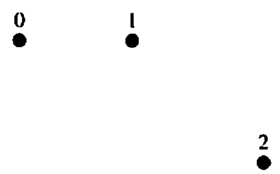
4 Kinematics in Two Dimensions

4.1 Acceleration

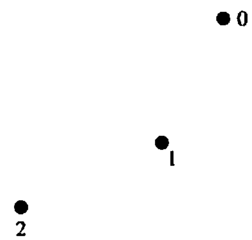
Exercises 1–2: The figures below show an object's position in three successive frames of film. The object is moving in the direction $0 \rightarrow 1 \rightarrow 2$. For each diagram:

- Draw and label the initial and final velocity vectors $\vec{v}_0$ and $\vec{v}_1$. Use **black**.
- Use the steps of Figures 4.2 and 4.3 to find the change in velocity $\Delta\vec{v}$.
- Draw and label $\vec{a}$ at the proper location on the motion diagram. Use **red**.
- Determine whether the object is speeding up, slowing down, or moving at a constant speed. Write your answer beside the diagram.

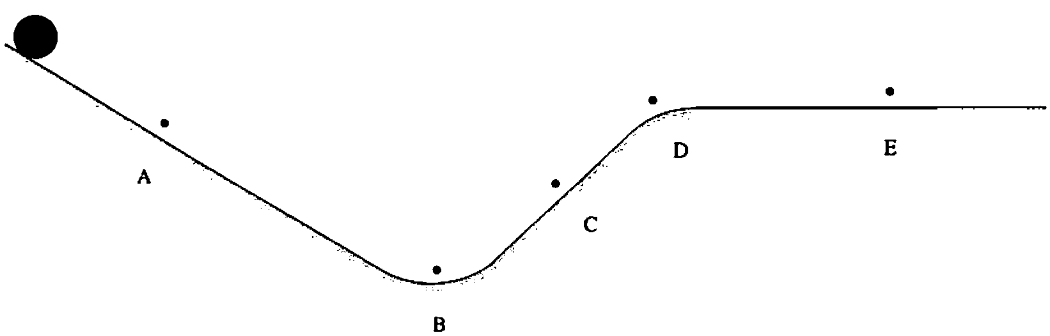
1.



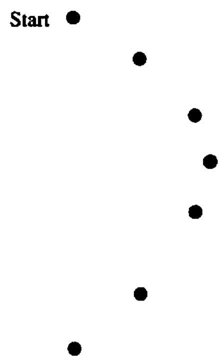
2.



3. The figure shows a ramp and a ball that rolls along the ramp. Draw vector arrows on the figure to show the ball's acceleration at each of the lettered points A to E (or write $\vec{a} = \vec{0}$, if appropriate).



4. Complete the motion diagram for this trajectory, showing velocity and acceleration vectors.



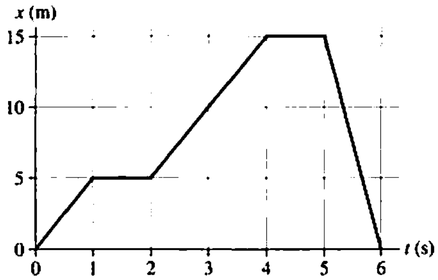
Exercises 5–6: Draw a complete motion diagram for each of the following.
- Draw and label the velocity vectors $\vec{v}$. Use **black**.
- Draw and label the acceleration vectors $\vec{a}$. Use **red**.

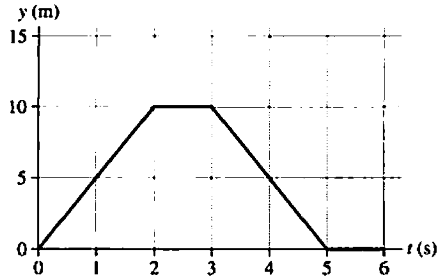
5. A cannon ball is fired from a Civil War cannon up onto a high cliff. Show the cannon ball's motion from the instant it leaves the cannon until a microsecond before it hits the ground.

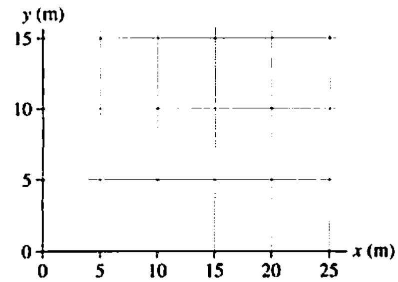
6. A plane flying north at 300 mph turns slowly to the west without changing speed, then continues to fly west. Draw the motion diagram from a viewpoint above the plane.

4.2 Kinematics in Two Dimensions

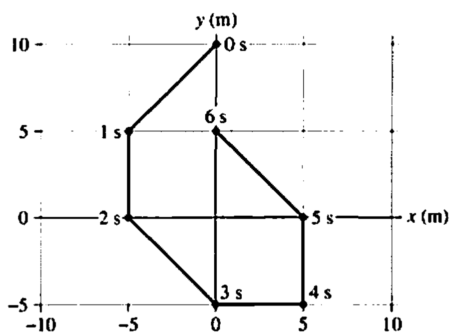
7. A particle moving in the xy-plane has the x-versus-t graph and the y-versus-t graphs shown below. Use the grid to draw a y-versus-x graph of the trajectory.

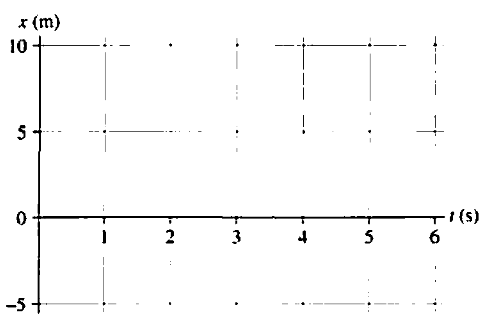


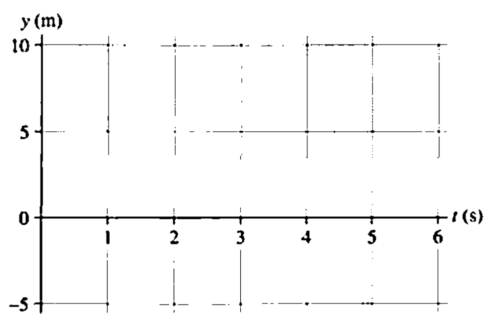




8. The trajectory of a particle is shown below. The particle's position is indicated with dots at 1-second intervals. The particle moves between each pair of dots at constant speed. Draw x-versus-t and y-versus-t graphs for the particle.

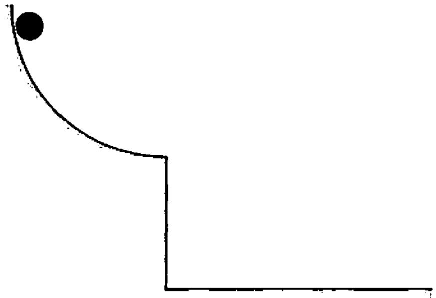




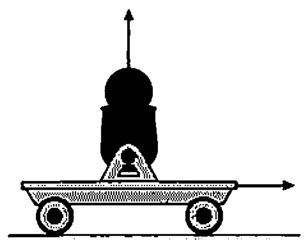


4.3 Projectile Motion

9. The figure shows a ball that rolls down a quarter-circle ramp, then off a cliff. Sketch the ball's trajectory from the instant it is released until it hits the ground.

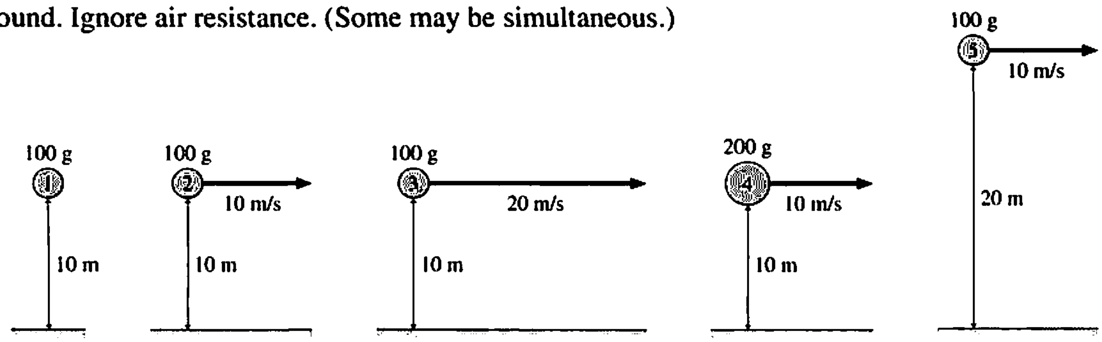


10. a. A cart that is rolling at constant velocity fires a ball straight up. When the ball comes back down, will it land in front of the launching tube, behind the launching tube, or directly in the tube? Explain.



b. Will your answer change if the cart is accelerating in the forward direction? If so, how?

11. Rank in order, from shortest to longest, the amount of time it takes each of these projectiles to hit the ground. Ignore air resistance. (Some may be simultaneous.)

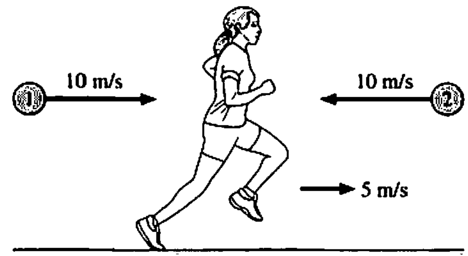


Order:

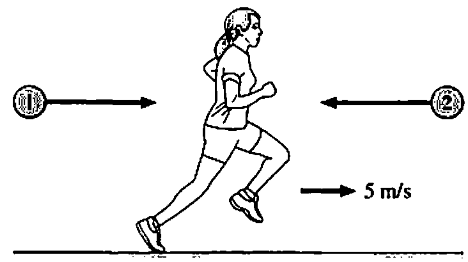
Explanation:

4.4 Relative Motion

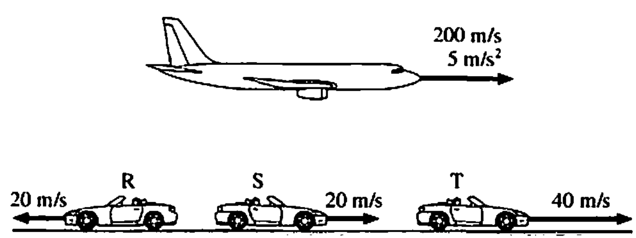
12. Anita is running to the right at 5 m/s. Balls 1 and 2 are thrown toward her at 10 m/s by friends standing on the ground. According to Anita, which ball is moving faster? Or are both speeds the same? Explain.



13. Anita is running to the right at 5 m/s. Balls 1 and 2 are thrown toward her by friends standing on the ground. According to Anita, both balls are approaching her at 10 m/s. Which ball was thrown at a faster speed? Or were they thrown with the same speed? Explain.



14. Ryan, Samantha, and Tomas are driving their convertibles. At the same instant, they each see a jet plane with an instantaneous velocity of 200 m/s and an acceleration of 5 m/s^2.

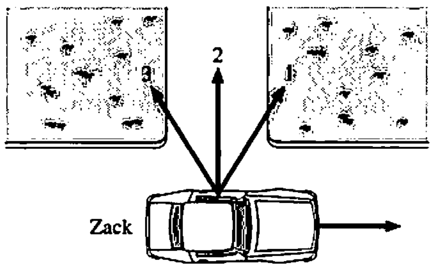


a. Rank in order, from largest to smallest, the jet's *speed* v_R, v_S, and v_T according to Ryan, Samantha, and Tomas. Explain.

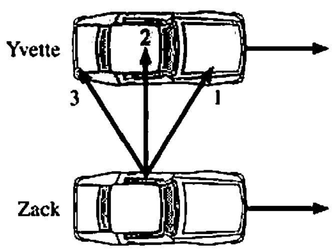
b. Rank in order, from largest to smallest, the jet's *acceleration* a_R, a_S, and a_T according to Ryan, Samantha, and Tomas. Explain.

15. An electromagnet on the ceiling of an airplane holds a steel ball. When a button is pushed, the magnet releases the ball. The experiment is first done while the plane is parked on the ground, and the point where the ball hits the floor is marked with an X. Then the experiment is repeated while the plane is flying level at a steady 500 mph. Does the ball land slightly in front of the X (toward the nose of the plane), on the X, or slightly behind the X (toward the tail of the plane)? Explain.

16. Zack is driving past his house. He wants to toss his physics book out the window and have it land in his driveway. If he lets go of the book exactly as he passes the end of the driveway, should he direct his throw outward and toward the front of the car (throw 1), straight outward (throw 2), or outward and toward the back of the car (throw 3)? Explain. (Ignore air resistance.)



17. Yvette and Zack are driving down the freeway side by side with their windows rolled down. Zack wants to toss his physics book out the window and have it land in Yvette's front seat. Should he direct his throw outward and toward the front of the car (throw 1), straight outward (throw 2), or outward and toward the back of the car (throw 3)? Explain. (Ignore air resistance.)



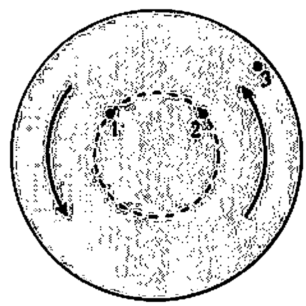
4.5 Uniform Circular Motion

4.6 Velocity and Acceleration in Uniform Circular Motion

18. a. The crankshaft in your car rotates at 3000 rpm. What is the frequency in revolutions per second?

b. A record turntable rotates at 33.3 rpm. What is the period in seconds?

19. The figure shows three points on a steadily rotating wheel.



a. Draw the velocity vectors at each of the three points.

b. Rank in order, from largest to smallest, the angular velocities ω_1, ω_2, and ω_3 of these points.

Order:

Explanation:

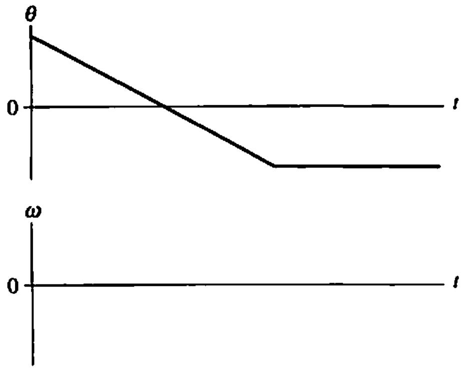
c. Rank in order, from largest to smallest, the speeds v_1, v_2, and v_3 of these points.

Order:

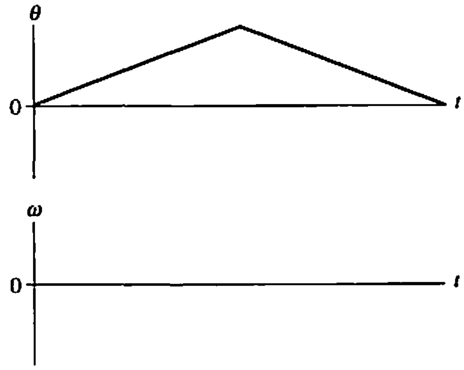
Explanation:

20. Below are two angular position-versus-time graphs. For each, draw the corresponding angular velocity-versus-time graph directly below it.

a.

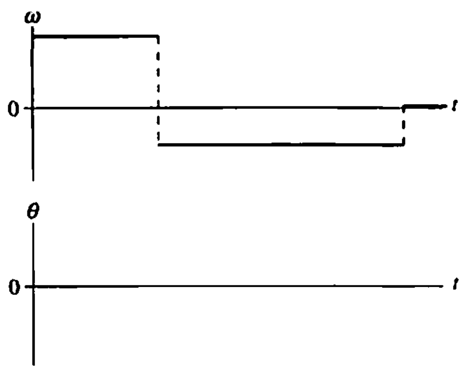


b.

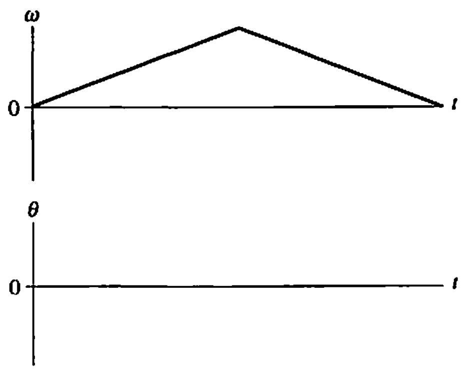


21. Below are two angular velocity-versus-time graphs. For each, draw the corresponding angular position-versus-time graph directly below it. Assume $\theta_0 = 0$ rad.

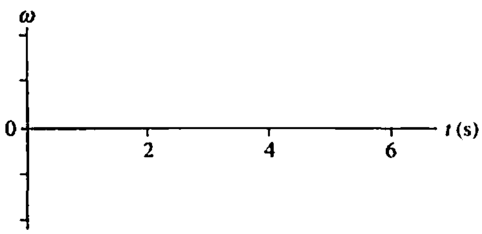
a.

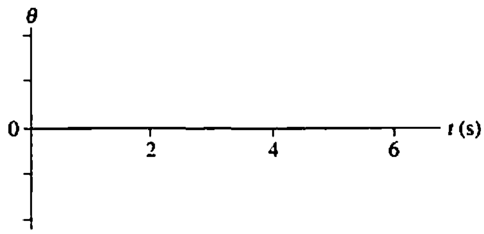


b.



22. A particle in circular motion rotates clockwise at 4 rad/s for 2 s, then counterclockwise at 2 rad/s for 4 s. The time required to change direction is negligible. Graph the angular velocity and the angular position, assuming $\theta_0 = 0$ rad.





23. A particle rotates in a circle with $a_r = 8\ \mathrm{m/s^2}$. What is a_r if

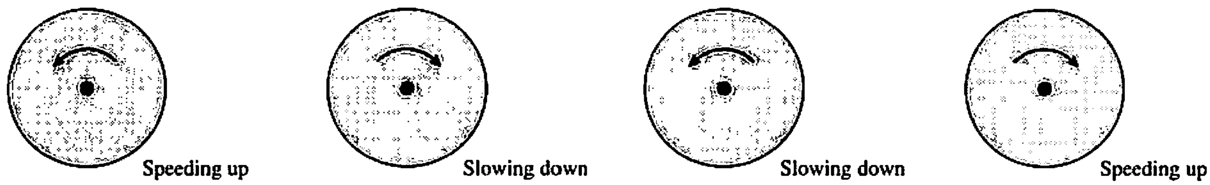
a. The radius is doubled without changing the angular velocity? __________

b. The radius is doubled without changing the particle's speed? __________

c. The angular velocity is doubled without changing the particle's radius? __________

4.7 Nonuniform Circular Motion and Angular Acceleration

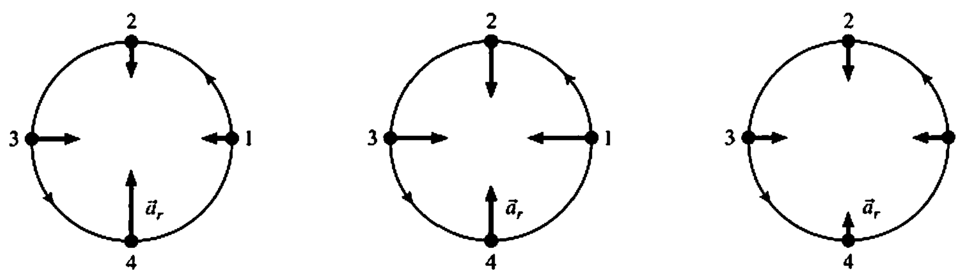
24. The following figures show a rotating wheel. Determine the signs (+ or –) of ω and α.



ω ______ ω ______ ω ______ ω ______

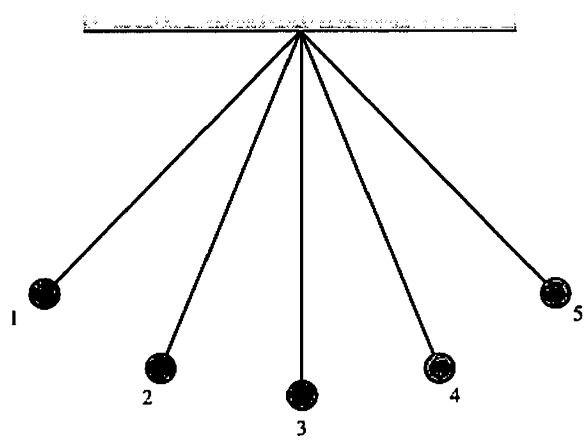
α ______ α ______ α ______ α ______

25. The figures below show the radial acceleration vector $\vec{a}_r$ at four successive points on the trajectory of a particle moving in a counterclockwise circle.
    a. For each, draw the tangential acceleration vector $\vec{a}_t$ at points 2 and 3 or, if appropriate, write $\vec{a}_t = \vec{0}$.
    b. Determine if the particle's angular acceleration α is positive (+), negative (–), or zero (0).

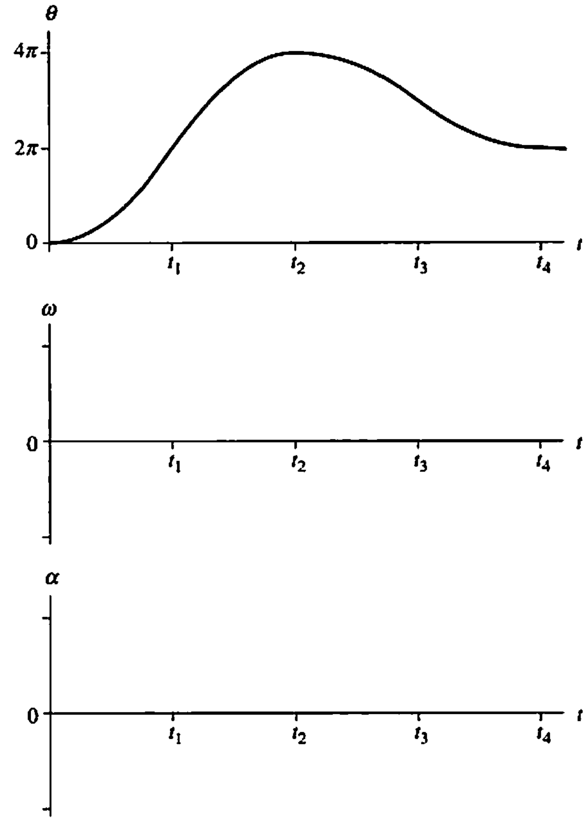


$\alpha =$ ________ $\alpha =$ ________ $\alpha =$ ________

26. A pendulum swings from its end point on the left (point 1) to its end point on the right (point 5). At each of the labeled points:
    a. Use a **black** pen or pencil to draw and label the vectors $\vec{a}_r$ and $\vec{a}_t$ at each point. Make sure the length indicates the relative size of the vector.
    b. Use a **red** pen or pencil to draw and label the total acceleration vector $\vec{a}$.



27. The figure shows the θ-versus-t graph for a particle moving in a circle. The curves are all sections of parabolas.
    a. Draw the corresponding ω-versus-t and α-versus-t graphs. Notice that the horizontal tick marks are equally spaced.
    b. Write a description of the particle's motion.



28. A wheel rolls to the left along a horizontal surface, up a ramp, then continues along the upper horizontal surface. Draw graphs for the wheel's angular velocity ω and angular acceleration α as functions of time.