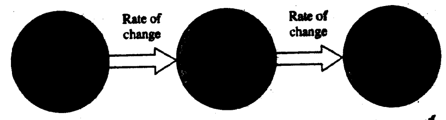
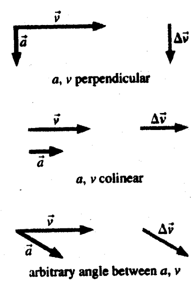
CHAPTER 3

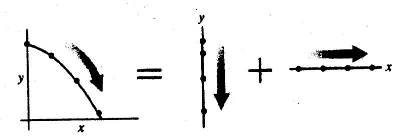
Quantities characterizing motion in two and three dimensions have both **magnitude** and **direction** and are described by **vectors**. Position, velocity, and acceleration are all vector quantities, related as they are in one dimension:



These vector quantities need not have the same direction. In particular, acceleration that's perpendicular to velocity changes the direction but not the magnitude of the velocity. Acceleration that's colinear changes only the magnitude of the velocity. In general, both change.



Components of motion in two perpendicular directions are independent. This reduces problems in two and three dimensions to sets of one-dimensional problems that can be solved with the methods of Chapter 2.



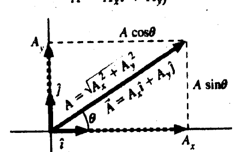
Vectors can be described by magnitude and direction or by components. In two dimensions these representations are related by

$$A = \sqrt{A_x^2 + A_y^2} \quad \text{and} \quad \theta = \tan^{-1}\frac{A_y}{A_x}$$

$$A_x = A\cos\theta \quad \text{and} \quad A_y = A\sin\theta$$

A compact way to express vectors involves unit vectors that have magnitude 1, have no units, and point along the coordinate axes:

$$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath}$$



Velocity is the rate of change of the position vector $\vec{r}$:

$$\vec{v} = \frac{d\vec{r}}{dt}$$

Acceleration is the rate of change of velocity:

$$\vec{a} = \frac{d\vec{v}}{dt}$$

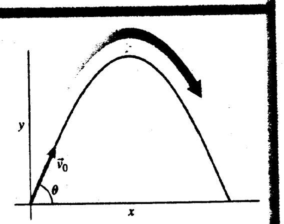
When acceleration is constant, motion is described by vector equations that generalize the one-dimensional equations of Chapter 2:

$$\vec{v} = \vec{v}_0 + \vec{a}t \qquad \vec{r} = \vec{r}_0 + \vec{v}_0t + \tfrac{1}{2}\vec{a}t^2$$

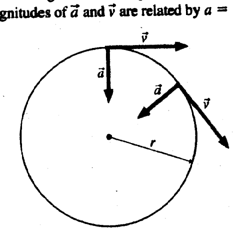
An important application of constant-acceleration motion in two dimensions is **projectile motion** under the influence of gravity.

Projectile trajectory:

$$y = x\tan\theta_0 - \frac{g}{2v_0^2\cos^2\theta_0}x^2$$



In **uniform circular motion** the magnitudes of velocity and acceleration remain constant, but their directions continually change. For an object moving in a circular path of radius r, the magnitudes of $\vec{a}$ and $\vec{v}$ are related by $a = v^2/r$.



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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? How about two vectors of unequal magnitude?
3. Repeat Question 2 for three vectors.
4. Can an object have a southward acceleration while moving northward? A westward acceleration while moving northward?
5. You're a passenger in a car rounding a curve. The driver claims the car isn't accelerating because the speedometer reading is unchanging. Explain why the driver is wrong.
6. In what sense is Equation 3.8 really two (or three) equations?
7. Is a projectile's speed constant throughout its parabolic trajectory?
8. Is there any point on a projectile's trajectory where velocity and acceleration are perpendicular?
9. How is it possible for an object to be moving in one direction but accelerating in another?
10. You're in a bus moving with constant velocity on a level road when you throw a ball straight up. When the ball returns, does it land ahead of you, behind you, or back at your hand? Explain.

Exercises and Problems

Exercises

Section 3.1 Vectors

11. You walk west 220 m, then north 150 m. What are the magnitude and direction of your displacement vector?
12. An ion in a mass spectrometer follows a semicircular path of radius 15.2 cm. What are (a) the distance it travels and (b) the magnitude of its displacement?
13. A migrating whale follows the west coast of Mexico and North America toward its summer home in Alaska. It first travels 360 km 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.
14. 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 vector $\vec{C}$ such that $\vec{A} + \vec{B} + \vec{C} = \vec{0}$.
15. Use unit vectors to express a displacement of 120 km at 29° counterclockwise from the x-axis.
16. Find the magnitude of the vector $34\hat{\imath} + 13\hat{\jmath}$ m and determine its angle to the x-axis.
17. (a) What's the magnitude of $\hat{\imath} + \hat{\jmath}$? (b) What angle does it make with the x-axis?

Section 3.2 Velocity and Acceleration Vectors

18. You're heading an international effort to save Earth from an asteroid heading toward us at 15 km/s. Your team mounts a rocket on the asteroid and fires it for 10 min, after which the asteroid is moving at 19 km/s at 28° to its original path. In a news conference, what do you report for the acceleration imparted to the asteroid?
19. An object is moving at 18 m/s at 220° counterclockwise from the x-axis. Find the x- and y-components of its velocity.
20. A car drives north at 40 mi/h for 10 min, then turns east and goes 5.0 mi at 60 mi/h. Finally, it goes southwest at 30 mi/h for 6.0 min. Determine the car's (a) displacement and (b) average velocity for this trip.
21. An object's velocity is $\vec{v} = ct^3\hat{\imath} + d\hat{\jmath}$, where t is time and c and d are positive constants with appropriate units. What's the direction of the object's acceleration?
22. A car, initially going eastward, rounds a 90° curve and ends up heading southward. If the speedometer reading remains constant, what's the direction of the car's average acceleration vector?
23. 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 noon to 6 PM? Use unit vector notation, with the x-axis pointing toward 3 and the y-axis toward noon.
24. An ice skater is gliding along at 2.4 m/s, when she undergoes an acceleration of magnitude 1.1 m/s² for 3.0 s. After that she's moving at 5.7 m/s. Find the angle between her acceleration vector and her initial velocity.
25. An object is moving in the x-direction at 1.3 m/s when it undergoes an acceleration $\vec{a} = 0.52\hat{\jmath}$ m/s². Find its velocity vector after 4.4 s.

Section 3.3 Relative Motion

26. You're a pilot beginning a 1500-km flight. Your plane's speed is 1000 km/h, and air traffic control says you'll have to head 15° west of south to maintain a southward course. If the flight takes 100 min, what's the wind velocity?
27. 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) What direction should you head? (b) How long will it take you to cross the river?
28. A plane with airspeed 370 km/h flies perpendicularly across the jet stream, its nose pointed into the jet stream at 32° from the perpendicular direction of its flight. Find the speed of the jet stream.
29. 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, what direction should they head?

Section 3.4 Constant Acceleration

30. The position of an object as a function of time is $\vec{r} = (3.2t + 1.8t^2)\hat{\imath} + (1.7t - 2.4t^2)\hat{\jmath}$ m, with t in seconds. Find the object's acceleration vector.
31. You're sailboarding at 6.5 m/s when a wind gust hits, lasting 6.3 s accelerating your board at 0.48 m/s² at 35° to your original direction. Find the magnitude and direction of your displacement during the gust.

Section 3.5 Projectile Motion

32. 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?
33. A carpenter tosses a shingle horizontally off an 8.8-m-high roof at 11 m/s. (a) How long does it take the shingle to reach the ground? (b) How far does it move horizontally?
34. An arrow fired horizontally at 41 m/s travels 23 m horizontally. From what height was it fired?
35. 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?
36. Protons drop 1.2 μm over the 1.7-km length of a particle accelerator. What's their approximate average speed?
37. If you can hit a golf ball 180 m on Earth, how far can you hit it on the Moon? (Your answer will be an underestimate because it neglects air resistance on Earth.)

Section 3.6 Uniform Circular Motion

38. How fast would a car have to round a 75-m-radius turn for its acceleration to be numerically equal to that of gravity?
39. Estimate the acceleration of the Moon, which completes a nearly circular orbit of 385,000 km radius in 27 days.

40. Global Positioning System (GPS) satellites circle Earth at altitudes of approximately 20,000 km, where the gravitational acceleration has 5.8% of its surface value. To the nearest hour, what's the orbital period of the GPS satellites?

Problems

41. Two vectors $\vec{A}$ and $\vec{B}$ have the same magnitude A and are at right angles. Find the magnitudes of (a) $\vec{A} + 2\vec{B}$ and (b) $3\vec{A} - \vec{B}$.
42. Vector $\vec{A}$ has magnitude 1.0 m and points 35° clockwise from the x-axis. Vector $\vec{B}$ has magnitude 1.8 m. Find the direction of $\vec{B}$ such that $\vec{A} + \vec{B}$ is in the y-direction.
43. Let $\vec{A} = 15\hat{\imath} - 40\hat{\jmath}$ and $\vec{B} = 31\hat{\jmath} + 18\hat{k}$. Find $\vec{C}$ such that $\vec{A} + \vec{B} + \vec{C} = \vec{0}$.
44. BIO A biologist looking through a microscope sees a bacterium at $\vec{r}_1 = 2.2\hat{\imath} + 3.7\hat{\jmath} - 1.2\hat{k}$ μm. After 6.2 s, it's at $\vec{r}_2 = 4.6\hat{\imath} + 1.9\hat{k}$ μm. Find (a) its average velocity, expressed in unit vectors, and (b) its average speed.
45. A particle's position is $\vec{r} = (ct^2 - 2dt^3)\hat{\imath} + (2ct^2 - dt^3)\hat{\jmath}$, where c and d are positive constants. Find expressions for times $t > 0$ when the particle is moving in (a) the x-direction and (b) the y-direction.
46. For the particle in Problem 45, is there any time $t > 0$ when the particle is (a) at rest and (b) accelerating in the x-direction? If either answer is "yes," find the time(s).
47. Attempting to stop on a slippery road, a car moving at 80 km/h skids at 30° to its initial motion, stopping in 3.9 s. Determine the average acceleration in m/s², in coordinates with the x-axis in the direction of the original motion and the y-axis toward the side to which the car skids.
48. An object undergoes acceleration $2.3\hat{\imath} + 3.6\hat{\jmath}$ m/s² for 10 s. 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?
49. The Singapore Flyer is the world's largest Ferris wheel. Its diameter is 150 m and it rotates once every 30 min. Find the magnitudes of (a) the average velocity and (b) the average acceleration at the wheel's rim, over a 5.0-min interval.
50. A ferryboat sails between towns directly opposite each other on a river, moving at speed v' relative to the water. (a) Find an expression for the angle it should head at if the river flows at speed V. (b) What's the significance of your answer if $V > v'$?
51. The sum of two vectors, $\vec{A} + \vec{B}$, is perpendicular to their difference, $\vec{A} - \vec{B}$. How do the vectors' magnitudes compare?
52. Write an expression for a unit vector at 45° clockwise from the x-axis.
53. An object is initially moving in the x-direction at 4.5 m/s, when it undergoes an acceleration 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's the magnitude of its acceleration?
54. A particle leaves the origin with initial velocity $\vec{v}_0 = 11\hat{\imath} + 14\hat{\jmath}$ m/s, undergoing constant acceleration $\vec{a} = -1.2\hat{\imath} + 0.26\hat{\jmath}$ m/s². (a) When does the particle cross the y-axis? (b) What's its y-coordinate at the time? (c) How fast is it moving, and in what direction?
55. A kid fires a squirt gun horizontally from 1.6 m above the ground. It hits another kid 2.1 m away square in the back, 0.93 m above the ground. What was the water's initial speed?
56. A projectile has horizontal range R on level ground and reaches maximum height h. Find an expression for its initial speed.
57. You throw a baseball at a 45° angle to the horizontal, aiming at a friend who's sitting in a tree a distance h above level ground. At the instant you throw your ball, your friend drops another ball. (a) Show that the two balls will collide, no matter what your ball's initial speed, provided it's greater than some minimum value. (b) Find an expression for that minimum speed.
58. In a chase scene, a movie stuntman runs horizontally off the flat roof of one building and lands on another roof 1.9 m lower. If the gap between the buildings is 4.5 m wide, how fast must he run to cross the gap?
59. Standing on the ground 3.0 m from a building, you want to throw a package from your 1.5-m shoulder level to someone in a window 4.2 m above the ground. At what speed and angle should you throw the package so it just barely clears the windowsill?
60. Derive a general formula for the horizontal distance covered by a projectile launched horizontally at speed v_0 from height h.
61. Consider two projectiles launched on level ground with the same speed, at angles 45° ± α. Show that the ratio of their flight times is tan(α + 45°).
62. You toss a protein 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 the bar reaches your friend moving horizontally.

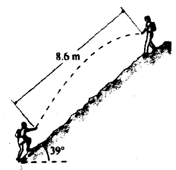


FIGURE 3.23 Problem 62

63. Prove that a projectile launched on level ground reaches maximum height midway along its trajectory.
64. A projectile launched at angle θ to the horizontal reaches maximum height h. Show that its horizontal range is $4h/\tan\theta$.
65. As an expert witness, you're testifying in a case involving a motorcycle accident. A motorcyclist driving in a 60-km/h zone hit a stopped car on a level road. The motorcyclist was thrown from his bike and landed 39 m down the road. You're asked whether he was speeding. What's your answer?
66. Show that, for a given initial speed, the horizontal range of a projectile is the same for launch angles 45° + α and 45° − α.
67. 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 from a height of 8.2 ft with a speed of 26 ft/s?
68. Two projectiles are launched simultaneously from the same point, with different launch speeds and angles. Show that no combination of speeds and angles will permit them to land simultaneously and at the same point.
69. 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.
70. Your 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; your job is to calculate the launch speed. What do you report?

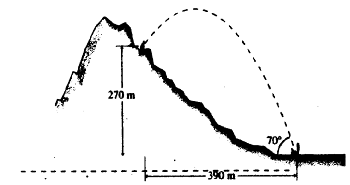


FIGURE 3.24 Problem 70

71. If you can throw a stone straight up to height h, what's the maximum horizontal distance you could throw it over level ground?
72. In a conversion from military to peacetime use, a missile with maximum horizontal range 180 km is being adapted for studying Earth's upper atmosphere. What is the maximum altitude it can achieve if launched vertically?
73. A soccer player can kick the ball 28 m on level ground, with its initial velocity at 40° to the horizontal. At the same initial speed and angle to the horizontal, what horizontal distance can the player kick the ball on a 15° upward slope?
74. A diver leaves a 3-m board on a trajectory that takes her 2.5 m above the board and then into the water 2.8 m horizontally from the end of the board. At what speed and angle did she leave the board?
75. Using calculus, you can find a function's maximum or minimum 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 θ = 45°.
76. You're a consulting engineer specializing in athletic facilities, and you've been asked to help design the Olympic ski jump pictured in Fig. 3.25. Skiers will leave the jump at 28 m/s and 9.5° below the horizontal, and land 55 m horizontally from the end of the jump. Your job is to specify the slope of the ground so skiers' trajectories make an angle of only 3.0° with the ground on landing, ensuring their safety. What slope do you specify?

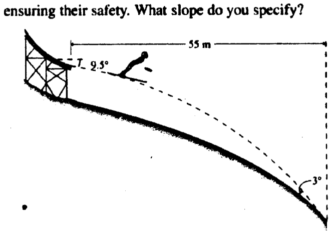


FIGURE 3.25 Problem 76

77. 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.
78. Your medieval history class is constructing a trebuchet, a catapult-like weapon for hurling stones at enemy castles. The plan is to launch stones off a 75-m-high cliff, with initial speed 36 m/s. Some members of the class think a 45° launch angle will give the maximum range, but others claim the cliff height makes a difference. What do you give for the angle that will maximize the range?
79. Generalize Problem 78 to find an expression for the angle that will maximize the range of a projectile launched with speed v_0 from height h above level ground.
80. (a) Show that the position of a particle on a circle of radius R with its center at the origin is $\vec{r} = R(\cos\theta\hat{\imath} + \sin\theta\hat{\jmath})$, where θ is the angle the position vector makes with the x-axis. (b) If the particle moves with constant speed v starting on the x-axis at $t = 0$, find an expression for θ in terms of time t and the period T to complete a full circle. (c) Differentiate the position vector twice with respect to time to find the acceleration, and show that its magnitude is given by Equation 3.16 and its direction is toward the center of the circle.

Passage Problems

Alice (A), Bob (B), and Carrie (C) all start from their dorm and head for the library for an evening study session. Alice takes a straight path, while the paths Bob and Carrie follow are portions of circular arcs, as shown in Fig. 3.26. Each student walks at a constant speed. All three leave the dorm at the same time, and they arrive simultaneously at the library.

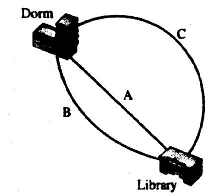


FIGURE 3.26 Passage Problems 81–84

81. Which statement characterizes the distances the students travel?
    a. They're equal.
    b. C > A > B
    c. C > B > A
    d. B > C > A
82. Which statement characterizes the students' displacements?
    a. They're equal.
    b. C > A > B
    c. C > B > A
    d. B > C > A
83. Which statement characterizes their average speeds?
    a. They're equal.
    b. C > A > B
    c. C > B > A
    d. B > C > A
84. Which statement characterizes their accelerations while walking (not starting and stopping)?
    a. They're equal.
    b. None accelerates.
    c. A > B > C
    d. C > B > A
    e. B > C > A
    f. There's not enough information to decide.

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.

CHAPTER 4

Big Picture

The big idea of this chapter—and of all Newtonian mechanics—is that **force** causes *change* in motion, not motion itself. Uniform motion—straight line, constant speed—needs no cause or explanation. Any deviation, in speed or direction, requires a **net force**. This idea is the essence of Newton's first and second laws. Combined with Newton's third law, these laws provide a consistent description of motion.

Newton's First Law
A body in uniform motion remains in uniform motion, and a body at rest remains at rest, unless acted on by a nonzero net force.
This law is implicit in Newton's second law.

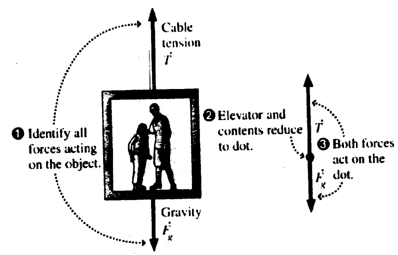
Newton's Second Law
The rate at which a body's momentum changes is equal to the net force acting on the body.
Here **momentum** is the "quantity of motion," the product of mass and velocity.

Newton's Third Law
If object A exerts a force on object B, then object B exerts an oppositely directed force of equal magnitude on A.
Newton's third law says that forces come in pairs.

Solving Problems with Newton's Laws

INTERPRET Interpret the problem to be sure that you know what it's asking and that Newton's second law is the relevant concept. Identify the object of interest and all the individual **interaction forces** acting on it.

DEVELOP Draw a **free-body diagram** as described in Tactics 4.1. Develop your solution plan by writing Newton's second law, $\vec{F}_{net} = m\vec{a}$, with $\vec{F}_{net}$ expressed as the sum of the forces you've identified. Then choose a coordinate system so you can express Newton's law in components.



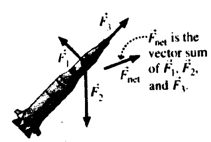
EVALUATE At this point the physics is done, and you're ready to execute your plan by solving Newton's second law and evaluating the numerical answer(s), if called for. Remember that even in the one-dimensional problems of this chapter, Newton's law is a vector equation; that will help you get the signs right. You need to write the components of Newton's law in the coordinate system you chose, and then solve the resulting equation(s) for the quantity(ies) of interest.

ASSESS Assess your solution to see that it makes sense. Are the numbers reasonable? Do the units work out correctly? What happens in special cases—for example, when a mass, a force, an acceleration, or an angle gets very small or very large?

Key Concepts and Equations

Mathematically, Newton's second law is $\vec{F}_{net} = d\vec{p}/dt$, where $\vec{p} = m\vec{v}$ is an object's momentum, and $\vec{F}_{net}$ is the sum of all the individual forces acting on the object. When an object has constant mass, the second law takes the familiar form

$$\vec{F}_{net} = m\vec{a} \quad \text{(Newton's second law)}$$



Newton's second law is a *vector* equation. To use it correctly, you must write the components of the equation in a chosen coordinate system. In one-dimensional problems the result is a single equation.

Applications

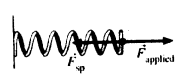
The force of gravity on an object is its **weight**. Since all objects at a given location experience the same gravitational acceleration, weight is proportional to mass:

$$\vec{w} = m\vec{g} \quad \text{(weight on Earth)}$$

In an accelerated reference frame, an object's **apparent weight** differs from its actual weight; in particular, an object in free fall experiences **apparent weightlessness**.

Springs are convenient force-measuring devices, stretching or compressing in response to the applied force. For an ideal spring, the stretch or compression is directly proportional to the force:

$$F_{sp} = -kx \quad \text{(Hooke's law)}$$



where k is the **spring constant**, with units of N/m.

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For Thought and Discussion

1. Distinguish the Aristotelian and Galilean/Newtonian views 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. Does a body necessarily move in the direction of the net force acting on it?
5. 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.
6. A barefoot astronaut kicks a ball, hard, across a space station. Does the ball's apparent weightlessness mean the astronaut's toes don't hurt? Explain.
7. The surface gravity on Jupiter's moon Io is one-fifth that on Earth. What would happen to your weight and to your mass if you were on Io?
8. In paddling a canoe, you push water backward with your paddle. What force actually propels the canoe forward?
9. Is it possible for a nonzero net force to act on an object without the object's speed changing? Explain.
10. 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.
11. A driver tells passengers to buckle their seatbelts, invoking 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

12. A subway train's mass is 1.5×10^6 kg. What force is required to accelerate the train at 2.5 m/s²?
13. A 61-Mg railroad locomotive can exert a 0.12-MN force. At what rate can it accelerate (a) by itself and (b) when pulling a 1.4-Gg train?
14. A small plane accelerates down the runway at 7.2 m/s². If its propeller provides an 11-kN force, what's the plane's mass?
15. A car leaves the road traveling at 110 km/h and hits a tree, coming to a stop in 0.14 s. What average force does a seatbelt exert on a 60-kg passenger during this collision?
16. By how much does the force required to stop a car increase if the initial speed is doubled while the stopping distance remains the same?
17. **BIO** Kinesin is a "motor protein" responsible for moving materials within living cells. If it exerts a 6.0-pN force, what acceleration will it give a molecular complex with mass 3.0×10^{-18} kg?
18. Starting from rest, a 940-kg racing car covers 400 m in 4.95 s. Find the average force on the car.
19. In an egg-dropping contest, a student encases an 85-g egg in a Styrofoam block. If the force on the egg can't exceed 1.5 N, and if the block hits the ground at 1.2 m/s, by how much must the Styrofoam compress on impact?
20. 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

21. 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?
22. Your spaceship crashes on one of the Sun's planets. Fortunately, the ship's scales are intact and show that your weight is 532 N. If your mass is 60 kg, where are you? (*Hint:* Consult Appendix E.)
23. Your friend can barely lift a 35-kg concrete block on Earth. How massive a block could she lift on the Moon?
24. A cereal box says "net weight 340 grams." What's the actual weight (a) in SI units and (b) in ounces?
25. You're a safety engineer for a bridge spanning the U.S.-Canadian border. U.S. specifications permit a maximum load of 10 tons. What load limit should you specify on the Canadian side, where "weight" is given in kilograms?
26. The gravitational acceleration at the International Space Station's altitude is about 89% of its surface value. What's the weight of a 68-kg astronaut at this altitude?

Section 4.5 Using Newton's Second Law

27. A 50-kg parachutist descends at a steady 40 km/h. What force does air exert on the parachute?
28. A 930-kg motorboat accelerates away from a dock at 2.3 m/s². Its propeller provides a 3.9-kN thrust force. What drag force does the water exert on the boat?
29. An elevator accelerates downward at 2.4 m/s². What force does the elevator's floor exert on a 52-kg passenger?
30. At 560 metric tons, the Airbus A-380 is the world's largest airliner. What's the upward force on an A-380 when the plane is (a) flying at constant altitude and (b) accelerating upward at 1.1 m/s²?
31. You're an engineer working on Ares I, NASA's replacement for the space shuttles. Performance specs call for a first-stage rocket capable of accelerating a total mass of 630 Mg vertically from rest to 7200 km/h in 2.0 min. You're asked to determine the required engine thrust (force) and the force exerted on a 75-kg astronaut during liftoff. What do you report?
32. 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 time compare with your actual weight?

Section 4.6 Newton's Third Law

33. What upward gravitational force does a 5600-kg elephant exert on Earth?
34. Your friend's mass is 65 kg. If she jumps off a 120-cm-high table, how far does Earth move toward her as she falls?
35. What force is necessary to stretch a spring 48 cm, if its spring constant is 270 N/m?
36. A 35-N force is applied to a spring with spring constant k = 220 N/m. How much does the spring stretch?
37. 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

38. A 1.25-kg object is moving in the x-direction at 17.4 m/s. Just 3.41 s later, it's moving at 26.8 m/s at 34.0° to the x-axis. Find the magnitude and direction of the force applied during this time.

39. 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?
40. A 74-kg tree surgeon rides a "cherry picker" lift to reach the upper branches of a tree. What force does the lift exert on the surgeon when it's (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/s^2; (e) accelerating downward at 1.7 m/s^2?
41. A dancer executes a vertical jump during which the floor pushes up on his feet with a force 50% greater than his weight. What's his upward acceleration?
42. Find expressions for the force needed to bring an object of mass m from rest to speed v (a) in time Δt and (b) over distance Δx.
43. An elevator moves upward at 5.2 m/s. What's its minimum stopping time 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). The forces are applied for 3.00 s, after which the object is at $x = 4.80$ m, $y = 10.8$ m. If $\vec{F}_1 = 15.0\hat{\jmath}$N, what's $\vec{F}_2$?
45. Blocks of 1.0, 2.0, and 3.0 kg are lined up on a frictionless table, as shown in Fig. 4.21, with a 12-N force 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, accelerating the wagon and handle at 2.3 m/s^2. Find the tension forces at each end of the handle. Why are they different?
47. A 2200-kg airplane pulls two gliders, the first of mass 310 kg and the second of mass 260 kg, down the runway with acceleration 1.9 m/s^2 (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. **BIO** A biologist is studying the growth of rats on the 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 rat and cage accelerate at 0.40 m/s^2, what's the rat's mass?
49. An elastic towrope has spring constant 1300 N/m. It's 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.
50. 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 50

51. You're an automotive engineer designing the "crumple zone" of a new car—the region that compresses as the car comes to a stop in a head-on collision. If the maximum allowable force on a passenger in a 70-km/h collision is 20 times the passenger's weight, what do you specify for the amount of compression in the crumple zone?
52. **BIO** Frogs' tongues dart out to catch insects, with maximum tongue accelerations of about 250 m/s^2. What force is needed to give a 500-mg tongue such an acceleration?
53. 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 factory floor by a horizontal force applied to the more massive crate. If the spring compresses 5.1 cm, what's the applied force?
54. What force do the blades of a 4300-kg helicopter exert on the air when the helicopter is (a) hovering at constant altitude; (b) dropping at 21 m/s with speed decreasing at 3.2 m/s^2; (c) rising at 17 m/s with speed increasing at 3.2 m/s^2; (d) rising at a steady 15 m/s; (e) rising at 15 m/s with speed decreasing at 3.2 m/s^2?
55. 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?
56. Your engineering firm is asked to specify the maximum load for the elevators in a new building. Each elevator has mass 490 kg when empty and maximum acceleration 2.24 m/s^2. The elevator cables can withstand a maximum tension of 19.5 kN before breaking. For safety, you need to ensure that the tension never exceeds two-thirds of that value. What do you specify for the maximum load? How many 70-kg people is that?
57. An F-16 jet fighter has mass 12 Mg and engine thrust 132 kN. An Airbus A-380 has mass 560 Mg and total engine thrust 1.5 MN. Could either aircraft climb vertically with no lift from its wings? If so, what vertical acceleration could it achieve?
58. Two springs have the same unstretched length but different spring constants, k_1 and k_2. (a) If they're 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're connected end to end (Fig. 4.24b) and the combination is stretched a distance x, show that they exert a force $k_1k_2x/(k_1 + k_2)$.

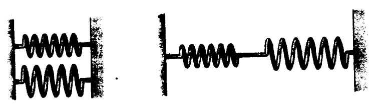
(a) (b)

FIGURE 4.24 Problem 58

59. Although we usually write Newton's second law for one-dimensional motion in the form $F = ma$, which holds when mass is constant, a more fundamental version is $F = \frac{d(mv)}{dt}$. Consider an object whose mass is changing, and use the product rule for derivatives to show that Newton's law then takes the form $F = ma + v\frac{dm}{dt}$.
60. 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 59 to find the force needed to keep the car moving at a constant 2.0 m/s.
61. A block 20% more massive than you hangs from a rope that goes over a frictionless, massless pulley. With what acceleration must you climb the other end of the rope to keep the block from falling?
62. You're asked to calibrate a device used to measure vertical acceleration in helicopters. The device consists of a mass m hanging from a massless spring of constant k. Your job is to express the acceleration as a function of the spring's stretch Δy from its equilibrium length. What's your expression?
63. Your airplane is caught in a brief, violent downdraft. To your amazement, pretzels rise vertically off your seatback tray, and you estimate their upward acceleration relative to the plane at 2 m/s^2. What's the plane's downward acceleration?
64. You're assessing the Engineered Material Arresting System (EMAS) at New York's JFK airport. The system consists of a 132-m-long bed of crushable cement blocks, designed to stop aircraft from sliding off the runway in emergencies. The EMAS can exert a 300-kN force on a 55-Mg jetliner that hits the system at 36 m/s. Can it stop the plane before it plows through all the blocks?
65. Two masses are joined by a massless string. A 30-N force applied vertically to the upper mass gives the system a constant upward acceleration of 3.2 m/s^2. If the string tension is 18 N, what are the two masses?
66. A mass M hangs from a uniform rope of length L and mass m. Find an expression for the rope tension as a function of the distance y measured downward from the top of the rope.
67. "Jerk" is the rate of change of acceleration, and it's what can make you sick on an amusement park ride. In a particular ride, a car and passengers with total mass M are subject to a force given by $F = F_0 \sin \omega t$, where F_0 and ω are constants. Find an expression for the maximum jerk.

Passage Problems

Laptop computers are equipped with accelerometers that sense when the device is dropped and then put the hard drive into a protective mode. Your computer geek friend has written a program that reads the accelerometer and calculates the laptop's apparent weight. You're amusing yourself with this program on a long plane flight. Your laptop weighs just 5 pounds, and for a long time that's what the program reports. But then the "Fasten Seatbelt" light comes on as the plane encounters turbulence. For the next 12 seconds, your laptop reports rapid changes in apparent weight, as shown in Fig. 4.25.

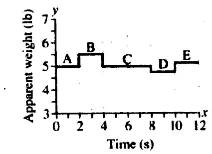

FIGURE 4.25 The laptop's apparent weight (Passage Problems 68–71).

68. At the first sign of turbulence, the plane's acceleration
    a. is upward.
    b. is downward.
    c. is impossible to tell from the graph.
69. The plane's vertical acceleration has its greatest magnitude
    a. during interval B.
    b. during interval C.
    c. during interval D.
70. During interval C, you can conclude for certain that the plane is
    a. at rest.
    b. accelerating upward.
    c. accelerating downward.
    d. moving with constant vertical velocity.
71. The magnitude of the greatest vertical acceleration the plane undergoes during the time shown on the graph is approximately
    a. 0.5 m/s^2.
    b. 1.0 m/s^2.
    c. 5 m/s^2.
    d. 10 m/s^2.

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; 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. 4.4b.
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).