Section 1 Projectile Motion: Practice Problems

1. You throw a stone horizontally at a speed of 5.0 m/s from the top of a cliff that is 78.4 m high.

a. How long does it take the stone to reach the bottom of the cliff?
b. How far from the base of the cliff does the stone hit the ground?
c. What are the horizontal and vertical components of the stone's velocity just before it hits the ground?

SOLUTION:

a.

Since $y_y = 0$, $y - y_y t = -\frac{1}{2}at^2$

becomes $y = -\frac{1}{2}at^2$

$$t = \sqrt{-\frac{2y}{a}}$$

or $$= \sqrt{\frac{-(2)(-78.4\text{ m})}{9.8\text{ m/s}^2}}$$

$$= 4.0\text{ s}$$

b.

$$x = v_x t$$
$$= (5.0\text{ m/s})(4.0\text{ s})$$
$$= 2.0\times10^1\text{ m}$$

c.

$v_x = 5.0$ m/s

This is the same as the initial horizontal speed because the acceleration of gravity influences only the vertical motion. For the vertical component, use $v = v_i + at$ with $v = v_y$ and v_i, the initial vertical component of velocity, zero.

At $t = 4.0$ s

$$v_y = at$$
$$= (9.8\text{ m/s}^2)(4.0\text{ s})$$
$$= 39\text{ m/s}$$

2. Lucy and her friend are working at an assembly plant making wooden toy giraffes. At the end of the line, the giraffes go horizontally off the edge of a conveyor belt and fall into a box below. If the box is 0.60 m below the level of the conveyor belt and 0.40 m away from it, what must be the horizontal velocity of giraffes as they leave the conveyor belt?

SOLUTION:

$$y = v_{iy}t + \frac{1}{2}at^2;\ t = \sqrt{\frac{-2y}{a}}$$

$$x = v_x t = v_x\sqrt{\frac{-2y}{a}}$$

$$\text{So, } v_x = \frac{x}{\sqrt{\frac{-2y}{a}}} = \frac{0.40\text{ m}}{\sqrt{\frac{(-2)(-0.60\text{ m})}{9.8\text{ m/s}^2}}}$$

$$= 1.1\text{ m/s}$$

3. **Challenge** You are visiting a friend from elementary school who now lives in a small town. One local amusement is the ice-cream parlor, where Stan, the short-order cook, slides his completed ice-cream sundaes down the counter at a constant speed of 2.0 m/s to the servers. (The counter is kept very well polished for this purpose.) If the servers catch the sundaes 7.0 cm from the edge of the counter, how far do they fall from the edge of the counter to the point at which the servers catch them?

SOLUTION:

$$x = v_x t;\ \ t = \frac{x}{v_x}$$

$$y = -\frac{1}{2}at^2$$

$$= -\frac{1}{2}a\left(\frac{x}{v_x}\right)^2$$

$$= -\frac{1}{2}(9.8\text{ m/s}^2)\left(\frac{0.070\text{ m}}{2.0\text{ m/s}}\right)^2$$

$$= 0.0060\text{ m or } 0.60\text{ cm}$$

4. A player kicks a football from ground level with an initial velocity of 27.0 m/s, 30.0° above the horizontal, as shown in **Figure 5.** Find each of the following. Assume that forces from the air on the ball are negligible.

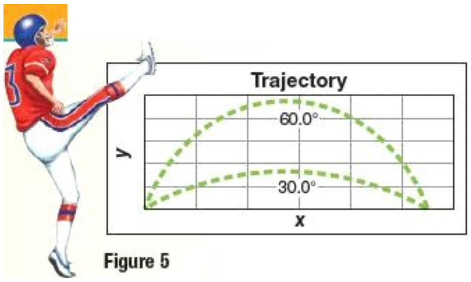


Figure 5

a. the ball's hang time
b. the ball's maximum height
c. the horizontal distance the ball travels before hitting the ground

SOLUTION:

a.

$v_y = v_i \sin\theta$

When it lands,

$y = v_y t - \frac{1}{2}at^2 = 0.$

Therefore,

$t^2 = \frac{2v_y t}{a}$

$t = \frac{2v_y}{a}$

$= \frac{2v_i \sin\theta}{a}$

$= \frac{(2)(27.0\text{ m/s})(\sin 30.0°)}{9.8\text{ m/s}^2}$

$= 2.8\text{ s}$

b.

Maximum height occurs at half the "hang time," or 1.4 s. Thus,

$y = v_y t - \frac{1}{2}at^2$

$= v_i \sin\theta\, t - \frac{1}{2}at^2$

$= (27.0\text{ m/s})(\sin 30.0°)(1.4\text{ s})$

$-\frac{1}{2}(+9.8\text{ m/s}^2)(1.4\text{ s}^2)^2$

$= 9.3\text{ m}$

c.

Distance:

$v_x = v_i \cos\theta$

$x = v_x t = (v_i \cos\theta)(t)$

$= (27.0\text{ m/s})(\cos 30.0°)(2.8\text{ s})$

$= 65\text{ m}$

5. The player in the previous problem then kicks the ball with the same speed but at 60.0° from the horizontal. What is the ball's hang time, horizontal distance traveled, and maximum height?

SOLUTION:

Following the method of the previous practice problem,

Hangtime:

$t = \frac{2v_i \sin\theta}{a}$

$= \frac{(2)(27.0\text{ m/s})(\sin 60.0°)}{9.8\text{ m/s}^2}$

$= 4.8\text{ s}$

Distance:

$x = v_i \cos\theta\, t$

$= (27.0\text{ m/s})(\cos 60.0°)(4.8\text{ s})$

$= 65\text{ m}$

Maximum height:

at $t = \frac{1}{2}(4.8\text{ s}) = 2.4\text{ s}$

$y = v_i \sin\theta\, t - \frac{1}{2}at^2$

$= (27.0\text{ m/s})(\sin 60.0°)(2.4\text{ s})$

$-\frac{1}{2}(+9.8\text{ m/s}^2)(2.4\text{ s})^2$

$= 28\text{ m}$

6. **CHALLENGE** A rock is thrown from a 50.0-m-high cliff with an initial velocity of 7.0 m/s at an angle of 53.0° above the horizontal. Find its velocity when it hits the ground below.

SOLUTION:

Magnitude:

$$v_{xi} = v_{xf} = v_i \cos\theta$$

= (7.0 m/s)(cos 53.0°)
=4.2 m/s

$$v_{xf} = (7.0\ \text{m/s})(\cos 53.0)$$
$$= 4.2\ \text{m/s}$$

$$v_{yf} = \sqrt{v_{yi}^2 + 2a\Delta y}$$
$$= \sqrt{(v_i \sin\theta)^2 + 2a\Delta y}$$
$$= \sqrt{((7.0\ \text{m/s})(\sin 53°))^2 + 2(9.8\ \text{m/s}^2)(50.0)}$$
$$v_{yf} = 32\ \text{m/s}$$

$$v_f = \sqrt{v_{xf}^2 + v_{yf}^2}$$
$$= \sqrt{(4.2\ \text{m/s})^2 + (32\ \text{m/s})^2}$$
$$= 32\ \text{m/s}$$

Direction:

$$\theta = \tan^{-1}\left(\frac{v_{yf}}{v_{xf}}\right)$$
$$= \tan^{-1}\left(\frac{\sqrt{(v_i \sin\theta)^2 + 2a\Delta y}}{v_i \cos\theta_i}\right)$$
$$= \tan^{-1}\left(\frac{\sqrt{((7.0\ \text{m/s})(\sin 53°))^2 + 2(9.8\ \text{m/s}^2)(50.0)}}{(7.0\ \text{m/s})(\cos 53.0°)}\right)$$

= 82° from horizontal

Section 1 Projectile Motion: Review

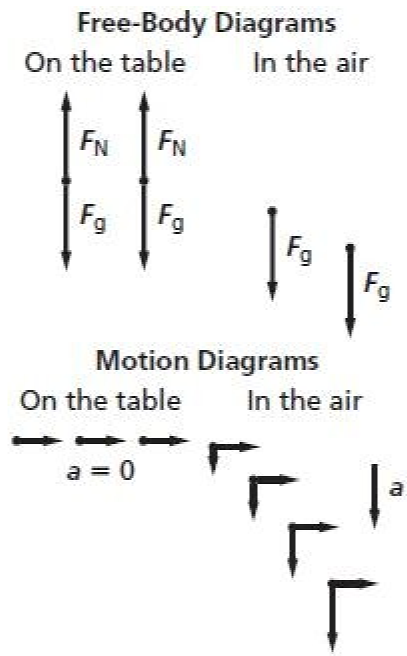
7. **Main Idea** Two baseballs are pitched horizontally from the same height but at different speeds. The faster ball crosses home plate within the strike zone, but the slower ball is below the batter's knees. Why do the balls pass the batter at different heights?

SOLUTION:

The faster ball is in the air a shorter time, and thus gains a smaller vertical velocity.

8. **Free-Body Diagram** An ice cube slides without friction across a table at a constant velocity. It slides off the table and lands on the floor. Draw free-body and motion diagrams of the ice cube at two points on the table and at two points in the air.

SOLUTION:



9. **Projectile Motion** A tennis ball is thrown out a window 28 m above the ground at an initial velocity of 15.0 m/s and 20.0° below the horizontal. How far does the ball move horizontally before it hits the ground?

SOLUTION:

$x = v_{0x}t$; need to find t

First, determine v_{yf}:

$$v_{yf}^2 = v_{yi}^2 + 2ay$$

$$v_{yf} = \sqrt{v_{yi}^2 + 2ay} = \sqrt{(v_i \sin\theta)^2 + 2ay}$$

$$= \sqrt{((15.0\text{ m/s})(\sin 20.0°))^2 + (2)(9.8\text{ m/s}^2)(28\text{ m})}$$

$$= 24\text{ m/s}$$

Now use $v_{yf} = v_{yi} + at$ to find t.

$$t = \frac{v_{yf} - v_{yi}}{a} = \frac{v_{yf} - v_i \sin\theta}{a}$$

$$= \frac{24\text{ m/s} - (15.0\text{ m/s})(\sin 20.0°)}{9.8\text{ m/s}^2}$$

$$= 1.9\text{ s}$$

$$x = v_{xi}t$$

$$= (v_i \cos\theta)(t)$$

$$= (15.0\text{ m/s})(\cos 20.0°)(1.9\text{ s})$$

$$= 27\text{ m}$$

10. **Projectile Motion** A softball player tosses a ball into the air with an initial velocity of 11.0 m/s, as shown in **Figure 7.** What will be the ball's maximum height?

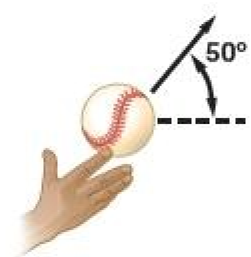


Figure 7

SOLUTION:

$$v_{fy}^2 = v_{iy}^2 + 2a(y_f - y_i)$$

$a = -9.8\text{ m/s}^2$; $y_i = 0$

At maximum height $v_{fy} = 0$, so

$$y_{fy} = -\frac{v_{iy}^2}{2a} = -\frac{(v_i \sin\theta)^2}{2a}$$

$$= -\frac{((11.0\text{ m/s})(\sin 50.0°))^2}{(2)(-9.8\text{ m/s}^2)}$$

$$= 3.6\text{ m}$$

11. **Critical Thinking** Suppose an object is thrown with the same initial velocity and direction on Earth and on the Moon, where the acceleration due to gravity is one-sixth its value on Earth. How will the vertical velocity, time of flight, maximum height, and the horizontal distance change?

SOLUTION:

The horizontal velocity (v_x) will not change.

The object's time of flight will be larger; $t = \frac{-2v_y}{a}$. The maximum height of the object (y_{max}) will be greater. The horizontal distance will be greater.

Section 2 Circular Motion: Practice Problems

12. A runner moving at a speed of 8.8 m/s rounds a bend with a radius of 25 m. What is the centripetal acceleration of the runner, and what agent exerts the centripetal force on the runner?

SOLUTION:

$$a_c = \frac{v^2}{r} = \frac{(8.8\ \text{m/s})^2}{25\ \text{m}} = 3.1\ \text{m/s}^2$$

The frictional force of the track acting on the runner's shoes exerts the force on the runner.

13. An airplane traveling at 201 m/s makes a turn. What is the smallest radius of the circular path (in kilometers) the pilot can make and keep the centripetal acceleration under 5.0 m/s^2?

SOLUTION:

$$a_c = \frac{v^2}{r},$$

$$\text{so } r = \frac{v^2}{a_c} = \frac{(201\ \text{m/s})^2}{5.0\ \text{m/s}^2} = 8.1\ \text{km}$$

14. A 45-kg merry-go-round worker stands on the ride's platform 6.3 m from the center, as shown in **Figure 11.** If her speed (v_{worker}) as she goes around the circle is 4.1 m/s, what is the force of friction (F_f) necessary to keep her from falling off the platform?

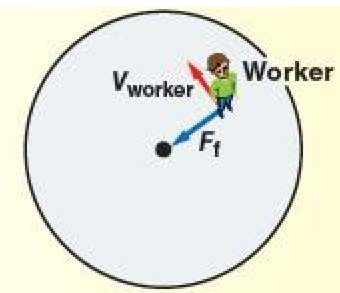


Figure 11

SOLUTION:

$$F_f = F_c = \frac{mv^2}{r} = \frac{(45\ \text{kg})(4.1\ \text{m/s})^2}{6.3\ \text{m}} = 1.2\times10^2\ \text{N}$$

15. A 16-g ball at the end of a 1.4-m string is swung in a horizontal circle. It revolves every 1.09 s. What is the magnitude of the string's tension?

SOLUTION:

$$a_c = \frac{4\pi r}{T^2} = \frac{4\pi(1.4\ \text{m})}{(1.09\ \text{s})^2} = 15\ \text{m/s}^2$$

$$F_T = ma_c = (0.016\ \text{kg})(15\ \text{m/s}^2) = 0.24\ \text{N}$$

16. **Challenge** A car racing on a flat track travels at 22 m/s around a curve with a 56-m radius. Find the car's centripetal acceleration. What minimum coefficient of static friction between the tires and the road is necessary for the car to round the curve without slipping?

SOLUTION:

$$a_c = \frac{v^2}{r} = \frac{(22\ \text{m/s})^2}{56\ \text{m}} = 8.6\ \text{m/s}^2$$

Recall $F_f = \mu F_N$. The friction force must supply the centripetal force so $F_f = ma_c$. The normal force is $F_N = -ma_{\text{grav}}$. The coefficient of friction must be at least

$$\mu = \frac{F_f}{F_N} = \frac{ma_c}{ma_{\text{grav}}} = \frac{a_c}{a_{\text{grav}}} = \frac{8.6\ \text{m/s}^2}{9.8\ \text{m/s}^2} = 0.88$$

Section 2 Circular Motion: Review

17. **Main Idea** If you attach a ball to a rope and swing it at a constant speed in a circle above your head, the ball is in uniform circular motion. In which direction does it accelerate? What force causes the acceleration?

SOLUTION:

The ball accelerates toward the center of the circle because of centripetal force.

18. **Uniform Circular Motion** What is the direction of the force that acts on the clothes in the spin cycle of a top-load washing machine? What exerts the force?

SOLUTION:

The force is toward the center of the tub. The walls exert the force on the clothes.

19. **Centripetal Acceleration** A newspaper article states that when turning a corner, a driver must be careful to balance the centripetal and centrifugal forces to keep from skidding. Write a letter to the editor that describes physics errors in this article.

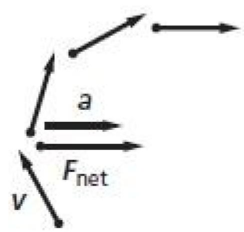
SOLUTION:

There is an acceleration because the direction of the velocity is changing. There must be a net force toward the center of the circle. The road supplies that force, and the friction between the road and the tires allows the force to be exerted on the tires. The seat exerts the force on the driver towards the center of the circle. The note should also make it clear that centrifugal force is not a real force.

20. **Free-Body Diagram** You are sitting in the back seat of a car going around a curve to the right. Sketch motion and free-body diagrams to answer these questions:

a. What is the direction of your acceleration?
b. What is the direction of the net force on you?
c. What exerts this force?

SOLUTION:



a. Your body accelerates to the right.
b. The net force is to the right.
c. The car's seat exerts the force.

21. **Centripetal Acceleration** An object swings in a horizontal circle, supported by a 1.8-m string. It completes a revolution in 2.2 s. What is the object's centripetal acceleration?

SOLUTION:

$$a_c = \frac{4\pi r}{T^2} = \frac{4\pi(1.8\text{ m})}{(2.2\text{ s})^2} = 4.7\text{ m/s}^2$$

22. **Centripetal Force** The 40.0-g stone in **Figure 13** is whirled horizontally at a speed of 2.2 m/s. What is the tension in the string?

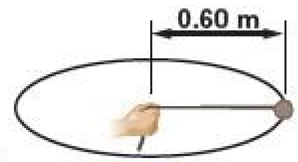


Figure 13

SOLUTION:

$$F_T = ma_c = \frac{mv^2}{r} = \frac{(0.0400\text{ kg})(2.2\text{ m/s})^2}{0.60\text{ m}} = 0.32\text{ N}$$

23. **Amusement-Park Ride** A ride at an amusement park has people stand around a 4.0-m radius circle with their backs to a wall. The ride then spins them with a 1.7-s period of revolution. What are the centripetal acceleration and velocity of the riders?

SOLUTION:

$$a_c = \frac{4\pi^2 r}{T^2} = \frac{4\pi^2(4.0\text{ m})}{(1.7\text{ s})^2} = 55\text{ m/s}^2$$

$$a_c = \frac{v^2}{r}$$

$$v = \sqrt{a_c r} = \sqrt{(55\text{ m/s}^2)(4.0\text{ m})} = 15\text{ m/s}$$

24. **Centripetal Force** A bowling ball has a mass of 7.3 kg. What force must you exert to move it at a speed of 2.5 m/s around a circle with a radius of 0.75 m?

SOLUTION:

$$F_{net} = ma_c = \frac{mv^2}{r} = \frac{(7.3\text{ kg})(2.5\text{ m/s})^2}{0.75\text{ m}} = 61\text{ N}$$

25. **Critical Thinking** Because of Earth's daily rotation, you always move with uniform circular motion. What is the agent that supplies the force that causes your centripetal acceleration? If you are standing on a scale, how does the circular motion affect the scale's measure of your weight?

SOLUTION:

Earth's gravity supplies the force that accelerates you. The scale will record a lower weight if you are in uniform circular motion.

Section 3 Relative Velocity: Practice Problems

26. You are riding in a bus moving slowly through heavy traffic at 2.0 m/s. You hurry to the front of the bus at 4.0 m/s relative to the bus. What is your speed relative to the street?

SOLUTION:

$$v_{y/s} = v_{b/s} + v_{y/s}$$
$$= 2.0\text{ m/s} + 4.0\text{ m/s}$$
$$= 6.0\text{ m/s relative to street}$$

27. Rafi is pulling a toy wagon through a neighborhood at a speed of 0.75 m/s. A caterpillar in the wagon is crawling toward the rear of the wagon at a rate of 2.0 cm/s. What is the caterpillar's velocity relative to the ground?

SOLUTION:

$$v_{c/g} = v_{w/g} + v_{c/w}$$
$$= 0.75\text{ m/s} - 0.02\text{ m/s} = 0.73\text{ m/s}$$

28. A boat is rowed directly upriver at a speed of 2.5 m/s relative to the water. Viewers on the shore see that the boat is moving at only 0.5 m/s relative to the shore. What is the speed of the river? Is it moving with or against the boat?

SOLUTION:

$$v_{b/g} = v_{b/w} + v_{w/g}$$
$$\text{so, } v_{w/g} = v_{b/g} - v_{b/w}$$
$$= 0.5\text{ m/s} - 2.5\text{ m/s}$$
$$= -2.0\text{ m/s}$$

The river is moving against the boat.

29. A boat is traveling east at a speed of 3.8 m/s. A person walks across the boat with a velocity of 1.3 m/s south.

a. What is the person's speed relative to the water?
b. In what direction, relative to the ground, does the person walk?

SOLUTION:

a.

$$v_{p/w}^2 = v_{p/b}^2 + v_{b/w}^2$$
$$v_{p/w} = \sqrt{v_{p/b}^2 + v_{b/w}^2}$$
$$v_{p/w} = \sqrt{(3.8\text{ m/s})^2 + (1.0\text{ m/s})^2}$$
$$= 4.0\text{ m/s}$$

b.

$$\theta = \tan^{-1}\left(\frac{v_{p/b}}{v_{b/w}}\right) = \tan^{-1}\left(\frac{1.3\text{ m/s}}{3.8\text{ m/s}}\right)$$
$$= 19^\circ\text{ south of east}$$

30. An airplane flies due north at 150 km/h relative to the air. There is a wind blowing at 75 km/h to the east relative to the ground. What is the plane's speed relative to the ground?

SOLUTION:

$$v_{p/g} = \sqrt{{v_{p/a}}^2 + {v_{a/g}}^2}$$
$$= \sqrt{(150\text{ km/h})^2 + (75\text{ km/h})^2}$$
$$= 1.7\times 10^2\text{ km/h}$$

31. **CHALLENGE** The airplane in **Figure 17** flies at 200.0 km/h relative to the air. What is the velocity of the plane relative to the ground if it flies during the following wind conditions?

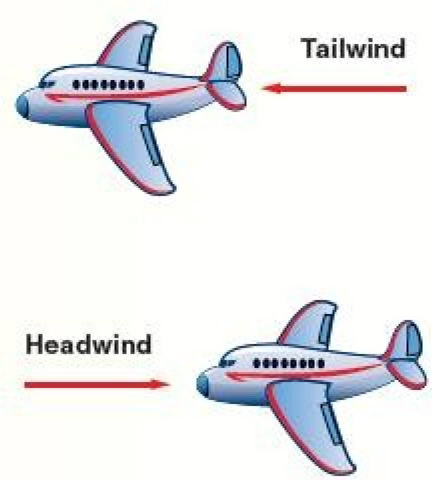


Figure 17

a. a 50.0-km/h tailwind
b. a 50.0-km/h headwind

SOLUTION:

a.

$$v_{p/g} = v_{p/a} + v_{a/g}$$
$$= 200.0 \text{ km/h} + 50.0 \text{ km/h}$$
$$= 250.0 \text{ km/h}$$

b.

$$v_{p/g} = v_{p/a} - v_{a/g}$$
$$= 200.0 \text{ km/h} - 50.0 \text{ km/h}$$
$$= 150.0 \text{ km/h}$$

Section 3 Relative Velocity: Review

32. **Main Idea** A plane has a speed of 285 km/h west relative to the air. A wind blows 25 km/h east relative to the ground. What is the plane's speed and direction relative to the ground?

SOLUTION:

$$v_{p/g} = v_{p/a} + v_{a/g}$$
$$= 285 \text{ km/h} - 25 \text{ km/h}$$
$$= 260 \text{ km/h west}$$

33. **Relative Velocity** A fishing boat with a maximum speed of 3 m/s relative to the water is in a river that is flowing at 2 m/s. What is the maximum speed the boat can obtain relative to the shore? The minimum speed? Give the direction of the boat, relative to the river's current, for the maximum speed and the minimum speed relative to the shore.

SOLUTION:

The maximum speed relative to the shore is when the boat moves at maximum speed in the same direction as the river's flow:

$$v_{b/s} = v_{b/w} + v_{w/s}$$
$$= 3 \text{ m/s} + 2 \text{ m/s} = 5 \text{ m/s}$$

The minimum speed relative to the shore is when the boat moves in the opposite direction of the river's flow with the same speed as the river:

$$v_{b/s} = v_{b/w} + v_{w/s}$$
$$= 2 \text{ m/s} + (-2 \text{ m/s}) = 0 \text{ m/s}$$

34. **Relative Velocity of a Boat** A motorboat heads due west at 13 m/s relative to a river that flows due north at 5.0 m/s. What is the velocity (both magnitude and direction) of the motorboat relative to the shore?

SOLUTION:

$$v_{b/s}^2 = v_{b/r}^2 + v_{r/s}^2$$
$$v_{b/s} = \sqrt{v_{b/r}^2 + v_{r/s}^2}$$
$$v_{b/s} = \sqrt{(13 \text{ m/s})^2 + (5.0 \text{ m/s})^2}$$
$$= 14 \text{ m/s}$$
$$\theta = \tan^{-1}\left(\frac{v_{b/r}}{v_{r/s}}\right) = \tan^{-1}\left(\frac{13 \text{ m/s}}{5.0 \text{ m/s}}\right)$$
$$= 69°$$

θ = 69° west of north

35. **Boating** You are boating on a river that flows toward the east. Because of your knowledge of physics, you head your boat 53° west of north and have a velocity of 6.0 m/s due north relative to the shore.

a. What is the velocity of the current?
b. What is the speed of your boat relative to the water?

SOLUTION:

a.

$$\tan\theta = \left(\frac{v_{w/s}}{v_{b/s}}\right), \text{ so}$$

$$v_{w/s} = (\tan\theta)(v_{b/s}) = (\tan 53°)(6.0 \text{ m/s}) = 8.0 \text{ m/s east}$$

b.

$$\cos\theta = \frac{v_{b/s}}{v_{b/w}},$$

$$\text{So, } V_{b/w} = \frac{v_{b/s}}{\cos\theta} = \frac{6.0 \text{ m/s}}{\cos 53°} = 1.0\times 10^1 \text{m/s}$$

36. **Boating** Martin is riding on a ferry boat that is traveling east at 3.8 m/s. He walks north across the deck of the boat at 0.62 m/s. What is Martin's velocity relative to the water?

SOLUTION:

$$v_{M/w} = \sqrt{v_{b/w}^2 + v_{M/b}^2}$$

$$v_{M/w} = \sqrt{(3.8 \text{ m/s})^2 + (0.62 \text{ m/s})^2} = 3.8 \text{ m/s}$$

$$\theta = \tan^{-1}\left(\frac{v_{M/b}}{v_{b/w}}\right) = \tan^{-1}\left(\frac{0.62 \text{ m/s}}{3.8 \text{ m/s}}\right) = 9.3° \text{ north of east}$$

37. **Relative Velocity** An airplane flies due south at 175 km/h relative to the air. There is a wind blowing at 85 km/h to the east relative to the ground. What are the plane's speed and direction relative to the ground?

SOLUTION:

$$v_{p/g} = \sqrt{v_{p/a}^2 + v_{a/g}^2}$$

$$v_{b/s} = \sqrt{(175 \text{ km/h})^2 + (85 \text{ km/h})^2} = 1.9\times 10^2 \text{ km/h}$$

$$\theta = \tan^{-1}\left(\frac{v_{p/a}}{v_{a/g}}\right) = \tan^{-1}\left(\frac{175 \text{ km/h}}{85 \text{ km/h}}\right) = 64° \text{ south of east}$$

38. **A Plane's Relative Velocity** An airplane flies due north at 235 km/h relative to the air. There is a wind blowing at 65 km/h to the northeast relative to the ground. What are the plane's speed and direction relative to the ground?

SOLUTION:

$$v_R = \sqrt{v_{RE}^{\ 2} + v_{RN}^{\ 2}}$$

$$= \sqrt{(v_{pE} + v_{aE})^2 + (v_{pN} + v_{wN})^2}$$

$$= \sqrt{(v_w \cos\theta)^2 + (v_p + v_w \sin\theta)^2}$$

$$= \sqrt{((65 \text{ km/h})(\cos 45°))^2 + (235 \text{ km/h} + (65 \text{ km/h})(\sin 45°))^2}$$

$$= 2.9\times 10^2 \text{ km/h}$$

$$\theta = \tan^{-1}\left(\frac{v_{RN}}{v_{RE}}\right) = \tan^{-1}\left(\frac{v_p + v_a \sin\theta}{v_a \cos\theta}\right)$$

$$= \tan^{-1}\left(\frac{235 \text{ km/h} + (65 \text{ km/h})(\sin 45°)}{(65 \text{ km/h})(\cos 45°)}\right)$$

θ = 81° north of east

39. **Critical Thinking** You are piloting the boat in **Figure 18** across a fast-moving river. You want to reach a pier directly opposite your starting point. Describe how you would navigate the boat in terms of the components of your velocity relative to the water.

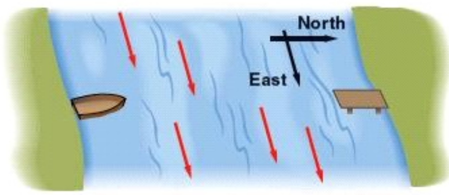


Figure 18

SOLUTION:

Choose the component of your velocity along the direction of the river to be equal and opposite to the velocity of the river.

Chapter Assessment
Section 1 Projectile Motion: Mastering Concepts

40. Some students believe the force that starts the motion of a projectile, such as the kick given a soccer ball, remains with the ball. Is this a correct viewpoint? Present arguments for or against.

SOLUTION:

It is not correct. A throw, kick, or other force is a contact force, and once there is no contact, there is no force.

41. Consider the trajectory of the cannonball shown in **Figure 19.**

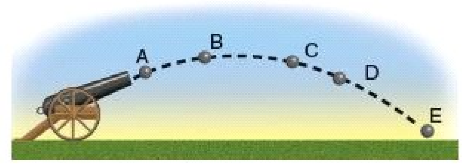


Figure 19

a. Where is the magnitude of the vertical-velocity component largest?
b. Where is the magnitude of the horizontal velocity component largest?
c. Where is the vertical velocity smallest?
d. Where is the magnitude of the acceleration smallest?

SOLUTION:

a. point E
b. Neglecting air resistance, the horizontal velocity at all points is the same. Horizontal velocity is constant and independent of vertical velocity.
c. points B and C
d. The acceleration is the same everywhere.

42. **Trajectory** Describe how forces cause the trajectory of an object launched horizontally to be different from the trajectory of an object launched upward at an angle.

SOLUTION:

After they are launched, the only force acting on both objects is gravity. Both objects immediately begin to accelerate downward, but the object launched upward at an angle has an initial upward velocity, causing it to go upward and then curve downward. The object launched horizontally immediately curves downward.

43. **Reverse Problem** Write a physics problem with real-life objects for which the following equations would be part of the solution. *Hint: The two equations describe the same object.*

$$x = (1.5\ \text{m/s})t$$

$$8.0\ \text{m} = \frac{1}{2}\left(9.8\ \text{m/s}^2\right)t^2$$

SOLUTION:

Answers will vary, but a correct form of the answer is, "A baseball is thrown horizontally at an initial speed of 1.5 m/s. How far does it travel horizontally before it hits the ground 8 m below?"

44. An airplane pilot flying at constant velocity and altitude drops a heavy crate. Ignoring air resistance, where will the plane be relative to the crate when the crate hits the ground? Draw the path of the crate as seen by an observer on the ground.

SOLUTION:

The plane will be directly over the crate when the crate hits the ground. Both have the same horizontal velocity. The crate will look like it is moving horizontally while falling vertically to an observer on the ground.

Chapter Assessment
Section 1 Projectile Motion: Mastering Problems

45. You accidentally throw your car keys horizontally at 8.0 m/s from a cliff 64 m high. How far from the base of the cliff should you look for the keys? (Level 1)

SOLUTION:

$$y = v_y t - \frac{1}{2}at^2$$

Since initial vertical velocity is zero,

$$t = \sqrt{\frac{-2y}{a}} = \sqrt{\frac{(-2)(-64\ \text{m})}{9.8\ \text{m/s}^2}}$$

$$= 3.6\ \text{s}$$

$$x = v_x t = (8.0\ \text{m/s})(3.6) = 28.8\ \text{m}$$

$$= 29\ \text{m}$$

46. A dart player throws a dart horizontally at 12.4 m/s. The dart hits the board 0.32 m below the height from which it was thrown. How far away is the player from the board? (Level 1)

SOLUTION:

$$y = v_{y0}t - \frac{1}{2}at^2$$

and because initial velocity is zero,

$$t = \sqrt{\frac{-2y}{a}} = \sqrt{\frac{(-2)(-0.32\ \text{m})}{9.8\ \text{m/s}^2}} = 0.26\ \text{s}$$

$$x = v_x t = (12.4\ \text{m/s})(0.26\ \text{s}) = 3.2\ \text{m}$$

47. The toy car in **Figure 20** runs off the edge of a table that is 1.225 m high. The car lands 0.400 m from the base of the table. (Level 1)

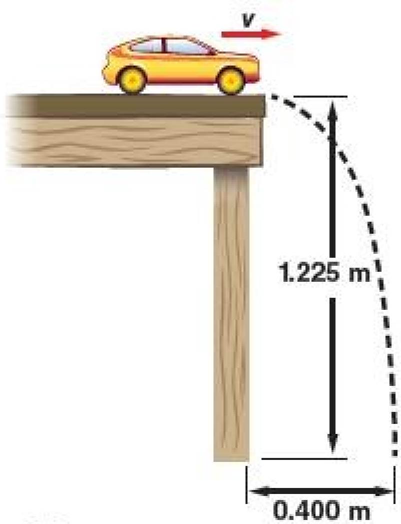


Figure 20

a. How long did it take the car to fall?
b. How fast was the car going on the table?

SOLUTION:

a.

$$y = v_{y0}t - \frac{1}{2}at^2$$

Since initial vertical velocity is zero,

$$t = \sqrt{\frac{-2y}{a}} = \sqrt{\frac{(-2)(-1.225\text{ m})}{9.8\text{ m/s}^2}}$$

$$= 0.50\text{ s}$$

b.

$$v_x = \frac{x}{t} = \frac{0.400\text{ m}}{0.50\text{ s}} = 0.80\text{ m/s}$$

48. **Swimming** You took a running leap off a high-diving platform. You were running at 2.8 m/s and hit the water 2.6 s later. How high was the platform, and how far from the edge of the platform did you hit the water? Assume your initial velocity is horizontal. Ignore air resistance. (Level 1)

SOLUTION:

$$y = v_{yi}t - \frac{1}{2}at^2$$

$$= 0(2.6\text{ s}) - \frac{1}{2}(9.8\text{ m/s}^2)(2.6\text{ s})^2$$

$= -33$ m, so the platform is 33 m high

$$x = v_xt = (2.8\text{ m/s})(2.6\text{ s}) = 7.3\text{ m}$$

49. **Archery** An arrow is shot at 30.0° above the horizontal. Its velocity is 49 m/s, and it hits the target. (Level 2)

a. What is the maximum height the arrow will attain?
b. The target is at the height from which the arrow was shot. How far away is it?

SOLUTION:

a.

$v_y{}^2 = v_{yi}{}^2 - 2ay$

At the high point $v_y = 0$, so

$$y = \frac{(v_{yi})^2}{2a} = \frac{(v_i \sin\theta)^2}{2a}$$

$$= \frac{((49 \text{ m/s})(\sin 30.0°))^2}{(2)(9.8 \text{ m/s}^2)}$$

$= 31$ m

b.

$$y = v_{yi}t - \frac{1}{2}at^2$$

but the arrow lands at the same height, so

$$y = 0 \text{ and } 0 = y_{yi} - \frac{1}{2}at$$

so $t = 0$ or

$$t = \frac{2vy_i}{a} = \frac{2v_i \sin\theta}{a}$$

$$= \frac{(2)(49 \text{ m/s})(\sin 30.0°)}{9.8 \text{ m/s}^2}$$

$= 5.0$ s

and $x = v_x t$

$= (v_i \cos\theta)(t)$

$= (49 \text{ m/s})(\cos 30.0°)(5.0 \text{ s})$

$= 2.1\times10^2$ m

50. **Big Idea** A pitched ball is hit by a batter at a 45° angle and just clears the outfield fence, 98 m away. If the top of the fence is at the same height as the pitch, find the velocity of the ball when it left the bat. Ignore air resistance. (Level 2)

SOLUTION:

The components of the initial velocity are $v_x = v_i \cos\theta_i$ and $v_{yi} = v_i \sin\theta_i$

Now $x = v_x t = (v_i \cos\theta_i)t$, so

$$t = \frac{x}{v_i \cos\theta_i}$$

And $y = v_{yi}t - \frac{1}{2}at^2$, but $y = 0$, so

$$0 = \left(v_{yi} - \frac{1}{2}at\right)t$$

so $t = 0$ or $v_{yi} - \frac{1}{2}at = 0$

From above,

$$v_i \sin\theta_i - \frac{1}{2}a\left(\frac{x}{v_i \cos\theta_i}\right) = 0$$

Multiplying by $v_i \cos\theta_i$ gives

$$v_i^2 \sin\theta_i \cos\theta_i - \frac{1}{2}ax = 0$$

so $$v_i^2 = \frac{ax}{(2)(\sin\theta_i)(\cos\theta_i)}$$

Thus,

$$v_i = \sqrt{\frac{ax}{(2)(\sin\theta_i)(\cos\theta_i)}}$$

$$= \sqrt{\frac{(9.8 \text{ m/s}^2)(98 \text{ m})}{(2)(\sin 45°)(\cos 45°)}}$$

$= 31$ m/s at 45°

51. **At-Sea Rescue** An airplane traveling 1001 m above the ocean at 125 km/h is going to drop a box of supplies to shipwrecked victims below. (Level 3)

a. How many seconds before the plane is directly overhead should the box be dropped?
b. What is the horizontal distance between the plane and the victims when the box is dropped?

SOLUTION:

a.

$$y = v_{yi}t - \frac{1}{2}at^2$$

but $v_{yi} = 0$, so

$$t = \sqrt{\frac{-2y}{a}} = \sqrt{\frac{(-2)(-1001\text{ m})}{9.8\text{ m/s}^2}} = 14\text{ s}$$

b.

Carry an extra digit from the part a calculation for time to avoid roundoff error: $t \approx 14.3$ s.

$$x = v_{xt}$$

$$= (125\text{ km/h})\left(\frac{1\text{ h}}{3600\text{ s}}\right)\left(\frac{1000\text{ m}}{1\text{ km}}\right)(14.3\text{ s})$$

$$= 5.0 \times 10^2\text{ m}$$

52. **Diving** Divers in Acapulco dive from a cliff that is 61 m high. If the rocks below the cliff extend outward for 23 m, what is the minimum horizontal velocity a diver must have to clear the rocks? (Level 3)

SOLUTION:

$$y = v_{yi}t - \frac{1}{2}at^2$$

and since $v_{yi} = 0$,

$$t = \sqrt{\frac{-2y}{a}} = \sqrt{\frac{(-2)(-61\text{ m})}{9.8\text{ m/s}^2}} = 3.53\text{ s}$$

An extra digit is included for time to avoid roundoff error in the next calculation.

$$x = v_x t$$

$$v_x = \frac{x}{t} = \frac{23\text{ m}}{3.53\text{ s}} = 6.5\text{ m/s}$$

53. **Jump Shot** A basketball player is trying to make a half-court jump shot and releases the ball at the height of the basket. Assume that the ball is launched at an angle of 51.0° above the horizontal and a horizontal distance of 14.0 m from the basket. What speed must the player give the ball in order to make the shot? (Level 3)

SOLUTION:

The components of the initial velocity are $v_{xi} = v_i \cos\theta_i$ and $v_{yi} = v_i \sin\theta_i$

Now $x = v_{xi}t = (v_i \cos\theta_i)t$, so

$$t = \frac{x}{v_i \cos\theta_i}$$

And $y = v_{yi}t - \frac{1}{2}at^2$, but $y = 0$, so

$$0 = \left(v_{yi} - \frac{1}{2}at\right)t$$

so $t = 0$ or $v_{yi} - \frac{1}{2}at = 0$

From above

$$v_i \sin\theta_i - \frac{1}{2}a\left(\frac{x}{v_i \cos\theta_i}\right) = 0$$

Multiplying by $v_i \cos\theta_i$ gives

$$v_i^2(\sin\theta_i)(\cos\theta_i) - \frac{1}{2}ax = 0$$

$$v_i = \sqrt{\frac{ax}{(2)(\sin\theta_i)(\cos\theta_i)}}$$

$$= \sqrt{\frac{(9.8\text{ m/s}^2)(14.0\text{ m})}{(2)(\sin 51.0°)(\cos 51.0°)}}$$

$$= 12\text{ m/s}$$

54. The two baseballs in **Figure 21** were hit with the same speed, 25 m/s. Draw separate graphs of *y* versus *t* and *x* versus *t* for each ball. (Level 1)

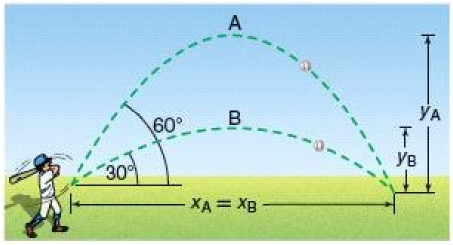
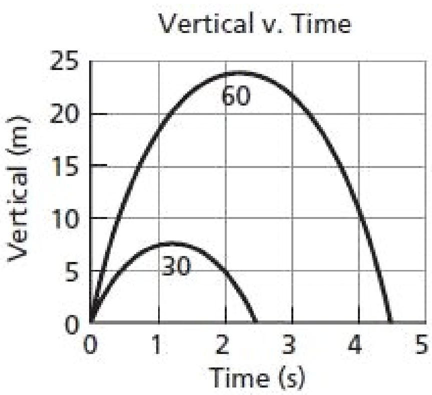
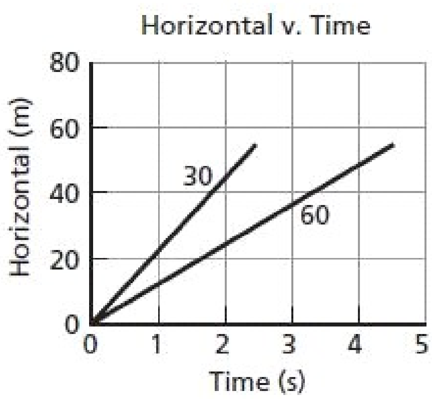


Figure 21

SOLUTION:





Chapter Assessment
Section 2 Circular Motion: Mastering Concepts

55. Can you go around a curve with the following acceleration? Explain.

a. zero acceleration vector
b. constant acceleration vector

SOLUTION:

a. No, going around a curve changes the direction of velocity. Thus, the acceleration cannot be zero.
b. No, the magnitude of acceleration may be constant, but the direction of the acceleration changes.

56. To obtain uniform circular motion, how must the net force that acts on a moving object depend on the speed of the object?

SOLUTION:

The net force is directly proportional to the square of the speed of the moving object.

57. Suppose you whirl a yo-yo about your head in a horizontal circle.

a. In what direction must a force act on the yo-yo?
b. What exerts the force?
c. If you let go of the string on the yo-yo, in which direction would the toy travel? Use Newton's laws in your answer.

SOLUTION:

a. The force is along the string toward the center of the circle that the yo-yo follows.
b. The string exerts the force.
c. If the string were released, the velocity of the yo-yo would not change. According to Newton's first law of motion, it would move tangent to the circle in the direction it had been moving. There would be a gravitational force on it, so according to Newton's second law of motion, it would also have a downward acceleration. It would act like a horizontally launched projectile.

Chapter Assessment
Section 2 Circular Motion: Mastering Problems

58. **Car Racing** A 615-kg racing car completes one lap in a time of 14.3 s around a circular track that has a radius of 50.0 m. Assume that the car moves at a constant speed. (Level 1)

a. What is the acceleration of the car?
b. What force must the track exert on the tires to produce this acceleration?

SOLUTION:

a.

$$a_c = \frac{v^2}{r} = \frac{2\pi^2 r}{T^2}$$
$$= \frac{4\pi^2(50.0\text{ m})}{(14.3\text{ s})^2} = 9.65\text{ m/s}^2$$

b.

To avoid roundoff error in the force calculation, carry an extra digit for the acceleration: $a_c \approx 9.653\text{ m/s}^2$.

$$F_c = ma_c = (615\text{ kg})(9.653\text{ m/s}^2)$$
$$= 5.94\times10^3\text{ N}$$

59. Ranking Task Rank the following objects according to their centripetal accelerations, from least to greatest. Specifically indicate any ties. (Level 2)
A: a 0.50-kg stone moving in a circle of radius 0.6 m at a speed of 2.0 m/s
B: a 0.50-kg stone moving in a circle of radius 1.2 m at a speed of 3.0 m/s
C: a 0.60-kg stone moving in a circle of radius 0.8 m at a speed of 2.4 m/s
D: a 0.75-kg stone moving in a circle of radius 1.2 m at a speed of 3.0 m/s
E: a 0.75-kg stone moving in a circle of radius 0.6 m at a speed of 2.4 m/s

SOLUTION:

$$\text{A: } a_c = \frac{v^2}{r} = \frac{(2.0\text{ m/s})^2}{0.6\text{ m}} \approx 6.7\text{ m/s}^2$$

$$\text{B: } a_c = \frac{v^2}{r} = \frac{(3.0\text{ m/s})^2}{1.2\text{ m}} = 7.5\text{ m/s}^2$$

$$\text{C: } a_c = \frac{v^2}{r} = \frac{(2.4\text{ m/s})^2}{0.8\text{ m}} \approx 7.2\text{ m/s}^2$$

$$\text{D: } a_c = \frac{v^2}{r} = \frac{(3.0\text{ m/s})^2}{1.2\text{ m}} = 7.5\text{ m/s}^2$$

$$\text{E: } a_c = \frac{v^2}{r} = \frac{(2.4\text{ m/s})^2}{0.6\text{ m}} \approx 9.6\text{ m/s}^2$$

So, $A < C < B = D < E$

Chapter Assessment
Section 2 Circular Motion: Mastering Problems

60. **Hammer Throw** An athlete whirls a 7.00-kg hammer 1.8 m from the axis of rotation in a horizontal circle, as shown in **Figure 22.** If the hammer makes one revolution in 1.0 s, what is the centripetal acceleration of the hammer? What is the tension in the chain? (Level 1)

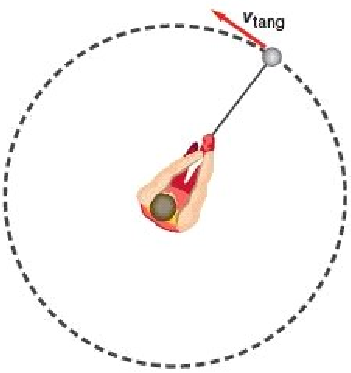


Figure 22

SOLUTION:

$$a_c = \frac{4\pi^2 r}{T^2} = \frac{(4\pi^2)(1.8\ \text{m})}{(1.0\ \text{s})^2} = 71\ \text{m/s}^2$$

$$F_c = ma_c = (7.00\ \text{kg})(71\ \text{m/s}^2) = 5.0\times10^2\ \text{N}$$

61. A rotating rod that is 15.3 cm long is spun with its axis through one end of the rod. The other end of the rod has a constant speed of 2010 m/s (4500 mph). (Level 2)

a. What is the centripetal acceleration of the end of the rod?
b. If you were to attach a 1.0-g object to the end of the rod, what force would be needed to hold it on the rod?

SOLUTION:

a.

$$a_c = \frac{v^2}{r} = \frac{(2010\ \text{m/s})^2}{0.153\ \text{m}} = 2.64\times10^7\ \text{m/s}^2$$

b.

$$F_c = ma_c = (0.0010\ \text{kg})(2.64\times10^7\ \text{m/s}^2) = 2.6\times10^4\ \text{N}$$

62. A carnival clown rides a motorcycle down a ramp and then up and around a large, vertical loop. If the loop has a radius of 18 m, what is the slowest speed the rider can have at the top of the loop so that the motorcycle stays in contact with the track and avoids falling? *Hint: At this slowest speed, the track exerts no force on the motorcycle at the top of the loop.* (Level 3)

SOLUTION:

$$F_c = ma_c = F_g = ma_{grav},\ \text{so}\ a_c = a_{grav}$$

$$\frac{v^2}{r} = a_{grav},\ \text{so}$$

$$v = \sqrt{a_{grav} r} = \sqrt{(9.8\ \text{m/s}^2)(18\ \text{m})} = 13\ \text{m/s}$$

63. A 75-kg pilot flies a plane in a loop as shown in **Figure 23.** At the top of the loop, when the plane is completely upside-down for an instant, the pilot hangs freely in the seat and does not push against the seat belt. The airspeed indicator reads 120 m/s. What is the radius of the plane's loop? (Level 3)

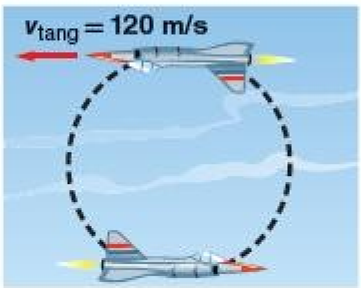


Figure 23

SOLUTION:

Because the net force is equal to the weight of the pilot,

$F_c = ma_c = F_g = ma_{grav}$, so

$a_c = a_{grav}$ or $\frac{v^2}{r} = a_{grav}$

$$r = \frac{(120\ \text{m/s})^2}{9.8\ \text{m/s}^2}$$
$$= 1.5 \times 10^3\ \text{m}$$

Chapter Assessment
Section 3 Relative Velocity: Mastering Concepts

64. Why is it that a car traveling in the opposite direction as the car in which you are riding on the freeway often looks like it is moving faster than the speed limit?

SOLUTION:

The magnitude of the relative velocity of that car to your car can be found by adding the magnitudes of the two cars' velocities together. Since each car probably is moving at close to the speed limit, the resulting relative velocity will be larger than the posted speed limit.

Chapter Assessment
Section 3 Relative Velocity: Mastering Problems

65. Odina and LaToya are sitting by a river and decide to have a race. Odina will run down the shore to a dock, 1.5 km away, then turn around and run back. LaToya will also race to the dock and back, but she will row a boat in the river, which has a current of 2.0 m/s. If Odina's running speed is equal to LaToya's rowing speed in still water, which is 4.0 m/s, what will be the outcome of the race? Assume they both turn instantaneously. (Level 1)

SOLUTION:

$x = vt$, so $t = \frac{x}{v}$

For Odina,

$$t = \frac{3.0 \times 10^3\text{m}}{4.0\ \text{m/s}} = 7.5\times10^2\ \text{s}$$

For LaToya (assume against current on the way to the dock),

$$t = \frac{x_1}{v_1} + \frac{x_2}{v_2}$$
$$= \frac{1.5 \times 10^3\ \text{m}}{4.0\ \text{m/s} - 2.0\ \text{m/s}} + \frac{1.5 \times 10^3\ \text{m}}{4.0\ \text{m/s} + 2.0\ \text{m/s}}$$
$$= 1.0\times10^3\ \text{s}$$

Odina wins.

66. **Crossing a River** You row a boat, such as the one in **Figure 24,** perpendicular to the shore of a river that flows at 3.0 m/s. The velocity of your boat is 4.0 m/s relative to the water. (Level 2)

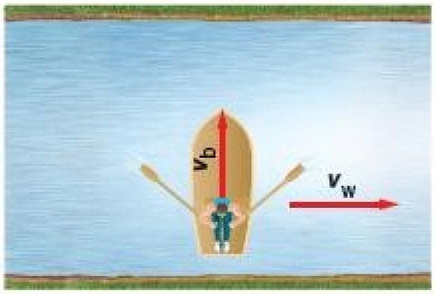


Figure 24

a. What is the velocity of your boat relative to the shore?
b. What is the component of your velocity parallel to the shore? Perpendicular to it?

SOLUTION:

a.

$$v_{b/s} = \sqrt{(v_{b/w})^2 + (v_{w/s})^2}$$
$$= \sqrt{(4.0\text{ m/s})^2 + (3.0\text{ m/s})^2}$$
$$= 5.0\text{ m/s}$$
$$\theta = \tan^{-1}\left(\frac{v_{b/w}}{v_{w/s}}\right) = \tan^{-1}\left(\frac{4.0\text{ m/s}}{3.0\text{ m/s}}\right)$$
$$= 53^\circ\text{ from shore}$$

b.

3.0 m/s; 4.0 m/s

67. **Air Travel** You are piloting a small plane, and you want to reach an airport 450 km due south in 3.0 h. A wind is blowing from the west at 50.0 km/h. What heading and airspeed should you choose to reach your destination in time? (Level 2)

SOLUTION:

$$v_{p/g} = \frac{x_s}{t} = \frac{450\text{ km}}{3.0\text{ h}} = 150\text{ km/h}$$
$$v_{p/a}^2 = v_{p/g}^2 + v_{a/g}^2$$
$$v_{p/a} = \sqrt{v_{p/g}^2 + v_{a/g}^2}$$
$$v_{p/a} = \sqrt{(150\text{ km/h})^2 + (50.0\text{ km/h})^2}$$
$$= 1.6 \times 10^2\text{ km/h}$$
$$\theta = \tan^{-1}\left(\frac{v_{a/g}}{v_{p/g}}\right) = \tan^{-1}\left(\frac{50.0\text{ km/h}}{150\text{ km/h}}\right)$$
$$= 18^\circ\text{ west of south}$$

68. **Problem Posing** Complete this problem so that it can be solved using the concept of relative velocity: "Hannah is on the west bank of a 55-m-wide river with a current of 0.7 m/s…." (Level 3)

SOLUTION:

Answers will vary. A possible form of the correct answer is, "... She wishes to reach a camp on the east bank that is 75 m downstream. If she rows at a speed of 5 m/s, at what angle should she direct the boat to go straight to the camp?"

Chapter Assessment
Section 3 Relative Velocity: Applying Concepts

69. **Projectile Motion** Explain how horizontal motion can be uniform while vertical motion is accelerated. How will projectile motion be affected when drag due to air resistance is taken into consideration? (Level 1)

SOLUTION:

The horizontal motion is uniform because there are no forces acting in that direction (ignoring friction). Vertically, there is acceleration due to the force of gravity. The projectile-motion equations in this book do not hold when friction is taken into account. Projectile motion in both directions will be impacted when air drag is taken into consideration, because air drag is a friction force.

70. **Baseball** A batter hits a pop-up straight up over home plate at an initial speed of 20 m/s. The ball is caught by the catcher at the same height at which it was hit. At what velocity does the ball land in the catcher's mitt? Neglect air resistance. (Level 1)

SOLUTION:

20 m/s downward

71. **Fastball** In baseball, a fastball takes about $\frac{1}{2}$ s to reach the plate. Assuming that such a pitch is thrown horizontally, compare the distance the ball falls in the first $\frac{1}{4}$ s with the distance it falls in the second $\frac{1}{4}$ s. (Level 1)

SOLUTION:

Because of the acceleration due to gravity, the baseball falls a greater distance during the second $\frac{1}{4}$ s than during the first $\frac{1}{4}$ s.

72. You throw a rock horizontally. In a second horizontal throw, you throw the rock harder and give it even more speed. (Level 1)

a. How will the time it takes the rock to hit the ground be affected? Ignore air resistance.
b. How will the increased speed affect the distance from where the rock left your hand to where the rock hits the ground?

SOLUTION:

a. The time does not change. The time it takes to hit the ground depends only on vertical velocities and acceleration.
b. A higher horizontal speed produces a longer horizontal distance.

73. **Field Biology** A zoologist standing on a cliff aims a tranquilizer gun at a monkey hanging from a tree branch that is in gun's range. The barrel of the gun is horizontal. Just as the zoologist pulls the trigger, the monkey lets go and begins to fall. Will the dart hit the monkey? Ignore air resistance. (Level 1)

SOLUTION:

Yes, in fact, the monkey would be safe if it did not let go of the branch. The vertical acceleration of the dart is the same as that of the monkey. Therefore the dart is at the same vertical height when it reaches the monkey.

74. **Football** A quarterback throws a football at 24 m/s at a 45° angle. If it takes the ball 3.0 s to reach the top of its path and the ball is caught at the same height at which it is thrown, how long is it in the air? Ignore air resistance. (Level 1)

SOLUTION:

6.0 s: 3.0 s up and 3.0 s down

75. **Track and Field** You are working on improving your performance in the long jump and believe that the information in this chapter can help. Does the height that you reach make any difference to your jump? What influences the length of your jump? (Level 1)

SOLUTION:

Both speed and angle of launch matter, so height does make a difference. Maximum range is achieved when the resultant velocity has equal vertical and horizontal components—in other words, a launch angle of 45°. For this reason, height and speed affect the range.

76. **Driving on a Freeway** Explain why it is that when you pass a car going in the same direction as you on the freeway, it takes a longer time than when you pass a car going in the opposite direction. (Level 2)

SOLUTION:

The relative speed of two cars going in the same direction is less than the relative speed of two cars going in the opposite direction. The passing with the lesser relative speed will take longer.

77. Imagine you are sitting in a car tossing a ball straight up into the air. (Level 2)

a. If the car is moving at a constant velocity, will the ball land in front of, behind, or in your hand?
b. If the car rounds a curve at a constant speed, where will the ball land?

SOLUTION:

a. The ball will land in your hand because you, the ball, and the car are all moving forward with the same speed.
b. The ball will land beside you, toward the outside of the curve. A top view would show the ball moving straight while you and the car moved out from under the ball.

78. You swing one yo-yo around your head in a horizontal circle. Then you swing another yo-yo with twice the mass of the first one, but you don't change the length of the string or the period. How do the tensions in the strings differ? (Level 2)

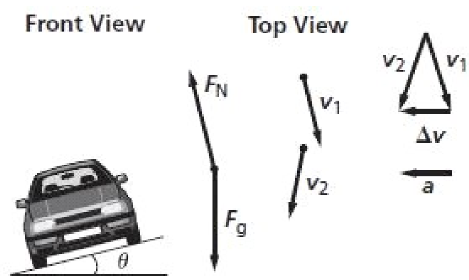
SOLUTION:

The tension in the string is doubled since $F_T = ma_c$.

79. **Car Racing** The curves on a race track are banked to make it easier for cars to go around the curves at high speeds. Draw a free-body diagram of a car on a banked curve. From the motion diagram, find the direction of the acceleration. (Level 3)

a. What exerts the force in the direction of the acceleration?
b. Can you have such a force without friction?

SOLUTION:



The acceleration is toward the center of the track.

a. The component of the normal force acting toward the center of the curve, and depending on the car's speed, the component of the friction force acting toward the center, both contribute to the net force in the direction of acceleration.
b. Yes, the centripetal acceleration need only be due to the normal force.

Chapter Assessment: Mixed Review

80. Early skeptics of the idea of a rotating Earth said that the fast spin of Earth would throw people at the equator into space. The radius of Earth is about 6.38×10^3 km. Show why this idea is wrong by calculating the following. (Level 1)

a. the speed of a 97-kg person at the equator
b. the force needed to accelerate the person in the circle
c. the weight of the person
d. the normal force of Earth on the person, that is, the person's apparent weight

SOLUTION:

a.

$$v = \frac{\Delta x}{\Delta t} = \frac{2\pi r}{T} = \frac{2\pi\left(6.38\times10^6\text{ m}\right)}{(24\text{ h})\left(\frac{3600\text{ s}}{1\text{ h}}\right)}$$

$$= 464\text{ m/s}$$

b.

$$F_c = ma_c = \frac{mv^2}{r}$$

$$= \frac{(97\text{ kg})(464\text{ m/s})^2}{6.38\times10^6\text{ m}} = 3.3\text{ N}$$

c.

$$F_g = ma_{grav} = (97)(9.8\text{ m/s}^2)$$
$$= 9.5\times10^2\text{ N}$$

d.

$$F_N = 9.5\times10^2\text{ N} - 3.3\text{ N} = 9.5\times10^2\text{ N}$$

81. **Firing a Missile** An airplane moving at 375 m/s relative to the ground fires a missile forward at a speed of 782 m/s relative to the plane. What is the missile's speed relative to the ground? (Level 1)

SOLUTION:

$$v_{m/g} = v_{p/g} + v_{m/p}$$
$$= 375\text{ m/s} + 782\text{ m/s} = 1157\text{ m/s}$$

82. **Rocketry** A rocket in outer space that is moving at a speed of 1.25 km/s relative to an observer fires its motor. Hot gases are expelled out the back at 2.75 km/s relative to the rocket. What is the speed of the gases relative to the observer? (Level 1)

SOLUTION:

$$v_{g/o} = v_{r/o} - v_{g/r}$$
$$= 1.25\text{ km/s} + (-2.75\text{ km/s})$$
$$= -1.50\text{ km/s}$$

83. A 1.13-kg ball is swung vertically from a 0.50-m cord in uniform circular motion at a speed of 2.4 m/s. What is the tension in the cord at the bottom of the ball's motion? (Level 2)

SOLUTION:

$$F_T = F_g + F_c = ma_{grav} + \frac{mv^2}{r}$$
$$= (1.13\text{ kg})(9.8\text{ m/s}^2) + \frac{(1.13\text{ kg})(2.4\text{ m/s})^2}{0.50\text{ m}}$$
$$= 24\text{ N}$$

84. Two dogs, initially separated by 500.0 m, are running toward each other, each moving with a constant speed of 2.5 m/s. A dragonfly, moving with a constant speed of 3.0 m/s, flies from the nose of one dog to the other, then turns around instantaneously and flies back to the other dog. It continues to fly back and forth until the dogs run into each other. What distance does the dragonfly fly during this time? (Level 2)

SOLUTION:

The dogs will meet in

$$\frac{500.0\text{ m}}{5.0\text{ m/s}} = 1.0\times10^2\text{ s}.$$

The dragonfly flies

$$(3.0\text{ m/s})(1.0\times10^2\text{ s}) = 3.0\times10^2\text{ m}.$$

85. **Banked Roads** Curves on roads often are banked to help prevent cars from slipping off the road. If the speed limit for a particular curve of radius 36.0 m is 15.7 m/s (35 mph), at what angle should the road be banked so that cars will stay on a circular path even if there were no friction between the road and the tires? If the speed limit was increased to 20.1 m/s (45 mph), at what angle should the road be banked? (Level 2)

SOLUTION:

Horizontal component:

$$F_N \sin\theta = ma = \frac{mv^2}{r}$$

Vertical component:

$$F_N \cos\theta - ma_{grav} = 0$$

$$F_N = \frac{ma_{grav}}{\cos\theta}$$

$$\text{So } \frac{mv^2}{r} = \frac{ma_{grav}\sin\theta}{\cos\theta}$$

$$\frac{v^2}{r} = a_{grav}\left(\frac{\sin\theta}{\cos\theta}\right) = a_{grav}\tan\theta$$

$$\theta = \tan^{-1}\left(\frac{v^2}{a_{grav}r}\right)$$

For 35 mph:

$$\theta = \tan^{-1}\left(\frac{v^2}{a_{grav}r}\right)$$

$$= \tan^{-1}\left(\frac{(15.7\text{ m/s})^2}{(9.8\text{ m/s}^2)(36.0\text{ m})}\right)$$

$$= 35°$$

For 45 mph:

$$\theta = \tan^{-1}\left(\frac{v^2}{a_{grav}r}\right)$$

$$= \tan^{-1}\left(\frac{(20.1\text{ m/s})^2}{(9.8\text{ m/s}^2)(36.0\text{ m})}\right)$$

$$= 49°$$

86. The 1.45-kg ball in **Figure 25** is suspended from a 0.80-m string and swung in a horizontal circle at a constant speed. (Level 3)

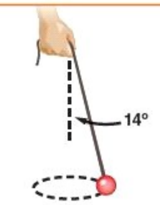


Figure 25

a. What is the tension in the string?
b. What is the speed of the ball?

SOLUTION:

a.

$$F_T \cos\theta = ma_{grav}$$

$$\text{so } F_T = \frac{ma_{grav}}{\cos\theta}$$

$$= \frac{(14.5\text{ kg})(9.8\text{ m/s}^2)}{\cos 14.0°}$$

$$= 15\text{ N}$$

b.

$$F_C = F_T \sin\theta = \frac{mv^2}{r}$$

$$\text{where } r = (0.80\text{ m})(\sin 14.0°)$$

$$= 0.1935\text{ m}$$

(carrying extra digits for r to avoid roundoff error)

$$\text{and } F_T\cos\theta = ma_{grav}$$

$$\text{so } F_T = \frac{ma_{grav}}{\cos\theta}$$

$$v = \sqrt{\frac{(F_T\sin\theta)r}{m}} = \sqrt{\frac{(ma_{grav}\sin\theta)r}{m\cos\theta}}$$

$$= \sqrt{ra_{grav}\tan\theta}$$

$$= \sqrt{(0.1935\text{ m})(9.8\text{ m/s}^2)(\tan 14.0°)}$$

$$= 0.69\text{ m/s}$$

87. A baseball is hit directly in line with an outfielder at an angle of 35.0° above the horizontal with an initial speed of 22.0 m/s. The outfielder starts running as soon as the ball is hit at a constant velocity of 2.5 m/s and barely catches the ball. Assuming that the ball is caught at the same height at which it was hit, what was the initial separation between the hitter and outfielder? *Hint: There are two possible answers.* (Level 3)

SOLUTION:

$\Delta x = v_{xi}t \pm v_p t = t(v_{xi} \pm v_p)$

To get t,

$y = v_{yi}t - \frac{1}{2}at^2$, where $y = 0$

so $v_{yi}t - \frac{1}{2}at^2$, $t = 0$ or

$v_{yi} = \frac{1}{2}at$

$t = \frac{2v_{yi}}{a}$

$= \frac{2v_i \sin\theta}{a}$

so

$$\Delta x = \frac{2v_i \sin\theta}{a}(v_{xi} \pm v_p)$$

$$= \left(\frac{(2)(22.0\text{ m/s})(\sin 53°)}{9.8\text{ m/s}^2}\right)((22.0\text{ m/s})(\cos 53°) \pm 2.5\text{ m/s})$$

$$= 53\text{ m or } 4.0 \times 10^1\text{ m}$$

88. **A Jewel Heist** You are serving as a technical consultant for a locally produced cartoon. In one episode, two criminals, Shifty and Crafty, have stolen some jewels. Crafty has the jewels when the police start to chase him. He runs to the top of a 60.0-m tall building in his attempt to escape. Meanwhile, Shifty runs to the convenient hot-air balloon 20.0 m from the base of the building and untethers it, so it begins to rise at a constant speed. Crafty tosses the bag of jewels horizontally with a speed of 7.3 m/s just as the balloon begins its ascent. What must the velocity of the balloon be for Shifty to easily catch the bag? (Level 3)

SOLUTION:

For Shifty to easily catch the bag, the balloon must cross the path of the bag. That is, at one instant in time (t_{catch}),

$x_{bag} = x_{balloon}$ and $y_{bag} = y_{balloon}$.

Horizontal position:

$x_{bag} = v_{bag,x}t$ and $x_{balloon} = 20\text{ m}$

Set the horizontal positions equal at $t = t_{catch}$:

$20\text{ m} = v_{bag,x}t_{catch}$.

This can be rearranged to get $t_{catch} = \frac{20\text{ m}}{v_{bag,x}}$.

Vertical position:

$y_{bag} = 60\text{ m} - \frac{1}{2}at^2$

(initial vertical velocity of the bag is 0 m/s) and

$y_{balloon} = v_{balloon,y}t$

(balloon is moving at a constant speed)

Set the vertical positions equal at $t = t_{catch}$:

$v_{balloon,y}t_{catch} = 60\text{ m} - \frac{1}{2}a(t_{catch})^2$

Substitute $t_{catch} = \frac{20\text{ m}}{v_{bag,x}}$ and solve for $v_{ballon,y}$:

$$v_{balloon,y} = \frac{60\text{ m} - \frac{1}{2}a\left(\frac{20\text{ m}}{v_{bag,x}}\right)^2}{\left(\frac{20\text{ m}}{v_{bag,x}}\right)}$$

$$= \frac{60\text{ m} - \frac{1}{2}(9.8\text{ m/s}^2)\left(\frac{20\text{ m}}{7.3\text{ m/s}}\right)^2}{\left(\frac{20\text{ m}}{7.3\text{ m/s}}\right)}$$

$$= 8.5\text{ m/s}$$

Chapter Assessment: Thinking Critically

89. **Apply Concepts** Consider a roller-coaster loop like the one in **Figure 26.** Are the cars traveling through the loop in uniform circular motion? Explain.

SOLUTION:

The vertical gravitational force changes the speed of the cars, so the motion is not uniform circular motion.

90. **Apply Computers and Calculators** A baseball player hits a belt-high (1.0 m) fastball down the left-field line. The player hits the ball with an initial velocity of 42.0 m/s at an angle 26° above the horizontal. The left-field wall is 96.0 m from home plate at the foul pole and is 14 m high. Write the equation for the height of the ball (*y*) as a function of its distance from home plate (*x*). Use a computer or graphing calculator to plot the path of the ball. Trace along the path to find how high above the ground the ball is when it is at the wall.

a. Is the hit a home run?
b. What is the minimum speed at which the ball could be hit and clear the wall?
c. If the initial velocity of the ball is 42.0 m/s, for what range of angles will the ball go over the wall?

SOLUTION:

a. (Extra digits are carried to avoid roundoff error.)

$$v_x = v_i \cos\theta$$
$$= (42.0\text{ m/s})\cos 26° = 37.7\text{ m/s}$$
$$v_{yi} = v_i \sin\theta$$
$$= (42.0\text{ m/s})\sin 26° = 18.4\text{ m/s}$$

Using $t = \frac{x}{v_x}$, the equation for y

can be written in terms of x.

$$y = y_i + v_{yi}t + \frac{1}{2}at^2$$
$$= y_i + v_{yi}\left(\frac{x}{v_x}\right) + \frac{1}{2}a\left(\frac{x}{v_x}\right)^2$$
$$= (1.0\text{ m}) + \left(\frac{18.4\text{ m/s}}{37.7\text{ m/s}}\right)x + \frac{(-9.8\text{ m/s}^2)}{2(37.7\text{ m/s})^2}x^2$$
$$= (1.0\text{ m}) + (0.488)\,x - (0.00345\text{ m}^{-1})\,x^2$$

If $x = 96.0$ m, then

$$y = (1.0\text{ m}) + (0.488)x - (0.00345\text{ m}^{-1})x^2$$
$$= (1.0\text{ m}) + (0.488)(96.0\text{ m}) - (0.00345\text{ m}^{-1})(96.0\text{ m})^2$$
$$\approx 16.1\text{ m}$$

Yes, the ball clears the wall by 2.1 m.

b.

$$v_i = \frac{x}{\cos\theta}\sqrt{\frac{a}{2((\tan\theta)\,x - \Delta y)}}$$
$$= \left(\frac{90.6\text{ m}}{\cos 26°}\right)\sqrt{\frac{9.8\text{ m/s}^2}{(2)((\tan 26°)(96.0\text{ m}) - 13\text{ m})}}$$
$$= 41\text{ m/s}$$

c.

$$y = y_i + (\tan\theta)\,x + \frac{ax^2}{2v_i^2\cos^2\theta}$$

Trial and error with a computer or calculator yields the range of angles to be 25° to 73°.

91. **Analyze** Albert Einstein showed that the rule you learned for the addition of velocities does not work for objects moving near the speed of light. For example, if a rocket moving at speed v_A releases a missile that has speed v_B relative to the rocket, then the speed of the missile relative to an observer that is at rest is given by $v = \frac{v_A + v_B}{1+\frac{v_A v_B}{c^2}}$, where c is the speed of light, 3.00×10^8 m/s. This formula gives the correct values for objects moving at slow speeds as well. Suppose a rocket moving at 11 km/s shoots a laser beam out in front of it. What speed would an unmoving observer find for the laser light? Suppose that a rocket moves at a speed $\frac{c}{2}$, half the speed of light, and shoots a missile forward at a speed of $\frac{c}{2}$ relative to the rocket. How fast would the missile be moving relative to a fixed observer?

SOLUTION:

$$v_{l/o} = \frac{(v_{r/o} + v_{l/r})}{\left(1+\frac{v_{r/o}\times v_{1/r}}{c^2}\right)}$$

$$= \frac{1.1\times10^4\ \text{m/s} + 3.00\times10^8\ \text{m/s}}{1+\frac{(1.1\times10^4\ \text{m/s})(3.00\times10^8\ \text{m/s})}{(3.00\times10^8\ \text{m/s})^2}}$$

$$= 3.0\times10^8\ \text{m/s}$$

$$v_{m/o} = \frac{v_{r/o} + v_{m/r}}{1+\frac{v_{r/o}v_{m/r}}{c^2}}$$

$$= \frac{\frac{c}{2}+\frac{c}{2}}{1+\frac{\left(\frac{c}{2}\right)\left(\frac{c}{2}\right)}{c^2}}$$

$$= \frac{4}{5}c$$

92. **Analyze and Conclude** A ball on a light string moves in a vertical circle. Analyze and describe the motion of this system. Be sure to consider the effects of gravity and tension. Is this system in uniform circular motion? Explain your answer.

SOLUTION:

It is not uniform circular motion. Gravity increases the speed of the ball when it moves downward and reduces the speed when it is moving upward. Therefore, the centripetal acceleration needed to keep it moving in a circle will be larger at the bottom and smaller at the top of the circle. At the top, tension and gravity are in the same direction, so the tension needed will be even smaller. At the bottom, gravity is outward while the tension is inward. Thus, the tension exerted by the string must be even larger.

Chapter Assessment: Writing in Physics

93. **Roller Coasters** The vertical loops on most roller coasters are not circular in shape. Research and explain the physics behind this design choice.

SOLUTION:

Answers will vary. Students should explain that the clothoid shape reduces the centripetal acceleration experienced by the riders, making the ride safer.

94. Many amusement-park rides utilize centripetal acceleration to create thrills for the park's customers. Choose two rides other than roller coasters that involve circular motion and explain how the physics of circular motion creates the sensations for the riders.

SOLUTION:

Answers will vary. Students might explain that a pendulum ride swings riders in an arc, with the centripetal acceleration acting opposite gravitational acceleration at the top of the arc. Riders on a carousel are in circular motion at a constant speed, but because their direction changes, they experience centripetal acceleration.

Chapter Assessment: Cumulative Review

95. Multiply or divide, as indicated, using significant figures correctly.

a. $(5\times10^{8}\text{ m})(4.2\times10^{7}\text{ m})$
b. $(1.67\times10^{-2}\text{ km})(8.5\times10^{-6}\text{ km})$
c. $(2.6\times10^{4}\text{ kg})/(9.4\times10^{3}\text{ m}^{3})$
d. $(6.3\times10^{-1}\text{ m})/(3.8\times10^{2}\text{ s})$

SOLUTION:

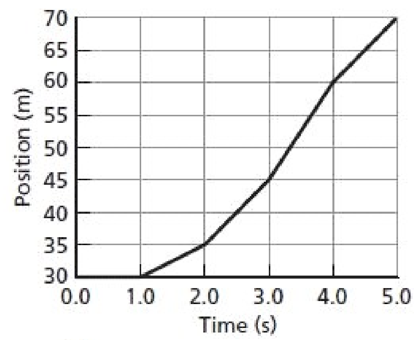
a. $\mathbf{2\times10^{16}\ m^{2}}$
b. $\mathbf{1.4\times10^{-7}\ km^{2}}$
c. $\mathbf{2.8\ kg/m^{3}}$
d. $\mathbf{1.7\times10^{-3}\ m/s}$

96. Plot the data in **Table 1** on a position-time graph. Find the average speed in the time interval between 0.0 s and 5.0 s.

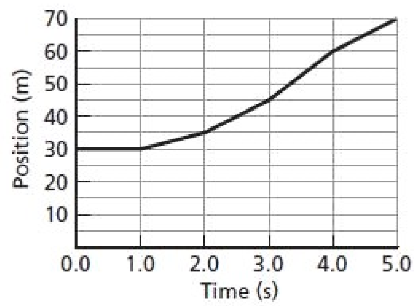
Table 1 Position v. Time

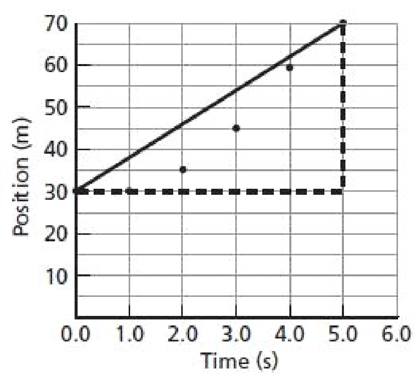
Clock Reading t (s)	Position x (m)
0.0	30
1.0	30
2.0	35
3.0	45
4.0	60
5.0	70

SOLUTION:



or





The average speed is the slope.

$$\text{slope} = \frac{\Delta x}{\Delta t} = \frac{70\text{ m} - 30\text{ m}}{5.0\text{ s} - 0.0\text{ s}} = 8\text{ m/s}$$

97. Carlos and his older brother Ricardo are at the grocery store. Carlos, with mass 17.0 kg, likes to hang on the front of the cart while Ricardo pushes it, even though both boys know this is not safe. Ricardo pushes the 12.4-kg cart with his brother on it such that they accelerate at a rate of 0.20 m/s^2.

a. With what force is Ricardo pushing?
b. What is the force the cart exerts on Carlos?

SOLUTION:

a. Identify Carlos and the cart together as the system, and the direction Ricardo pushes as positive.

$$\begin{aligned} F_{\text{net}} &= F_{\text{Ricardo on system}} \\ &= ma \\ &= (12.4\text{ kg} + 17.0\text{ kg})(0.20\text{ m/s}^2) \\ &= 5.9\text{ N} \end{aligned}$$

b. Identify Carlos as the system and the direction Ricardo pushes as positive.

$$\begin{aligned} F_{\text{net}} &= F_{\text{cart on Carlos}} \\ &= ma \\ &= (17.0\text{ kg})(0.20\text{ m/s}^2) \\ &= 3.4\text{ N} \end{aligned}$$