CHAPTER 4

Newton’s Laws

Note: For all problems we shall take the upward direction as positive unless otherwise stated.

1* · How can you tell if a particular reference frame is an inertial reference frame?
   If Newton’s first law is obeyed, the reference frame is an inertial reference frame.

2 · Suppose you find that an object in a particular frame has an acceleration \( a \) when there are no forces acting on it.
   How can you use this information to find an inertial reference frame?
   If the object has an acceleration \( a \) in the absence of external forces, its reference frame has an acceleration \(-a\). An
   inertial reference frame is then one that accelerates with acceleration \(-a\) relative to the reference frame in which the
   object has the acceleration \( a \) in the absence of external forces.

3 · If an object has no acceleration in an inertial reference frame, can you conclude that no forces are acting
   on it?
   No; one can only conclude that the net force is zero.

4 · If only a single force acts on an object, must the object accelerate in an inertial reference frame? Can it ever
   have zero velocity?
   Yes, it must accelerate. It can have zero velocity at some instant.

5* · If an object is acted upon by a single known force, can you tell in which direction the object will move using no
   other information?
   No; only its acceleration is known (assuming one knows the mass).

6 · An object is observed to be moving at constant velocity in an inertial reference frame. It follows that \(a\) no
   forces act on the object. \(b\) a constant force acts on the object in the direction of motion. \(c\) the net force acting
   on the object is zero. \(d\) the net force acting on the object is equal and opposite to its weight.
   \(c\) See Problem 4-3.

7 · A body moves with constant speed in a straight line in an inertial reference frame. Which of the following
   statements must be true? \(a\) No force acts on the body. \(b\) A single constant force acts on the body in the
direction of motion. (c) A single constant force acts on the body in the direction opposite to the motion. (d) A net force of zero acts on the body. (e) A constant net force acts on the body in the direction of motion.

(d) \( a = 0 \), therefore \( \mathbf{F}_{net} = 0 \).

8 · Figure 4-23 shows the position \( x \) versus time \( t \) of a particle moving in one dimension. During what time intervals is there a net force acting on the particle? Give the direction (+ or -) of the net force during these time intervals.

Between \( t = 0 \) and \( t = 2 \) s, and between \( t = 8 \) s and \( t = 10 \) s, the velocity is constant and \( a = 0 \) and \( \mathbf{F}_{net} = 0 \). Between \( t = 2 \) s and \( t = 5 \) s, \( a \) is negative and \( \mathbf{F}_{net} \) is negative; between \( t = 5 \) s and \( t = 8 \) s, \( a \) is positive and so is \( \mathbf{F}_{net} \).

9* · A particle of mass \( m \) is traveling at an initial speed \( v_0 = 25.0 \) m/s. It is brought to rest in a distance of 62.5 m when a net force of 15.0 N acts on it. What is \( m \)? (a) 37.5 kg (b) 3.00 kg (c) 1.50 kg (d) 6.00 kg (e) 3.75 kg

\[ a = \frac{v^2}{2s} = \frac{F}{m} \]

\[ m = \frac{v^2}{2Fs} \]

10 · (a) An object experiences an acceleration of 3 m/s

\( ^2 \) when a certain force \( F_0 \) acts on it. What is its acceleration when the force is doubled? (b) A second object experiences an acceleration of 9 m/s

\( ^2 \) under the influence of the force \( F_0 \). What is the ratio of the masses of the two objects? (c) If the two objects are tied together, what acceleration will the force \( F_0 \) produce?

(a) Use \( \mathbf{F} = ma \)

\[ a = 2 \times \frac{(3 \text{ m/s}^2)}{6} = 6 \text{ m/s}^2 \]

(b) \[ m_2a_2 = m_1a_1 = F_0; m_2m_1 = a_1a_2 \]

\[ m_2m_1 = 3/9 = 1/3 \]

(c) \[ m_1 + m_2 = (4/3)m_1; a = (3/4)a_1 \]

\[ a = (3/4)(3 \text{ m/s}^2) = 2.25 \text{ m/s}^2 \]

11 · A tugboat tows a ship with a constant force \( F_1 \). The increase in the ship’s speed in a 10-s interval is 4 km/h.

When a second tugboat applies a second constant force \( F_2 \) in the same direction, the speed increases by 16 km/h in a 10-s interval. How do the magnitudes of the two forces compare? (Neglect water resistance.)

\[ F_1 = ma_1; F_1 + F_2 = 4ma_1 = 4F_1. \] Consequently, \( F_2 = 3F_1 \).

12 · A force \( F_0 \) causes an acceleration of 3 m/s

\( ^2 \) when it acts on an object of mass \( m \) sliding on a frictionless surface. Find the acceleration of the same object in the circumstances shown in Figure 4-24a and b.

(a) \[ F = (F_0^2 + F_7^2)^{1/2} = \sqrt{2} F_0 \]

\[ a = \sqrt{2} (3 \text{ m/s}^2) = 4.24 \text{ m/s}^2 \]

(b) \[ F_7 = 2F_0 + F_0 \cos 45^\circ; F_7 = F_0 \sin 45^\circ \]

\[ F_7 = 2.707F_0; F_7 = 0.707F_0; F = 2.8F_0; a = 8.39 \text{ m/s}^2 \]

13* · A force \( \mathbf{F} = 6 \text{ N } \mathbf{i} - 3 \text{ N } \mathbf{j} \) acts on an object of mass 1.5 kg. Find the acceleration \( \mathbf{a} \). What is the magnitude \( a \)?

\[ a = \mathbf{F}/m = (4\mathbf{i} - 2\mathbf{j}) \text{ m/s}^2; a = (16 + 4)^{1/2} \text{ m/s}^2 = 4.46 \text{ m/s}^2. \]

14 · A single force of 12 N acts on a particle of mass \( m \). The particle starts from rest and travels in a straight line a distance of 18 m in 6 s. Find \( m \).

\[ a = \frac{2s^2}{F/m; m = Fr^2/2s} \]

\[ m = [(12 \times 36)/(2 \times 18)] \text{ kg} = 12 \text{ kg} \]

15 · To drag a 75-kg log along the ground at constant velocity, you have to pull on it with a horizontal force of 250 N. (a) What is the resistive force exerted by the ground? (b) What force must you exert if you want to give the log an acceleration of 2 m/s

\( ^2 \)?

(a) Since \( a = 0 \), \( \mathbf{F}_{net} = 0; \mathbf{F}_{res} \) resistive force = 250 N.

(b) \[ \mathbf{F}_{net} = (75 \text{ kg})(2 \text{ m/s}^2) = 150 \text{ N} = \mathbf{F}_{appl} - \mathbf{F}_{res}; \mathbf{F}_{appl} = (250 + 150) \text{ N} = 400 \text{ N}. \]
16 · Figure 4-25 shows a plot of $v_x$ versus $t$ for an object of mass 8 kg moving in a straight line. Make a plot of the net force acting on the object as a function of time.

Between $t = 0$ and $t = 3$ s, $a = 1$ m/s$^2$ and $F = 8$ N;
between $t = 5$ s and 6.5 s, $a = -2.75$ m/s$^2$ and $F = -22$ N;
between $t = 7.5$ s and 8.5 s, $a = 2$ m/s$^2$ and $F = 16$ N;
between $t = 3$ s and 5 s, $F$ decreases from 8 N to -22 N;
between $t = 6.5$ s and 7.5 s, $F$ increases from -22 N to 16 N

A sketch of $F$ versus $t$ is shown.

17* · A 4-kg object is subjected to two forces, $F_1 = 2$ N $\hat{i} - 3$ N $\hat{j}$ and $F_2 = 4$ N $\hat{i} - 11$ N $\hat{j}$. The object is at rest at the origin at time $t = 0$. (a) What is the object’s acceleration? (b) What is its velocity at time $t = 3$ s? (c) Where is the object at time $t = 3$ s?

(a) Find the net force, $F = F_1 + F_2$

$$a = \frac{F}{m} = \frac{(2\hat{i} + 4\hat{i}) N - (3\hat{j} + 11\hat{j}) N}{4 \text{ kg}} = (1.5\hat{i} - 3.5\hat{j}) \text{ m/s}^2$$

(b) $v = at$

$$v = (4.5\hat{i} - 10.5\hat{j}) \text{ m/s}$$

(c) $r = v_{av}t; v_{av} = \frac{1}{2}v(3 \text{ s})$

$$r = (6.75\hat{i} - 15.75\hat{j}) \text{ m}$$

18 · Suppose an object was sent far out in space, away from galaxies, stars, or other bodies. How would its mass change? Its weight?

Its mass does not change. Its weight would be zero.

19 · How would an astronaut in apparent weightlessness be aware of her mass?

To accelerate, she must exert a force proportional to her mass.

20 · Under what circumstances would your apparent weight be greater than your true weight?

When in a reference frame that is accelerating upward.

21* · On the moon, the acceleration due to gravity is only about 1/6 of that on earth. An astronaut whose weight on earth is 600 N travels to the lunar surface. His mass as measured on the moon will be (a) 600 kg. (b) 100 kg. (c) 61.2 kg. (d) 9.81 kg. (e) 360 kg.

(c) The mass is $600 \text{ N}/(9.81 \text{ m/s}^2) = 61.2 \text{ kg}$, and remains the same on the moon.

22 · Find the weight of a 54-kg girl in (a) newtons and (b) pounds.

(a) $w = mg$

$$w = 54 \times 9.81 \text{ N} = 530 \text{ N} = (530/4.45) \text{ lb} = 119 \text{ lb}$$

23 · Find the mass of a 165-lb man in kilograms.

$$165 \text{ lb} = 165 \times 4.45 \text{ N} = 734 \text{ N}; m = \frac{w}{g} = \frac{(734 \text{ N})/(9.81 \text{ m/s}^2)}{74.8 \text{ kg}}$$

24 · After watching a space documentary, Lou speculates that there is money to be made by combining the phenomenon of weightlessness in space with the widespread longing for weight loss in the general population.
Reseaching the matter, he learns that the gravitational force on a mass \( m \) at a height \( h \) above the earth’s surface is given by
\[
F = mgR_E^2/(R_E + h)^2,
\]
where \( R_E \) is the radius of the earth (about 6370 km) and \( g \) is the acceleration due to gravity at the earth’s surface. (a) Using this expression, find the weight in newtons and pounds of an 83-kg person at the earth’s surface. (b) If this person were weight-conscious and rich, and Lou managed to sell the person a trip to a height of 400 km above the earth’s surface, how much weight would the person lose? (c) What is the person’s mass at this altitude?

(a) \( w = mg \)
\[
w = (83 \times 9.81) \text{ N} = 814 \text{ N} = (814/4.45) \text{ lb} = 183 \text{ lb}
\]

(b) Find change in acceleration of gravity, \( \Delta g \)
\[
\Delta g = g_E[1 - R_E^2/(R_E + h)^2] = g_E(1 - 6370^2/6770^2)
\]
\[
\Delta g = 0.115g_E
\]
Weight loss is 11.5%
\[
\Delta w = (814 \times 0.115) \text{ N} = 93 \text{ N} = 21 \text{ lb}
\]

(c) Mass is unchanged
\[
m = 83 \text{ kg}
\]

25* ··· Caught without a map again, Hayley lands her spacecraft on an unknown planet. Visibility is poor, but she finds someone on a local communications channel and asks for directions to Earth. “You are already on Earth,” is the reply, “Wait there and I’ll be right over.” Hayley is suspicious, however, so she drops a lead ball of mass 76.5 g from the top of her ship, 18 m above the surface of the planet. It takes 2.5 s to reach the ground. (a) If Hayley’s mass is 68.5 kg, what is her weight on this planet? (b) Is she on Earth?

(a) Use \( s = \frac{1}{2}at^2 \) to find accel. of gravity, \( g' \)
\[
w = mg'
\]
\[
g' = (2 \times 18/2.5^2) \text{ m/s}^2 = 5.76 \text{ m/s}^2
\]
\[
w = (68.5 \times 5.76) \text{ N} = 395 \text{ N}
\]

(b) Evidently, she is not on Earth.

26 · True or false: (a) Action-reaction forces never act on the same object. (b) Action equals reaction only if the objects are not accelerating.

(a) True (b) False

27 · An 80-kg man on ice skates pushes a 40-kg boy also on skates with a force of 100 N. The force exerted by the boy on the man is (a) 200 N. (b) 100 N. (c) 50 N. (d) 40 N.

(b) 100 N; the reaction force = action force, in magnitude.

28 · A boy holds a bird in his hand. The reaction force to the force exerted on the bird by the boy’s hand is (a) the force of the earth on the bird. (b) the force of the bird on the hand. (c) the force of the hand on the bird. (d) the force exerted by the bird on the hand.

The reaction force to the weight of the bird is (a) the force of the earth on the bird. (b) the force of the bird on the earth. (c) the force of the hand on the bird. (d) the force of the bird on the hand. (e) the force of the earth on the hand.

(b) the force exerted by the bird on the earth.

29* ··· A baseball player hits a ball with a bat. If the force with which the bat hits the ball is considered the action force, what is the reaction force? (a) The force the bat exerts on the batter’s hands. (b) The force on the ball exerted by the glove of the person who catches it. (c) The force the ball exerts on the bat. (d) The force the pitcher exerts on the ball while throwing it. (e) Friction, as the ball rolls to a stop.
(c) Dean reads in his physics book that when two people pull on the end of a rope in a tug-of-war, the forces exerted by each on the other are equal and opposite, according to Newton’s third law. Misunderstanding the law tragically, Dean runs out to challenge Hugo the Large, convinced that the laws of physics guarantee a tie. Hugo lumbers over, picks up the rope, pulls Dean off his feet, and then drags him through a puddle, across the road, and up the steps of the physics building. Use a force diagram to show Dean that, in spite of Newton’s third law, it is possible for one side to win a tug-of-war.

In the figure, (1) is Dean. The two persons pull directly on each other’s hands with forces $F_{12}$ and $F_{21}$ of equal magnitude (action-reaction). However, the forces that their feet exert on the ground, and the corresponding reaction forces of the ground on their feet (friction force) need not be the same. So (1), Dean, will be pulled to the right.

31 · A 2.5-kg object hangs at rest from a string attached to the ceiling.

(a) Draw a diagram showing all forces acting on the object and indicate each reaction force. (b) Do the same for each force acting on the string.

(a) The forces acting on the 2.5-kg mass are its weight, $W$, and the tension $T_1$ in the string. The reaction forces are $W'$ and $T_1'$ as shown.

(b) The forces acting on the string are $T_1$, the force that the mass exerts on the string, which is the same as $T_1'$ of part (a), and $T_2$, the force that the ceiling exerts on the string. The reaction forces are shown as $T_1'$ and $T_2'$.

32 · A 9-kg box rests on a 12-kg box that rests on a horizontal table. (a) Draw a diagram showing all forces acting on the 9-kg box and indicate each reaction force. (b) Do the same for all forces acting on the 12-kg box.
(a) The forces acting on the 9-kg box, \( m_1 \), are its weight, \( W_1 \), and the normal reaction force of the 12-kg box, \( m_2 \), on \( m_1 \), \( F_{n1} \). The reaction forces are \( F_{n1}' \) and \( W_1' \). (b) The forces acting on \( m_2 \) are \( F_{n1}' \) (equal to \( W_1 \)), its weight, \( W_2 \), and the normal reaction force of the table on \( m_2 \), \( F_{n2} \). The reaction forces are \( F_{n1} \), \( F_{n2}' \), and \( W_2' \).
Chapter 4  Newton’s Laws

(a) \( F = ma \); since \( m = 0.5 \) kg, the values of \( F \) are \( 1/2a \). The plot of \( F \) versus \( L \) is shown.

(b) From the graph one finds that for \( L = 12.5 \) cm,

\( F = 7.15 \) N

(c) \( F = mg = 4.905 \) N; for \( F = 4.905 \) N, \( L = 9.3 \) cm.

Extension, \( x = L - L_0 = (9.3 - 4.0) \) cm = 5.3 cm.

36 · A picture is supported by two wires as in Example 4-9. Do you expect the tension in the wire that is more nearly vertical to be greater than or less than the tension in the other wire?

The tension in the more nearly vertical wire is greater. (Consider a picture supported by one wire, and then pulled slightly to one side by a second wire.)

37* · A clothesline is stretched taut between two poles. Then a wet towel is hung at the center of the line. Can the line remain horizontal? Explain.

No; the tension in the line must have a vertical component to support the weight of the towel.

38 · Which of the free-body diagrams in Figure 4-26 represents a block sliding down a frictionless inclined surface?

(c) Two forces act on the block, its weight, acting vertically downward, and the normal reaction force of the surface on the block. The magnitude of the normal force is less than that of the weight, since it supports only a portion of the weight.

39 · A lamp with a mass \( m = 42.6 \) kg is hanging from wires as shown in Figure 4-27. The tension \( T_1 \) in the vertical handle is (a) 209 N. (b) 418 N. (c) 570 N. (d) 360 N. (e) 730 N.

(b) \( T_1 \) supports the full weight \( mg = 418 \) N.

40 · A 40.0-kg object supported by a vertical rope is initially at rest. The object is then accelerated upward. The tension in the rope needed to give the object an upward speed of 3.50 m/s in 0.700 s is (a) 590 N. (b) 390 N. (c) 200 N. (d) 980 N. (e) 720 N.

(a) \( a = (3.5/0.7) \) m/s\(^2\) = 5 m/s\(^2\). \( F_{\text{net}} = (40 \times 5) \) N = 200 N = \( T - (40 \times 9.81) \) N; \( T = 592 \) N.

41* · A hovering helicopter of mass \( m_h \) is lowering a truck of mass \( m_t \). If the truck’s downward speed is increasing at the rate 0.1g, what is the tension in the supporting cable? (a) 1.1m_g (b) m_g (c) 0.9m_g (d) 1.1 (m_h + m_t)g (e) 0.9 (m_h + m_t)g

(c) similar to Problem 4-40.

42 · A 10-kg object on a frictionless table is subjected to two horizontal forces, \( F_1 \) and \( F_2 \), with magnitudes \( F_1 = 20 \) N and \( F_2 = 30 \) N, as shown in Figure 4-28. (a) Find the acceleration \( a \) of the object. (b) A third force \( F_3 \) is applied so that the object is in static equilibrium. Find \( F_3 \).

(a) Find the components of \( F_1 \) and \( F_2 \); add \( F_1 = 20 \) \( j \) N; \( F_2 = (30 \cos 30^\circ i - 30 \sin 30^\circ j) \) N =
43. A vertical force \( T \) is exerted on a 5-kg body near the surface of the earth, as shown in Figure 4-29. Find the acceleration of the body if (a) \( T = 5 \text{ N} \), (b) \( T = 10 \text{ N} \), and (c) \( T = 100 \text{ N} \).

\[
\begin{align*}
(a) & \quad a = \frac{60 \text{ N}}{50 \text{ kg}} = 1.2 \text{ m/s}^2; \\
(b) & \quad a = \frac{120 \text{ N}}{50 \text{ kg}} = 2.4 \text{ m/s}^2; \\
(c) & \quad a = \frac{1200 \text{ N}}{50 \text{ kg}} = 24 \text{ m/s}^2.
\end{align*}
\]

44. To compensate for a distinct lack of personality, Herbert relies on the Grand Entrance technique when he attends parties. His latest plan for appearing at a pool party is to arrive by helicopter and then slide down a nylon rope as the helicopter hovers above poolside. However, as the helicopter approaches its destination, the pilot tells Herbert that the rope will break if the tension exceeds 300 N. Herbert, whose mass is 61.2 kg, realizes that the rope won’t hold him unless he slides down with an appropriate acceleration. What must his acceleration be if the rope is not to break and ruin the whole effect?

\[
ma = T - mg; \quad a = \frac{T}{m} - g
\]

45. A student has to escape from his girlfriend’s dormitory through a window that is 15.0 m above the ground. He has a 24-m rope, but it will break when the tension exceeds 360 N, and the student weighs 600 N. The student will be injured if he hits the ground with a speed greater than 8 m/s. (a) Show that he cannot safely slide down the rope. (b) Find a strategy using the rope that will permit the student to reach the ground safely.

\[
\begin{align*}
(a) & \quad a = \frac{26 \text{ N}}{24 \text{ kg}} = 1.08 \text{ m/s}^2; \\
(b) & \quad a = \frac{37.5 \text{ N}}{24 \text{ kg}} = 1.57 \text{ m/s}^2.
\end{align*}
\]

46. A rifle bullet of mass 9 g starts from rest and exits from the 0.6-m barrel at 1200 m/s. Find the force exerted on the bullet, assuming it to be constant, while the bullet is in the barrel.

\[
a = \frac{v^2}{2s}; \quad F = ma = \frac{mv^2}{2s}
\]

47. A 2-kg picture is hung by two wires of equal length. Each makes an angle of \( \theta \) with the horizontal, as shown in Figure 4-30. (a) Find the general equation for the tension \( T \), given \( \theta \) and weight \( w \) for the picture. For what angle \( \theta \) is \( T \) the least? The greatest? (b) If \( \theta = 30^\circ \), what is the tension in the wires?

\[
\begin{align*}
(a) & \quad T = \frac{w}{2 \sin \theta}; \\
(b) & \quad T = \frac{2 \times 9.81}{2 \times \sin 30^\circ} = 19.6 \text{ N}.
\end{align*}
\]

48. A bullet of mass \( 1.8 \times 10^{-3} \text{ kg} \) moving at 500 m/s impacts with a large fixed block of wood and travels 6 cm before coming to rest. Assuming that the deceleration of the bullet is constant, find the force exerted by the wood on the bullet.

\[
\text{Proceed as in Problem 4-46}; \quad F = \frac{mv^2}{2s}
\]

49. A 1000-kg load is being moved by a crane. Find the tension in the cable that supports the load as (a) it is accelerated upward at 2 m/s\(^2\), (b) it is lifted at constant speed, and (c) it moves upward with speed decreasing by 2 m/s each second.
Chapter 4  
Newton’s Laws

(a), (b), and (c)  \( T = m(a - g); \)  \( g = -9.81 \text{ m/s}^2 \)  \( (a) T = 11810 \text{ N}; (b) T = 9810 \text{ N}; (c) T = 7810 \text{ N} \)

50  
A horse-drawn coach is decelerating at 3.0 m/s\(^2\) while moving in a straight line. A lamp of mass 0.844 kg is hanging from the ceiling of the coach on a string 0.6 m long. The angle that the string makes with the vertical is (a) 8.5° toward the front of the coach. (b) 17° toward the front of the coach. (c) 17° toward the back of the coach. (d) 2.5° toward the front of the coach. (e) 0° or straight down.

\[ \theta = \tan^{-1} \left( \frac{a}{g} \right); \theta = 17° \text{ toward front of the coach. (e) is correct.} \]

51  
For the systems in equilibrium in Figure 4-31, find the unknown tensions and masses.

In each case, consider the junction of the three strings.

(a) Set \( \Sigma F_x = 0, \Sigma F_y = 0 \)

Solve for \( T_1 \) and \( T_2 \)

\[ M = T_2/g \]

(b) Proceed as in part (a)

\[ T_1 \sin 60° = 80 \cos 60° \text{ N}; T_1 \cos 60° + T_2 = 80 \sin 60° \text{ N} \]

\[ T_1 = (80 \text{ N})/\tan 60° = 46.2 \text{ N}; T_2 = 46.2 \text{ N} \]

\[ M = (46.2/9.81) \text{ kg} = 4.71 \text{ kg} \]

(c) Proceed as in part (a); note that \( Mg = T_1 \)

\[ T_1 \sin 30° = T_3 \sin 30°; T_1 = T_3; \]

\[ 2T_1 \cos 30° = T_3 = 6 \times 9.81 \text{ N} \]

\[ T_1 = T_3 = 34 \text{ N}; M = (34/9.81) \text{ kg} = 3.46 \text{ kg} \]

52  
Your car is stuck in a mudhole. You are alone, but you have a long, strong rope. Having studied physics, you tie the rope tautly to a telephone pole and pull on it sideways, as shown in Figure 4-32. (a) Find the force exerted by the rope on the car when the angle \( \theta \) is 3° and you are pulling with a force of 400 N but the car does not move. (b) How strong must the rope be if it takes a force of 600 N to move the car when \( \theta = 4° \)?

(a) \( \Sigma F_y = 0; \) solve for \( T \)

\[ 2T \sin 3° = 400 \text{ N}; T = 3.82 \text{ kN} \]

(b) Proceed as in (a)

\[ T = (600/2 \sin 4°) \text{ N} = 4.30 \text{ kN} \]

53*  
A box slides down a frictionless inclined plane. Draw a diagram showing the forces acting on the box. For each force in your diagram, indicate the reaction force.

The forces acting on the box are its weight, \( W \), and the normal reaction force of the inclined plane on the box, \( F_n \). The reaction forces are indicated with primes.

54  
The system shown in Figure 4-33 is in equilibrium. It follows that the mass \( m \) is (a) 3.5 kg. (b) 3.5 sin 40° kg. (c) 3.5 tan 40° kg. (d) none of the above.

(d) \( M \) must be greater than 3.5 kg.
In Figure 4-34, the objects are attached to spring balances calibrated in newtons. Give the readings of the balances in each case, assuming that the strings are massless and the incline is frictionless.  
(a) and (b) $F = 98.1$ N. (c) $F$ (per spring balance) = 49 N. (d) $F = (98.1 \sin 30^\circ)$ N = 49 N.

A box is held in position by a cable along a frictionless incline (Figure 4-35). (a) If $q = 60^\circ$ and $m = 50$ kg, find the tension in the cable and the normal force exerted by the incline.  
(b) Find the tension as a function of $\theta$ and $m$, and check your result for $\theta = 0^\circ$ and $\theta = 90^\circ$.

We shall use a coordinate system with $x$ pointing to the right and parallel to the inclined plane, $y$ along $F_n$.

(a) Use results of (b) with $m = 50$ kg, $\theta = 60^\circ$  
$T = mg \sin \theta$; $F_n = mg \cos \theta$. For $\theta = 0^\circ$, $T = 0$, $F_n = mg$, and for $\theta = 90^\circ$, $T = mg$ and $F_n = 0$, as should be

$T = 508$ N, $F_n = 245$ N

A horizontal force of 100 N pushes a 12-kg block up a frictionless incline that makes an angle of 25° with the horizontal.  
(a) What is the normal force that the incline exerts on the block?  
(b) What is the acceleration of the block?

Draw a free-body diagram for the box. Let $x$ point to the right and up along the plane with $y$ in the direction of $F_n$.

(a) Write $\Sigma F_y = 0$ and solve for $F_n$  
$F_n - mg \cos 25^\circ - (100 \text{ N}) \sin 25^\circ = 0$; $F_n = 149$ N

(b) Write $\Sigma F_x = ma$ and solve for $a$  
$(100 \text{ N}) \cos 25^\circ - mg \sin 25^\circ = ma$; $a = 3.41$ m/s²

A 65-kg boy weighs himself by standing on a scale mounted on a skateboard that is rolling down an incline, as shown in Figure 4-36. Assume there is no friction so that the force exerted by the incline on the skateboard is perpendicular to the incline. What is the reading on the scale if $\theta = 30^\circ$?

The force on the scale is the normal reaction force; $F_n = 65 \times 9.81 \times \cos 30^\circ$ N = 552 N.

An object is suspended from the ceiling of an elevator that is descending at a constant speed of 9.81 m/s. The tension in the string holding the object is (a) equal to the weight of the object. (b) less than the weight of the object but not zero. (c) greater than the weight of the object. (d) zero.

(a) The acceleration is zero, so $T = mg$.

What effect does the velocity of an elevator have on the apparent weight of a person in the elevator?

None.

Suppose you are standing on a scale in a descending elevator as it comes to a stop on the ground floor. Will the scale’s report of your weight be high, low, or correct?

It will be high because the acceleration is upward.

A person of weight $w$ is in an elevator going up when the cable suddenly breaks. What is the person’s apparent weight immediately after the cable breaks? (a) $w$ (b) Greater than $w$ (c) Less than $w$ (d) 9.8w (e) Zero
(e) zero; the floor of the elevator exerts no force on the person.

63 · A person in an elevator is holding a 10-kg block by a cord rated to withstand a tension of 150 N. When the elevator starts up, the cord breaks. What was the minimum acceleration of the elevator?

\[ 150 \text{ N} = (10 \text{ kg})(a - g) = (10 \text{ kg})(a + 9.81 \text{ m/s}^2); \] \[ a = 5.19 \text{ m/s}^2. \]

64 · A 60-kg girl weighs herself by standing on a scale in an elevator. What does the scale read when

(a) the elevator is descending at a constant rate of 10 m/s;
(b) the elevator is descending at 10 m/s and gaining speed at a rate of 2 m/s^2;
(c) the elevator is ascending at 10 m/s but its speed is decreasing by 2 m/s each second?

(a) \[ a = 0; \quad w = mg = 589 \text{ N}. \] (b) \[ a = -2 \text{ m/s}^2; \quad w = (60 \times 7.81) \text{ N} = 469 \text{ N}. \] (c) Again, \[ a = -2 \text{ m/s}^2 \] and \[ w = 469 \text{ N}. \]

65* ·· A 2-kg block hangs from a spring balance calibrated in newtons that is attached to the ceiling of an elevator (Figure 4-37). What does the balance read when

(a) the elevator is moving up with a constant velocity of 30 m/s;
(b) the elevator is moving down with a constant velocity of 30 m/s;
(c) the elevator is ascending at 20 m/s and gaining speed at a rate of 10 m/s^2?

From \( t = 0 \) to \( t = 2 \) s, the elevator moves up at 10 m/s. Its velocity is then reduced uniformly to zero in the next 2 s, so that it is at rest at \( t = 4 \) s. Describe the reading of the balance during the interval \( 0 < t < 4 \) s.

(a) \[ a = 0; \quad F = mg = 19.6 \text{ N}. \] (b) \[ F = 19.6 \text{ N}. \] (c) \[ a = 10 \text{ m/s}^2; \quad F = (2 \text{ kg})[(10 + 9.81) \text{ m/s}^2] = 39.6 \text{ N}. \]

66 ·· A man stands on a scale in an elevator that has an upward acceleration \( a \). The scale reads 960 N. When he picks up a 20-kg box, the scale reads 1200 N. Find the mass of the man, his weight, and the acceleration \( a \).

1. A mass of 20 kg has an apparent weight of 240 N

\[ 240/20 = 9.81 \text{ m/s}^2 + a; \quad a = 2.19 \text{ m/s}^2 \]

2. Finds the mass and weight of the man

\[ m = (960/12.0) \text{ kg} = 80 \text{ kg}; \quad w = (80 \times 9.81) \text{ N} = 785 \text{ N} \]

67 ·· Two boxes of mass \( m_1 \) and \( m_2 \) connected together by a massless string are accelerated uniformly on a frictionless surface, as shown in Figure 4-38. The ratio of the tensions \( T_1/T_2 \) is given by

(a) \[ m_1/m_2. \] (b) \[ m_2/m_1. \] (c) \[ (m_1+m_2)/m_2. \] (d) \[ m_1/(m_1 + m_2) \] (e) \[ m_2/(m_1 + m_2) \]

\[ T_2 = (m_1 + m_2)a; \quad T_1 = m_1a; \quad T_1/T_2 = m_1/(m_1 + m_2). \] (d) is correct.

68 ·· A box of mass \( m_2 = 3.5 \) kg rests on a frictionless horizontal shelf and is attached by strings to boxes of masses \( m_1 = 1.5 \) kg and \( m_3 = 2.5 \) kg, which hang freely, as shown in Figure 4-39. Both pulleys are frictionless and massless. The system is initially held at rest. After it is released, find

(a) the acceleration of each of the boxes and
(b) the tension in each string.

Evidently, \( m_1 \) will accelerate up, \( m_2 \) to the right, and \( m_3 \) down, with the same acceleration \( a \).

1. Draw free-body diagrams for each box
(a) Write $\Sigma F = m_ia$ for each box.

Add the three equations to find $a$.

(b) Use the three equations to find the tensions.

Then, solve for $a$ and $T$.

Two blocks are in contact on a frictionless, horizontal surface. The blocks are accelerated by a horizontal force $F$ applied to one of them (Figure 4-40). Find the acceleration and the contact force for (a) general values of $F$, $m_1$, and $m_2$, and (b) for $F = 3.2$ N, $m_1 = 2$ kg, and $m_2 = 6$ kg.

(a) $a = F/(m_1 + m_2)$ and contact force $F_c = m_2a$. So $F_c = Fm_2/(m_1 + m_2)$.

(b) Substitute numerical values in above expressions. $a = (3.2/8) m/s^2 = 0.4 m/s^2$; $F_c = (3.2 \times 2/8)$ N = 0.8 N.

Repeat the previous problem, but with the two blocks interchanged.

(a) Interchange subscripts 1 and 2.

(b) $a = 0.4 m/s^2$; $F_c = (3.2 \times 2/8)$ N = 0.8 N.

Two 100-kg boxes are dragged along a frictionless surface with a constant acceleration of 1.6 m/s$^2$, as shown in Figure 4-41. Each rope has a mass of 1 kg. Find the force $F$ and the tension in the ropes at points A, B, and C.

1. Total mass accelerated is 202 kg. $F = ma$ $F = 323.2$ N
2. Apply $F = ma$ at points A, B, and C $F_A = 160$ N; $F_B = 161.2$ N; $F_C = 321.6$ N

Two objects are connected by a massless string, as shown in Figure 4-42. The incline and pulley are frictionless. Find the acceleration of the objects and the tension in the string for (a) general values of $\theta$, $m_1$, and $m_2$, and (b) $\theta = 30^\circ$ and $m_1 = m_2 = 5$ kg.

(a) Draw a free-body diagram for each of the two masses.

Take the x axis for the first diagram to the right to be along the inclined plane.

1. Write $\Sigma F_x = m_1a; T - m_1g \sin \theta = m_1a$ $T = g[m_1m_2/(m_1 + m_2)](1 + \sin \theta)$
2. Write $\Sigma F = m_2a; m_2g - T = m_2a$
3. Add the two equations and solve for $a$.

(b) Substitute numerical values into expressions for $a$ and $T$; $T = 36.8$ N; $a = 2.45$ m/s$^2$

Two climbers on an icy (frictionless) slope, tied together by a 30-m rope, are in the predicament shown in Figure 4-43. At time $t = 0$, the speed of each is zero, but the top climber, Paul (mass 52 kg), has taken one step too many and his friend Jay (mass 74 kg) has dropped his pick. (a) Find the tension in the rope as Paul falls and his speed just before he hits the ground. (b) If Paul unhooks his rope after hitting the ground, find Jay’s speed as he hits the ground.

(a) Use results of Problem 4-72 to find $a$ and $T$ $a = (9.81)[(52 - 74 \sin 40^\circ)/126] m/s^2 = 0.345$ m/s$^2$ $T = (9.81)(52 \times 74/126)(1 + \sin 40^\circ) = 492$ N
$v = (2as)^{1/2}$

1. Find the distance Jay slides
2. Find the acceleration of Jay
3. Find $v_J = (2a_s s_J)^{1/2}$

$v = (2 \times 0.345 \times 20)^{1/2} \text{ m/s} = 3.71 \text{ m/s}$

$s_J = (25 \text{ m})/\sin 40^\circ = 33.9 \text{ m}$

$a_J = g \sin 40^\circ = 6.31 \text{ m/s}^2$

$v_J = (2 \times 33.9 \times 6.31)^{1/2} \text{ m/s} = 20.7 \text{ m/s}$

74 · The northwest face of Half Dome, a large rock in Yosemite National Park, makes an angle of $\theta = 7.0^\circ$ with the vertical. Suppose a rock climber lying horizontal on the top is trying to support her unfortunate friend of equal mass who is hanging from a rope over the edge, as shown in Figure 4-44. If friction is negligible (the top is icy!), at what acceleration will they slide down before the top partner manages to grab someone’s hand and stop?

1. Write the $\Sigma F = ma$ for each mass $ma = T; mg \cos 7^\circ - T = ma$
2. Solve for $a$
   $a = (g \cos 7^\circ)/2 = 4.87 \text{ m/s}^2$

75 · In a stage production of Peter Pan, the 50-kg actor playing Peter has to fly in vertically, and to be in time with the music, he must be lowered a distance of 3.2 m in 2.2 s. Backstage, a smooth surface sloped at 50° supports a counterweight of mass $m$, as shown in Figure 4-45. Show the calculations that the stage manager must perform to find (a) the mass of the counterweight that must be used, and (b) the tension in the wire.

We can use the results of Problem 4-72.

(a) Find the acceleration $a = 2s/t^2$
   $a = (2 \times 3.2)/2.2^2 \text{ m/s}^2 = 1.32 \text{ m/s}^2$

(b) Set $a = 0$ and find ratio $m_1/m_2$
   $T - 8g \sin 40^\circ = 8a; 10g \sin 50^\circ - T = 10a$

76 · An 8-kg block and a 10-kg block connected by a rope that passes over a frictionless peg slide on frictionless inclines, as shown in Figure 4-46. (a) Find the acceleration of the blocks and the tension in the rope. (b) The two blocks are replaced by two others of mass $m_1$ and $m_2$ such that there is no acceleration. Find whatever information you can about the mass of these two new blocks.

(a) Draw the free-body diagrams for the two boxes.

We shall use coordinate systems with the $x$ axis pointing toward the right and parallel to the inclined planes.

Write $\Sigma F_x = ma$ for the two boxes

Solve for $a$ $a = (10g \sin 50^\circ - 8g \sin 40^\circ)/18 \text{ m/s}^2 = 1.37 \text{ m/s}^2$

Solve for $T$ using $a = 1.37 \text{ m/s}^2$ $T = 61.4 \text{ N}$

(b) Set $a = 0$ and find ratio $m_1/m_2$

$0 = m_1 \sin 40^\circ - m_2 \sin 50^\circ; m_1/m_2 = 1.19$

77* ·· A heavy rope of length 5 m and mass 4 kg lies on a frictionless horizontal table. One end is attached to a
6-kg block. At the other end of the rope, a constant horizontal force of 100 N is applied. (a) What is the acceleration of the system? (b) Give the tension in the rope as a function of position along the rope.

(a) \( F = (m_1 + m_2)a \) 
\[ a = \frac{100}{10} \text{ m/s}^2 = 10 \text{ m/s}^2 \]

(b) \( T \) at 6-kg mass is 60 N. \( x \) is distance from 6-kg. 
\[ T(x) = [60 + (40/5)x] \text{ N} = 60 + 8x \text{ N} \]

78 ··· A 60-kg housepainter stands on a 15-kg aluminum platform. The platform is attached to a rope that passes through an overhead pulley, which allows the painter to raise herself and the platform (Figure 4-47). (a) To accelerate herself and the platform at a rate of 0.8 m/s\(^2\), with what force must she pull on the rope? (b) When her speed reaches 1 m/s, she pulls in such a way that she and the platform go up at a constant speed. What force is she exerting on the rope? (Ignore the mass of the rope.)

(a) \( \Sigma F = ma; \ 2T - mg = ma \)
\[ T = \frac{1}{2}m(a + g) = [75 \times 10.61/2] \text{ N} = 398 \text{ N} \]

(b) Set \( a = 0 \) and solve for \( T \)
\[ T = (75 \times 9.81/2) \text{ N} = 368 \text{ N} \]

79 ··· Figure 4-48 shows a 20-kg block sliding on a 10-kg block. All surfaces are frictionless. Find the acceleration of each block and the tension in the string that connects the blocks.

1. Draw a free-body diagram for each block

2. Write \( \Sigma F_x = ma \) for each block
\[ T - 20g \sin 20^\circ = 20a_{20}; \ T - 10g \sin 20^\circ = 10a_{10}; \]
\[ a_{20} = -a_{10} \]

3. Solve for \( a_{20} \) and \( a_{10} \).
\[ a_{10} = [(10g \sin 20^\circ)/30] \text{ m/s}^2 = 1.12 \text{ m/s}^2; \]
\[ a_{20} = -1.12 \text{ m/s}^2 \]

4. Solve for \( T \)
\[ T = [11.2 + 98.1 \sin 20^\circ] \text{ N} = 44.8 \text{ N} \]

80 ··· A 20-kg block with a pulley attached slides along a frictionless ledge. It is connected by a massless string to a 5-kg block via the arrangement shown in Figure 4-49. Find the acceleration of each block and the tension in the connecting string.
Chapter 4  Newton’s Laws

1. Draw a free-body diagram for each block.
   Note that the distance the 5-kg block moves in a time \( \Delta t \) is twice the distance the 20-kg block moves. Thus, if we designate by \( a \) the acceleration of the 20-kg block, that of the 5-kg block is 2\( a \).

2. Write \( \Sigma F = ma \) for each block

3. Solve for \( T \) and \( a \)

\[
2T = 20a; \quad 5g - T = 5 \times 2a
\]

\[
T = 24.5N; \quad a = a_{2a} = 2.45 \text{ m/s}^2, \quad a_5 = 4.9 \text{ m/s}^2
\]

81* The apparatus in Figure 4-50 is called an Atwood’s machine and is used to measure acceleration due to gravity \( g \) by measuring the acceleration of the two blocks. Assuming a massless, frictionless pulley and a massless string, show that the magnitude of the acceleration of either body and the tension in the string are

\[
a = \frac{m_1 - m_2}{m_1 + m_2} \quad \text{and} \quad T = \frac{2m_1m_2}{m_1 + m_2} g
\]

This is identical to Problem 4-72 with \( \theta = 90^\circ \). Setting \( \sin \theta = 1 \) in the expressions for \( a \) and \( T \) one obtains the above.

82 If one of the masses of the Atwood’s machine of Figure 4-50 is 1.2 kg, what should the other mass be so that the displacement of either mass during the first second following release is 0.3 m?

1. Find the acceleration \( a = 2s/t^2 \)

\[
a = 0.6 \text{ m/s}^2
\]

2. Solve for \( m_1 \)

\[
m_1 = m_2[(g + a)/(g - a)] = m_2(10.41/9.21)
\]

3. Find the second mass for \( m_2 \) or \( m_1 = 1.2 \) kg

\[
m_1 = 1.356 \text{ kg, or } m_2 = 1.06 \text{ kg}
\]

83 A small pebble of mass \( m \) rests on the block of mass \( m_2 \) of the Atwood’s machine in Figure 4-50. Find the force exerted by the pebble on \( m_2 \).

Since \( m_2 < m_1 \), \( m_2 \) accelerates up. Hence, the force on a small mass \( m \) exerted by \( m_2 \) is:

\[
F = m(g + a) = mg[1 + (m_1 - m_2)/(m_1 + m_2)] = 2m_1mg/(m_1 + m_2).
\]

84 Find the force exerted by the Atwood’s machine on the hanger to which the pulley is attached, as shown in Figure 4-50, while the blocks accelerate. Neglect the mass of the pulley. Check your answer by considering appropriate variations for \( m_1 \) and/or \( m_2 \).

\[
F = 2T = 4m_1m_2g/(m_1 + m_2). \text{ If } m_1 = m_2 = m, F = 4m^2g/2m = 2mg \text{ as expected; if either } m_1 \text{ or } m_2 = 0, F = 0.
\]

85* The acceleration of gravity \( g \) can be determined by measuring the time \( t \) it takes for a mass \( m_2 \) in an Atwood’s machine to fall a distance \( L \), starting from rest. (a) Find an expression for \( g \) in terms of \( m_1, m_2, L, \) and \( t \). (b) Show
that if there is a small error in the time measurement \( dt \), it will lead to an error in the determination of \( g \) by an amount \( dg \) given by \( dg/g = -2\, dt/t \). If \( L = 3 \) m and \( m_1 \) is 1 kg, find the value of \( m_2 \) such that \( g \) can be measured with an accuracy of \( \pm 5\% \) with a time measurement that is accurate to 0.1 s. Assume that the only significant uncertainty in the measurement is the time of fall.

(a) Use \( a = 2L/t^2 \); from Problem 4-81, \( g = a[(m_1 + m_2)/(m_1 - m_2)] = (2L/t^2)[(m_1 + m_2)/(m_1 - m_2)] \).

(b) Differentiate with respect to \( t \). \( dg/dt = -2g/t \) or \( dg/g = -2dt/t \).

With \( dg/g = \pm 0.05, \) \( dt/t = \pm 0.025 \) and \( t = (0.1 \text{ s})/0.025 = 4 \) s. Now find \( a = 2L/t^2 = 0.375 \) m/s\(^2 \) and solve for \( m_2 \) with \( m_1 = 1 \) kg, using the result of Problem 4-82. \( m_2 = 0.926 \) kg or 1.08 kg.

86 · True or false: (a) If there are no forces acting on an object, it will not accelerate. (b) If an object is not accelerating, there must be no forces acting on it. (c) The motion of an object is always in the direction of the resultant force. (d) The mass of an object depends on its location.

(a) True (b) False (c) False (d) False

87 · A skydiver of weight \( w \) is descending near the surface of the earth. What is the magnitude of the force exerted by her body on the earth? (a) \( w \) (b) Greater than \( w \) (c) Less than \( w \) (d) 9.8\( w \) (e) 0 (f) It depends on the air resistance.

(a) It is the reaction force of \( w \).

88 · The net force on a moving object is suddenly reduced to zero. As a consequence, the object (a) stops abruptly. (b) stops during a short time interval. (c) changes direction. (d) continues at constant velocity. (e) changes velocity in an unknown manner. (d) See Newton’s first law.

89* · A force of 12 N is applied to an object of mass \( m \). The object moves in a straight line, with its speed increasing by 8 m/s every 2 s. Find \( m \).

1. Find \( a \)
2. \( F = ma; \) \( m = F/a \)

\[
\begin{align*}
a &= (8/2) \text{ m/s}^2 = 4 \text{ m/s}^2 \\
m &= (12/4) \text{ kg} = 3 \text{ kg}
\end{align*}
\]

90 · A certain force \( F_1 \) gives an object an acceleration of \( 6 \times 10^6 \) m/s\(^2 \). Another force \( F_2 \) gives the same object an acceleration of \( 15 \times 10^6 \) m/s\(^2 \). What is the acceleration of the object if (a) the two forces act together on the object in the same direction; (b) the two forces act in opposite directions on the object; (c) the two forces act on the object at 90° to each other?

(a) \( F_1 = ma_1; \) \( F_2 = ma_2; \) \( F_1 + F_2 = m(a_1 + a_2) = ma \)  \( a = 21 \times 10^6 \) m/s\(^2 \)

(b) \( F_1 - F_2 = m(a_1 - a_2) = ma \)  \( a = 9 \times 10^6 \) m/s\(^2 \)

(c) \( F = (F_1^2 + F_2^2)^{1/2}, \) \( a = (a_1^2 + a_2^2)^{1/2} \)  \( a = 16.2 \times 10^6 \) m/s\(^2 \)

91 · A certain force applied to a particle of mass \( m_1 \) gives it an acceleration of 20 m/s\(^2 \). The same force applied to a particle of mass \( m_2 \) gives it an acceleration of 50 m/s\(^2 \). If the two particles are tied together and the same force is applied to the pair, find the acceleration.

\[
m_1 = F/a_1; \) \( m_2 = F/a_2; \) \( m_1 + m_2 = F(1/a_1 + 1/a_2) \)  \( a = F/(m_1 + m_2) = (1/20 + 1/50)^{-1} \text{ m/s}^2 = 14.3 \text{ m/s}^2
\]
92 A 6-kg object is pulled along a frictionless horizontal surface by a horizontal force of 10 N. (a) If the object is at rest at $t = 0$, how fast is it moving after 3 s? (b) How far does it travel during these 3 s?

(a) $v = at = \frac{Ft}{m}$

$v = (10 \times 3/6) \text{ m/s} = 5 \text{ m/s}$

(b) $s = \frac{1}{2}vt$

$s = (1/2 \times 5 \times 3) \text{ m} = 7.5 \text{ m}$

93* If you weigh 125 lb on the earth, what would your weight be in pounds on the moon, where the free-fall acceleration due to gravity is 5.33 ft/s$^2$?

$g_E = 32 \text{ ft/s}^2$, $w_M = w_E \left(\frac{g_M}{g_E}\right)$

$w_M = (125 \times 5.33/32) \text{ lb} = 20.8 \text{ lb}$

94 A redheaded woodpecker hits the bark of a tree extremely hard—the speed of its head reaches approximately $v = 3.5 \text{ m/s}$ before impact. If the mass of the bird’s head is 0.060 kg, and the average force acting on the head during impact is $F = 6.0 \text{ N}$, find (a) the acceleration of its head (assuming it is constant); (b) the depth of penetration into the bark; (c) the time it takes the woodpecker’s head to stop.

(a) $a = \frac{F}{m}$

$a = (6/0.06) \text{ m/s}^2 = 100 \text{ m/s}^2$

(b) $s = \frac{v^2}{2a}$

$s = (3.5^2/200) \text{ m} = 6.13 \text{ cm}$

(c) $t = \frac{v}{a}$

$t = (3.5/100) \text{ s} = 35 \text{ ms}$

95 A simple accelerometer can be made by suspending a small object from a string attached to a fixed point on an accelerating object—to the ceiling of a passenger car, for example. When there is an acceleration, the object will deflect and the string will make some angle with the vertical. (a) How is the direction in which the suspended object deflects related to the direction of the acceleration? (b) Show that the acceleration $a$ is related to the angle $\theta$ that the string makes by $a = g \tan \theta$; (c) Suppose the accelerometer is attached to the ceiling of an automobile that brakes to rest from 50 km/h in a distance of 60 m. What angle will the accelerometer make? Will the object swing forward or backward?

(a) The object will swing backward; see figure.

(b) $T_x = ma; T_y = mg$. $T_x/T_y = \tan \theta = a/g$. $a = g \tan \theta$.

(c) The object will swing forward

Find $a = \frac{v^2}{2s}$

$a = (13.9^2/120) \text{ m/s}^2 = 1.6 \text{ m/s}^2$

Find $\theta = \tan^{-1}(a/g)$

$\theta = \tan^{-1}(1.6/9.81) = 9.3^\circ$
Chapter 4   Newton’s Laws

96  The mast of a sloop is supported at bow and stern by stainless steel wires, the forestay and backstay, anchored 10 m apart (Figure 4-51). The 12-m long mast weighs 800 N and stands vertically on the deck of the sloop. The mast is positioned 3.6 m behind where the forestay is attached. The tension in the forestay is 500 N. Find the tension in the backstay and the force that the mast exerts on the deck of the sloop.

Take as the “free-body” the top of the mast.

1. Find the angles that the forestay and backstay make with the vertical
   \[ \theta_F = \tan^{-1}(3.6/12) = 16.7^\circ; \theta_B = \tan^{-1}(6.4/12) = 28.1^\circ \]

2. \( \Sigma F_x = 0 \)
   \[ 500 \sin 16.7^\circ = T_F \sin 28.1^\circ; T_F = 305 \text{ N} \]

3. Find \( \Sigma F_y \)
   \[ F_y = -(500 \cos 16.7^\circ + 305 \cos 28.1^\circ) \text{ N} = 748 \text{ N} \]

4. Set \( \Sigma F_y = 0 \) at deck; \( F_n = (800 + 748) \text{ N} \)

97* A box of mass \( m_1 \) is pulled along a smooth horizontal surface by a force \( F \) exerted at the end of a rope that has a much smaller mass \( m_2 \), as shown in Figure 4-52. (a) Find the acceleration of the rope and block, assuming them to be one object. (b) What is the net force acting on the rope? (c) Find the tension in the rope at the point where it is attached to the block. (d) The diagram, with the rope perfectly horizontal along its length, is not quite accurate. Correct the diagram, and state how this correction affects your solution.

(a) \( a = F/(m_1 + m_2) \). (b) \( F_{net} = m_2 a = Fm_2/(m_1 + m_2) \). (c) \( T = m_1 a = Fm_1/(m_1 + m_2) \).

(d) The rope sags and \( F \) has a vertical component and its horizontal component is less than \( F \).

Consequently, \( a \) will be somewhat smaller.

98 Joe and Sal are in a rollerbladers’ club that is building a ramp to reach new levels of extremeness. The ramp is to be a simple incline, so that after coasting horizontally, a skater will ride up the slope at some angle \( \theta \). Sal suggests making the slope as steep as possible to maximize the height that will be reached. Joe whips out a pencil and paper to prove to Sal that, if the surfaces are smooth, the height reached is independent of the angle of the slope. Sal acknowledges that even though Joe is being smug and obnoxious, his argument is sound. Show Joe’s proof.

The acceleration along the length of the slope is \( g \sin \theta \). The distance traveled along the slope is \( s = v^2/(2g \sin \theta) \) and the height reached is \( h = s \sin \theta = v^2/2g \), independent of \( \theta \).

99 A car traveling 90 km/h crashes into the rear end of an unoccupied stalled vehicle. Fortunately, the driver is wearing a seat belt. Using reasonable values for the mass of the driver and the stopping distance, estimate the force (assuming it to be constant) exerted on the driver by the seat belt.

Assume a stopping distance of 25 m. Then the acceleration is 50 m/s². Assume the mass of the driver is 80 kg. Then \( F = 4000 \text{ N} \).

100 A 2-kg body rests on a frictionless wedge that has an inclination of 60° and an acceleration \( a \) to the right such that the mass remains stationary relative to the wedge (Figure 4-53). (a) Find \( a \). (b) What would happen if the wedge were given a greater acceleration?
101* The masses attached to each side of an Atwood’s machine consist of a stack of five washers each of mass \( m \), as shown in Figure 4-54. The tension in the string is \( T_0 \). When one of the washers is removed from the left side, the remaining washers accelerate and the tension decreases by 0.3 N. (a) Find \( m \). (b) Find the new tension and the acceleration of each mass when a second washer is removed from the left side.

(a) Use the result of Problem 4-81

\[
T_0 = 5mg; \quad T_0 - T = 5mg - (2 \times 4m \times 5m)g/9m = 0.3 N
\]

Solve for \( m \)

\[
m = (0.3 N) \times 9/5g = 0.055 kg = 55 g
\]

(b) Use the results of Problem 4-81

\[
T = (2 \times 3 \times 5 \times 9.81m/8) N = 2.02 N; \quad a = (2/8)g
\]

\[
= 2.45 \text{ m/s}^2
\]

102 Consider the Atwood’s machine in Figure 4-54. When \( N \) washers are transferred from the left side to the right side, the right side drops 47.1 cm in 0.40 s. Find \( N \).

1. Find the acceleration \( a = 2sl^2 \)

\[
a = (2 \times 0.471/0.16) \text{ m/s}^2 = 5.89 \text{ m/s}^2 = 0.6g
\]

2. Use the result of Problem 4-81

\[
0.6 = 2N/10; \quad N = 3
\]

103 Blocks of mass \( m \) and \( 2m \) are connected by a string (Figure 4-55). (a) If the forces are constant, find the tension in the connecting string. (b) If the forces vary with time as \( F_1 = Ct \) and \( F_2 = 2Ct \), where \( C \) is a constant and \( t \) is time, find the time \( t_0 \) at which the tension in the string is \( T_0 \).

(a) Find the acceleration \( a \)

\[
a = (F_2 - F_1)/3m
\]

Find the force acting on \( m \), and solve for \( T \)

\[
T - F_1 = ma = (F_2 - F_1)/3; \quad T = (F_2 + 2F_1)/3
\]

(b) Write the expression for \( T_0 \) and solve for \( t_0 \)

\[
T_0 = 4Ct_0/3; \quad t_0 = 3T_0/4C
\]

104 Find the normal force and the tangential force exerted by the road on the wheels of your bicycle (a) as you climb an 8% grade at constant speed, (b) as you descend the 8% grade at constant speed. (An 8% grade means that the angle of inclination \( \theta \) is given by \( \tan \theta = 0.08 \).)

Assume a total mass of 80 kg. Then \( mg = 785 N \). The angle \( \theta = \tan^{-1}(0.08) = 4.57^\circ \). The total normal and tangential forces on the bicycle are \( F_n = mg \cos \theta \) and \( F_t = mg \sin \theta \). Thus, \( F_n = 782 N, F_t = 62.6 N \). Since there is no acceleration, these forces are the same going up and going down. The forces on each wheel are \( F_n = 391 N, F_t = 31.3 N \).

105* The pulley in an Atwood’s machine is given an upward acceleration \( a \), as shown in Figure 4-56. Find the acceleration of each mass and the tension in the string that connects them.

A constant upward acceleration has the same effect as an increase in the acceleration of gravity from \( g \) to \( g + a \).

Thus, the tension in the string is given by the expression of Problem 4-81 with \( g \) replaced by \( (g + a) \):

\[
T = 2m_1m_2(g + a)/(m_1 + m_2). \quad \text{To find the acceleration of the mass} \ m_2 \ \text{consider the forces acting on} \ m_2; \ \text{they are the tension} \ T \ \text{and the weight} \ m_2g. \ \text{Thus,} \ a_2 = (T - m_2g)/m_2. \ \text{Substituting} \ \text{the expression just derived for} \ T \ \text{and simplifying, one obtains} \ a_2 = [(m_1 - m_2)g + 2ma]/(m_1 + m_2). \ \text{To check these results consider the some limiting cases.}
1. \( a = 0; \)  2. \( m_1 = m_2 = m; \)  3. \( a = -g \) (free fall of the system).

1. Setting \( a = 0, \) \( T \) and \( a_2 \) reduce to the expression given in Problem 4-81, as they should.

2. Setting \( m_1 = m_2 = m, \) the tension in the string is \( T = m(g + a), \) as expected, and \( a_2 = a, \) as expected.

3. Setting \( a = -g, \) as in free fall, \( T = 0, \) as expected, and \( a_2 = -g, \) as expected.

The expression for \( a_1 \) is the same as for \( a_2 \) with all subscripts interchanged, i.e., \( a_1 = \frac{(m_2 - m_1)g + 2ma}{(m_1 + m_2)}. \)

The pulley in an Atwood’s machine has a mass \( m_p. \) A force \( F \) is exerted on the pulley, as shown in Figure 4-57. Find the acceleration of each mass and the tension in the string that connects them.

Consider the pulley of mass \( m_p \) as a free body, and list the forces acting on it; they are \( F, \) directed up, the tension \( T \) in each string, directed down, and \( m_p g, \) directed down. The acceleration of the pulley is therefore

\[
a_p = \frac{(F - 2T - m_p g)}{m_p}.
\]

The problem now is the same as Problem 4-105, with \( a \) replaced by \( a_p. \) Substituting the expression for \( a_p \) into the expression for \( T \) of Problem 4-105 and simplifying, one obtains

\[
T = \frac{2m_1m_2F}{m_p(m_1 + m_2) + 4m_1m_2}.
\]

To find the acceleration of the mass \( m_2, \) we again write \( a_2 = \frac{(T - m_2 g)}{m_2} \) and use the above expression for \( T \) to obtain \( a_2 = \frac{(2m_1F)}{m_p(m_1 + m_2) + 4m_1m_2} - g. \) To check, again consider special cases: 1. \( F = 0; \)  2. \( m_1 = m_2 = m \) and \( F = (2m + m_p)g; \)

1. If \( F = 0, \) the system is in free fall. \( T = 0 \) and \( a_2 = -g, \) as expected.

2. If \( m_1 = m_2 = m \) and \( F = (2m + m_p)g, \) the system is at rest. \( a_2 = 0 \) and \( T = mg, \) as expected.