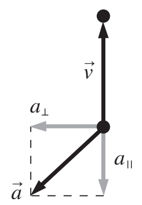
Chapter 4, Conceptual Questions

4.1. **(a)** As shown in the figure below, the acceleration $\vec{a}$ can be divided into components perpendicular ($\perp$) and parallel ($\parallel$) to the velocity. $a_{\parallel}$ will slow the particle down since it is in the opposite direction to $\vec{v}$.

(b) The perpendicular component of $\vec{a}$, $a_{\perp}$, is pointing to the left, and changes the particle direction to the left.



4.2. A constant downward acceleration causes the particle to follow a parabolic trajectory, as with gravity.

4.3. Approximate Tarzan as a particle in nonuniform circular motion.

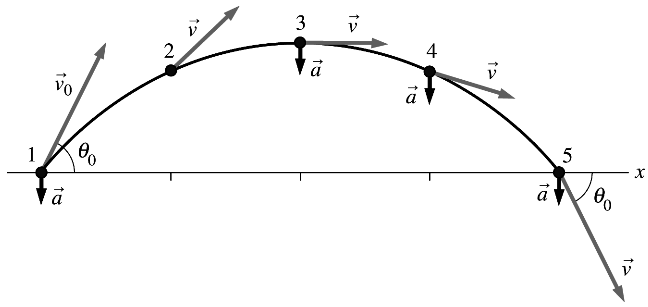
(a) As Tarzan just steps off the vine, his velocity is zero, but increasing along his trajectory, so $\vec{a}$ is along the trajectory. The component of $\vec{a}$ that is the centripetal acceleration $a_r = \dfrac{v^2}{r} = 0$ because $v = 0$.

(b) At the bottom of the swing, $a_r = \dfrac{v_t^2}{r} \neq 0$, but the velocity is at a maximum, so $a_t = \dfrac{dv_t}{dt} = 0$, so $\vec{a}$ is not zero and points up.

4.4. A typical trajectory of a projectile is shown in the figure below. The acceleration due to gravity always points down. The velocity changes direction from the launch angle $\theta = \theta_0$ above the $+x$-axis to zero at the top of the trajectory, to $\theta = \theta_0$ below the $+x$-axis when it hits the ground.

(a) At no time are $\vec{v}$ and $\vec{a}$ parallel if $\theta_0 < 90°$.

(b) At the top of the trajectory $\vec{v}$ and $\vec{a}$ are perpendicular.



4.5. For a projectile, only v_x and a_y are constant during the flight. Since the acceleration $a_y = -g$ is down, $a_x = 0$ and v_x is constant. The nonzero a_y is constantly changing v_y, so the total speed $v = \sqrt{v_x^2 + v_y^2}$ changes as well. The positions *x* and *y* change, so $r = \sqrt{x^2 + y^2}$ changes, too.

4.6. **(a)** The ball fired upward is a projectile with a horizontal component of initial velocity equal to the cart's speed. Without air friction, there is no horizontal component of the acceleration, so the ball stays over the cart during the whole flight, and lands directly back in the tube.

(b) The cart accelerates after launching the ball, the horizontal component of the ball's velocity is less than the velocity of the cart, so the ball will land behind the cart.

4.7. **(a)** After the rock is released it is in free fall, so its acceleration is equal to *g*.

(b) During the rock's flight as it falls from the bridge its speed is increasing, so at the instant of impact the rock's speed is greater than the speed with which it was thrown.

4.8. All of the projectiles have initial velocities that are purely horizontal. Their time to hit the ground is therefore the same as an object dropped from the same height at rest. Since only the height above the ground determines the time of fall, the ranking is $5 > 1 = 2 = 3 = 4$ from greatest to least time.

4.13. In uniform circular motion the tangential acceleration is zero, and the speed is constant. All vector quantities (velocity and radial acceleration) have constant magnitudes but changing directions. Note that the tangential velocity is the same as the instantaneous velocity in uniform circular motion.

4.14. **(a)** $\omega_1 = \omega_2 = \omega_3$. All points on an object turn at the same *angular* rate.

(b) $v_3 > v_1 = v_2$. Since $v = \omega r$ and ω is the same for all of the rotating wheel, the speeds are ranked by how far from the center (r) they are.

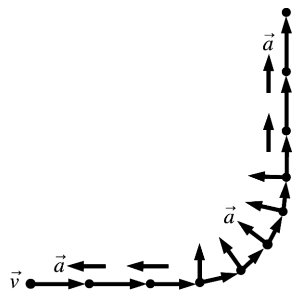
4.15. **(a)** ω:+ α:+ Rotation is counterclockwise and increasing in the counterclockwise direction.
(b) ω:− α:+ Rotation is clockwise and decreasing, so the angular acceleration is counterclockwise
(c) ω:+ α:− Rotation is counterclockwise and decreasing, so the angular acceleration is clockwise.
(d) ω:− α:− Rotation is clockwise and increasing in the clockwise direction.

4.16. **(a)** The instantaneous speed v is zero, and so $\omega = \frac{v}{r} = 0$.

(b) Rotation is beginning in the clockwise direction, so $\alpha < 0$.

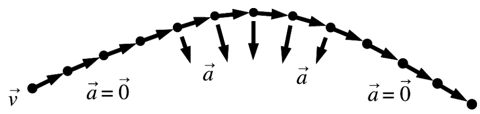
Chapter 4, Exercises and Problems

4.1. Solve: (a)



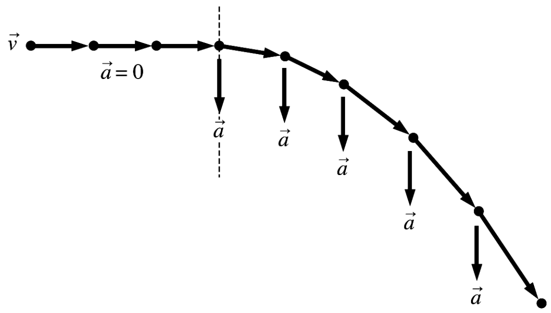
(b) A race car slows from an initial speed of 100 mph to 50 mph in order to negotiate a tight turn. After making the 90° turn the car accelerates back up to 100 mph in the same time it took to slow down.

4.2. Solve: (a)



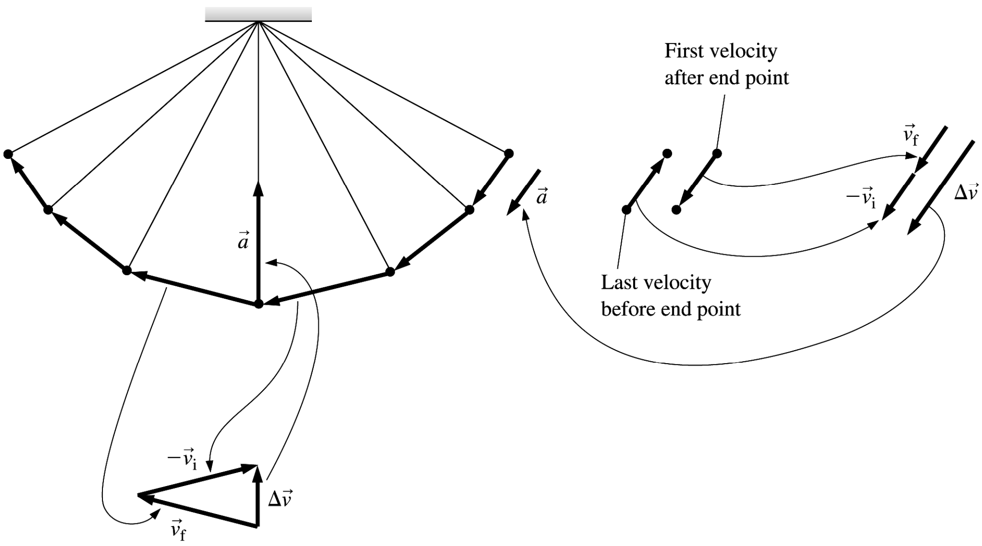
(b) A car drives up a hill, over the top, and down the other side at constant speed.

4.3. Solve: (a)



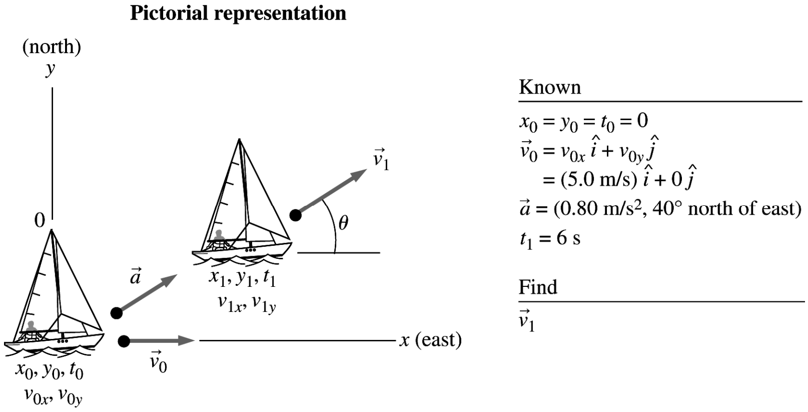
(b) A ball rolls along a level table at 3 m/s. It rolls over the edge and falls 1 m to the floor. How far away from the edge of the table does it land?

4.4. Solve: (a) The figure shows a motion diagram of a pendulum as it swings from one side to the other. It's clear that the velocity at the lowest point is not zero. The velocity vector at this point is tangent to the circle. We can use the method of Tactics Box 1.3 to find the acceleration at the lowest point. The acceleration is not zero. Instead, you can see that the acceleration vector points toward the center of the circle.



(b) The end of the arc is like the highest point of a ball tossed straight up. The velocity is zero for an instant as the vector changes from pointing outward to pointing inward. However, the acceleration is not zero at this point. The velocity is *changing* at the end point, and this requires an acceleration. The motion diagram shows that $\Delta\vec{v}$, and thus $\vec{a}$, is tangent to the circle at the end of the arc.

4.5. Model: The boat is treated as a particle whose motion is governed by constant-acceleration kinematic equations in a plane.
Visualize:



Solve: Resolving the acceleration into its x and y components, we obtain

$$\vec{a} = \left(0.80 \text{ m/s}^2\right)\cos 40°\hat{i} + \left(0.80 \text{ m/s}^2\right)\sin 40°\hat{j} = \left(0.613 \text{ m/s}^2\right)\hat{i} + \left(0.514 \text{ m/s}^2\right)\hat{j}$$

From the velocity equation $\vec{v}_1 = \vec{v}_0 + \vec{a}\left(t_1 - t_0\right)$,

$$\vec{v}_1 = (5.0 \text{ m/s})\hat{i} + \left[\left(0.613 \text{ m/s}^2\right)\hat{i} + \left(0.514 \text{ m/s}^2\right)\hat{j}\right](6 \text{ s} - 0 \text{ s}) = (8.68 \text{ m/s})\hat{i} + (3.09 \text{ m/s})\hat{j}$$

The magnitude and direction of $\vec{v}$ are

$$v = \sqrt{(8.68 \text{ m/s})^2 + (3.09 \text{ m/s})^2} = 9.21 \text{ m/s}$$

$$\theta = \tan^{-1}\left(\frac{v_{1y}}{v_{1x}}\right) = \tan^{-1}\left(\frac{3.09 \text{ m/s}}{8.68 \text{ m/s}}\right) = 20° \text{ north of east}$$

Assess: An increase of speed from 5.0 m/s to 9.21 m/s is reasonable.

4.6. Solve: (a) At $t = 0$ s, $x = 0$ m and $y = 0$ m, or $\vec{r} = (0\hat{i} + 0\hat{j})$ m. At $t = 4$ s, $x = 0$ m and $y = 0$ m, or $\vec{r} = (0\hat{i} + 0\hat{j})$ m. In other words, the particle is at the origin at both $t = 0$ s and at $t = 4$ s. From the expressions for x and y,

$$\vec{v} = \frac{dx}{dt}\hat{i} + \frac{dy}{dt}\hat{j} = \left[\left(\frac{3}{2}t^2 - 4t\right)\hat{i} + (t - 2)\hat{j}\right] \text{ m/s}$$

At $t = 0$ s, $\vec{v} = -2\hat{j}$ m/s, $v = 2$ m/s. At $t = 4$ s, $\vec{v} = \left(8\hat{i} + 2\hat{j}\right)$ m/s, $v = 8.3$ m/s.

(b) At $t = 0$ s, $\vec{v}$ is along $-\hat{j}$, or 90° south of $+x$. At $t = 4$ s,

$$\theta = \tan^{-1}\left(\frac{2 \text{ m/s}}{8 \text{ m/s}}\right) = 14° \text{ north of } +x$$

4.7. Visualize: Refer to Figure EX4.7.
Solve: From the figure, identify the following:

$x_1 = 0$ m	$y_1 = 0$ m
$x_2 = 2000$ m	$y_2 = 1000$ m
$v_{1x} = 0$ m/s	$v_{1y} = 200$ m/s
$v_{2x} = 200$ m/s	$v_{2y} = -100$ m/s

The components of the acceleration can be found by applying $v_2^2 = v_1^2 + 2a\Delta s$ for the x and y directions. Thus

$$a_x = \frac{v_{2x}^2 - v_{1x}^2}{2\Delta x} = \frac{(200\text{ m/s})^2 - (0\text{ m/s})^2}{2(2000\text{ m} - 0\text{ m})} = 10.00\text{ m/s}^2$$

$$a_y = \frac{(-100\text{ m/s})^2 - (200\text{ m/s})^2}{2(1000\text{ m} - 0\text{ m})} = -15.00\text{ m/s}^2$$

So $\vec{a} = (10.00\hat{i} - 15.00\hat{j})\text{ m/s}^2$.

Assess: A time of 20 s is needed to change $v_{1x} = 0$ m/s to $v_{2x} = 200$ m/s at $a_x = 10\text{ m/s}^2$. This is the same time needed to change v_{1y} to v_{2y} at $a_y = -15\text{ m/s}^2$.

4.8. Model: The puck is a particle and follows the constant-acceleration kinematic equations of motion.
Visualize: Please refer to Figure EX4.8.
Solve: (a) At $t = 2$ s, the graphs give $v_x = 16$ cm/s and $v_y = 30$ cm/s. The angle made by the vector $\vec{v}$ with the *x*-axis can thus be found as

$$\theta = \tan^{-1}\left(\frac{v_y}{v_x}\right) = \tan^{-1}\left(\frac{30\text{ cm/s}}{16\text{ cm/s}}\right) = 62° \text{ above the } x\text{-axis}$$

(b) After $t = 5$ s, the puck has traveled a distance given by:

$$x_1 = x_0 + \int_0^{5s} v_x\,dt = 0\text{ m} + \text{area under } v_x\text{-}t \text{ curve} = \tfrac{1}{2}(40\text{ cm/s})(5\text{ s}) = 100\text{ cm}$$

$$y_1 = y_0 + \int_0^{5s} v_y\,dt = 0\text{ m} + \text{area under } v_y\text{-}t \text{ curve} = (30\text{ cm/s})(5\text{ s}) = 150\text{ cm}$$

$$\Rightarrow r_1 = \sqrt{x_1^2 + y_1^2} = \sqrt{(100\text{ cm})^2 + (150\text{ cm})^2} = 180\text{ cm}$$

4.9. Model: Use the particle model for the puck.
Visualize: Please refer to Figure EX4.9
Solve: (a) Since the v_x vs *t* and v_y vs *t* graphs are straight lines, the puck is undergoing constant acceleration along the *x*- and *y*- axes. The components of the puck's acceleration are

$$a_x = \frac{dv_x}{dt} = \frac{\Delta v_x}{\Delta t} = \frac{(-10\text{ m/s} - 10\text{ m/s})}{10\text{ s} - 0\text{ s}} = -2.0\text{ m/s}^2$$

$$a_y = \frac{(10\text{ m/s} - 0\text{ m/s})}{(10\text{ s} - 0\text{ s})} = 1.0\text{ m/s}^2$$

The magnitude of the acceleration is $a = \sqrt{a_x^2 + a_y^2} = 2.2\text{ m/s}^2$.

(b) The puck is undergoing constant acceleration in both the *x* and *y* directions. Identify from the graphs $v_{i_x} = 10$ m/s, $v_{i_y} = 0$ m/s. Since the puck starts at the origin, $x_i = y_i = 0$ m, and set $t_i = 0$ s. Using kinematics,

$$x = 0\text{ m} + (10\text{ m/s})t + \tfrac{1}{2}(-2.0\text{ m/s}^2)t^2$$

$$y = 0\text{ m} + 0\text{ m/s} + \tfrac{1}{2}(1.0\text{ m/s}^2)t^2$$

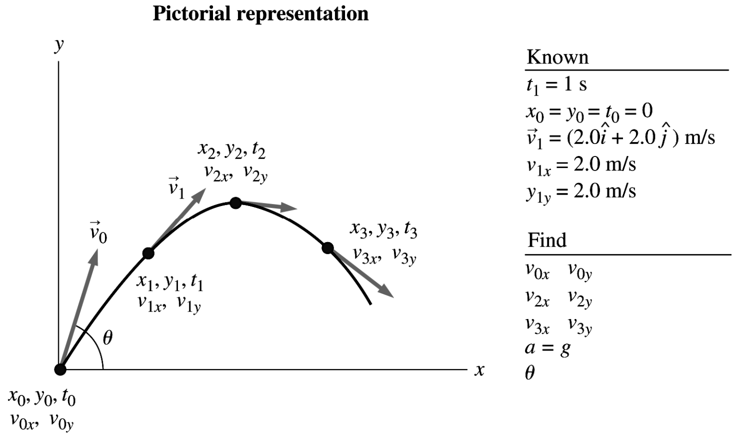
The distance from the origin at time *t* is $r = \sqrt{x^2 + y^2}$. The table below shows the values of *x*, *y*, and *r* at the times $t = 0$, 5, 10 s.

	x	*y*	*R*
$t = 0$ s	0 m	0 m	0 m
5 s	25 m	12.5 m	28 m
10 s	0 m	50 m	50 m

Assess: The puck turns around at $t = 5$ s in the *x* direction, and constantly accelerates in the *y* direction. Traveling 50 m from the starting point in 10 s is reasonable.

4.10. Model: Assume the particle model for the ball, and apply the constant-acceleration kinematic equations of motion in a plane.

Visualize:



Solve: **(a)** We know the velocity $\vec{v}_1 = (2.0\hat{i} + 2.0\hat{j})$ m/s at $t = 1$ s. The ball is at its highest point at $t = 2$ s, so $v_y = 0$ m/s. The horizontal velocity is constant in projectile motion, so $v_x = 2.0$ m/s at all times. Thus $\vec{v}_2 = 2.0\hat{i}$ m/s at $t = 2$ s. We can see that the y-component of velocity *changed* by $\Delta v_y = -2.0$ m/s. between $t = 1$ s and $t = 2$ s. Because a_y is constant, v_y changes by –2.0 m/s in *any* 1-s interval. At $t = 3$ s, v_y is 2.0 m/s less than its value of 0 at $t = 2$ s. At $t = 0$ s, v_y must have been 2.0 m/s more than its value of 2.0 m/s at $t = 1$ s. Consequently, at $t = 0$ s,

$$\vec{v}_0 = (2.0\hat{i} + 4.0\hat{j}) \text{ m/s}$$

At $t = 1$ s,

$$\vec{v}_0 = (2.0\hat{i} + 2.0\hat{j}) \text{ m/s}$$

At $t = 2$ s,

$$\vec{v}_0 = (2.0\hat{i} + 0.0\hat{j}) \text{ m/s}$$

At $t = 3$ s,

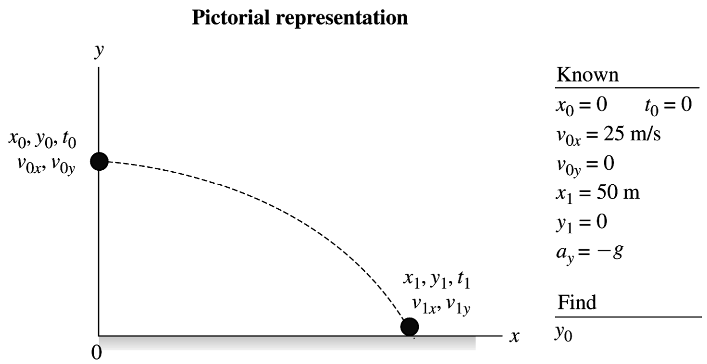
$$\vec{v}_0 = (2.0\hat{i} - 2.0\hat{j}) \text{ m/s}$$

(b) Because v_y is changing at the rate –2.0 m/s per s, the y-component of acceleration is $a_y = -2.0$ m/s^2. But $a_y = -g$ for projectile motion, so the value of g on Exidor is $g = 2.0$ m/s^2.
(c) From part (a) the components of $\vec{v}_0$ are $v_{0x} = 2.0$ m/s and $v_{0y} = 4.0$ m/s. This means

$$\theta = \tan^{-1}\left(\frac{v_{0y}}{v_{0x}}\right) = \tan^{-1}\left(\frac{4.0 \text{ m/s}}{2.0 \text{ m/s}}\right) = 63.4° \text{ above } +x$$

Assess: The y-component of the velocity vector decreases from 2.0 m/s at $t = 1$ s to 0 m/s at $t = 2$ s. This gives an acceleration of -2 m/s^2. All the other values obtained above are also reasonable.

4.11. Model: The ball is treated as a particle and the effect of air resistance is ignored.
Visualize:



Solve: Using $x_1 = x_0 + v_{0x}(t_1 - t_0) + \frac{1}{2}a_x(t_1 - t_0)^2$,

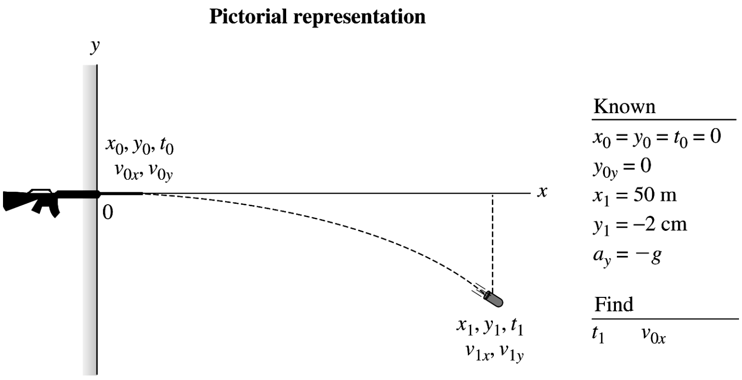
$$50\text{ m} = 0\text{ m} + (25\text{ m/s})(t_1 - 0\text{ s}) + 0\text{ m} \Rightarrow t_1 = 2.0\text{ s}$$

Now, using $y_1 = y_0 + v_{0y}(t_1 - t_0) + \frac{1}{2}a_y(t_1 - t_0)^2$,

$$y_1 = 0\text{ m} + 0\text{ m} + \tfrac{1}{2}(-9.8\text{ m/s}^2)(2.0\text{ s} - 0\text{ s})^2 = -19.6\text{ m}$$

Assess: The minus sign with y_1 indicates that the ball's displacement is in the negative y direction or downward. A magnitude of 19.6 m for the height is reasonable.

4.12. Model: The bullet is treated as a particle and the effect of air resistance on the motion of the bullet is neglected.
Visualize:



Solve: **(a)** Using $y_1 = y_0 + v_{0y}(t_1 - t_0) + \frac{1}{2}a_y(t_1 - t_0)^2$, we obtain

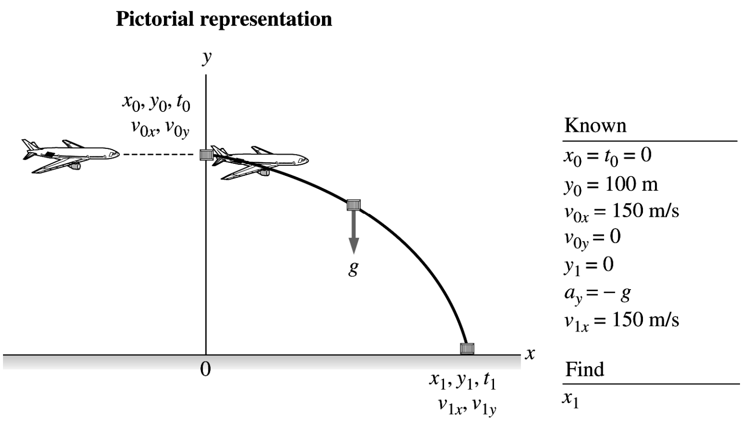
$$(-2.0\times10^{-2}\text{ m}) = 0\text{ m} + 0\text{ m} + \tfrac{1}{2}(-9.8\text{ m/s}^2)(t_1 - 0\text{ s})^2 \Rightarrow t_1 = 0.0639\text{ s}$$

(b) Using $x_1 = x_0 + v_{0x}(t_1 - t_0) + \frac{1}{2}a_x(t_1 - t_0)^2$,

$$(50\text{ m}) = 0\text{ m} + v_{0x}(0.0639\text{ s} - 0\text{ s}) + 0\text{ m} \Rightarrow v_{0x} = 782\text{ m/s}$$

Assess: The bullet falls 2 cm during a horizontal displacement of 50 m. This implies a large initial velocity, and a value of 782 m/s is understandable.

4.13. Model: We will use the particle model for the food package and the constant-acceleration kinematic equations of motion.
Visualize:



Solve: For the horizontal motion,

$$x_1 = x_0 + v_{0x}(t_1 - t_0) + \tfrac{1}{2}a_x(t_1 - t_0)^2 = 0\text{ m} + (150\text{ m/s})(t_1 - 0\text{ s}) + 0\text{ m} = (150\text{ m/s})t_1$$

We will determine t_1 from the vertical y-motion as follows:

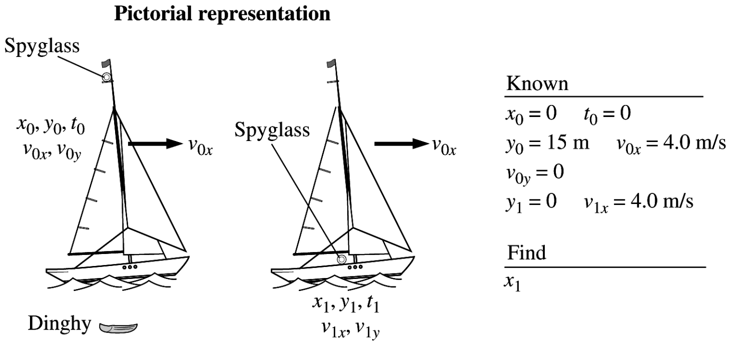
$$y_1 = y_0 + v_{0y}(t_1 - t_0) + \tfrac{1}{2}a_y(t_1 - t_0)^2$$

$$\Rightarrow 0 \text{ m} = 100 \text{ m} + 0 \text{ m} + \tfrac{1}{2}(-9.8 \text{ m/s}^2)t_1^2 \Rightarrow t_1 = \sqrt{\frac{200 \text{ m}}{9.8 \text{ m/s}^2}} = 4.518 \text{ s}$$

From the above x-equation, the displacement is $x_1 = (150 \text{ m/s})(4.518 \text{ s}) = 678 \text{ m}$.

Assess: The horizontal distance of 678 m covered by a freely falling object from a height of 100 m and with an initial horizontal velocity of 150 m/s (≈ 335 mph) is reasonable.

4.14. Model: Assume the particle model for the spyglass and use the projectile motion equations.
Visualize:



Solve: **(a)** The spyglass has an initial horizontal velocity equal to that of the ship. As the spyglass falls, it and the ship move forward together at the same velocity, so the spyglass lands at the bottom of the mast directly vertically below on the ship where the sailor dropped it.
(b) The time the spyglass takes to fall can be found by considering the vertical motion:

$$y_1 = y_0 + v_{0y}(t_1 - t_0) + \tfrac{1}{2}a_y(t_1 - t_0)^2 \Rightarrow 0 \text{ m} = 15 \text{ m} + 0 \text{ m} + \tfrac{1}{2}(-9.8 \text{ m/s}^2)(t_1 - 0 \text{ s})^2 \Rightarrow t_1 = 1.749 \text{ s}$$

Therefore, $x_1 = 0 \text{ m/s} + (4.0 \text{ m/s})(1.749 \text{ s}) = 7.0 \text{ m}$. The spyglass lands 7.0 m to the right of the fisherman.

4.27. Model: The rider is assumed to be a particle.
Solve: Since $a_r = v^2/r$, we have

$$v^2 = a_r r = (98 \text{ m/s}^2)(12 \text{ m}) \Rightarrow v = 34 \text{ m/s}$$

Assess: $34 \text{ m/s} \approx 70 \text{ mph}$ is a large yet understandable speed.

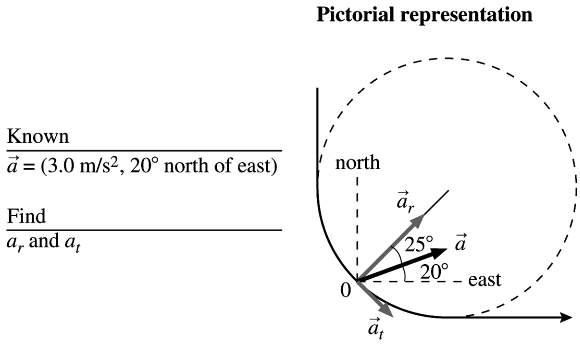
4.29. Solve: The pebble's angular velocity $\omega = (3.0 \text{ rev/s})(2\pi \text{ rad/rev}) = 18.8 \text{ rad/s}$. The speed of the pebble as it moves around a circle of radius $r = 30 \text{ cm} = 0.30 \text{ m}$ is

$$v = \omega r = (18.8 \text{ rad/s})(0.30 \text{ m}) = 5.7 \text{ m/s}$$

The radial acceleration is

$$a_r = \frac{v^2}{r} = \frac{(5.7 \text{ m/s})^2}{0.30 \text{ m}} = 107 \text{ m/s}^2$$

4.34. Model: Model the car as a particle in nonuniform circular motion.
Visualize:



Note that halfway around the curve, the tangent is 45° south of east. The perpendicular component of the acceleration is 45° north of east.
Solve: The radial and tangential components of the acceleration are

$$a_r = a\cos 25° = \left(3.0 \text{ m/s}^2\right)\cos 25° = 2.7 \text{ m/s}^2$$

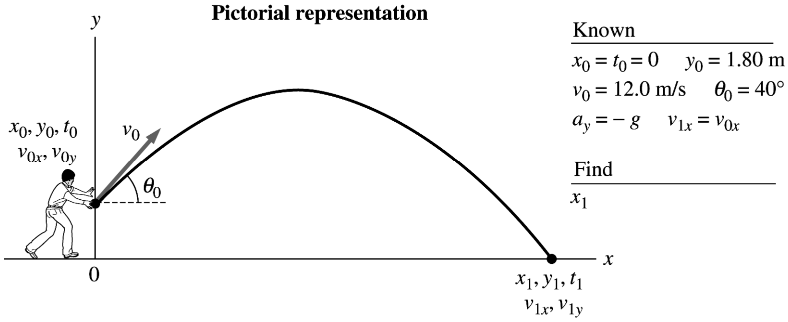
$$a_t = a\sin 25° = \left(3.0 \text{ m/s}^2\right)\sin 25° = 1.27 \text{ m/s}^2$$

4.40. Solve: From the expression for R, $R_{max} = v_0^2/g$. Therefore,

$$R = \frac{R_{max}}{2} = \frac{v_0^2 \sin 2\theta}{g} \Rightarrow \sin 2\theta = \frac{1}{2} \Rightarrow \theta = 15° \text{ and } 75°$$

Assess: The discussion of Figure 4.22 explains why launch angles θ and $(90° - \theta)$ give the same range.

4.43. Model: Assume the particle model and motion under constant-acceleration kinematic equations in a plane.
Visualize:



Solve: **(a)** Using $y_1 = y_0 + v_{0y}(t_1 - t_0) + \frac{1}{2}a_y(t_1 - t_0)^2$,

$$0 \text{ m} = 1.80 \text{ m} + v_0 \sin 40°(t_1 - 0 \text{ s}) + \tfrac{1}{2}\left(-9.8 \text{ m/s}^2\right)(t_1 - 0 \text{ s})^2$$

$$= 1.80 \text{ m} + (7.713 \text{ m/s})t_1 - \left(4.9 \text{ m/s}^2\right)t_1^2 \Rightarrow t_1 = -0.206 \text{ s and } 1.780 \text{ s}$$

The negative value of t_1 is unphysical for the current situation. Using $t_1 = 1.780$ s and $x_1 = x_0 + v_{0x}(t_1 - t_0)$, we get

$$x_1 = 0 + (v_0 \cos 40° \text{ m/s})(1.780 \text{ s} - 0 \text{ s}) = (12.0 \text{ m/s})\cos 40°(1.78 \text{ s}) = 16.36 \text{ m}$$

(b) We can repeat the calculation for each angle. A general result for the flight time at angle θ is

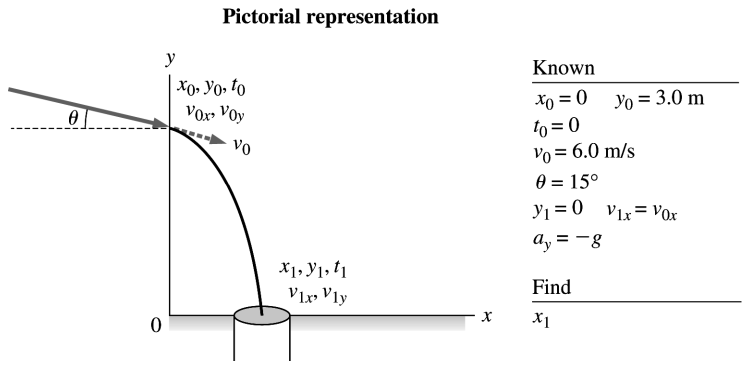
$$t_1 = \left(12\sin\theta + \sqrt{144\sin^2\theta + 35.28}\right)/9.8 \text{ s}$$

and the distance traveled is $x_1 = (12.0)\cos\theta \times t_1$. We can put the results in a table.

θ	t_1	x_1
40.0°	1.780 s	16.36 m
42.5°	1.853 s	16.39 m
45.0°	1.923 s	16.31 m
47.5°	1.990 s	16.13 m

Maximum distance is achieved at $\theta \approx 42.5°$.
Assess: The well-known "fact" that maximum distance is achieved at 45° is true only when the projectile is launched and lands at the *same* height. That isn't true here. The extra $0.03 \text{ m} = 3 \text{ cm}$ obtained by increasing the angle from 40.0° to 42.5° could easily mean the difference between first and second place in a world-class meet.

4.50. Model: We will assume a particle model for the sand, and use the constant-acceleration kinematic equations.
Visualize:



Solve: Using the equation $x_1 = x_0 + v_{0x}(t_1 - t_0) + \frac{1}{2}a_x(t_1 - t_0)^2$,

$$x_1 = 0 \text{ m} + (v_0 \cos 15°)(t_1 - 0 \text{ s}) + 0 \text{ m} = (60 \text{ m/s})(\cos 15°)t_1$$

We can find t_1 from the y-equation, but note that $v_{0y} = -v_0 \sin 15°$ because the sand is launched at an angle below horizontal.

$$y_1 = y_0 + v_{0y}(t_1 - t_0) + \tfrac{1}{2}a_y(t_1 - t_0)^2 \Rightarrow 0 \text{ m} = 3.0 \text{ m} - (v_0 \sin 15°)t_1 - \tfrac{1}{2}gt_1^2$$

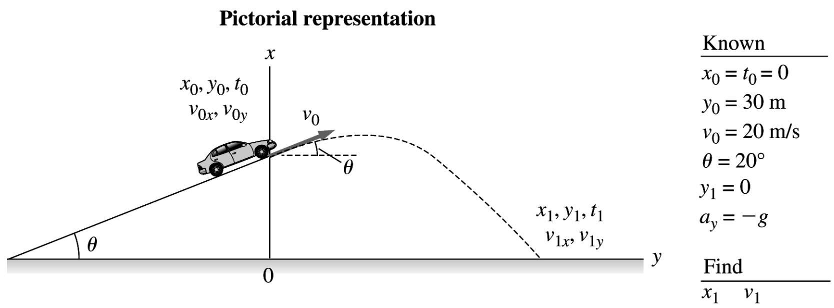
$$= 3.0 \text{ m} - (6.0 \text{ m/s})(\sin 15°)t_1 - \tfrac{1}{2}(9.8 \text{ m/s}^2)t_1^2$$

$$\Rightarrow 4.9t_1^2 + 1.55t_1 - 3.0 = 0 \Rightarrow t_1 = 0.6399 \text{ s and } -0.956 \text{ s (unphysical)}$$

Substituting this value of t_1 in the x-equation gives the distance

$$d = x_1 = (6.0 \text{ m/s})\cos 15°(0.6399 \text{ s}) = 3.71 \text{ m}$$

4.52. Model: We will use the particle model and the constant-acceleration kinematic equations for the car.
Visualize:



Solve: (a) The initial velocity is

$$v_{0x} = v_0 \cos\theta = (20 \text{ m/s})\cos 20° = 18.79 \text{ m/s}$$

$$v_{0y} = v_0 \sin\theta = (20 \text{ m/s})\sin 20° = 6.840 \text{ m/s}$$

Using $y_1 = y_0 + v_{0y}(t_1 - t_0) + \frac{1}{2}a_y(t_1 - t_0)^2$,

$$0 \text{ m} = 30 \text{ m} + (6.840 \text{ m/s})(t_1 - 0 \text{ s}) + \tfrac{1}{2}(-9.8 \text{ m/s}^2)(t_1 - 0 \text{ s})^2 \Rightarrow 4.9t_1^2 - 6.840t_1 - 30 = 0$$

The positive root to this equation is $t_1 = 3.269$ s. The negative root is physically unreasonable in the present case. Using $x_1 = x_0 + v_{0x}(t_1 - t_0) + \frac{1}{2}a_x(t_1 - t_0)^2$, we get

$$x_1 = 0 \text{ m} + (18.79 \text{ m/s})(3.269 \text{ s} - 0 \text{ s}) + 0 = 61.4 \text{ m}$$

The car lands 61 m from the base of the cliff.
(b) The components of the final velocity are $v_{1x} = v_{0x} = 18.79$ m/s and

$$v_{1y} = v_{0y} + a_y(t_1 - t_0) = 6.840 \text{ m/s} - (9.8 \text{ m/s}^2)(3.269 \text{ s} - 0 \text{ s}) = -25.2 \text{ m/s}$$

$$\Rightarrow v = \sqrt{(18.79 \text{ m/s}) + (-25.2 \text{ m/s})^2} = 31.4 \text{ m/s}$$

The car's impact speed is 31 m/s.
Assess: A car traveling at 45 mph and being driven off a 30-m high cliff will land at a distance of approximately 200 feet (61.4 m). This distance is reasonable.

4.62. Model: We will use the particle model for the astronaut undergoing nonuniform circular motion.

Solve: (a) The initial conditions are $\omega_0 = 0$ rad/s, $\theta_0 = 0$ rad, $t_0 = 0$ s, and $r = 6.0$ m. After 30 s,

$$\omega_1 = \frac{1 \text{ rev}}{1.3 \text{ s}} = \frac{1}{1.3} \times \frac{\text{rev}}{\text{s}} \times \frac{2\pi \text{ rad}}{\text{rev}} = 4.83 \text{ rad/s}$$

Using these values at $t_1 = 30$ s,

$$\omega_1 = \omega_0 + (a_t/r)(t_1 - t_0) = 0 + (a_t/r)t_1$$

$$\Rightarrow a_t = (6.0 \text{ m})(4.83 \text{ rad/s})\left(\frac{1}{30 \text{ s}}\right) = 0.97 \text{ m/s}^2$$

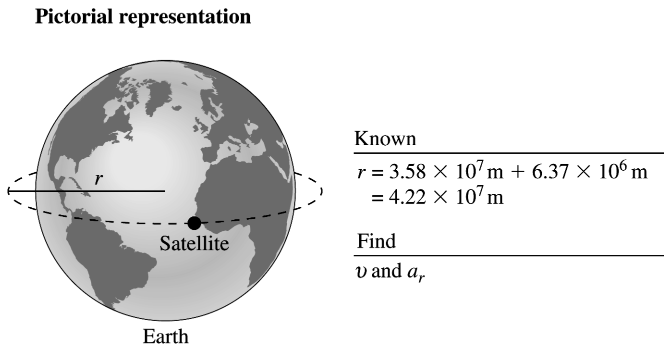
(b) The radial acceleration is

$$a_r = r\omega_1^2 = (6.0 \text{ m})(4.83 \text{ rad/s})^2 \frac{g}{(9.8 \text{ m/s}^2)} = 14.3g$$

Assess: The above acceleration is typical of what astronauts experience during liftoff.

4.65. Model: The satellite is a particle in uniform circular motion.

Visualize:



Solve: (a) The satellite makes one complete revolution in 24 h about the center of the earth. The radius of the motion of the satellite is

$$r = 6.37 \times 10^6 \text{ m} + 3.58 \times 10^7 \text{ m} = 4.22 \times 10^7 \text{ m}$$

The speed of the satellite is $v = \frac{(\text{distance traveled})}{(\text{time taken})} = \frac{2\pi r}{24 \text{ h}} = 3.07 \times 10^3$ m/s.

(b) The acceleration of the satellite is centripetal, with magnitude

$$a_r = \frac{v^2}{r} = \frac{(3.07 \times 10^3 \text{ m/s})^2}{4.22 \times 10^7 \text{ m}} = 0.223 \text{ m/s}^2$$

Assess: The small centripetal acceleration makes sense when realized it is for an object traveling in a circle with radius ≈26,400 miles.