and a maximum acceleration of 2.24 m/s². Engineering safety standards require that the cable tension never exceed two-thirds of the breaking tension. How many 65-kg people can the elevator safely accommodate?
56. An F-14 jet fighter has a mass of 1.6×10^4 kg and an engine thrust of 2.7×10^5 N. A 747 jumbo jet has a mass of 3.6×10^5 kg and a total engine thrust of 7.7×10^5 N. Is it possible for either plane to climb vertically with no lift from its wings? If so, what vertical acceleration could it achieve?
57. Two springs have the same unstretched length but different spring constants, k_1 and k_2. (a) If they are connected side by side and stretched a distance x, as shown in Fig. 4.24a, show that the force exerted by the combination is $(k_1 + k_2)x$. (b) If they are connected end to end and the combination is stretched a distance x (Fig. 4.24b), show that they exert a force $k_1k_2x/(k_1 + k_2)$.

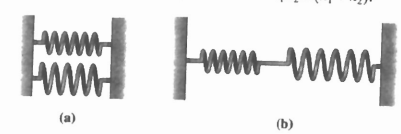


FIGURE 4.24 Problem 57

58. Although we usually write Newton's second law for one-dimensional motion in the form $F = ma$, the most basic version of the law is $F = \frac{d(mv)}{dt}$. The simpler form holds only when the

mass is constant. Consider an object whose mass may be changing, and show that the rule for the derivative of a product (see Appendix A) can be used to write Newton's law in the form

$$F = ma + v\frac{dm}{dt}.$$

59. A railroad car is being pulled beneath a grain elevator that dumps grain at the rate of 450 kg/s. Use the result of Problem 58 to find the force that must be applied to keep the car moving at a constant 2.0 m/s.

60. A block 20% more massive than you hangs from a rope. The other end of the rope goes over a massless, frictionless pulley, and dangles freely. With what acceleration must you climb the rope to keep the block from falling?

61. A crane lifts a 1200-kg bucket of concrete at a construction site, giving it an initial acceleration of 2.6 m/s^2 upward. Find the tension in the cable supporting the bucket.

62. Your airplane is caught in a brief, violent downdraft. To your amazement, the pretzels on your seatback tray rise vertically, and you estimate their upward acceleration relative to the plane at 2 m/s^2. What's the downward acceleration of the plane?

63. Airport runways are generally designed with a buffer zone around 300 m long beyond the runway end, to accommodate aircraft that land too fast or too far down the runway and go off the end. Where that's not possible, airports are increasingly installing so-called Engineered Material Arresting Systems (EMAS) to prevent runaway aircraft from entering nearby roads, neighborhoods, or waterways. One such system, at New York's JFK airport, consists of a 132-m-long bed of crushable cement blocks. What average force must this system exert on a 55-Mg jetliner that enters the arrestor bed at 36 m/s if the jet is to stop 120 m into the bed?

64. Two masses are joined together by a massless, inextensible string. A vertical force of 30 N applied to the upper mass gives the system a constant upward acceleration of 3.2 m/s^2. If the tension in the connecting string is 18 N, what are the two masses?

65. A 65-kg person stands on a scale in a moving elevator while holding a 5-kg mass suspended from a massless spring with spring constant 1.08 kN/m. None of the objects in the elevator is moving relative to the elevator, but the spring is stretched by 5 cm. (a) Is the elevator accelerating, and if so, what are the magnitude and direction of its acceleration? (b) What is the reading of the scale on which the person stands?

66. A block of mass M hangs from a uniform rope of length L and mass m. Find an expression for the tension in the rope as a function of the distance y measured vertically downward from the top of the rope.

67. In Einstein's special theory of relativity, the momentum of a particle is given by $p = mu/\sqrt{1 - u^2/c^2}$, where the mass m and speed of light c are constants and u is the particle's speed. For such a particle moving in one dimension along a straight line, Equation 4.3 no longer applies. How does the general form of Newton's second law, Equation 4.2, relate the net force in the direction of motion to the acceleration, $a = du/dt$?

68. Your science fiction–writing friend is working on a screenplay concerning a civilization that lives on a neutron star (10 km in diameter and extremely massive). Your friend decided the people would have an average mass of 75 kg but does not know how much they should weigh in pounds. An astrophysics book tells you the acceleration due to gravity on a typical neutron star is 5.73×10^{12} m/s^2. What is the weight of the inhabitants of this strange world?

69. You read about a car accident in the newspaper. A car traveling at 70 km/h collided with a concrete bridge support. The front end of the car was compressed 0.94 m, and the car came to a complete stop within this distance. You wonder, How many "g's" of acceleration did the occupant of the car experience? *Hint.* The "g's" of acceleration are the ratio of the acceleration to 9.8 m/s^2.

70. You and your lab partner devise a clever experiment to measure the force applied to a ball when it is thrown. You throw a 200-g ball vertically upward. A high-speed video image of the throw indicates your hand pushed on the ball for 0.32 s. The ball rises to a maximum height of 7.23 m above your hand. What force did you apply?

Answers to Chapter Questions

Answer to Chapter Opening Question

The human body exerts a contact force; wind and water are fluids that exert pressure forces, and gravity is an action-at-a-distance force between Earth and the sailboard.

Answers to GOT IT? Questions

4.1 (b).
4.2 No. Look at Fig. 4.5b.
4.3 All would move in straight lines.
4.4 (a) greater; (b) less; (c) less; (d) greater; (e) equal.
4.5 (c) less than 2 N
4.6 (a) No, the acceleration is still 0; (b) no, the direction of velocity is irrelevant (this situation would occur if the helicopter were moving downward but slowing).

5 Using Newton's Laws

Why doesn't the roller coaster fall off its loop-the-loop track?

► To Learn

By the end of this chapter you should be able to

- Use Newton's second law to solve problems involving the motion of a single object in two dimensions under the influence of multiple forces (5.1).
- Solve Newton's law problems involving multiple objects (5.2).
- Explain that circular motion is just a special case of Newton's second law, and solve circular-motion problems involving multiple forces (5.3).
- Describe the force of friction, both static and kinetic, and solve Newton's law problems in which one of the forces is friction (5.4).
- Explain drag forces qualitatively (5.5).

◄ To Know

- You first met Newton's laws in Chapter 4, and you should be familiar with all three of them (4.2).
- This chapter builds especially on applications of Newton's second law, now generalizing to the case where the forces acting on an object no longer lie along a line (4.5).

Chapter 4 introduced Newton's three laws of motion and used them in one-dimensional applications. Now we apply Newton's laws in two dimensions. This material is at the heart of Newtonian physics, from textbook problems to systems that guide spacecraft to distant planets. The chapter consists largely of examples, to help you learn to apply Newton's laws and also to appreciate their wide range of applicability. We also introduce frictional forces and elaborate on circular motion. As you study the diverse examples, keep in mind that they all follow from the underlying principles embodied in Newton's laws.

5.1 Using Newton's Second Law

Newton's second law, $\vec{F}_{net} = m\vec{a}$, is the cornerstone of mechanics. We can use it to develop faster skis, engineer skyscrapers, design safer roads, compute a rocket's thrust, and solve myriad other practical problems.

We'll work Example 5.1 in great detail, applying Problem Solving Strategy 4.1. Follow this example closely, and try to understand how our strategy is grounded in Newton's basic statement that the net force on an object determines that object's acceleration.