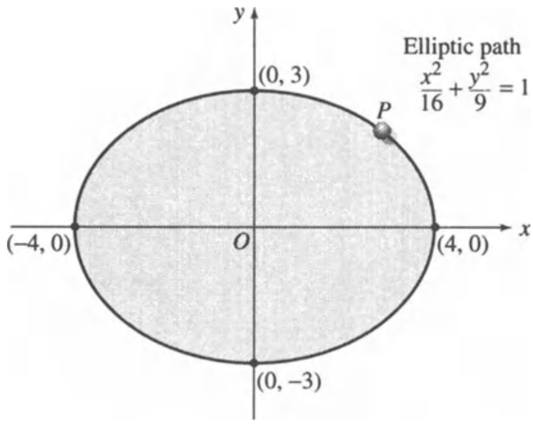

FIGURE P13.114.

that instant. Determine the total acceleration of the car at this instant and show this vector on a sketch of the path.

13.115 In Figure P13.115 a particle moves along a hyperbolic path given by the equation $\frac{x^2}{36} - \frac{y^2}{25} = 1$. Consider the particle moving along the branch in the first and fourth quadrants. When the particle crosses the positive x axis, it is moving upward with a speed of 2 m/s, and this speed is increasing at the rate of 1 m/s^2 at that instant. Determine the total acceleration of the particle at that instant and show this vector on a sketch of the path.

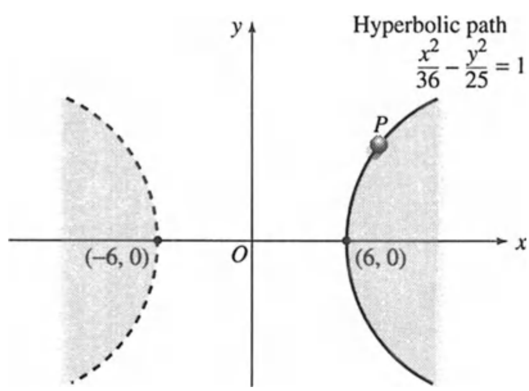

FIGURE P13.115.

13.116 A particle moves along a path in the x-y plane such that $x = t$ ($t \geq 0$) and $y = -t^2$ where x and y are in inches and t is in seconds. Determine (a) the path of the particle and sketch it, (b) for $t = 1$ s, the velocity and acceleration vectors of the particle, and (c), for $t = 1$ s, the tangential and normal components of the acceleration. Show a sketch of these components on the path of the particle.

13.117 A particle moves along a straight-line path whose equation is $y = 20 - x$. It intercepts the y axis when $t = 0$ and moves such that $s = t^2 - 8t$ where s is the distance measured down to the right along the line given in inches, time is given in seconds. Direct a unit tangent vector positively down to the right along the line, and determine the velocity and acceleration vectors of the particle.

13.118 The path of a particle in the x-y plane is given parametrically by $x = -4t^2$, $y = 2t$ ($t \geq 0$) where x and y are in meters and t is in seconds. Determine (a) the path of the particle and sketch it, (b) for $t = 0.5$ s, the velocity and acceleration vectors of the particle, and (c), for $t = 0.5$ s, the tangential and normal components of the acceleration. Show a sketch of these components on the path of the particle.

13.119 A circular path is traversed by a particle as shown in Figure P13.119 such that $s = \frac{1}{3}t^3 - \frac{3}{2}t^2 + 2t$ where units are ft and s. The path center lies at the origin and the particle begins moving at $t = 0$ in a cw sense around the 2 ft. radius circle from its initial position on the positive x axis. Determine the velocity and the normal and tangential components of acceleration of the particle when $t = 2$ s. Show the position

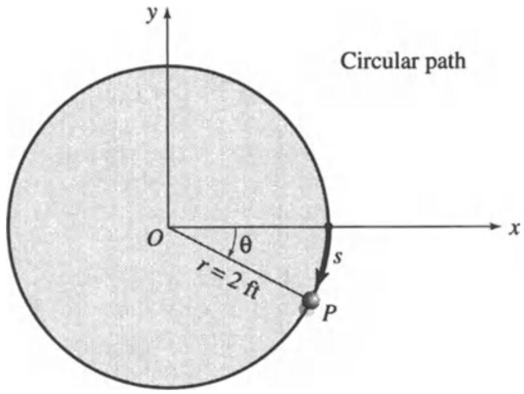

FIGURE P13.119.

of the particle and these vectors on a sketch.

13.120 A toy train moves along the path given by $y = \sinh x$. When $x = 2$ ft, the particle has a speed of 16 ft/s which is increasing at the rate of 20 ft/s^2. The train is moving up to the right at this instant. Locate the train on a sketch of the path. Determine the total acceleration of the train when $x = 2$ ft. Sketch this acceleration vector along with its normal and tangential components.

13.121 The path of a vehicle is given by $y = \cosh x$. When $x = -2$ m, the car is moving down to the right with a speed of 20m/s which is decreasing at the rate of 24 m/s^2. Locate the car on a sketch of the path. Determine the total acceleration of the car when $x = -2$ m. Sketch this acceleration vector along with its normal and tangential components.

13.122 A roller coaster is depicted in Figure P13.122. At point A, the radius of curvature of the path has a magnitude of 80 ft. A coaster car arrives at this point with a speed of 60 ft/s which is increasing at the rate of 20 ft/s^2 at the instant. Determine the instantaneous acceleration of the car in magnitude and direction at the instant when it is at point A, the low point on the track.

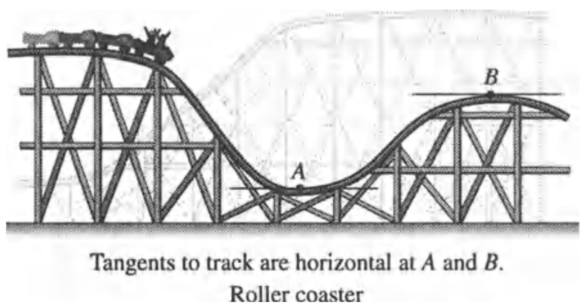

FIGURE P13.122.

13.123 Refer to the roller coaster shown in Figure P13.122. At point B, the track has a radius of curvature of 25 m. A coaster car arrives at this point with a speed of 18 m/s which is decreasing at the rate of 6 m/s^2 at the instant. Determine the instantaneous acceleration of the car in magnitude and direction at the instant it arrives at point B.

13.124 A carnival swing is depicted in Figure P13.124. Cables of length L are attached to a shaft which rotates about a vertical axis and swings so that P moves along a circular path in a hori-

13.132 A circular path of radius $b = 2$ m is traversed such that $s = t^3 + t^2 + t$ where s is in meters and t is in seconds. For $t = 1$ s, determine the velocity vector $\mathbf{v}$ and the acceleration vector $\mathbf{a}$ using (a) radial and transverse unit vectors and (b) tangential and normal unit vectors. Draw a sketch showing the position of the particle on its path when $t = 1$ s, and show $\mathbf{v}$ and $\mathbf{a}$ at the same instant on a sketch. When $t = 0$, $s = 0$ and $\theta = 0$. The angle θ is positive ccw.

13.133 A particle moves on a hyperbolic spiral given by $r\theta = a$, $\theta > 0$ and $\theta = \omega t$ where ω and a are constants. Note that, as $r \to \infty$, $\theta \to 0$. Let $\omega = 2$ rad/s and $a = 4$ m. Determine, for $t = 1$ s, the velocity and acceleration vectors, and show them on sketches. The angle θ is positive ccw.

13.134 A particle moves on a hyperbolic spiral given by $r\theta = -a$, $\theta < 0$, and $\theta = \omega t$ where ω and a are constants. Note that as $r \to \infty$, $\theta \to 0$. Let $\omega = 4$ rad/s and $a = 4$ m. For $t = 0.25$ s, determine the velocity and acceleration vectors.

13.135 Show that the equation of a vertical straight-line path of Figure P13.135 may be written in polar form as $r \cos \omega t = b$ where $\theta = \omega t$ and ω and b are constants. For $b = 1$ ft, $\omega = 2$ rad/s, and $t = 0.5$ s, determine the magnitude and direction of the velocity vector using (a) transverse and radial components and (b) a coordinate s measured vertically along the straight path with $s = 0$ when $t = 0$. Hint: $s = b \tan \omega t$ where $\theta = \omega t$.

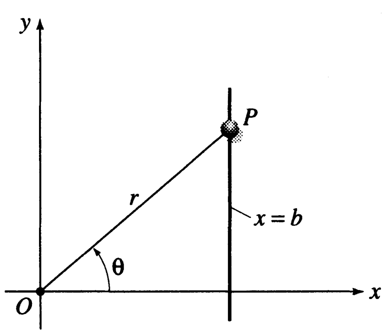

FIGURE P13.135.

13.136 Refer to Figure P13.136 and show that the equation of the horizontal straight-line path may be written in polar form as $r \sin \omega t = b$ where $\theta = \omega t$ and ω and b are constants. For $b = 2$ m, $\omega = 4$ rad/s, and $t = 0.25$ s, determine the magnitude and direction of the velocity vector using (a) transverse and radial components and (b) a coordinate s measured along the straight path. Hint: $s = b \operatorname{cotan} \theta$ where $\theta = \omega t$.

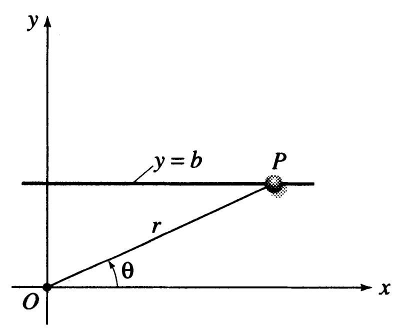

FIGURE P13.136.

13.137 Refer to Problem 13.135 and determine the magnitude and direction of the acceleration vector for the particle at $t = 0.5$ s, using radial and transverse components.

13.138 Refer to Problem 13.136 and determine the magnitude and direction of the acceleration vector for the particle at $t = 0.25$ s, using radial and transverse components.

13.139 Figure P13.139 shows a path known as a lemniscate. A toy train is constrained

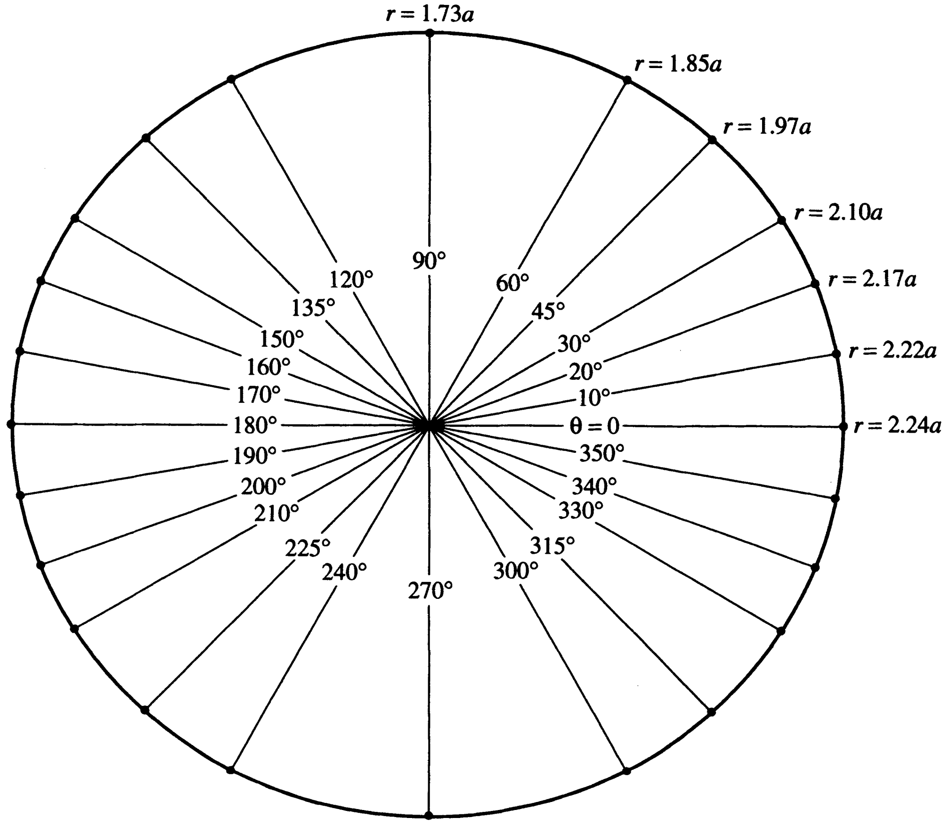

FIGURE P13.139.

to move on this path such that the parametric equations of the path are $r^4 - 2a^2r^2 \cos 2\theta - 15a^4 = 0$ where $\theta = t^2$. If $a = 3$ ft, determine, for $t = 0.5$ s, (a) the position vector and (b) the velocity vector using transverse and radial unit vectors which move with the train.

13.140 An elliptic path is given parametrically as $r = \dfrac{100}{(1 - 0.5\cos\theta)}$ and $\theta = \omega t$ where ω is a constant equal to 2 rad/s. For $t = 0$, determine the velocity and acceleration of a particle moving on this path, using radial and transverse unit vectors which move with the particle. Sketch these vectors showing their relationship to the path (units are m and s).

13.141 A hyperbolic path is given parametrically as $r = \dfrac{200}{(1 - 1.5\cos\theta)}$ and $\theta = \omega t$ where ω is a constant equal to 4 rad/s. For $t = 0.25$ s, determine the velocity and acceleration of a particle moving on this path, using radial and transverse unit vectors which move with the particle (units are ft and s).

13.142 A logarithmic spiral path is defined by $r = be^{\theta}$ where $\theta = \omega t$. For $b = 1$ ft, $\omega = 2$ rad/s, and $t = 0.5$ s, determine (a) the position vector and (b) the velocity vector, using radial and transverse unit vectors.

11.142 Racing cars A and B are traveling on circular portions of a race track. At the instant shown, the speed of A is decreasing at the rate of 7 m/s^2, and the speed of B is increasing at the rate of 2 m/s^2. For the positions shown, determine (*a*) the velocity of B relative to A, (*b*) the acceleration of B relative to A.

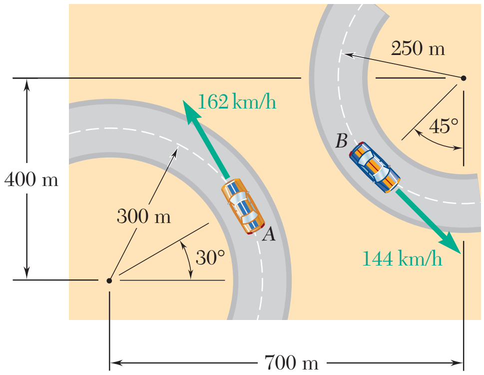

Fig. *P11.142*

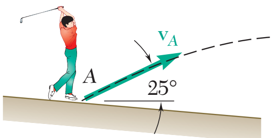

Fig. P11.143

11.143 A golfer hits a golf ball from point A with an initial velocity of 50 m/s at an angle of 25° with the horizontal. Determine the radius of curvature of the trajectory described by the ball (*a*) at point A, (*b*) at the highest point of the trajectory.

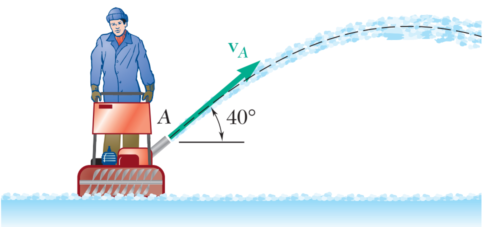

Fig. P11.144

11.144 From a photograph of a homeowner using a snowblower, it is determined that the radius of curvature of the trajectory of the snow was 8.5 m as the snow left the discharge chute at A. Determine (*a*) the discharge velocity $\mathbf{v}_A$ of the snow, (*b*) the radius of curvature of the trajectory at its maximum height.

11.145 A basketball is bounced on the ground at point A and rebounds with a velocity $\mathbf{v}_A$ of magnitude 7.5 ft/s as shown. Determine the radius of curvature of the trajectory described by the ball (*a*) at point A, (*b*) at the highest point of the trajectory.

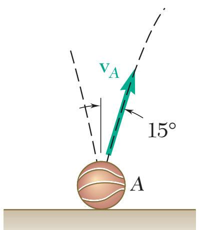

Fig. P11.145

11.146 Coal is discharged from the tailgate A of a dump truck with an initial velocity $\mathbf{v}_A = 6$ ft/s $\measuredangle$ 50°. Determine the radius of curvature of the trajectory described by the coal (*a*) at point A, (*b*) at the point of the trajectory 3 ft below point A.

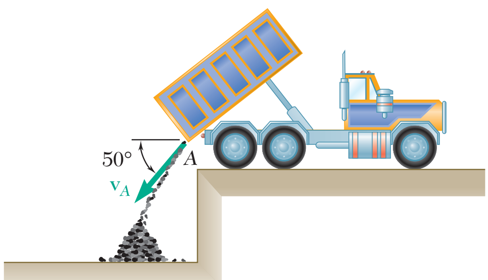

Fig. P11.146

11.147 A horizontal pipe discharges at point A a stream of water into a reservoir. Express the radius of curvature of the stream at point B in terms of the magnitudes of the velocities $\mathbf{v}_A$ and $\mathbf{v}_B$.

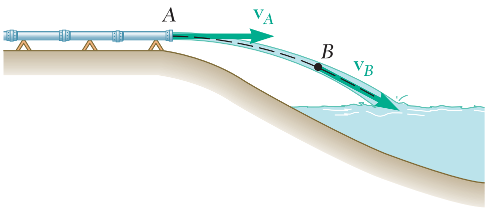

Fig. P11.147

11.148 A child throws a ball from point A with an initial velocity $\mathbf{v}_A$ of 20 m/s at an angle of 25° with the horizontal. Determine the velocity of the ball at the points of the trajectory described by the ball where the radius of curvature is equal to three-quarters of its value at A.

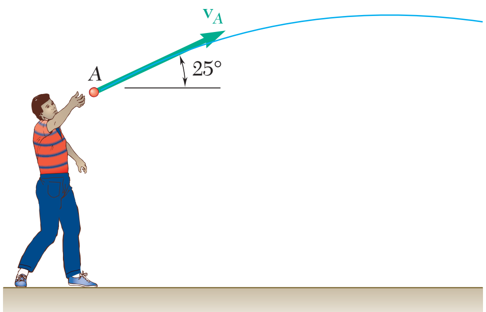

Fig. P11.148

11.149 A projectile is fired from point A with an initial velocity $\mathbf{v}_0$. (*a*) Show that the radius of curvature of the trajectory of the projectile reaches its minimum value at the highest point B of the trajectory. (*b*) Denoting by θ the angle formed by the trajectory and the horizontal at a given point C, show that the radius of curvature of the trajectory at C is $\rho = \rho_{min}/\cos^3\theta$.

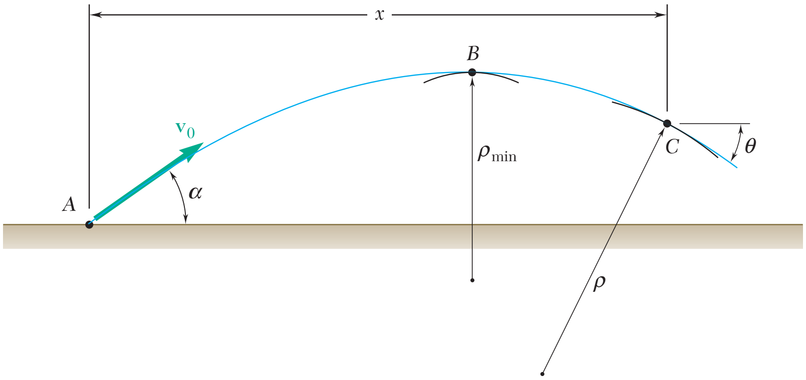

Fig. *P11.149* and *P11.150*

11.150 A projectile is fired from point A with an initial velocity $\mathbf{v}_0$ which forms an angle α with the horizontal. Express the radius of curvature of the trajectory of the projectile at point C in terms of x, v_0, α, and g.

***11.151** Determine the radius of curvature of the path described by the particle of Prob. 11.95 when $t = 0$.

***11.152** Determine the radius of curvature of the path described by the particle of Prob. 11.96 when $t = 0$, $A = 3$, and $B = 1$.

11.153 through 11.155 A satellite will travel indefinitely in a circular orbit around a planet if the normal component of the acceleration of the satellite is equal to $g(R/r)^2$, where g is the acceleration of gravity at the surface of the planet, R is the radius of the planet, and r is the distance from the center of the planet to the satellite. Determine the speed of a satellite relative to the indicated planet if the satellite is to travel indefinitely in a circular orbit 160 km above the surface of the planet.

- **11.153** Venus: $g = 8.53$ m/s^2, $R = 6161$ km.
- **11.154** Mars: $g = 3.83$ m/s^2, $R = 3332$ km.
- **11.155** Jupiter: $g = 26.0$ m/s^2, $R = 69\,893$ km.

11.156 and 11.157 Knowing that the diameter of the sun is 864,000 mi and that the acceleration of gravity at its surface is 900 ft/s^2, determine the radius of the orbit of the indicated planet around the sun assuming that the orbit is circular. (See information given in Probs. 11.153–11.155.)

11.156 Earth: $(v_{\text{mean}})_{\text{orbit}} = 66{,}600$ mi/h
11.157 Saturn: $(v_{\text{mean}})_{\text{orbit}} = 21{,}580$ mi/h

11.158 Knowing that the radius of the earth is 6370 km, determine the time of one orbit of the Hubble Space Telescope knowing that the telescope travels in a circular orbit 590 km above the surface of the earth. (See information given in Probs. 11.153–11.155.)

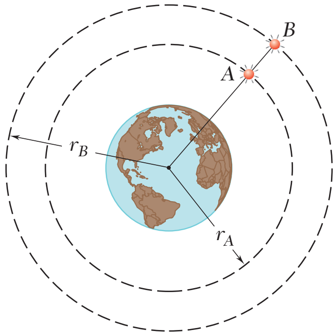

Fig. *P11.160*

11.159 A satellite is traveling in a circular orbit around Mars at an altitude of 180 mi. After the altitude of the satellite is adjusted, it is found that the time of one orbit has increased by 10 percent. Knowing that the radius of Mars is 2071 mi, determine the new altitude of the satellite. (See information given in Probs. 11.153–11.155).

11.160 Satellites A and B are traveling in the same plane in circular orbits around the earth at altitudes of 120 and 200 mi, respectively. If at $t = 0$ the satellites are aligned as shown and knowing that the radius of the earth is $R = 3960$ mi, determine when the satellites will next be radially aligned. (See information given in Probs. 11.153–11.155.)

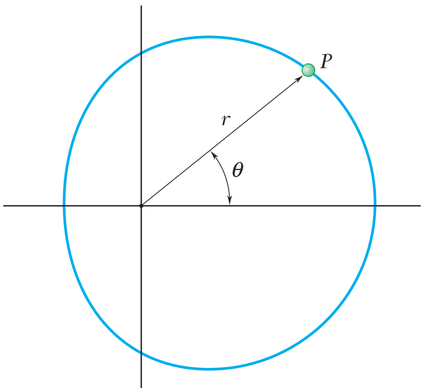

Fig. P11.161

11.161 The path of a particle P is a limacon. The motion of the particle is defined by the relations $r = b(2 + \cos \pi t)$ and $\theta = \pi t$, where t and θ are expressed in seconds and radians, respectively. Determine (*a*) the velocity and the acceleration of the particle when $t = 2$ s, (*b*) the values of θ for which the magnitude of the velocity is maximum.

11.162 The two-dimensional motion of a particle is defined by the relation $r = 2b \cos \omega t$ and $\theta = \omega t$, where b and ω are constant. Determine (*a*) the velocity and acceleration of the particle at any instant, (*b*) the radius of curvature of its path. What conclusions can you draw regarding the path of the particle?

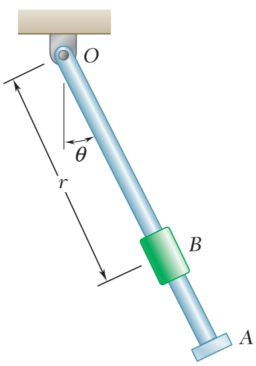

Fig. P11.163 and *P11.164*

11.163 The rotation of rod OA about O is defined by the relation $\theta = \pi(4t^2 - 8t)$, where θ and t are expressed in radians and seconds, respectively. Collar B slides along the rod so that its distance from O is $r = 10 + 6 \sin \pi t$, where r and t are expressed in inches and seconds, respectively. When $t = 1$ s, determine (*a*) the velocity of the collar, (*b*) the total acceleration of the collar, (*c*) the acceleration of the collar relative to the rod.

11.164 The oscillation of rod OA about O is defined by the relation $\theta = (2/\pi)(\sin \pi t)$, where θ and t are expressed in radians and seconds, respectively. Collar B slides along the rod so that its distance from O is $r = 25/(t + 4)$ where r and t are expressed in inches and seconds, respectively. When $t = 1$ s, determine (*a*) the velocity of the collar, (*b*) the total acceleration of the collar, (*c*) the acceleration of the collar relative to the rod.

11.165 The path of particle P is the ellipse defined by the relations $r = 2/(2 - \cos \pi t)$ and $\theta = \pi t$, where r is expressed in meters, t is in seconds, and θ is in radians. Determine the velocity and the acceleration of the particle when (*a*) $t = 0$, (*b*) $t = 0.5$ s.

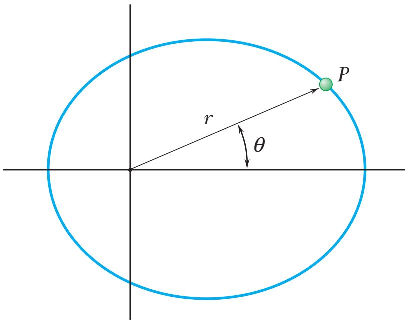

Fig. P11.165

11.166 The two-dimensional motion of a particle is defined by the relations $r = 2a \cos \theta$ and $\theta = bt^2/2$, where a and b are constants. Determine (*a*) the magnitudes of the velocity and acceleration at any instant, (*b*) the radius of curvature of the path. What conclusion can you draw regarding the path of the particle?

11.167 To study the performance of a race car, a high-speed motion-picture camera is positioned at point A. The camera is mounted on a mechanism which permits it to record the motion of the car as the car travels on straightaway BC. Determine the speed of the car in terms of b, θ, and $\dot{\theta}$.

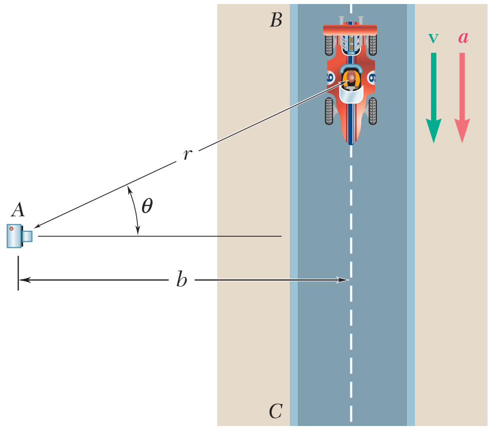

Fig. *P11.167*

11.168 Determine the magnitude of the acceleration of the race car of Prob. 11.167 in terms of b, θ, $\dot{\theta}$, $\ddot{\theta}$.

11.169 After taking off, a helicopter climbs in a straight line at a constant angle β. Its flight is tracked by radar from point A. Determine the speed of the helicopter in terms of d, β, θ, and $\dot{\theta}$.

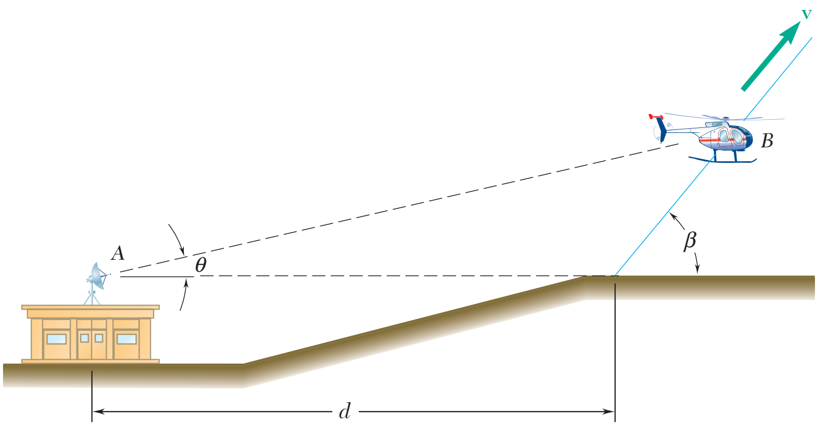

Fig. P11.169