

2 Motion, Forces, and Newton's Laws

CONCEPT CHECK

2.1 | Force and Motion

The motion in (a) is inconsistent with Aristotle's law of motion, Equation 2.1, since the puck slides without any force propelling it in the direction of its velocity, and (b) is inconsistent with Equation 2.1 for the same reason. The motion in (c) does appear to be consistent with Aristotle's law of motion because a piano will generally stop moving as soon as the force is removed.

2.2 | Estimating the Instantaneous Velocity

Yes, there is a value of t at which the velocity is zero in Figure 2.9. The instantaneous velocity is equal to the slope of the $x - t$ graph, and this slope is zero at $t \approx 1.6$ s in Figure 2.9.

2.3 | The Relation between Velocity and Position

Velocity is the slope of the $x - t$ curve.

- (a) The slope and velocity increase with time for graph 3 in Figure 2.13.
- (b) The slope and velocity decrease with time for graph 2.
- (c) The slope and velocity are constant (do not change with time) for graph 1.

2.4 | Analyzing a Position-Time Graph

The correct answers are (b) and (d). To understand the motion described by an $x - t$ graph, consider the behavior of the velocity as found from the slope of the $x - t$ plot. In Figure 2.18, this slope—and therefore the velocity—are largest at early times and fall to zero at the end of the motion. Hence, this object is slowing to a stop.

2.5 | Finding the Velocity

The answer is (b) Curve 2. The velocity at any point along the displacement time curve is the slope of a tangent line at that point. This slope starts positive at $t = 0$, grows less and less

positive until it is zero at the highest point, and then becomes increasingly negative, just as curve 2 does.

2.6 | Action-Reaction Force Pairs

The two forces in an action-reaction pair must act on the two objects involved in an interaction. Hence, the forces in (a) are *not* an action-reaction pair because the pitcher does not act directly on the bat. For the same reason, the forces in (c) are *not* an action-reaction pair. The forces in (b) are an action-reaction pair because they involve the two “objects” (your hands and the wall) that are involved in the interaction.

QUESTIONS

Q2.1 See Figure Qans 2.1.

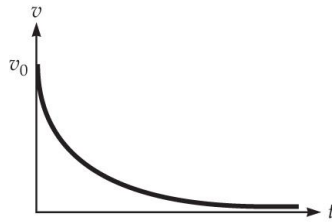
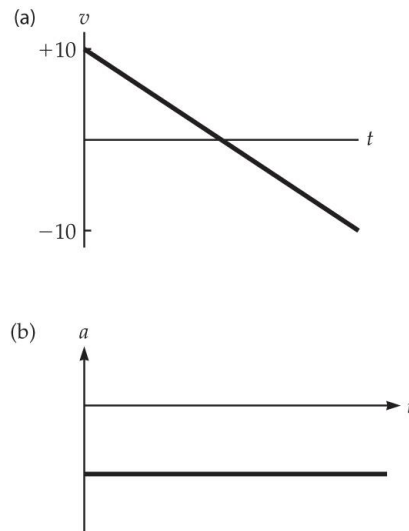


Figure QAns 2.1

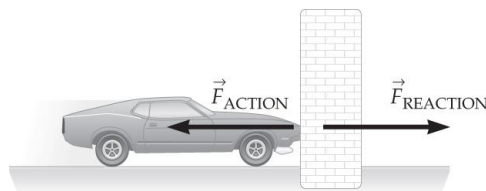
This sketch represents an object ejected from a planet into space, for example from Earth's surface. If the initial velocity is large enough, the object will always have a positive velocity. However, the acceleration is always negative (pointing toward the planet), so the velocity will diminish, but never reach zero.

Q2.2 Graphs for parts (a) and (b) are sketched below:

**Figure QAns 2.2**

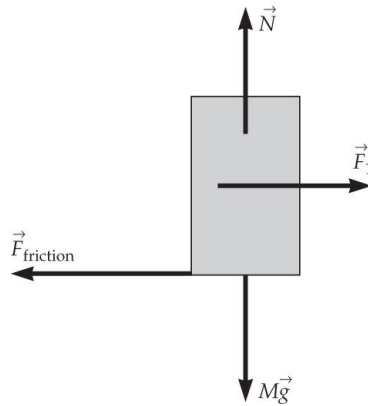
- (c) On the trip upward, it has a positive (upward) velocity, which is getting smaller in magnitude. (We would say the ball is slowing down.) This represents a negative change in velocity over time, or a negative acceleration. On the way down, the ball has a downward (negative) velocity which is INCREASING in magnitude. This also represents a negative change in velocity over time—or a negative acceleration, even though the ball is now “speeding up”!

Q2.3 See Figure QAns 2.3.

**Figure QAns 2.3**

The wall provides the force on the car to cause it to stop. The reaction force is the force provided by the car on the wall which may do damage to the wall.

Q2.4 See Figure QAns 2.4.

**Figure QAns 2.4**

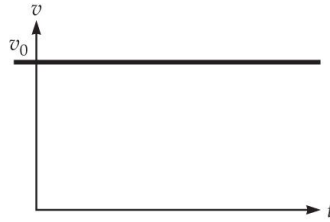
According to Newton's second law, the acceleration of the refrigerator is due to the sum of the forces on the object. Your push is countered by a frictional force of equal magnitude and opposite direction. Here the forces on the refrigerator sum to zero, so the net force on the refrigerator is zero, thus making the acceleration of the refrigerator zero as well. Newton's second law applies to the net force on an object, not just to the force you apply to the object.

Q2.5 According to Newton's first law, the only way the velocity of an object can change is if there is a net force on the object. A car changes speed and/or direction when its tires experience a force exerted by the road. If the road is too slippery, the tires can no longer apply these forces and therefore the velocity of the car does not change.

Q2.6 If the wheels of the car are slipping, they cannot apply any forces in the horizontal direction. Because there are no net forces on it, the car will remain at rest.

Q2.7 For an object orbiting at a constant speed about the origin (say a ball on the end of a string), the average velocity will be zero around the center point, but the speed will never change. A race car driving around an oval track is another example.

Q2.8 See Figure QAns2.8. An example of such a motion is when an object is moving at a constant speed in one direction.

**Figure QAns 2.8**

[SSM] Q2.9 Abracadabra! The place-settings are initially at rest (that is they have an initial velocity of 0 m/s). The principle of inertia states that a body will move with constant velocity unless acted upon by a force. Here the pulling of the tablecloth out from under the place-settings is done so quickly that the force and any associated acceleration on them is very small, and thus the place-settings barely change their velocity from 0.

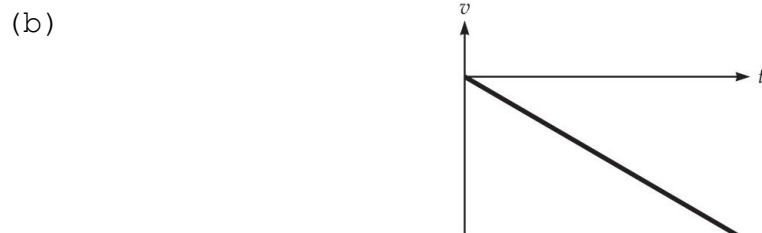
Q2.10

- (a) A spaceship leaving the surface of a planet, accelerated under the power of its engines.
- (b) An apple falling from a tree.
- (c) A car coming to rest as it approaches a stop light.

Q2.11 Yes it is possible. This happens all the time on race tracks. The cars start at the origin at $t = 0$. After just completing a lap, they have a positive velocity, but they are back at the origin, i.e., the displacement is zero.

Q2.12

- (a) Yes. The object's acceleration is a constant value, and so is the same at all times. This makes the average acceleration the same as the acceleration at any instant.

**Figure QAns 2.12b**

- (c) No. As seen in answer (b), the velocity grows more negative with time. The average velocity over an arbitrary interval

is therefore not equal to the velocity at any instant.

Q2.13 See Figure QAns 2.13.

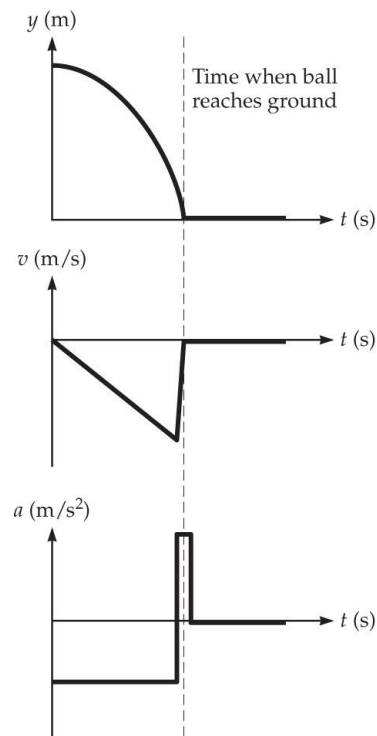
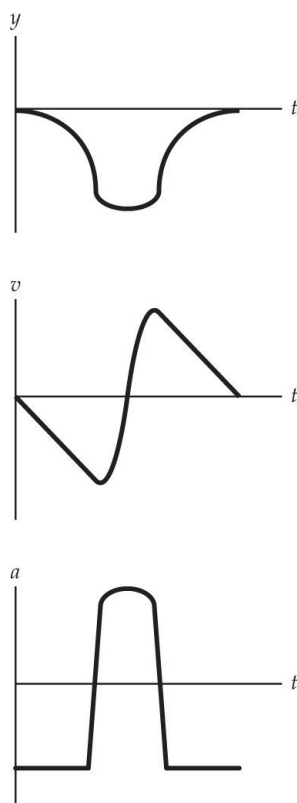


Figure QAns 2.13

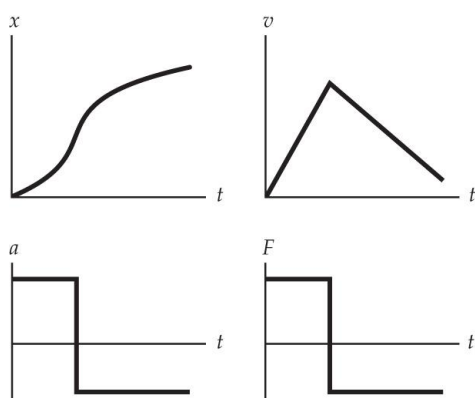
Note the large positive acceleration as the ball hits the ground.

Q2.14 See Figure QAns 2.14.

**Figure QAns 2.14**

The force on the yo-yo is nonzero except for two instants in time when the acceleration reverses direction, as seen where the acceleration vs. time curve passes through zero.

[SSM] Q2.15 See Figure QAns 2.15.

**Figure QAns 2.15**

Q2.16

(a) Yes the person is exerting a force on the ball in order to

accelerate it upward. After the ball leaves his hand, he exerts no force on the ball.

- (b) Yes the ball exerts a force on the person according to Newton's third law of motion. The direction of this force is downward.
- (c) The person does not accelerate because the Earth exerts an equal and opposite upward force on the person. The net force on the person is zero.

Q2.17

- (a) The Moon's acceleration is nonzero. The Moon's speed may be pretty close to constant, but its direction is changing at every instant in time, so it must be accelerating.
- (b) The force responsible for the Moon's acceleration is the gravitational force the Earth exerts on the Moon.

Q2.18 If there is no acceleration, then there is no net force. In the case of the marble in honey it means that the forces acting on the marble are equal but opposite in direction, so when summed as vectors they are equal to zero. In this case the force of gravity is exactly equal and opposite to the drag force.

Q2.19

- (a) Because the surface is frictionless, there are no horizontal forces and so the horizontal velocity is constant. The vertical forces (weight and normal force) do not affect the puck's horizontal motion.
- (b) Because the surface has friction, velocity is not constant, and the mug will accelerate opposite its motion.
- (c) Because the surface has friction, velocity is not constant, and the car will accelerate opposite its motion.

Q2.20

- (1) The force exerted on block 1 by the table, and the force exerted on the table by block 1.
- (2) The force exerted on block 2 by block 1 and the force exerted by block 2 on block 1.
- (3) The force exerted on block 3 by block 2 and the force exerted by block 3 on block 2.

Q2.21 See Figure QAns2.21.

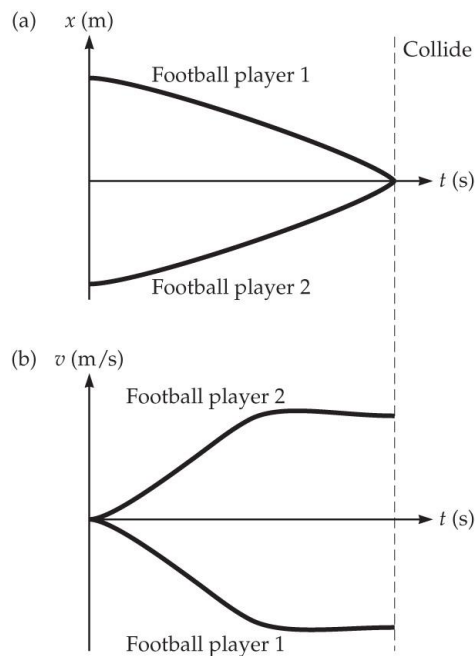


Figure QAns 2.21

Q2.22 If we let the direction the car is traveling be the positive direction, then:

- (a) When the car is speeding up, the net force is in the positive direction.
- (b) When the car is slowing down, the net force is in the negative direction.
- (c) When the car moves at a constant speed, the net force is zero.

PROBLEMS

P2.1 Recognize the principle. Apply dimensional analysis.

Sketch the problem. No sketch needed.

Identify the relationships. Dimensions of $v: \frac{L}{T}$

Solve. Since velocity is a distance per time, we can see (a), (d), (e), and (f) are all velocities.

(c) is not because it is distance cubed per distance squared

multiplied by time squared, or distance per time squared, which is an acceleration.

- (b) is not because it is distance per time squared, which is an acceleration.
- (g) is not because it will be dimensionless, since it is a distance per distance.

What does it mean? Dimensional analysis should be used to check answers for appropriate units.

P2.2 Recognize the principle. Apply unit conversion. (Section 1.4)

Sketch the problem. No sketch needed.

Identify the relationships. Using the conversion $1 \text{ mi/h} = 0.447 \text{ m/s}$, we can convert the miles per hour to m/s.

Solve. The solution to two significant figures is:

$$400 \text{ mi/h} \times \left(\frac{0.447 \text{ m/s}}{1 \text{ mi/s}} \right) = \boxed{180 \text{ m/s}}$$

What does it mean? Note that 1 m/s is approximately 2 mi/h .

P2.3 Recognize the principle. Apply dimensional analysis.

Sketch the problem. No sketch needed.

Identify the relationships. Dimensions of a : $\frac{L}{T^2}$

Solve. Since acceleration is a distance per time squared, we can see $\boxed{\text{(b), (c), (d), and (f)}}$ are all accelerations. Choice (c) is an acceleration because distance is cubed in the numerator and squared in the denominator. This cancels to leave distance in the numerator and time squared in the denominator, which are the dimensions of acceleration.

- (a) is not because it represents distance per time, which is a velocity.
- (e) is not because it also represents distance per time, which is again a velocity.

What does it mean? Dimensional analysis should be used to check answers for appropriate units.

P2.4 Recognize the principle. Apply unit conversion. (Section 1.4)

Sketch the problem. No sketch needed.

Identify the relationships. Looking up the conversion $1 \text{ m} = 3.28 \text{ ft}$ and applying this, we can calculate the acceleration in ft/s^2 .

Solve.

$$a = 9.8 \text{ m/s}^2 \times \left(\frac{3.28 \text{ ft}}{1 \text{ m}} \right) = \boxed{32 \text{ ft/s}^2}$$

What does it mean? This is the average value of the gravitational acceleration, the downward acceleration near the Earth's surface. You will use this acceleration frequently in future chapters.

P2.5 Recognize the principle. The average speed is the total distance traveled per time.

Sketch the problem. No sketch needed.

Identify the relationships. The average speed is defined by:

$$|v_{\text{ave}}| = \frac{d}{t}$$

Solve. Inserting the given values:

$$|v_{\text{ave}}| = \frac{1500 \text{ m}}{215 \text{ s}} = \boxed{7.0 \text{ m/s}}$$

What does it mean? Since speed is a distance per time, this tells us nothing about the direction in which the runner moved.

*** [Life Sci] P2.6 Recognize the principle.** Apply graphical analysis of motion, including the definitions of velocity and acceleration.

Sketch the problem. See Figure Ans 2.6.

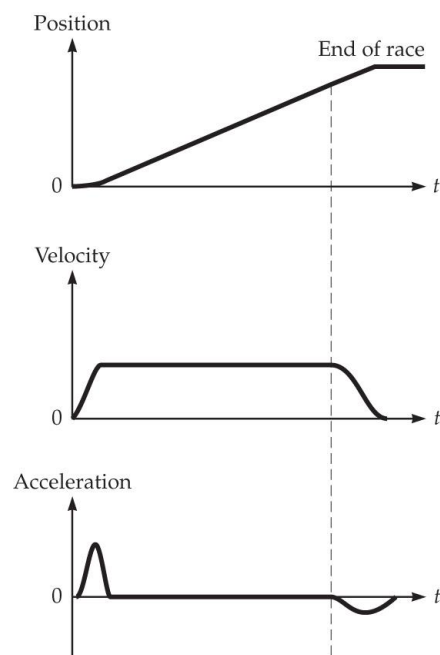


Figure Ans 2.6

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figure Ans2.6. The runner will want to quickly accelerate (large positive acceleration, assuming the direction down the track is positive). Then assume approximately constant velocity until the finish, followed by a more gradual slowdown after the finish line (smaller negative acceleration).

What does it mean? While these graphs assume constant velocity during most of the race, the runner's strategy might involve a further acceleration before the finish.

*** P2.7 Recognize the principle.** Analysis of motion. (Section 2.2)

Sketch the problem. No sketch needed.

Identify the relationships. His average velocity can be found using the definition of average velocity: the total distance traveled, Δx_{tot} , divided by the time it took to travel that distance, $\Delta t_{\text{tot}} = \Delta t_1 + \Delta t_2 + \Delta t_3$

Solve.

$$(a) \quad \Delta x_{\text{tot}} = \Delta x_1 + \Delta x_2 + \Delta x_3 = 200 \text{ m} + 0 \text{ m} + 50 \text{ m} = 250 \text{ m}$$

$$\Delta x_1 = \frac{\Delta x_1}{v_1} = \frac{200 \text{ m}}{3.0 \text{ m/s}} = 67 \text{ s}, \Delta t_2 = 30 \text{ s}$$

and

$$\Delta t_3 = \frac{\Delta x_3}{v_3} = \frac{50 \text{ m}}{3.5 \text{ m/s}} = 14 \text{ s}$$

$$\Delta t_{\text{tot}} = \Delta t_1 + \Delta t_2 + \Delta t_3 = 67 \text{ s} + 30 \text{ s} + 14 \text{ s} = 111 \text{ s}$$

$$v_{\text{ave}} = \frac{\Delta x_{\text{tot}}}{\Delta t_{\text{tot}}} = \frac{250 \text{ m}}{111 \text{ s}}$$

$$v_{\text{ave}} = \boxed{2.3 \text{ m/s}}$$

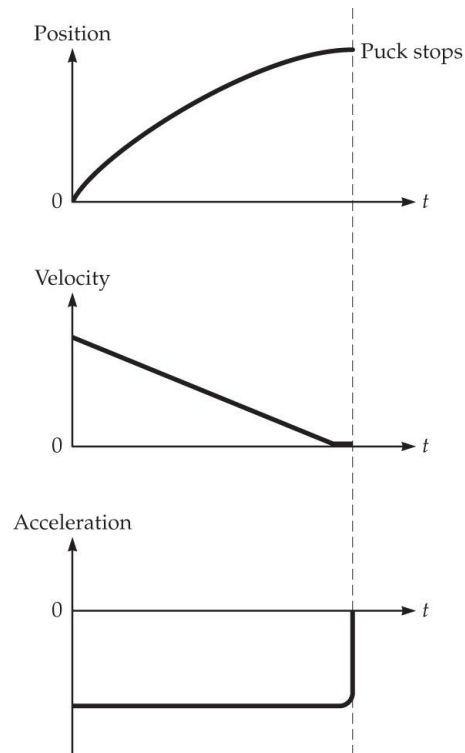
- (b) The minimum velocity was when he was waiting at the stoplight, $v_{\text{min}} = \boxed{0 \text{ m/s}}$, and the maximum was $\boxed{3.5 \text{ m/s}}$.

The average was closer to the maximum.

What does it mean? Note that the jogger did not run at the average velocity for any significant period of time (perhaps only an instant). This problem is useful in illustrating the difference between an average velocity and instantaneous velocity. The fact that the 30 seconds of zero velocity is included in the average makes an important point.

*** P2.8 Recognize the principle.** Apply graphical analysis of motion, including the definitions of velocity and acceleration.

Sketch the problem. See Figure Ans 2.8.

**Figure Ans 2.8**

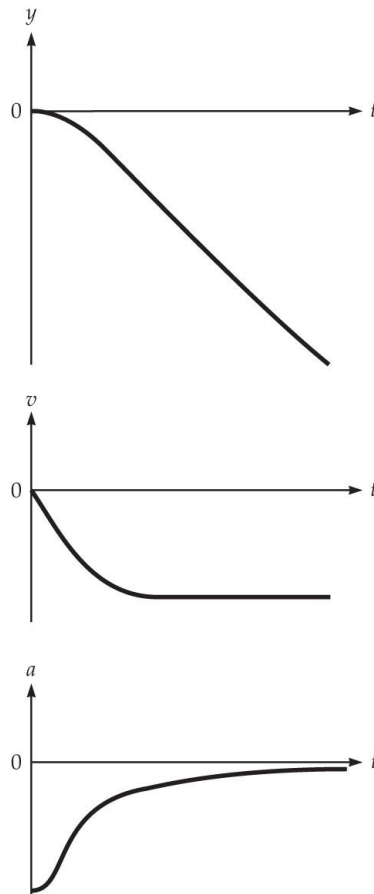
Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figure Ans2.8. These graphs are sketched assuming that the direction of motion of the puck is the positive direction. The frictional force (and acceleration) will be nearly constant for this motion.

What does it mean? Note that the acceleration is negative because the puck is moving in the positive direction and slowing down. The acceleration caused by friction will only exist until the puck comes to rest.

*** P2.9 Recognize the principle.** Apply graphical analysis of motion.

Sketch the problem. See Figure Ans2.9.

**Figure Ans 2.9**

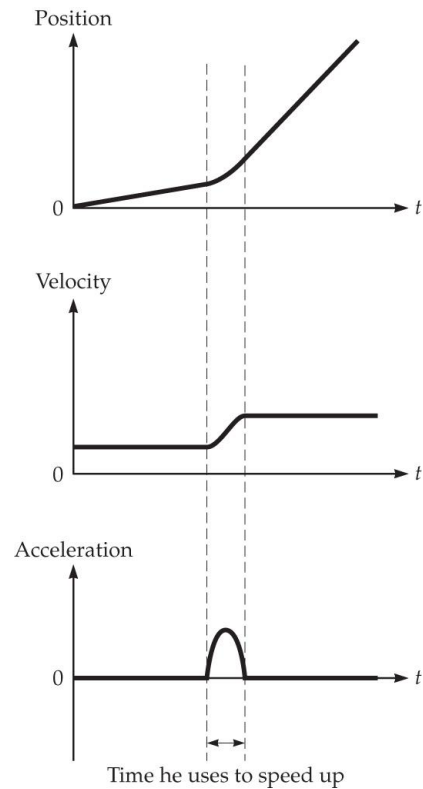
Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figure Ans2.9. Here the acceleration is not constant.

What does it mean? After accelerating at first, the marble descends in the molasses at a constant velocity.

*** P2.10 Recognize the principle.** Apply graphical analysis of motion, including the definitions of velocity and acceleration.

Sketch the problem. See Figure Ans 2.10.

**Figure Ans 2.10**

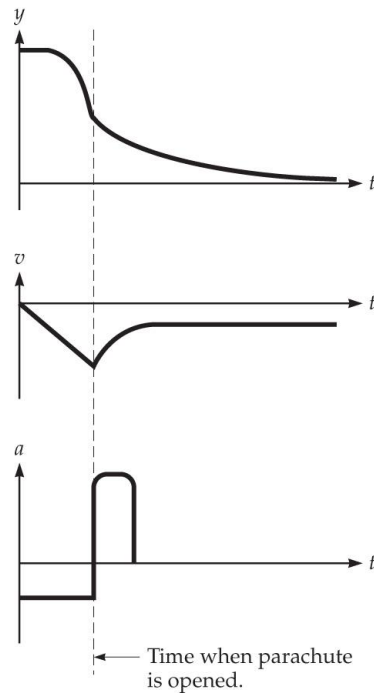
Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figure Ans2.10, which is sketched assuming that the direction of motion is in the positive direction. Here the acceleration is not constant.

What does it mean? If the skateboard has very low friction, the motion has close to zero acceleration except for the short time interval when the rider pushes on the ground.

*** P2.11 Recognize the principle.** Apply graphical analysis of motion.

Sketch the problem. See Figure Ans 2.11.

**Figure Ans 2.11**

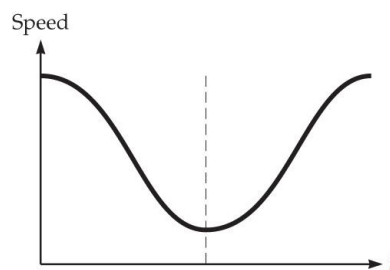
Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figure Ans2.11.

What does it mean? Here the acceleration is not constant. It actually reverses direction for a short time when the chute is first opened and then goes to zero. Note that zero acceleration does not imply zero velocity. The final velocity (before touch down) is called terminal velocity.

*** P2.12 Recognize the principle.** Apply graphical analysis of motion, including the definitions of velocity and acceleration.

Sketch the problem. See Figure Ans 2.12.

**Figure Ans 2.12**

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figure Ans2.12.

What does it mean? The actual amount of acceleration (rate of change of speed) that the skier will experience depends on the slope of the ground under her skis at each position on the hill. Note that the speed is not necessarily zero at the top of the hill.

[SSM] * P2.13 Recognize the principles. Since the dots represent the location of an object between equal time intervals, then as the object's speed increases the spacing between the dots also increases. Similarly, as the object slows down the spacing between the dots decreases.

Sketch the problem. Figure P2.13 provides the diagrams to analyze. Figure Ans2.13 provides sketches of the motion as part of the solution to the problem.

Identify the relationships. The diagrams in Figure P2.13 give the position of the object as a function of time. Graphs of x vs. t can be made using these diagrams. Then, the velocity is the rate of change of position (slope of the tangent to the x vs. t curve), and the acceleration is the rate of change of velocity (slope of the tangent to the v vs. t curve).

Solve. See Figure Ans 2.13(1-3).

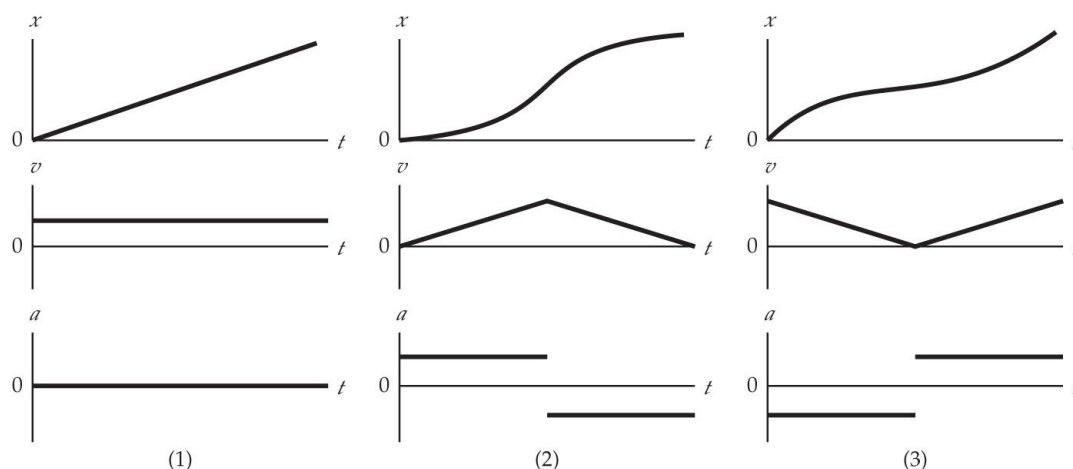


Figure Ans 2.13

What does it mean? It's rather impressive to see that from a series of dots representing the positions of an object we're able to determine how the object's position, velocity, and acceleration vary as functions of time!

*** P2.14 Recognize the principle.** Apply graphical analysis of motion, including the definitions of velocity and acceleration.

Sketch the problem. See Figure Ans 2.14.

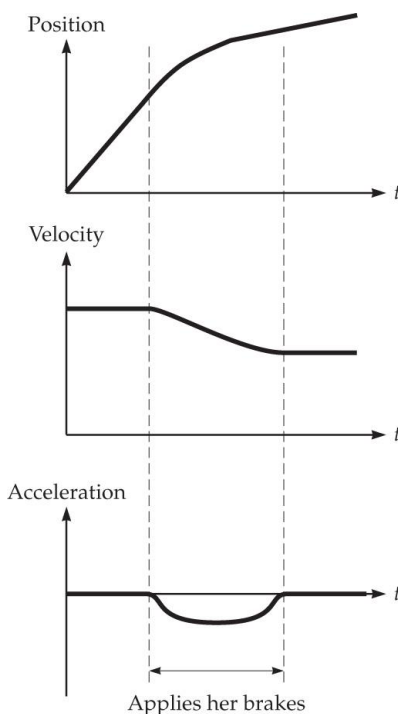


Figure Ans 2.14

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. In Figure Ans2.14, the positive direction is taken as the direction of her motion. Therefore, the acceleration when her brakes are applied is negative.

What does it mean? Note that if all other friction is negligible, the acceleration is zero when the bike is coasting at either speed, and negative when the bike is slowing down.

*** P2.15 Recognize the principle.** Apply graphical analysis of motion, in particular the definition of instantaneous velocity as the slope of the tangent line drawn to the position vs. time curve.

Sketch the problem. See Figure Ans 2.15.

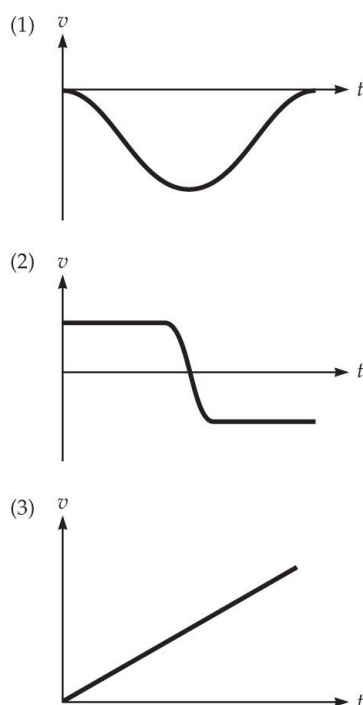


Figure Ans 2.15

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figure Ans 2.15.

What does it mean? Note that in Cases 1 and 2, at least part of the motion is toward the origin (negative velocity), while in Case 3, the motion is always away from the origin.

*** P2.16 Recognize the principle.** Note: This is an open-ended problem with no unique answer. Apply graphical analysis of motion, including the definitions of velocity and acceleration.

Sketch the problem. Use Figure P2.15.

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve.

- (1) This object started from rest, moved in the negative x direction and then ended at rest at a closer distance to the origin. This could be a car at rest at its destination, beginning its journey back home at a constant velocity and

ending at rest, where the positive direction is from home to its destination.

- (2) This object was headed in the positive x direction at a constant speed, reversed its direction, and headed back to its original position at a constant speed. It could be a ball heading toward a tennis racket, and hit back at a somewhat faster speed. The positive direction is toward the racket.
- (3) This object looks like it has a steadily increasing velocity, and a constant, positive acceleration. It could be a rocket moving with constant acceleration in space.

What does it mean? While a sketch of a position vs. time graph cannot tell you exact information about the velocity and acceleration of an object, it can give you an idea about these quantities.

*** P2.17 Recognize the principle.** Apply graphical analysis of motion, in particular the definition of the instantaneous acceleration as the slope of the tangent line to the velocity vs. time curve.

Sketch the problem. See Figures P2.17 and Ans 2.17.

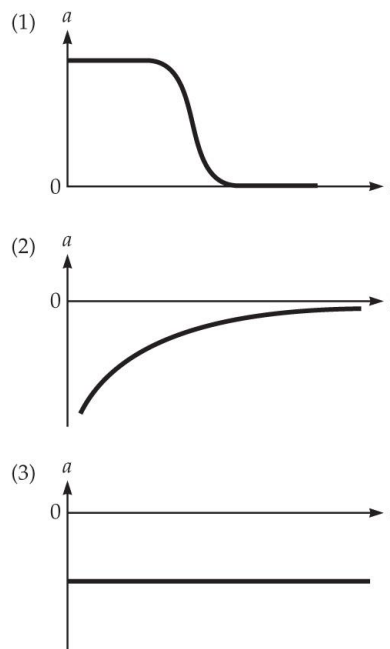


Figure Ans 2.17

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figure Ans 2.17.

What does it mean? Note that in Case 2, the velocity is always decreasing, while in Case 3 the velocity is always becoming more negative. Both of these situations are represented by a negative acceleration. Only in Case 1 does the velocity increase during part of the motion, and this is the only Case in which a portion of the acceleration vs. time graph is positive.

*** P2.18 Recognize the principle.** Apply graphical analysis of motion, including the definitions of velocity and acceleration.

Sketch the problem. See Figures P2.17 and Ans 2.18.

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figure Ans 2.18 for one possible answer. The slope of the position vs. time graph at any time must correspond to the instantaneous velocity at that time.

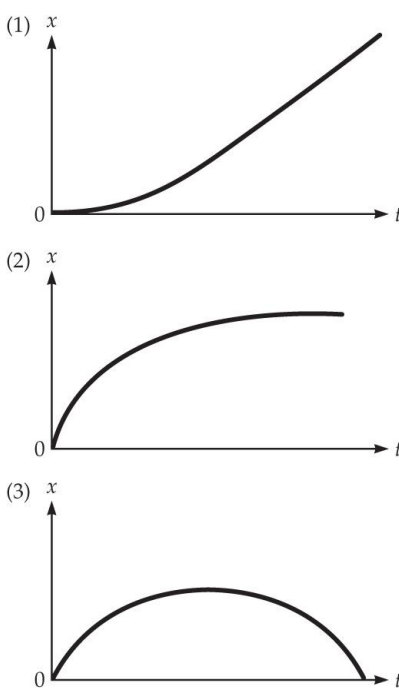


Figure Ans 2.18

What does it mean? Notice that the velocity vs. time graph does not tell you the position at the initial time. In other words, the graphs in Figure Ans 2.18 are not unique, but could be shifted up or down by the initial position value.

*** P2.19 Recognize the principle.** Note: This is an open-ended problem with no unique answer. Apply graphical analysis of motion.

Sketch the problem. See Figure P2.17.

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve

Case 1: An example is a car starting from a traffic light (at rest), accelerating to the speed limit, and then traveling at that speed.

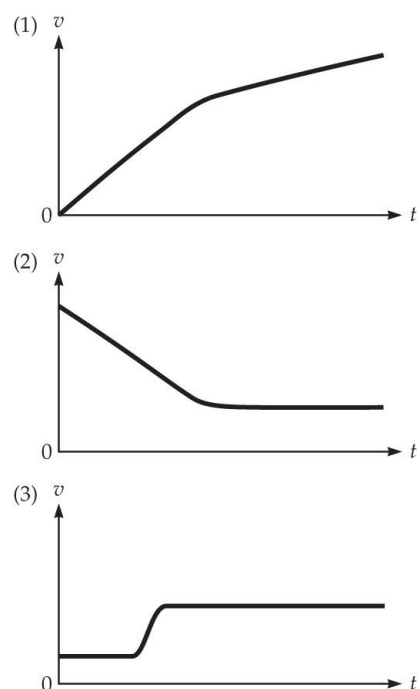
Case 2: An example is a car slowing to a stop at a traffic light. Note that the acceleration is not constant here, so the car slows down rapidly at first, and then more and more slowly.

Case 3: An example is a ball thrown upward. The ball starts with some initial velocity that decreases linearly due to gravity. The ball stops at the top, then reverses direction and falls downward, with an ever increasing speed (more negative velocity).

What does it mean? A velocity vs. time graph yields considerable information about the motion of an object.

*** P2.20 Recognize the principle.** Apply graphical analysis of motion, including the definitions of velocity and acceleration.

Sketch the problem. See Figures P2.20 and Ans 2.20 for one possible answer.

**Figure Ans 2.20**

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figure Ans 2.20. The slope of the velocity vs. time graph at any time must correspond to the instantaneous acceleration at that time.

What does it mean? Notice that the acceleration vs. time graph does not tell you the velocity at the initial time. In other words, the graphs in Figure Ans 2.20 are not unique, but could be shifted up or down by the initial velocity value.

*** P2.21 Recognize the principle.** Apply graphical analysis of motion.

Sketch the problem. See Figures P2.20.

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve.

(1) A driver keeps his foot steady on the gas pedal to keep the car moving at constant acceleration. The driver then shifts gears and the car is still accelerating, but the value of a is then smaller than at the start.

(2) A motorist applies his brakes so as to slow down to match the speed of a car in front of him. Afterwards the motorist continues at constant speed.

(3) An example is a car moving at constant velocity in a lane on the freeway when the driver decides to momentarily accelerate and change to a faster-moving lane. The driver then continues at a constant, but greater speed.

What does it mean? Notice that only in Case 2 is there a region in which the motion is slowing down. Even though Cases 1 and 3 have accelerations that increase and/or decrease, the acceleration is always positive or zero.

*** P2.22 Recognize the principle.** Apply graphical analysis of motion, including the definition of velocity.

Sketch the problem. See Figure P2.22.

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve.

- (a) A person beginning a race is accelerating from rest, perhaps with a nearly constant acceleration. Because the slope of the tangent to Case 2 is increasing, this corresponds to an increasing velocity.
- (b) After crossing the finish line, a runner is slowing down until she is at rest. Because the slope of the tangent to Case 4 is decreasing, this corresponds to a decreasing velocity.
- (c) Only Case 3 represents motion in which the position decreases and then increases several times. Thus, this must represent the bouncing ball.
- (d) After leaving a bowler's hand, the ball will roll down the alley with a velocity that is nearly constant. Case 1 has a constant slope, indicating a constant velocity.

(a) Case 2, (b) Case 4, (c) Case 3, and (d) Case 1

What does it mean? By examining the slope of the tangent at points on a position vs. time graph, it is possible to determine how the velocity is changing. This tells a lot about the motion.

*** P2.23 Recognize the principle.** Apply graphical analysis of motion.

Sketch the problem. See Figures P2.22 and P2.23.

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve.

Figure P2.23 Case 1 matches the bowling ball, example d) from 2.22.

Figure P2.23 Case 2 matches the runner beginning the race, example a) from 2.22.

Figure P2.23 Case 3 matches the bouncing ball, example c) from 2.22.

Figure P2.23 Case 4 matches the runner slowing down after race, example b) from 2.22.

What does it mean? A graph of the instantaneous velocity can be made by examining the description of the behavior of the velocity over time.

*** P2.24 Recognize the principle.** Apply graphical analysis of motion, including the definition of velocity as the rate of change of position.

Sketch the problem. See Figures P2.24 and Ans 2.24.

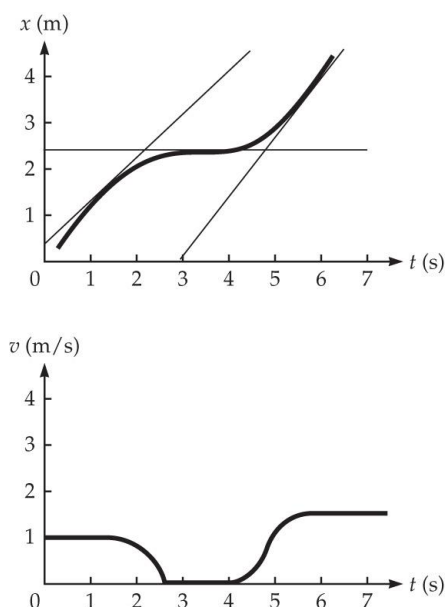


Figure Ans 2.24

Identify the relationships. Use the graphical techniques as discussed in Section 2.2, namely that the instantaneous velocity at a given time is the slope of the tangent to the position vs. time graph at that time.

Solve. The graph in Figure P2.24 has two segments of approximately constant velocity motion, the segments from $t = 0.0$ to $t = 1.8$ s, and the segments from $t = 5.0$ to $t = 6.2$ s. For the first segment, the left line has a slope of approximately

$$v = \frac{\Delta x}{\Delta t} = \frac{4.5 \text{ m} - 0.4 \text{ m}}{4.5 \text{ s} - 0.0 \text{ s}} = 0.9 \text{ m/s}$$

For the second segment, the right line has a slope of approximately

$$v = \frac{\Delta x}{\Delta t} = \frac{4.5 \text{ m} - 0 \text{ m}}{6.5 \text{ s} - 3.0 \text{ s}} = 1.3 \text{ m/s}$$

For the time interval $t = 2.5$ to $t = 4.0$ s, the tangent line is horizontal, and the slope of the tangent is zero. To find several velocities for the segments of the velocity vs. time graph between $t = 1.8$ and 2.5 s and between $t = 4.0$ and $t = 5.0$ s, it is necessary to draw tangents to the curve at several times, and find the slopes. These values have been incorporated into Figure Ans2.24.

The maximum velocity of the object during the entire interval is during the rightmost segment of the graph,

$$v_{\text{max}} = \boxed{1.3 \text{ m/s}}$$

What does it mean? Approximate values of the instantaneous velocity of an object can easily be calculated from the slope of the tangent to the position vs. time curve.

P2.25 Recognize the principle. Use the definition of average velocity.

Sketch the problem. Use Figure P2.24.

Identify the relationships. The definition of average velocity is

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t}$$

Solve. Applying the definition of average velocity to the two intervals, we can estimate the velocity. The intervals of position can be estimated from the graph in Figure P2.24.

$$(a) \quad v_{\text{ave}} = \frac{\Delta x}{\Delta t} = \frac{2.4 \text{ m} - 2.0 \text{ m}}{4.0 \text{ s} - 2.0 \text{ s}} = \boxed{0.2 \text{ m/s}}$$

$$(b) \quad v_{\text{ave}} = \frac{\Delta x}{\Delta t} = \frac{2.8 \text{ m} - 1.3 \text{ m}}{5.0 \text{ s} - 1.0 \text{ s}} = \boxed{0.4 \text{ m/s}}$$

What does it mean? Notice that the average velocity over a time interval is the slope of the line joining the two points on the position vs. time curve, while the instantaneous velocity is the slope of a tangent drawn at a point.

P2.26 Recognize the principle. Apply graphical analysis of motion, including the definition of velocity as the rate of change of position.

Sketch the problem. See Figures P2.26 and Ans 2.26 (a) and (b).

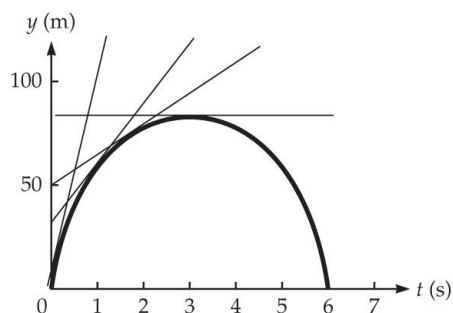


Figure Ans 2.26a

Identify the relationships. Use the graphical techniques as discussed in Section 2.2, namely that the instantaneous velocity at a given time is the slope of the tangent to the position vs. time graph at that time.

Solve. See Figure Ans 2.26. Four tangents are drawn, the tangent line at $t = 0$, the tangent line at $t = 1.0 \text{ s}$, the tangent line at $t = 1.5 \text{ s}$, and the tangent line at $t = 3.0 \text{ s}$. Thus, the velocities at these times are

$$v_0 = \frac{\Delta x}{\Delta t} = \frac{120 \text{ m} - 0 \text{ m}}{1.2 \text{ s} - 0 \text{ s}} = 100 \text{ m/s}$$

$$v_1 = \frac{\Delta x}{\Delta t} = \frac{120 \text{ m} - 31 \text{ m}}{3.0 \text{ s} - 0 \text{ s}} = 30 \text{ m/s}$$

$$v_{1.5} = \frac{\Delta x}{\Delta t} = \frac{120 \text{ m} - 50 \text{ m}}{4.5 \text{ s} - 0 \text{ s}} = 16 \text{ m/s}$$

$$v_3 = 0$$

This procedure is carried out at enough points along the curve to be able to plot velocity vs. time. Since the position vs. time graph is symmetrical about $t = 3 \text{ s}$, values of velocity only need be calculated between $t = 0$ and $t = 3 \text{ s}$. The resulting graph is in Figure Ans 2.26(b).

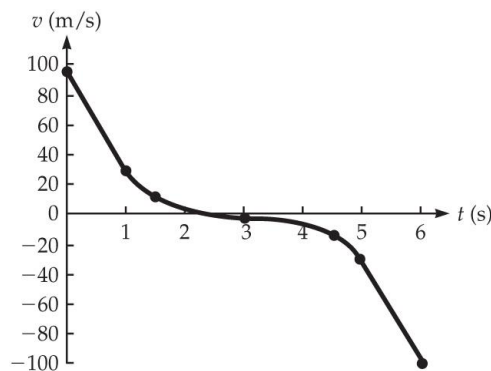


Figure Ans 2.26b

The maximum velocity is at $t = 0$, and its approximate value is

$$v_{\max} = 100 \text{ m/s}$$

What does it mean? Approximate values of the instantaneous velocity of an object can easily be calculated from the slope of the tangent to the position vs. time curve.

P2.27 Recognize the principle. Apply graphical analysis of motion, specifically the definition of acceleration.

Sketch the problem. See Figure P2.27.

Identify the relationships. The velocity curve here is a linear relationship. The slope of the curve at 3 s (the instantaneous acceleration) is the same as the slope of the entire curve. Since the velocity is changing at a constant rate, the acceleration is constant and given by:

$$a = \frac{\Delta v}{\Delta t}$$

Solve. Taking the rise over the run of the line in Figure P2.27,

$$a = \frac{(-60 \text{ m/s}) - (-10 \text{ m/s})}{(6.0 \text{ s}) - (1.0 \text{ s})} = \frac{-50 \text{ m/s}}{5.0 \text{ s}} = -10 \text{ m/s}^2$$

We find the acceleration at $t = 3.0 \text{ s}$ to be $\boxed{-10 \text{ m/s}^2}$.

What does it mean? The motion of the brick is with constant acceleration, so the velocity increases by equal amounts every second.

*** P2.28 Recognize the principle.** Apply graphical analysis of motion, and specifically the definition of acceleration.

Sketch the problem. Use Figure P2.28 and Figure Ans 2.28.

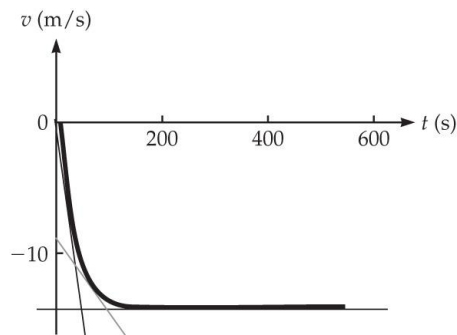


Figure Ans 2.28

Identify the relationships. The slope at any given point on the graph is equal to the instantaneous acceleration at that time. We can draw tangent lines to the velocity vs. time curve at a given time, and calculate the slope of the tangent to find the acceleration at that time:

$$a = \frac{\Delta v}{\Delta t}$$

Solve. Three tangent lines are drawn. Over the time interval $t = 0 \text{ s}$ to $t = 40 \text{ s}$, the curve is fairly linear and we can use the slope of the line with negative slope line as the acceleration:

$$a = \frac{\Delta v}{\Delta t} = \frac{-16 \text{ m/s} - 0 \text{ m/s}}{60 \text{ s} - 0 \text{ s}} = -0.3 \text{ m/s}^2$$

Over the interval 150 to 550 s, the tangent is a horizontal line, and the slope and acceleration are 0. The rate of change of the velocity changes rapidly between 40 and 150 s. At $t = 60$ s, for example, the grey line is the tangent. Its slope is

$$a = \frac{\Delta v}{\Delta t} = \frac{-16 \text{ m/s} - (-9) \text{ m/s}}{130 \text{ s} - 0 \text{ s}} = -0.05 \text{ m/s}^2$$

What does it mean?

So, in summary, the acceleration begins with its largest negative value for the first roughly 40 s, changes to smaller and smaller negative values from 40 s to roughly 150 s, and then is zero for the rest of the motion.

P2.29 Recognize the principle. This problem requires the determination of acceleration from a velocity vs. time graph. Apply graphical analysis of motion, and specifically the definition of average acceleration.

Sketch the problem. Use Figure P2.28.

Identify the relationships. The average acceleration over a time interval is given by

$$a_{\text{ave}} = \frac{\Delta v}{\Delta t}$$

Solve. For the time interval $t = 0$ to $t = 50$ s, estimating velocity values from the graph

$$a_{\text{ave}} = \frac{\Delta v}{\Delta t} = \frac{25 \text{ m/s} - 10 \text{ m/s}}{50 \text{ s} - 0 \text{ s}} = \boxed{0.3 \text{ m/s}^2}$$

For the time interval $t = 100$ to $t = 200$ s, estimating velocity values from the graph

$$a_{\text{ave}} = \frac{\Delta v}{\Delta t} = \frac{30 \text{ m/s} - 8 \text{ m/s}}{200 \text{ s} - 100 \text{ s}} = \boxed{0.2 \text{ m/s}^2}$$

What does it mean? Notice that the average velocity over a time interval is the slope of the line joining the two points on the position vs. time curve, while the instantaneous velocity is the slope of a tangent drawn at a point.

*** P2.30 Recognize the principle.** Apply graphical analysis of motion.

Sketch the problem. See Figures P2.28-29 and Ans 2.30a-b for one possible answer.

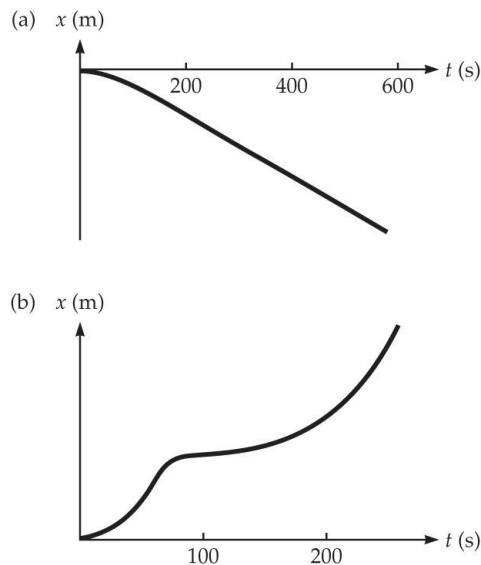


Figure Ans 2.30

Identify the relationships. Use the graphical techniques as discussed in Section 2.2, specifically the relationship between velocity and position. Therefore, the slope of the tangent to the position vs. time graph at any time is equal to the velocity at that point. Keep in mind that these graphs could shift up or down depending on the initial position.

Solve. In Figure P2.28, the velocity is always negative. Therefore, the position vs. time graph must always have a negative slope that decreases until after around 150 s where it has a constant negative slope (no change in velocity). Figure Ans 2.30(a) is sketched to have these properties.

In Figure P2.29, the velocity is always positive. Therefore, the position vs. time graph must always have a positive slope that changes according to the changes in velocity. Figure Ans 2.30(b) is sketched to have these properties.

What does it mean? Don't be fooled by the slope of the velocity vs. time graph which in Figure P2.28 changes from negative to zero and in Figure P2.29 changes from positive to negative several times. It is the slope of the position vs. time graph that must match the values on the velocity vs. time graph.

*** P2.31 Recognize the principle.** Apply graphical analysis of motion, and in particular the definitions of acceleration and velocity.

Sketch the problem. See Figure Ans 2.31.

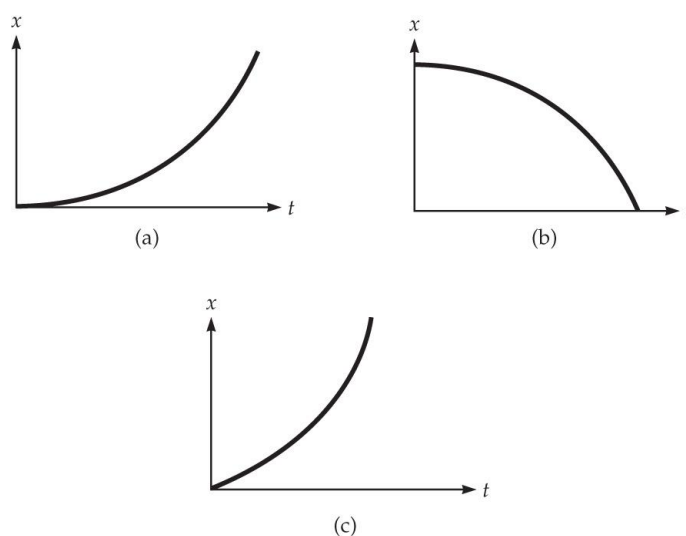


Figure Ans 2.31

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figures Ans 2.31a-c.

What does it mean? Knowing how the acceleration varies in time allows you to sketch the shape of the position vs. time graph (and the velocity vs. time graph).

P2.32 Recognize the principle. Use the definition of average velocity.

Sketch the problem. No sketch needed.

Identify the relationships. The definition of average velocity is

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t}$$

Solve. Applying the average velocity equation to the two time intervals, you can estimate the average velocities.

For the interval from $t = 0$ to $t = 5$ s,

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t} = \frac{(100 \text{ m}) - (25 \text{ m})}{5.0 \text{ s} - 0.0 \text{ s}} = \boxed{15 \text{ m/s}}$$

For the interval from $t = 5$ to $t = 8$ s,

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t} = \frac{(300 \text{ m}) - (100 \text{ m})}{8.0 \text{ s} - 5.0 \text{ s}} = \boxed{67 \text{ m/s}}$$

What does it mean? Since the car covers a much larger distance in the last 3 seconds than in the first 5 seconds, it is not surprising that the average velocity increases from the first interval to the second.

*** [SSM] P2.33 Recognize the principle.** Use the concepts of average velocity and average acceleration.

Sketch the problem. Figure Ans 2.33.

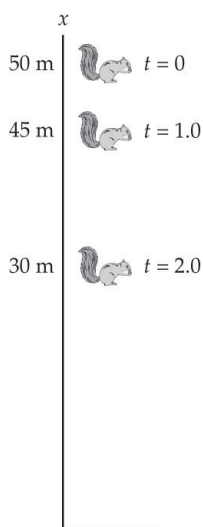


Figure Ans 2.33

Identify the relationships. Use the definition of average velocity,

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t}$$

and average acceleration,

$$a_{\text{ave}} = \frac{\Delta v}{\Delta t}$$

Solve. For the interval from $t = 0$ to $t = 1$ s,

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t} = \frac{(45 \text{ m}) - (50 \text{ m})}{1.0 - 0 \text{ s}} = \boxed{-5 \text{ m/s}}$$

For the interval from $t = 1$ to $t = 2$ s,

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t} = \frac{(30 \text{ m}) - (45 \text{ m})}{2.0 \text{ s} - 1.0 \text{ s}} = \boxed{-15 \text{ m/s}}$$

Using the average velocities just calculated, which can be taken as the velocity at the center of each time interval, we can find the average acceleration,

$$a_{\text{ave}} = \frac{\Delta v}{\Delta t} = \frac{(-15 \text{ m/s}) - (-5.0 \text{ m/s})}{1.5 \text{ s} - 0.5 \text{ s}} = \boxed{-10 \text{ m/s}^2}$$

What does it mean? Since the positive direction is upward, and the squirrel falls 5 m in the first second and 15 m in the second, it is expected that it has a nonzero, negative acceleration.

P2.34 Recognize the principle. Use the concepts of average speed and average velocity.

Sketch the problem. No sketch needed.

Identify the relationships. Use the definitions of average speed

$$\text{average speed} = \frac{\text{distance traveled}}{\text{time interval}}$$

and average velocity

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t}$$

Solve.

- (a) The total distance the space shuttle travels is 18 times the length of the circular orbit. The time to travel this distance is 24 hours and 15 minutes.

$$|v_{\text{ave}}| = \frac{18 \times 2\pi r}{24.25 \text{ h}}$$

with r being the radius of the orbit. The average speed is then,

$$|v_{\text{ave}}| = \frac{18 \times 2\pi(6.7 \times 10^6 \text{ m})}{24.25 \text{ h}} \times \frac{1 \text{ h}}{3600 \text{ s}}$$

$$|v_{\text{ave}}| = \boxed{8.7 \times 10^3 \text{ m/s}}$$

- (b) The total displacement is zero, since the space shuttle started at Cape Canaveral and ended at Cape Canaveral. Therefore, the average velocity is $\boxed{0 \text{ m/s}}$.

*** P2.35 Recognize the principle.** Apply graphical analysis of motion, and in particular the definitions of average and instantaneous acceleration.

Sketch the problem. See Figure Ans 2.35.

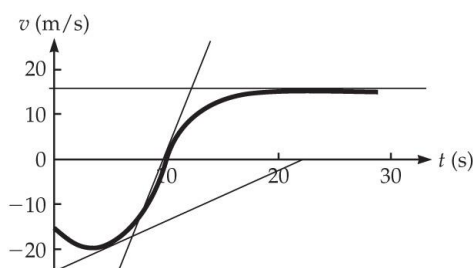


Figure Ans 2.35

Identify the relationships. Average acceleration is given by Equation 2.6, $a_{\text{ave}} = \frac{\Delta v}{\Delta t}$, and instantaneous acceleration is given by the slope of the tangent to a graph of velocity vs. time.

Solve.

- (a) From the graph, the velocity at $t = 0$ is -15 m/s and the velocity at $t = 20 \text{ s}$ is 15 m/s . Therefore,

$$a_{\text{ave}} = \frac{15 \text{ m/s} - (-15 \text{ m/s})}{20 \text{ s} - 0 \text{ s}}$$

$$a_{\text{ave}} = \boxed{1.5 \text{ m/s}^2}$$

Using the slopes of the tangents for parts (b)–(d):

- (b) The slope at $t = 5.0 \text{ s}$ is

$$a = \frac{\Delta v}{\Delta t} = \frac{0 \text{ m/s} - (-25 \text{ m/s})}{22 \text{ s} - 0 \text{ s}} = \boxed{1.1 \text{ m/s}^2}$$

(c) The slope at $t = 10.0$ s is

$$a = \frac{\Delta v}{\Delta t} = \frac{25 \text{ m/s} - (-25 \text{ m/s})}{13.5 \text{ s} - 5.5 \text{ s}} ; \boxed{6.3 \text{ m/s}^2}$$

(d) Since the curve is a horizontal line at $t = 20$ s the slope is $\boxed{0 \text{ m/s}^2}$.

What does it mean? The average acceleration is calculated from the change in velocity divided by the time interval, while the instantaneous acceleration is the slope of the tangent to the velocity vs. time curve.

*** P2.36 Recognize the principle.** Apply graphical analysis of motion, in particular the relationship between velocity and acceleration.

Sketch the problem. Use Figure P2.36.

Identify the relationships. The graph shows two regions of constant acceleration. For these,

$$a = a_{\text{ave}} = \frac{\Delta v}{\Delta t}$$

and,

$$\Delta v = a\Delta t$$

Solve.

(a) The acceleration is constant over the range of $t = 0$ s to $t = 10$ s. During the interval $t = 0$ s to $t = 10$ s, $a = 5.0 \text{ m/s}^2$. The change in velocity is

$$\Delta v = v(t) - v(0) = a\Delta t = (5.0 \text{ m/s}^2)(t - 0 \text{ s}) = (5.0 \text{ m/s}^2)t$$

Since the velocity at $t = 0$, $v(0)$, is given as zero,

$$\boxed{v(t) = (5.0 \text{ m/s}^2)t \quad \text{for } 0 < t < 10 \text{ s}}$$

From $t = 10$ s to $t = 26$ s, the acceleration is constant at 15 m/s^2 so,

$$\Delta v = v(t) - v(10 \text{ s}) = a\Delta t = (15 \text{ m/s}^2)(t - 10 \text{ s}) = (15 \text{ m/s}^2)t - 150 \text{ m/s}$$

From the first part,

$$v(10 \text{ s}) = 50 \text{ m/s}$$

Therefore,

$$v(t) = (15.0 \text{ m/s}^2)t - 100 \text{ m/s} \text{ for } 10 < t < 26 \text{ s}$$

- (b) If the initial velocity is increased to 40 m/s, then $v(0) = 40 \text{ m/s}$. The only change would be to add 40 m/s to each equation, i.e.,

$$v(t) = \begin{cases} (5.0 \text{ m/s}^2)t + 40 \text{ m/s} & \text{for } 0 \text{ s} < t < 10 \text{ s} \\ (15 \text{ m/s}^2)t - 60 \text{ m/s} & \text{for } 10 \text{ s} < t < 10 \text{ s} \end{cases}$$

What does it mean? Note that for a constant acceleration, the velocity is just a linear function of time.

*** P2.37 Recognize the principle.** Apply the concept of average velocity.

Sketch the problem. No sketch needed.

Identify the relationships. The definition of average velocity

is $v_{\text{ave}} = \frac{\Delta x}{\Delta t}$. This problem requires setting up equations describing the velocity, time, and distance traveled for three separate intervals. The problem can be broken into three time intervals, 1, 2, and 3, with the first interval with a velocity of +1.5 m/s, the second interval with a velocity of 0 m/s, and the final interval with a velocity of +0.60 m/s.

Solve.

Time interval 1: The distance traveled is x_1 , the change in time is Δt_1 , and the velocity is $v_1 = +1.5 \text{ m/s}$.

Time interval 2: The distance traveled is $x_2 = 0$, the change in time is $\Delta t_2 = 10 \text{ s}$, and the velocity is $v_2 = 0 \text{ m/s}$.

Time interval 3: The distance traveled is x_3 , the change in time is Δt_3 , and the velocity is $v_3 = +0.60 \text{ m/s}$.

By definition, for each time interval you can write an equation for the distance traveled in terms of velocity and time,

$$\begin{aligned}
 x_1 &= v_1 \Delta t_1 \\
 x_2 &= v_2 \Delta t_2 = 0 \\
 x_3 &= v_3 \Delta t_3
 \end{aligned}$$

Also, two more equations can be written, since the average velocity and total distance are given. The total distance, x , is just the sum of each distance,

$$x = x_1 + x_2 + x_3 = x_1 + x_3$$

Inserting the above equations for each interval into this equation,

$$x = v_1 \Delta t_1 + v_3 \Delta t_3 \quad (1)$$

The average velocity is given by Equation 2.4,

$$\begin{aligned}
 v_{\text{ave}} &= \frac{\Delta x}{\Delta t} \\
 v_{\text{ave}} &= \frac{x_f - x_i}{t_f - t_i}
 \end{aligned}$$

Defining the initial position as $x = 0$ at $t = 0$,

$$v_{\text{ave}} = \frac{x}{t}$$

The total time, t , is the sum of each individual time interval,

$$t = \Delta t_1 + \Delta t_2 + \Delta t_3$$

Inserting this into the above equation,

$$\frac{x}{v_{\text{ave}}} = \Delta t_1 + \Delta t_2 + \Delta t_3 \quad (2)$$

Solving for Δt_1 ,

$$\Delta t_1 = \frac{x}{v_{\text{ave}}} - \Delta t_2 - \Delta t_3$$

Inserting this into Equation (1) and solving for Δt_3 ,

$$\begin{aligned}
 x &= v_1 \left(\frac{x}{v_{\text{ave}}} - \Delta t_2 - \Delta t_3 \right) + v_3 \Delta t_3 \\
 x &= v_1 \frac{x}{v_{\text{ave}}} - v_1 \Delta t_2 - v_1 \Delta t_3 + v_3 \Delta t_3 \\
 v_1 \Delta t_3 - v_3 \Delta t_3 &= v_1 \frac{x}{v_{\text{ave}}} - v_1 \Delta t_2 - x \\
 \Delta t_3 &= \frac{v_1 \frac{x}{v_{\text{ave}}} - v_1 \Delta t_2 - x}{v_1 - v_3}
 \end{aligned}$$

Inserting values,

$$\begin{aligned}
 \Delta t_3 &= \frac{(1.5 \text{ m/s}) \frac{1200 \text{ m}}{0.80 \text{ m/s}} - (1.5 \text{ m/s})(10 \text{ s}) - 1200 \text{ m}}{1.5 \text{ m/s} - 0.60 \text{ m/s}} \\
 \text{(b) } \Delta t_3 &= 1150 \text{ s} = \boxed{1200 \text{ s}}
 \end{aligned}$$

Inserting this into Equation (2) above, Δt_1 can be found,

$$\begin{aligned}
 \frac{x}{v_{\text{ave}}} &= \Delta t_1 + \Delta t_2 + \Delta t_3 \\
 \Delta t_1 &= \frac{x}{v_{\text{ave}}} - \Delta t_2 - \Delta t_3 \\
 \Delta t_1 &= \frac{1200 \text{ m}}{0.8 \text{ m/s}} - 10 \text{ s} - 1150 \text{ s} \\
 \text{(a) } \Delta t_1 &= \boxed{340 \text{ s}}
 \end{aligned}$$

What does it mean? Note that the average velocity tells nothing about how the trip was made; i.e., it is just the total distance traveled divided by the total time. You can easily check your answers. The total distance for the three parts of the trip is $(1.5 \text{ m/s})(340 \text{ s}) + 0 + (0.6 \text{ m/s})(1150 \text{ s}) = 1200 \text{ m}$. The average velocity for the trip is

$$(1200 \text{ m}) / (340 \text{ s} + 10 \text{ s} + 1150 \text{ s}) = (1200 \text{ m}) / (1500 \text{ s}) = 0.80 \text{ m/s}.$$

*** [SSM] P2.38 Recognize the principle.** As the ball rolls up the incline it will slow down at a constant rate until it momentarily comes to rest. The ball will then begin rolling back down the incline speeding up at a constant rate.

Sketch the problem. The sketch of the problem is provided in Figure 2.22, and the sketched solutions are shown in Figure Ans 2.38.

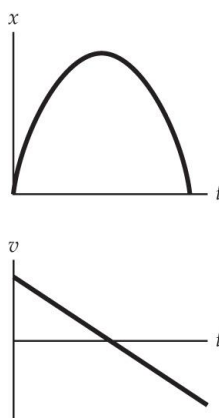


Figure Ans 2.38

Identify the relationships. The slope of the velocity vs. time graph is the acceleration, and the slope of the tangent to the position vs. time graph at any instant in time is the instantaneous velocity.

Solve. See Figure Ans 2.38. If we define the positive x -direction to be up the incline then the ball will have a constant negative acceleration during its entire motion. The ball begins with a positive velocity that decreases to zero and then becomes negative and increasing. The velocity vs. time graph for this motion should be a straight line sloping downward and passing through $v = 0$ at the moment the ball reverses its direction. The position vs. time graph should form a downward curving arc, starting and ending at $x = 0$. In fact, the shape of the curve should be a parabola.

What does it mean? Since the slope of the velocity vs. time graph remains constant throughout the entire process, the acceleration of the ball must remain constant as well. Newton's second law tells us that the force on the ball must also be constant for this situation. As we will see in the next chapter, the force of gravity on the ball is responsible for this observed motion and is indeed a constant in this case.

*** P2.39 Recognize the principle.** Apply graphical analysis of motion.

Sketch the problem. See Figure 2.23(a) and Figure Ans 2.39.

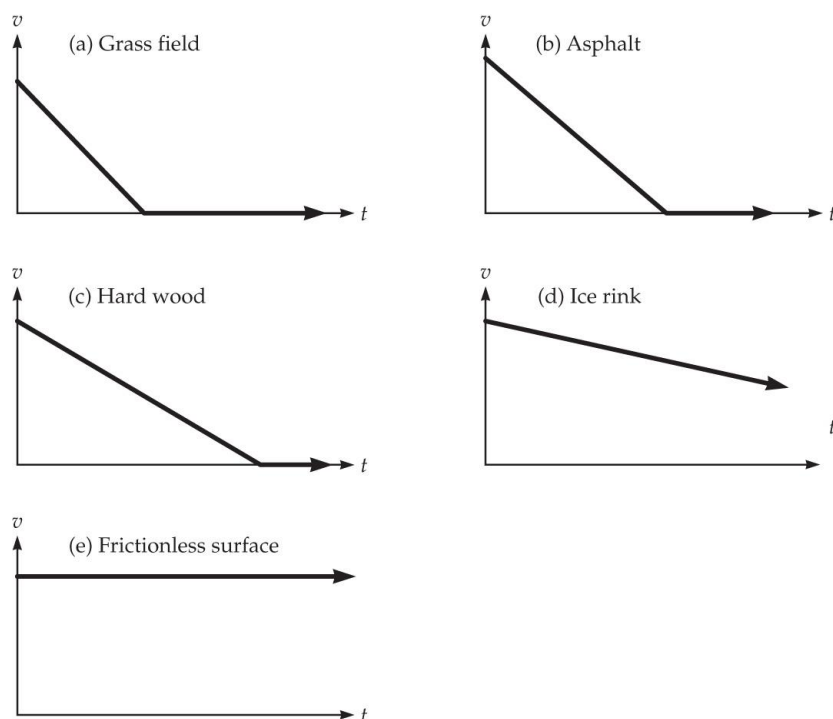


Figure Ans 2.39

Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figures Ans 2.39.

What does it mean? This problem emphasizes the use of velocity-time diagrams and also shows a second approach applied by Galileo in conceptualizing the ideal of “to remain in motion forever” to complement the discussion on pages 40–41. Here the flat surface on which the block slides tends toward a limit of no friction as we go from rough to smooth, which results in a family of curves illustrating this limit. The limit of “to remain in motion forever” is the velocity curve that remains flat as a function of time.

[Life Sci Icon] * P2.40 Recognize the principle. Apply graphical analysis of motion and Newton’s first law.

Sketch the problem. See Figure Ans 2.40.

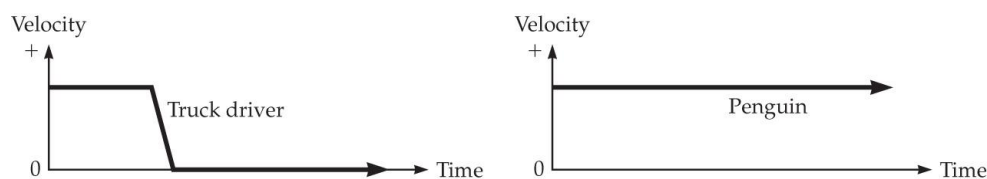


Figure Ans 2.40

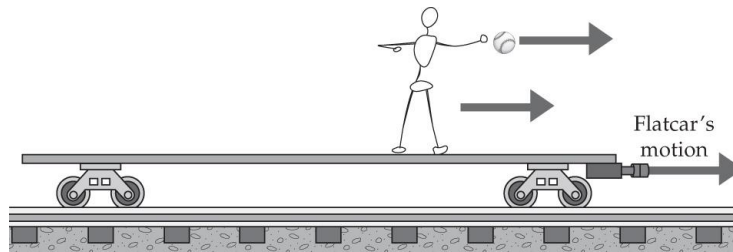
Identify the relationships. Use the graphical techniques as discussed in Section 2.2.

Solve. See Figures Ans2.40. The penguin tends to remain in motion at its constant speed, since the force exerted on it by the ice is negligible. The truck driver comes to rest with the truck because the seat belt exerts a net force on her producing an acceleration the same as the truck's.

What does it mean? According to Newton's first law the penguin will stay in motion at constant velocity. As the truck comes to rest, the penguin will remain at 20 m/s and fly off the ice in the direction of the truck's original motion.

*** P2.41 Recognize the principle.** Apply graphical analysis of motion and Newton's first law.

Sketch the problem. See Figure Ans 2.41.

**Figure Ans 2.41**

Identify the relationships. Newton's first law of inertia applies because there is no net force on the ball after it is released (neglecting any effects of air resistance).

Solve. Both the man and the baseball share the same constant velocity as the railcar (see Figure Ans2.41). When the man releases the ball, by the principle of inertia, it keeps its same sideways velocity, exactly that of the railcar. So it continues to move exactly below the release point and hits the bed of the railcar directly below the release point. Answer: a.

What does it mean? From the point of view of the man on the flatcar, the path of the ball is identical to what it would look like if he were to drop it while standing still on a sidewalk.

P2.42 Recognize the principle. Apply Newton's second law.

Sketch the problem. Use Figure 2.1 from the text.

Identify the relationships. From Newton's second law, the acceleration in the horizontal direction is

$$a = \frac{\sum F}{m}$$

where $\sum F$ is the net force along the horizontal.

Solve. Since the only force on the refrigerator is exerted by the person, $\sum F = 120 \text{ N}$. Using the mass given,

$$a = \frac{120 \text{ N}}{180 \text{ kg}} = \boxed{0.67 \text{ m/s}^2}$$

What does it mean? The velocity of the refrigerator will continue to increase as long as the man continues to apply the force.

*** P2.43 Recognize the principle.** Apply Newton's second and third laws.

Sketch the problem. Use Figure 2.1 from the text.

Identify the relationships. By Newton's third law the force on the man is equal and opposite to the force on the refrigerator,

$$F_{\text{on man}} = -F_{\text{on frig}}$$

where the minus sign indicates that the forces are in opposite directions.

Solve. This implies

$$F_{\text{on man}} = 120 \text{ N}$$

Using Newton's second law we can then calculate the acceleration of the man:

$$a_{\text{man}} = \frac{F_{\text{on man}}}{m} = \frac{-120 \text{ N}}{60 \text{ kg}} = -2.0 \text{ m/s}^2$$

The magnitude of the acceleration is then 2.0 m/s^2 .

What does it mean? Although the action-reaction forces are equal and opposite, the accelerations of the man and refrigerator are inversely proportional to the masses of each. Since there is no friction between the floor and either the man or the refrigerator, after a brief time during which the two are in contact and push on each other, they will slide in opposite directions at constant (but different) velocities.

P2.44 Recognize the principle. Apply Newton's second law.

Sketch the problem. No sketch needed.

Identify the relationships. Use Newton's second law and solve for the mass,

$$a = \frac{\Sigma F}{m}$$

$$m = \frac{\Sigma F}{a}$$

Solve. Inserting the values,

$$m = \frac{200 \text{ N}}{12 \text{ m/s}^2} = \boxed{17 \text{ kg}}$$

What does it mean? The acceleration is always proportional to the net force on an object and inversely proportional to the mass of the object.

P2.45 Recognize the principle. Apply dimensional analysis.

Sketch the problem. No sketch needed.

Identify the relationships. Looking at the units, we can see force has dimensions of mass multiplied by length divided by time squared. We can write this as $(\text{M L})/\text{T}^2$.

Solve.

- (a) is not a unit of force because this is mass times length divided by time.
- (b) is not a unit of force because this is mass times length squared divided by time.
- (c) is a unit of force because we can write this as $(\text{M L}^4)/(\text{T}^2 \text{L}^3)$. Canceling like terms, we see this is just $(\text{M L})/\text{T}^2$.

(d) is a unit of force because this is mass times length divided by time squared.

(e) is a unit of force because this is again mass times length divided by time squared. (c), (d), and (e)

What does it mean? While these combinations are dimensionally correct, they do not represent SI units.

P2.46 Recognize the principle. Apply unit conversion.

Sketch the problem. No sketch needed.

Identify the relationships. Looking up the conversion, we find a slug is equal to 14.59 kg.

Solve. $15 \text{ kg} = 15 \text{ kg} \times \left(\frac{1.0 \text{ slug}}{14.59 \text{ kg}} \right) = \boxed{1.0 \text{ slug}}$

What does it mean? A slug is a rather large unit of mass compared to the kilogram.

P2.47 Recognize the principle. Apply unit conversion.

Sketch the problem. No sketch needed.

Identify the relationships. Looking up the conversion we find 1 lb is equal to 4.448 N.

Solve.

$$150 \text{ lb} = 150 \text{ lb} \times \left(\frac{4.448 \text{ N}}{1 \text{ lb}} \right) = \boxed{670 \text{ N}}$$

What does it mean? A good rule of thumb is that 1 pound is about 4.5 N.

P2.48 Recognize the principle. Apply unit conversion.

Sketch the problem. No sketch needed.

Identify the relationships. A newton has units of $\text{kg} \cdot \text{m}/\text{s}^2$.

Solve. Since there are 1000 g in 1 kg and 100 cm in 1 m,

$$\begin{aligned}
 240 \text{ g} \cdot \text{cm} / \text{s}^2 &= 240 \text{ g} \cdot \text{cm} / \text{s}^2 \times \left(\frac{1 \text{ kg}}{1000 \text{ g}} \right) \times \left(\frac{1 \text{ m}}{100 \text{ cm}} \right) \\
 &= 0.0024 \text{ kg} \cdot \text{m} / \text{s}^2 \text{ or } \boxed{2.4 \times 10^{-3} \text{ N}}
 \end{aligned}$$

What does it mean? A $\text{g} \cdot \text{cm} / \text{s}^2$ is a much smaller force unit than a N.

[SSM] * P2.49. Recognize the principle. Apply Newton's second and third laws.

Sketch the problem. Make a sketch of the forces on the shell and the cannon. See Figure Ans 2.49.

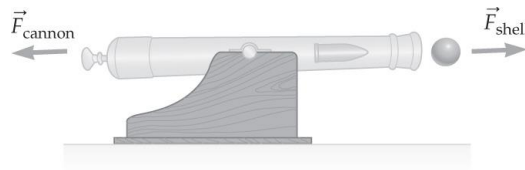


Figure Ans 2.49

Identify the relationships. By Newton's third law, the shell will exert a force on the cannon equal and opposite to the force exerted by the cannon on the shell

$$F_{\text{SC}} = -F_{\text{CS}} \quad (1)$$

Newton's second law can be used to write down the accelerations of the shell and the cannon:

$$\Sigma F_s = m_s a_s \text{ and } \Sigma F_c = m_c a_c \quad (2)$$

Solve. Since the platform rests on an icy surface, which is frictionless, there will be no friction forces when the canon fires. Also assume no friction force on the shell. Therefore there is only one force on the shell and one force on the cannon.

Using Equations (1) and (2)

$$F_{\text{SC}} = m_c a_c \text{ and } F_{\text{CS}} = m_s a_s$$

$$m_c a_c = -m_s a_s$$

Solving for the mass of the cannon,

$$m_c = -\frac{m_s a_s}{a_c}$$

Inserting values,

$$m_c = \frac{-(3.2 \text{ kg})(2500 \text{ m/s}^2)}{(-0.76 \text{ m/s}^2)}$$

$$m_c = \boxed{11,000 \text{ kg}}$$

What does it mean? Although the action-reaction forces are equal and opposite, the acceleration of the cannon is much smaller than the acceleration of the shell due to the cannon's great mass.

P2.50 Recognize the principle. Newton's third law.

Sketch the problem. Diagrams like that in Figure 2.30 will be helpful. In each of the examples, (a)-(h), there are contact forces between two objects. These are the action-reaction pairs of forces. The diagrams for (a) are shown in Figure Ans2.50. Only forces between the two objects are shown in this diagram.

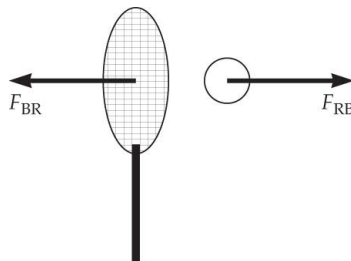


Figure Ans 2.50

Identify the relationships. Newton's third law tells us for every force there is an equal and opposite reaction force.

Solve.

- (a) The force the tennis racket exerts on the tennis ball, and the force exerted by the tennis ball on the racket, which is felt in the player's arm at time of contact.
- (b) The skater exerts a force on the back of the other, and the back of the other skater exerts a force on the first skater's hands. This force causes the first skater to recoil backwards.

- (c) The force the car exerts on the tree, and the force the tree exerts on the car, causing it to rapidly decelerate to a stop and crumple.
- (d) The force exerted by the first car on the second car, and the force the second car exerts on the first, causing rapid and unhealthy accelerations on both.
- (e) The force the person exerts on the wall, and the force the wall exerts back on the person.
- (f) The force the hammer exerts on the nail, and the force the nail exerts on the hammer.
- (g) The force the mass exerts on the string, and the force the string exerts on the mass.
- (h) The force the bird exerts on the telephone pole, and the force the telephone pole exerts on the bird.

What does it mean? To find an action-reaction pair of forces, first isolate the two objects A and B. Then, for every force exerted by A on B, find the force exerted back by B on A.

ADDITIONAL PROBLEMS

*** P2.51 Recognize the principle.** Use the definition of average velocity.

Sketch the problem. No sketch needed.

Identify the relationships. Use the definition of average velocity,

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t}$$

Solve. (a) Hwy 99:

$$\Delta t_{99} = \frac{\Delta x_{99}}{v_{99}} = \frac{45.0 \text{ mi}}{65.0 \text{ mi/h}} = 0.692 \text{ h} = 41.5 \text{ min}$$

Interstate 5:

$$\Delta t_5 = \frac{\Delta x_5}{v_5} = \frac{57.0 \text{ mi}}{75 \text{ mi/h}} = 0.76 \text{ h} = 45.6 \text{ min}$$

Highway 99 gets him home fastest.

Time saved: 45.6 min - 41.5 min = 4.1 min

$$(b) \quad \Delta t_{99\text{speeding}} = \frac{\Delta x_{99}}{v_{99\text{speed}}} = \frac{45.0 \text{ mi}}{75.0 \text{ mi/h}} = 0.600 \text{ h} = 36.0 \text{ min}$$

Time saved: 41.5 min - 36.0 min = 5.5 min

What does it mean? Speeding is a fairly substantial risk to take to "save" less than 6 minutes.

[SSM] * P2.52 Recognize the principle. Use the definition of average velocity.

Sketch the problem. No sketch needed.

Identify the relationships. Use the definition of average velocity,

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t}.$$

Solve.

(a) Find the speed of the baseball in ft/s.

$$90.0 \text{ mi/h} = (90.0 \text{ mi/h}) \left(\frac{5280 \text{ ft}}{1 \text{ mi}} \right) \left(\frac{1 \text{ h}}{3600 \text{ s}} \right) = 132 \text{ ft/s}$$

Now find the travel time of the ball:

$$\Delta t_{\text{baseball}} = \frac{\Delta x_{\text{baseball}}}{v_{\text{baseball}}} = \frac{60.5 \text{ ft}}{132 \text{ ft/s}} = 0.458 \text{ s} = \span style="border: 1px solid black; padding: 2px;">0.46 \text{ s}$$

(b) This time leaves the batter 0.458 s - 0.200 s = 0.26 s or about a quarter of a second to react!

(c) Find the speed of softball in ft/s.

$$60.0 \text{ mi/h} = (60.0 \text{ mi/h}) \left(\frac{5280 \text{ ft}}{1 \text{ mi}} \right) \left(\frac{1 \text{ h}}{3600 \text{ s}} \right) = 88 \text{ ft/s}$$

So the travel time is:

$$\Delta t_{\text{softball}} = \frac{\Delta x_{\text{softball}}}{v_{\text{softball}}} = \frac{40.0 \text{ ft}}{88.0 \text{ ft/s}} = \boxed{0.45 \text{ s}}$$

What does it mean? Although a softball pitch has only two-thirds the velocity of a baseball pitch, since the home plate is two-thirds closer the batter, each sport allows the batter about the same limited time to react.

*** P2.53 Recognize the principle.** Apply graphical analysis of motion, specifically the definition of average velocity.

Sketch the problem. No sketch needed.

Identify the relationships. Average velocity is defined by

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t}$$

Solve.

- (a) Reading positions off the graph, the average velocity between $t = 0.0 \text{ s}$ and $t = 10.0 \text{ s}$ is,

$$\begin{aligned} v_{\text{ave, a}} &= \frac{x_{10.0 \text{ s}} - x_{0.0 \text{ s}}}{t_{10.0 \text{ s}} - t_{0.0 \text{ s}}} \\ v_{\text{ave, a}} &= \frac{30 \text{ m} - 0 \text{ m}}{10 \text{ s} - 0 \text{ s}} \\ v_{\text{ave, a}} &= \boxed{3.0 \text{ m/s}} \end{aligned}$$

- (b) Reading positions off the graph, the average velocity between $t = 0.0 \text{ s}$ and $t = 5.0 \text{ s}$ is,

$$\begin{aligned} v_{\text{ave, b}} &= \frac{x_{5.0 \text{ s}} - x_{0.0 \text{ s}}}{t_{5.0 \text{ s}} - t_{0.0 \text{ s}}} \\ v_{\text{ave, b}} &= \frac{22.5 \text{ m} - 0 \text{ m}}{5 \text{ s} - 0 \text{ s}} \\ v_{\text{ave, b}} &= \boxed{4.5 \text{ m/s}} \end{aligned}$$

- (c) Reading positions off the graph, the average velocity between $t = 5.0 \text{ s}$ and $t = 10.0 \text{ s}$ is

$$v_{\text{ave, c}} = \frac{x_{10.0 \text{ s}} - x_{5.0 \text{ s}}}{t_{10.0 \text{ s}} - t_{5.0 \text{ s}}}$$

$$v_{\text{ave, c}} = \frac{30 \text{ m} - 22.5 \text{ m}}{10 \text{ s} - 5 \text{ s}}$$

$$v_{\text{ave, c}} = 1.5 \text{ m/s}$$

- (d) The total average velocity over the time interval $t = 0.0 \text{ s}$ to $t = 10.0 \text{ s}$ must be equal to the average of the individual average velocities for the time intervals $t = 0.0 \text{ s}$ to $t = 5.0 \text{ s}$ and $t = 5.0 \text{ s}$ to $t = 10.0 \text{ s}$. Since parts (b) and (c) involve equal-length time intervals which add to the total time in part (a), then simply taking the average of the answers in (b) and (c) should yield the same answer as part (a).

$$v_{\text{ave, a}} = 3.0 \text{ m/s}$$

$$v_{\text{ave, a}} = \frac{v_{\text{ave, b}} + v_{\text{ave, c}}}{2}$$

$$v_{\text{ave, a}} = \frac{4.5 \text{ m/s} + 1.5 \text{ m/s}}{2}$$

$$v_{\text{ave, a}} = \frac{6.0 \text{ m/s}}{2}$$

$$v_{\text{ave, a}} = 3.0 \text{ m/s}$$

What does it mean? Looking at Figure P2.53, it is clear that the average velocity tells little about what is going on at various instants in the motion.

[SSM] [Reasoning] P2.54 Recognize the principle. Apply graphical analysis of motion.

Sketch the problem. See Figure Ans 2.54.

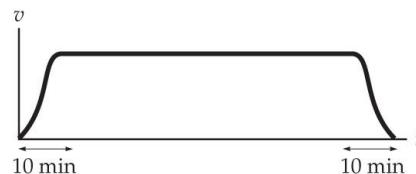


Figure Ans 2.54

Identify the relationships. Use the graphical techniques as discussed in Section 2.2 and Equations 2.4, $v_{\text{ave}} = \frac{\Delta x}{\Delta t}$, and 2.6,

$$a_{\text{ave}} = \frac{\Delta v}{\Delta t}.$$

Solve.

(a) See Figure Ans 2.54.

(b) Inserting values,

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t} = \frac{3400 \text{ km}}{4.0 \text{ h}} \times \frac{1000 \text{ m}}{1 \text{ km}} \times \frac{1 \text{ h}}{3600 \text{ s}}$$

$$v_{\text{ave}} = \boxed{240 \text{ m/s}}$$

(c) Assuming that the acceleration during the first 10 minutes and the last 10 minutes is constant, then the average speed during those times will be half the top speed. The plane then traveled at $v_{\text{top speed}}$ for 3 hours and 40 minutes, and at $\frac{v_{\text{top speed}}}{2}$ for 20 minutes. The total distance traveled is then,

$$v_{\text{top speed}} \times (3.0 \text{ h } 40 \text{ min}) + \frac{v_{\text{top speed}}}{2} \times (20 \text{ min}) = \text{distance}$$

Converting the times to seconds and inserting the value for the distance,

$$v_{\text{top speed}} \times (13,200 \text{ s}) + \frac{v_{\text{top speed}}}{2} \times (1200 \text{ s}) = 3.4 \times 10^6 \text{ m}$$

$$v_{\text{top speed}} = \frac{3.4 \times 10^6 \text{ m}}{13,800 \text{ s}}$$

$$v_{\text{top speed}} = \boxed{250 \text{ m/s}}$$

(d) Average acceleration is given by Equation 2.6,

$$a_{\text{ave}} = \frac{\Delta v}{\Delta t}$$

Inserting values,

$$a_{\text{ave}} = \frac{250 \text{ m/s}}{10 \text{ min}} \times \frac{1 \text{ min}}{60 \text{ s}}$$

$$a_{\text{ave}} = \boxed{0.42 \text{ m/s}^2}$$

- (e) During the central hour of the trip, the top speed has been reached. This should be constant, so the acceleration will be zero.

What does it mean? Note that this is only one possible trip over 3400 km that would give an average velocity of 240 m/s.

*** P2.55 Recognize the principle.** Apply graphical analysis of motion.

Sketch the problem. See Figures P2.55 and Ans 2.55(b and c).

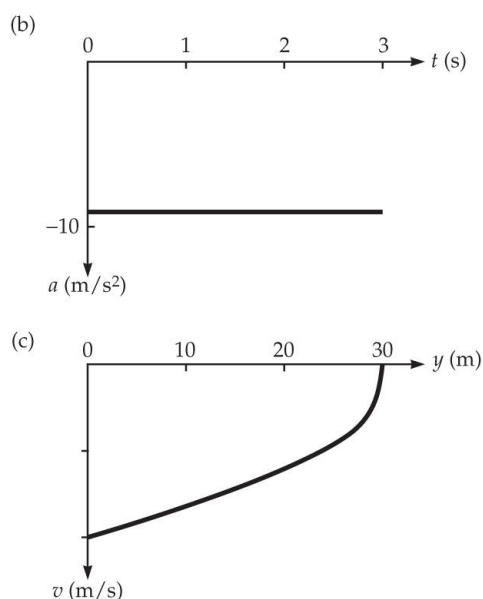


Figure Ans 2.55

Identify the relationships. Use the graphical techniques as discussed in Section 2.2. In part (c) the graph axes are velocity vs. position.

Solve.

- (a) According to the graph, the apple would hit the ground at $y = 0 \text{ m}$, which corresponds to $t = \boxed{2.4 \text{ s}}$.
- (b) See Figure Ans 2.55(b)
- (c) See Figure Ans 2.55(c)

What does it mean? It is useful to cross check a graph such as that in part (c). Although the apple starts at a positive position, the starting point is located on the right in the graph (note that this diagram does not have a time axis). When the apple begins to fall it has no initial velocity, and the closer it gets to the ground the greater the magnitude of the velocity. The velocity is directed downward, and is thus a negative quantity. So the plot makes sense.

[Life Sci] * P2.56 Recognize the principle. Apply the definition of average velocity.

Sketch the problem. No sketch needed.

Identify the relationships. This problem requires the understanding that average speed is averaged over time and not distance. Use Equation 2.4, $v_{\text{ave}} = \frac{\Delta x}{\Delta t}$.

Solve. The time for the cheetah to run the first 100 m is

$$\begin{aligned} t_1 &= \frac{\Delta x_1}{v_1} \\ t_1 &= \frac{100 \text{ m}}{25 \text{ m/s}} \\ t_1 &= 4.0 \text{ s} \end{aligned}$$

The time for the cheetah to run the second 100 m is

$$\begin{aligned} t_2 &= \frac{\Delta x_2}{v_2} \\ t_2 &= \frac{100 \text{ m}}{35 \text{ m/s}} \\ t_2 &= 2.9 \text{ s} \end{aligned}$$

To find the average speed, the total displacement is 200 m, with a total time interval of 6.9 s.

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t} = \frac{200 \text{ m}}{6.9 \text{ s}} = \boxed{29 \text{ m/s}}$$

What does it mean? Since the cheetah travels at the slower speed for a longer time, the average speed is closer to 25 m/s than to 35 m/s. The average speed is less than the average of the speeds for each of the two segments because the average speed depends on the total time rather than the total distance. Another way to say this is:

$$v_{\text{ave}} = \frac{\Delta x_{\text{tot}}}{\Delta t_1 + \Delta t_2} = \frac{\Delta x_1 + \Delta x_2}{\Delta t_1 + \Delta t_2} \neq \frac{\Delta x_1 / \Delta t_1 + \Delta x_2 / \Delta t_2}{2} = \frac{v_1 + v_2}{2}$$

P2.57 Recognize the principle. Apply the definition of average velocity.

Sketch the problem. No sketch needed.

Identify the relationships. Use Equation 2.4, $v_{\text{ave}} = \frac{\Delta x}{\Delta t}$. Here the distance traveled is not in a straight line, but in an orbit around the Earth. Since we are using average speed, the distance traveled is used instead of displacement for Δx .

Solve. Solving for the distance traveled in Equation 2.4,

$$\Delta x = v_{\text{ave}} \Delta t$$

Inserting values,

$$\Delta x = v_{\text{ave}} \Delta t$$

$$\Delta x = (8900 \text{ m/s})(7.5 \text{ days}) \times \left(\frac{24 \text{ h}}{1 \text{ day}} \right) \times \left(\frac{3600 \text{ s}}{1 \text{ h}} \right)$$

$$\Delta x = \boxed{5.8 \times 10^9 \text{ m}}$$

What does it mean? Converting to U.S. customary units for comparison, we see that 7.5 days of travel in a typical space shuttle orbit corresponds to 3.6 million miles!

*** P2.58 Recognize the principle.** Concept of average velocity.

Sketch the problem. No sketch needed.

Identify the relationships. This problem requires solving two equations based on the average speed given by Equation 2.4,

$v_{\text{ave}} = \frac{\Delta x}{\Delta t}$. The cat ran a distance, x , in 6.5 s. Since the dog had to cover the initial difference of 3.5 m plus the distance the cat ran, the dog ran a distance $x + 3.5$ m in the same amount of time.

Solve. The cat's average speed is then given in terms of x by,

$$v_{\text{ave, cat}} = \frac{\Delta x}{\Delta t} = \frac{x}{6.5 \text{ s}}$$

The dog's average speed in terms of x is,

$$v_{\text{ave, dog}} = \frac{\Delta x}{\Delta t} = \frac{x + 3.5 \text{ m}}{6.5 \text{ s}} = 8.5 \text{ m/s}$$

Solving for the distance x in the second equation,

$$\frac{x + 3.5 \text{ m}}{6.5 \text{ s}} = 8.5 \text{ m/s}$$

$$x + 3.5 \text{ m} = (8.5 \text{ m/s}) \times (6.5 \text{ s})$$

$$x = (8.5 \text{ m/s}) \times (6.5 \text{ s}) - 3.5 \text{ m} = 51.8 \text{ m}$$

and inserting this into the first equation to obtain,

$$\begin{aligned} v_{\text{ave, cat}} &= \frac{x}{6.5 \text{ s}} \\ v_{\text{ave, cat}} &= \frac{51.8 \text{ m}}{6.5 \text{ s}} \\ v_{\text{ave, cat}} &= \boxed{8.0 \text{ m/s}} \end{aligned}$$

What does it mean? The answer makes sense, since the dog eventually catches up with the cat.

[Life Sci] * P2.59 Recognize the principle. Apply the concept of average (in this case constant) velocity.

Sketch the problem. See Figure P2.59.

Identify the relationships. This problem requires solving two equations based on the average speed given by Equation 2.4

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t}$$

Solve. The cat's average speed is then given in terms of w by,

$$v_{\text{ave, cat}} = \frac{\Delta x}{\Delta t} = \frac{w}{\Delta t} \quad (1)$$

The chipmunk's average speed in terms of L is,

$$v_{\text{ave, chip}} = \frac{\Delta x}{\Delta t} = \frac{L}{\Delta t} \quad (2)$$

Solving for Δt in (1) and for L in (2),

$$\Delta t = \frac{w}{v_{\text{ave, cat}}}$$

and

$$L = v_{\text{ave, chip}} \Delta t = v_{\text{ave, chip}} \frac{w}{v_{\text{ave, cat}}} = \frac{(4.5 \text{ m/s})}{(7.5 \text{ m/s})} (30 \text{ m}) = \boxed{18 \text{ m}}$$

What does it mean? This is a little more than half the width of the yard, which makes sense since the chipmunk's top speed is more than half of the cat's.

*** P2.60 Recognize the principle.** Apply the definition of average (in this case constant) velocity.

Sketch the problem. See Figure P2.60.

Identify the relationships. This problem requires two equations based on the average speed given by Equation 2.4,

$$v_{\text{ave}} = \frac{\Delta x}{\Delta t}$$

Solve. The time for the thief to reach the door is the distance divided by the speed,

$$\Delta t = \frac{\Delta x}{v} = \frac{L}{v} = \frac{30 \text{ m}}{12 \text{ m/s}} = 2.5 \text{ s}$$

During that time the door moves downward at 0.20 m/s. The dis-

tance is then the velocity multiplied by the time,

$$\Delta y_{\text{door}} = v_{\text{door}} \Delta t = (0.20 \text{ m/s}) (2.5 \text{ s}) = 0.5 \text{ m}$$

The door started at 2.0 m and moved downward 0.5 m to 1.5 m off the ground. Since the thief's car is 1.4 m tall, the thief will escape.

What does it mean? This is a straightforward application of motion with constant velocity. Note that the solution ignores the length of the car. For a 5-m-long car, it would take an extra $\frac{5 \text{ m}}{12 \text{ m/s}} = 0.4 \text{ s}$ to clear the door. Since the door only moves $(0.20 \text{ m/s}) (0.4 \text{ s}) = 0.08 \text{ m}$ in that time, the car still barely clears the door.