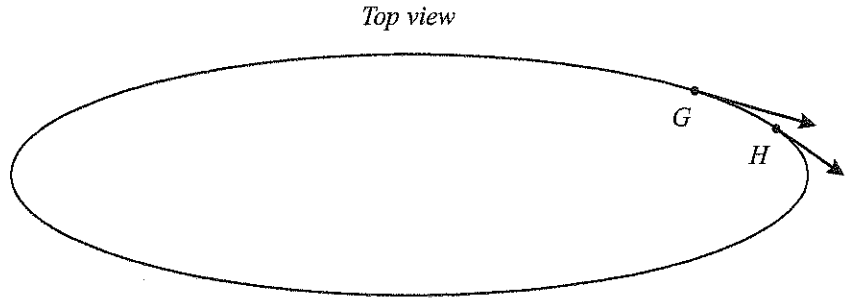
1. An object moves clockwise with *decreasing speed* around an oval track. The velocity vectors at points G and H are shown below.



a. Copy the vectors $\vec{v}_G$ and $\vec{v}_H$ in the space at right, and determine the change-in-velocity vector, $\Delta\vec{v}$.

$\vec{v}_G$, $\vec{v}_H$, and $\Delta\vec{v}$

b. If point H were chosen to lie closer to point G, describe how $\Delta\vec{v}$ would change.

c. Describe how you would determine the acceleration at point G (both magnitude and direction). In the space at right, indicate the direction of the acceleration of the object at point G. (Your drawing need only be qualitatively correct.)

Direction of $\vec{a}_G$

d. Copy $\vec{v}_G$ and $\vec{a}_G$ (placed "tail-to-tail") in the space at right. Is the angle between the acceleration and the velocity *greater than, less than,* or *equal to* 90°?

$\vec{v}_G$ and $\vec{a}_G$ (placed "tail-to-tail")

e. Generalize your results above and from tutorial to answer the following question:

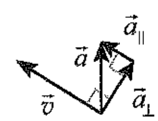
For an object moving along a curved trajectory, how does the angle between the acceleration and the velocity compare to 90° if the object moves with (i) constant speed, (ii) increasing speed, and (iii) decreasing speed?

2. Each diagram below shows the velocity and acceleration for an object at a certain instant in time.

	Instant *1*	Instant *2*	Instant *3*	Instant *4*
Acceleration	↑	↑	↑	→
Velocity	↖	←	↙	→

a. For each instant, state whether the object is *speeding up, slowing down,* or *neither (e.g., moving with constant speed).* Base your answers on what you have done in tutorial and problem 1.

b. The diagram at right illustrates how the acceleration at instant *1* can be treated as having two components: one parallel to the velocity ($\vec{a}_{\parallel}$) and one perpendicular to the velocity ($\vec{a}_{\perp}$).



For each of the other instants, draw a diagram similar to the one given for instant *1*. Label the parallel and perpendicular components of the acceleration relative to the velocity. If either component is zero, state so explicitly.

Instant *2*	Instant *3*	Instant *4*

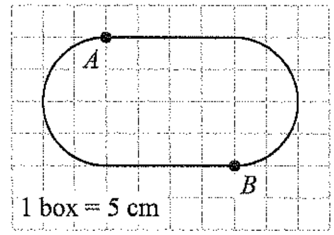
c. For each of the instants *1–4,* compare your descriptions of the motion in part a with the components of the acceleration in part b. Then answer the following:

i. Give a general rule that describes how the component of the acceleration *parallel* to the velocity affects the motion of an object.

ii. Give a general rule that describes how the component of the acceleration *perpendicular* to the velocity affects the motion of an object.

3. Some students used two straight segments and two half circles to make a track for a toy car, shown in the scale diagram at right. Each box on the diagram is 5 cm on a side.

   The car moves clockwise around the track at constant speed. It takes the car 8 s to go around the track once.

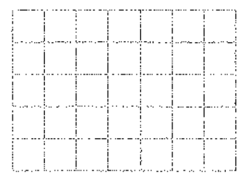


   a. Determine the speed of the car. Show your work.

   b. Consider the interval that begins when the car passes point *A* and ends when the car passes point *B* (halfway around the track).

      i. On the diagram at right, draw an arrow to represent the direction of the *average velocity* over this interval. Explain your reasoning.

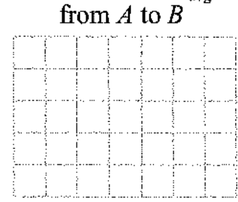
Direction of $\vec{v}_{avg}$ from *A* to *B*



      ii. Determine the magnitude of the *average velocity* of the car over this interval. Show your work.

      iii. On the diagram at right, draw an arrow to represent the direction of the *average acceleration* over this interval. Explain your reasoning.

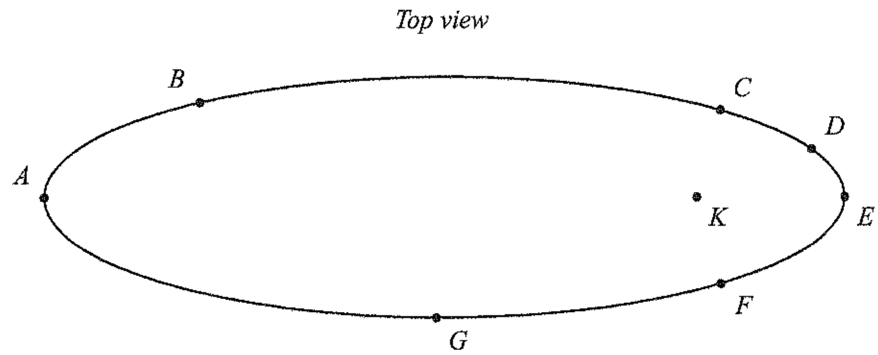
Direction of $\vec{a}_{avg}$ from *A* to *B*



      iv. Determine the magnitude of the *average acceleration* of the car over this interval. Show your work.

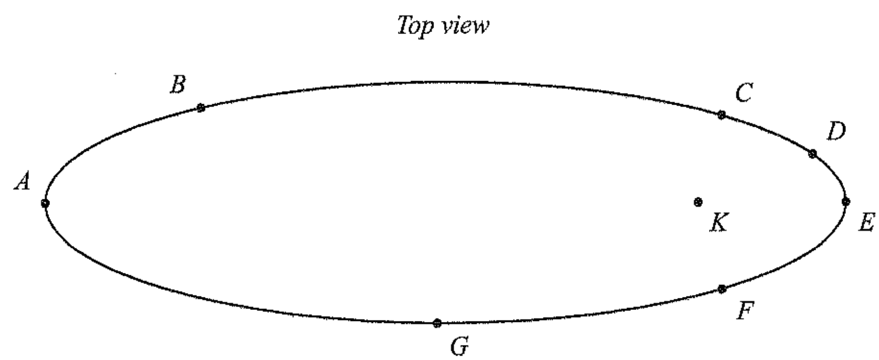
4. An object moves clockwise along the trajectory below (top view shown). The acceleration varies, but is *always* directed toward point K.

   a. On the diagram below, indicate the *direction* of the acceleration at each of the points A–G.



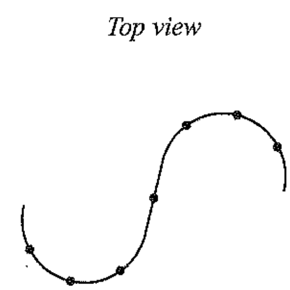
   b. For each of the points A–G, state whether the object is *speeding up, slowing down,* or *neither*.

   c. On the diagram below, draw a velocity vector for each of the points A–G. The relative magnitudes of these vectors should be qualitatively correct.



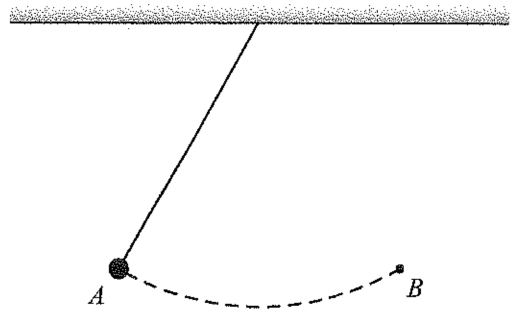
5. Suppose that an object were to move at constant speed around an S-shaped curve as shown at right. The S-shaped curve is made of two half circles and a straight segment.

   At each of the indicated points on the diagram, draw a vector to represent the acceleration of the object. If the magnitude of the acceleration is zero at any of these points, indicate so explicitly.



Acceleration vectors for constant speed

6. A pendulum bob swings back and forth. At the instant shown, the bob is at one of the turnaround points, labeled *A*. The other turnaround point, labeled *B*, and the bob's trajectory (dashed) are shown.



   a. Choose a point slightly after point *A*, and label it point *C*. Draw a vector to represent the velocity of the bob at point *C*.

   b. Determine the change-in-velocity vector $\Delta\vec{v}$ between points *A* and *C*.

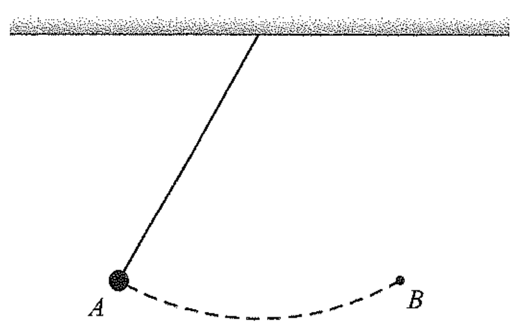
   c. How would you characterize the direction of $\Delta\vec{v}$ as point *C* is chosen to lie closer and closer to point *A?*

   d. Each of the following statements is *incorrect.* Discuss the flaws in the reasoning.

      i. "The acceleration at point A is zero. As point C becomes closer and closer to point A, the change-in-velocity vector becomes smaller and smaller. Eventually, it becomes zero."

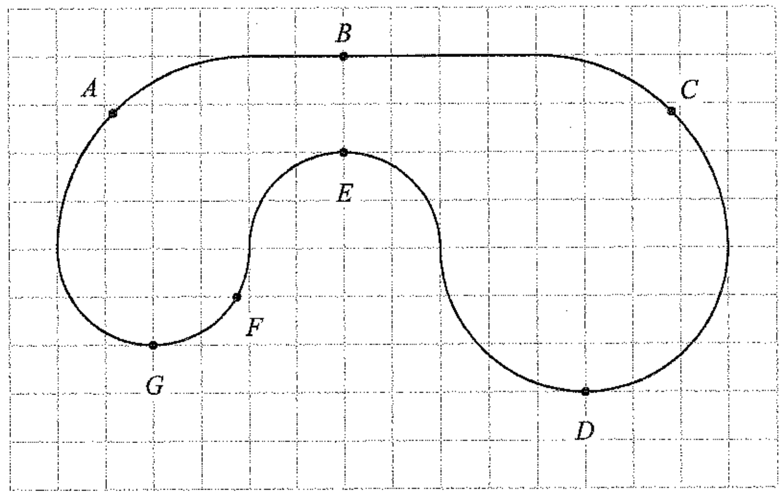
      ii. "At point A, the acceleration makes an angle with the tangent to the trajectory that is greater than 0° but less than 90° because the trajectory is curved and the object is speeding up."

   e. On the diagram at right, draw arrows at points *A* and *B* to indicate the direction of the acceleration at those points. (*Hint:* Your answer should be consistent with your answer to parts c and d.) Explain.



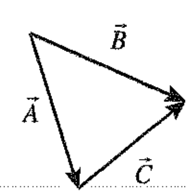
7. A car travels clockwise once around the track shown below. Starting from rest at point *A*, the car speeds up at a constant rate until it is just past point *C*. By the time it reaches point *D*, it is traveling at a constant speed. It then travels at a constant speed the rest of the way around the track.

   a. On the diagram at right, indicate the direction of the acceleration at each of the points *A*–*G*. If it is possible to indicate the exact direction of the acceleration, do so, and write "E" for exact. Otherwise, indicate the approximate direction of the acceleration. If the magnitude of the acceleration is zero at any point(s), state so explicitly.

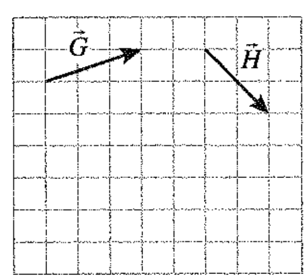


   b. Is the *magnitude* of the acceleration at point *G greater than, less than,* or *equal to* that at point *D?* Explain.

8. Write a vector equation (*e.g.*, $\vec{D} + \vec{E} + \vec{F} = \vec{0}$) that relates the vectors $\vec{A}$, $\vec{B}$, and $\vec{C}$ shown at right.

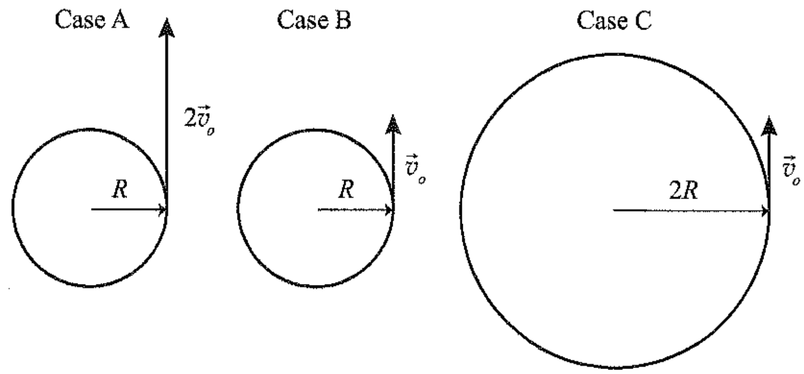


On the grid at right, draw a diagram that shows how to find the vector $\vec{I}$ that must be added to $\vec{G}$ to give the vector $\vec{H}$. Clearly label this vector.



9. Three cars move at constant speed around three circular tracks as shown in the top-view diagram at right.

   In cases A and B, the radius of the track is R; in case C, $2R$. In case A, the speed of the car is $2v_o$; in cases B and C, v_o.



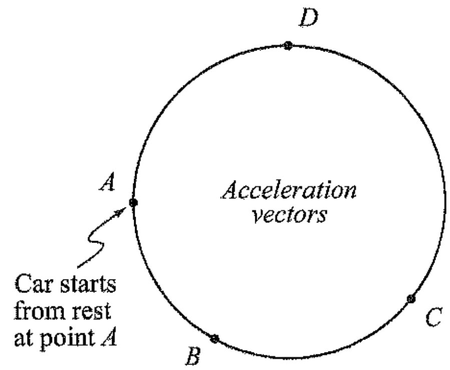
a. Rank the three cases according to the *magnitude of the acceleration,* from largest to smallest. If the magnitude of the acceleration is the same in any of the cases, state so explicitly. Explain your reasoning using the general rules you devised in tutorial.

b. Explain how your ranking above is consistent with the result for the magnitude of the acceleration for the case of uniform circular motion: $a = v^2/r$, where v is the speed of the object and r is the radius of the circular trajectory.

10. A car on a circular track starts from rest at point *A* and moves *counterclockwise* with increasing speed. The speed of the car increases at a constant rate.

    a. On the diagram at right, draw *vectors* that represent the *acceleration* of the car at each labeled point.

    b. Explain how your acceleration vector at point *A* is consistent with your answer to problem 6.



    c. Explain how the fact that the car is speeding up at a constant rate is represented by the acceleration vectors you have drawn. (*Hint:* Consider the component of the acceleration parallel to the velocity.)