

# (RK.L1.1) Familiarize Stage

Thursday, March 29, 2018 8:34 PM

## Rotational Kinematics (RK)

### Familiarization Stage:

#### Pre-lecture 1: Angular Position, Velocity, and Acceleration for Non-Uniform Circular Motion

##### ▢ Reading

1. Read

##### Lecture Videos

1. Watch

##### Example Problems

1. Watch

##### Simulations

1. Sim

##### Other Suggested Content

1. Check out

##### Practice

1. Try

##### Homework

##### **RK.L1.1-01**

**Description:** Infographic quiz average angular acceleration - label matching

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Match each term in the equation with the correct description from the following list.  
 (1) Change in time, (2) Change in angular position, (3) Average angular velocity

The diagram shows the equation  $\omega = \frac{\Delta\theta}{\Delta t}$ . The Greek letter  $\omega$  is in blue.  $\Delta\theta$  is in green, and  $\Delta t$  is in black. Label (a) has an arrow pointing to  $\omega$ . Label (b) has an arrow pointing to  $\Delta\theta$ . Label (c) has an arrow pointing to  $\Delta t$ .

**Answer:** (a) Average angular velocity, (b) Change in angular position, (c) Change in time

### RK.L1.1-02

**Description:** Infographic quiz average angular acceleration - label matching

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Match each term in the equation with the correct description from the following list.  
 (1) Change in time, (2) Average angular acceleration, (3) Change in angular velocity

The diagram shows the equation  $\alpha = \frac{\Delta\omega}{\Delta t}$ . The Greek letter  $\alpha$  is in red.  $\Delta\omega$  is in blue, and  $\Delta t$  is in black. Label (a) has an arrow pointing to  $\alpha$ . Label (b) has an arrow pointing to  $\Delta\omega$ . Label (c) has an arrow pointing to  $\Delta t$ .

$\Delta t$ 

**Answer:** (a) Average angular acceleration, (b) Change in angular velocity, (c) Change in time

### RK.L1.1-03

**Description:** Infographic quiz kinematics equation I - label matching

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Match each term in the equation with the correct description from the following list.  
 (1) Initial angular velocity, (2) Change in time, (3) Final angular position, (4) Angular acceleration, (5) Initial angular position

The image shows the kinematics equation  $\theta_f = \theta_i + \omega_i \Delta t + \frac{1}{2} \alpha \Delta t^2$ . Labels (a) through (e) are placed above and below the equation with arrows pointing to specific terms:

- (a) points to  $\theta_f$
- (b) points to  $\theta_i$
- (c) points to  $\alpha$
- (d) points to  $\omega_i$
- (e) points to  $\Delta t$

**Answer:** (a) Final angular position, (b) Initial angular position, (c) Angular acceleration, (d) Initial angular velocity, (e) Change in time

### RK.L1.1-04

**Description:** Infographic quiz kinematics equation II - label matching

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Match each term in the equation with the correct description from the following list.  
 (1) Angular acceleration, (2) Change in time, (3) Final angular velocity, (4) Initial angular velocity

The diagram shows the equation  $\omega_f = \omega_i + \alpha \Delta t$ . Arrows point from labels to terms: (a) points to  $\omega_f$ , (b) points to  $\alpha$ , (c) points to  $\Delta t$ , and (d) points to  $\omega_i$ .

**Answer:** (a) Final angular velocity, (b) Angular acceleration, (c) Change in time, (d) Initial angular velocity


### RK.L1.1-05

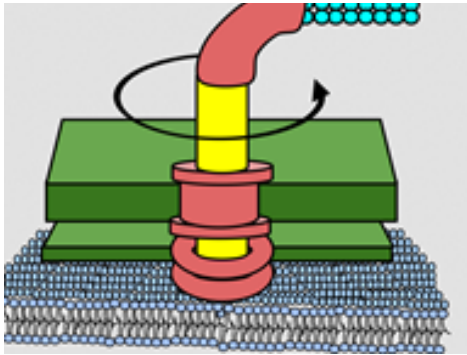
**Description:** Positive and negative conventions in rotational mechanics

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Prokaryotic bacteria use their flagellum as biological mechanical rotators for propulsion. If the flagellum is rotating counter clock-wise as viewed from above, what is the sign of its angular velocity?

Prokaryotic flagellum





- (1) Positive
- (2) Negative
- (3) Unable to determine

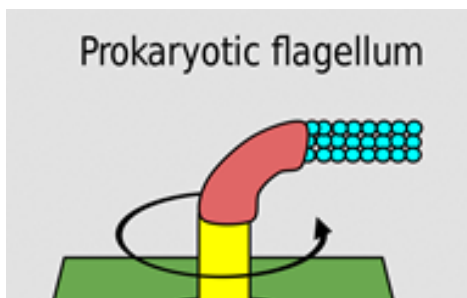
**Answer:** (1) Positive

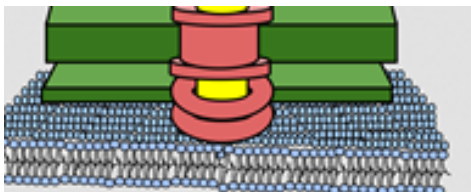
### RK.L1.1-06

**Description:** Positive and negative conventions in rotational mechanics

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Prokaryotic bacteria use their flagellum as biological mechanical rotators for propulsion. If the flagellum is rotating counter clock-wise as viewed from above, what is the sign of its change in angle between some initial and final position?





- (1) Positive
- (2) Negative
- (3) Unable to determine

**Answer:** (1) Positive

### RK.L1.1-07

**Description:** Sign conventions in kinematics

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Which of the following statements regarding displacement, velocity, and acceleration for a system that can be analyzed in 1-D are true? (Choose all that apply)

- (1) If an object is speeding up than the acceleration has the same sign (positive or negative) as the velocity.
- (2) If an object is speeding up than the acceleration has the opposite sign (positive or negative) as the velocity.
- (3) If an object is slowing down than the acceleration has the opposite sign (positive or negative) as the velocity.
- (4) If an object is slowing down than the acceleration has the same sign (positive or negative) as the velocity.
- (5) If an object is speeding up than the displacement has the same sign (positive or negative) as its velocity.
- (6) If an object is speeding up than the displacement has the opposite sign (positive or negative) as its velocity.

(7) If an object is slowing down then the displacement has the same sign (positive or negative) as its average velocity.

(8) If an object is slowing down then the displacement has the opposite sign (positive or negative) as its average velocity.

**Answer:** 1, 3, 5, 7

### **RK.L1.1-01**

**Description:** One (or two) sentence quick description of the problem

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Write the problem statement here

**Answer:** a

## (RK.L1.2.sols) Foundation Stage Solutions

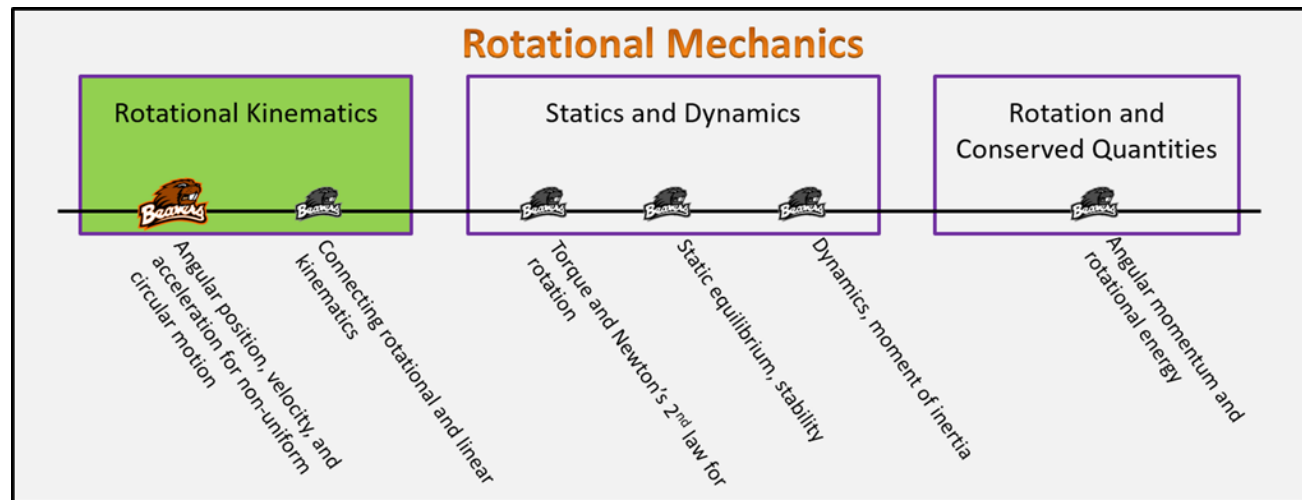
Monday, January 22, 2018 5:44 PM

## Rotational Kinematics

### Foundation Stage (RK.2.L1)

#### lecture 1

Angular position, velocity, and acceleration for non-uniform circular motion



#### Textbook Chapters (\* Calculus version)

- **BoxSand** :: KC videos ( [rotational kinematics](#) )
- **Knight** (College Physics : A strategic approach 3<sup>rd</sup>) :: 3.8 ; 7.1 ; 7.2
- **\*Knight** (Physics for Scientists and Engineers 4<sup>th</sup>) :: 4.4 ; 4.5 ; 4.6 ; 12.1
- **Giancoli** (Physics Principles with Applications 7<sup>th</sup>) :: 5-1 ; 5-2 ; 5-3 ; 5-4 ; 8-1

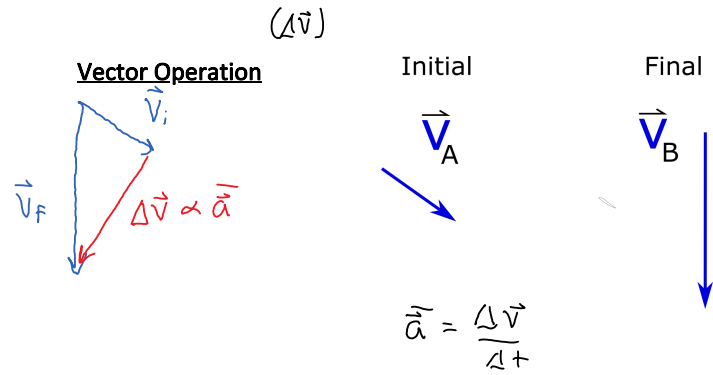
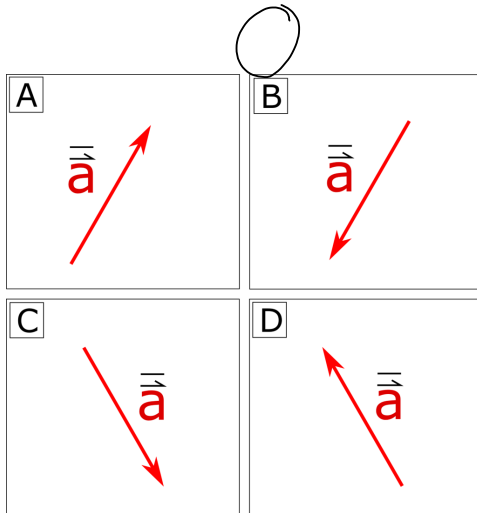
#### Warm up

##### RK.2.L1-1

**Description:** Given initial and final velocity vectors, determine direction of average acceleration.

**Learning Objectives:** [?] - Can you identify the objectives from the previous lecture, and this lecture, that this question is relevant to?

**Problem Statement:** A GPS is used to display the instantaneous velocity vector of Matt the moth at snapshot **A** and **B** as seen below. Use a vector operation diagram to determine the direction of the average acceleration for Matt between snapshots **A** and **B**.



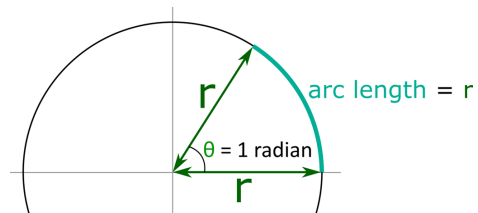
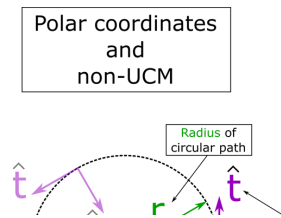
**Selected Learning Objectives**

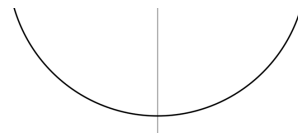
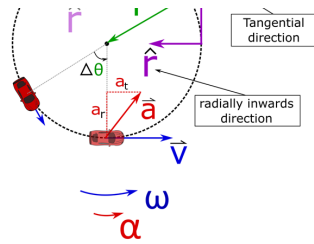
- Coming soon to a lecture template near you.

**Key Terms**

- Angular position
- Change in angular position (i.e. angular displacement)
- Angular velocity
- Angular acceleration
- Tangential velocity
- Tangential acceleration
- Radial velocity
- Radial acceleration
- Frequency
- Period

**Key Equations**





1 Revolution = 360°

1 Revolution = 2π Radians

360° = 2π Radians

$$\vec{V} = \langle v_r, v_t \rangle \implies \vec{V} = \langle 0, v_t \rangle$$

$$\vec{a} = \langle a_r, a_t \rangle \implies \vec{a} = \langle a_r, 0 \rangle$$

Change in angular position (angular displacement)      Initial angular position

Final angular position

$$\Delta\theta = \theta_f - \theta_i$$

In words: The change in angular position is equal to the final angular position minus the initial angular position.

Average angular velocity

Change in angular position (angular displacement)

$$\bar{\omega} = \frac{\Delta\theta}{\Delta t}$$

Change in time

In words: The average angular velocity is equal to the change in angular position divided by the change in time.

Average angular acceleration

Change in angular velocity

$$\bar{\alpha} = \frac{\Delta\omega}{\Delta t}$$

Change in time

In words: The average angular acceleration is equal to the change in angular velocity divided by the change in time.

Frequency

$$f = \frac{1}{T}$$

Period

In words: Frequency is equal to one divided by the period.

Angular velocity

frequency

$$\omega = 2\pi f$$

In words: The angular velocity is equal to 2 pi times the frequency.

**Key Concepts**

- When an object is traveling in a circle, the position, velocity, and acceleration (in Cartesian coordinates) are all functions of time. To simplify this analysis, we use polar coordinates which uses an angular position to determine where the object is along the circle. The position, velocity, and acceleration in polar coordinates are vectors, however, the vector nature of these quantities in polar coordinates is beyond the scope of this class. Thus we use angular position ( $\theta$ ), angular velocity ( $\omega$ ), and angular acceleration ( $\alpha$ ) which are all components of their respective position, velocity, and acceleration vectors in polar coordinates. Even though angular position, angular velocity, and angular acceleration are components (i.e. scalars), they can still be positive or negative. The most widely used convention to determine if these angular components are positive or negative is the following: if the object is traveling

counter-clockwise (CCW) then the angular displacement and angular velocity are positive, if traveling clockwise (CW) then negative. The sign of angular acceleration can then be determined based off of the definition of average angular acceleration.

- It's important to emphasize that angular position, angular velocity, and angular acceleration are not vectors; they are components of vectors in polar coordinates. Their sign (+ or -) is determined by the CCW(+) and CW(-) convention. However, we would still like a nice way to communicate which way an object is traveling around a circle with a physical representation, thus we use curved arrows to show CW or CCW direction. Be careful, these angular quantities are not vectors and the curved arrows are not vectors (vectors must be straight arrows).
- Much like assigning an  $x = 0$  or  $y = 0$  location for linear motion, you can choose where to define your  $\theta = 0$ .
- In polar coordinates, the radial direction points radially inwards or outwards depending on your choice. Choosing radially inwards is often wise because it makes the radial component of acceleration a positive value.
- In circular motion, the velocity vector is always tangent to the circular path. In polar coordinates, the tangential direction is tangent to the circular path; you can choose which way so long as it's tangent.
- Recall in Uniform Circular Motion (UCM), the acceleration is always pointing towards the center, thus there is no tangential component of acceleration. The velocity is always tangent to the circular path in UCM, thus no radial component.
- If an object is traveling in a circle and speeding up or slowing down (i.e. non-UCM), then the acceleration has both a radial and tangential component. The velocity is still always tangent to the circular path, thus no radial component.
- Frequency is the number of repeated events per one unit of time (e.g. 1000 revolutions per minute, 5 cycles per second, 70 beats per second, 1020 hand claps per minute, etc..)
- Period is the amount of time per one repeated event (e.g. 10 seconds per 1 revolution, 24 hours per 1 revolution, 5 seconds per 1 clap, 42 seconds per one click noise).

Questions

Act I: Linear acceleration vector

RK.2.L1-2

Description: Choose FBDs for objects traveling in a circle. (2 minutes + 3 minutes)

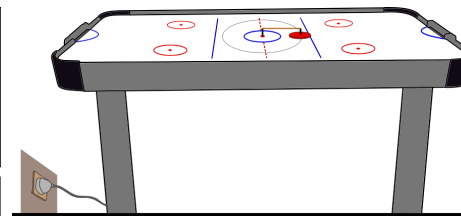
Learning Objectives: [1, 12, 13]

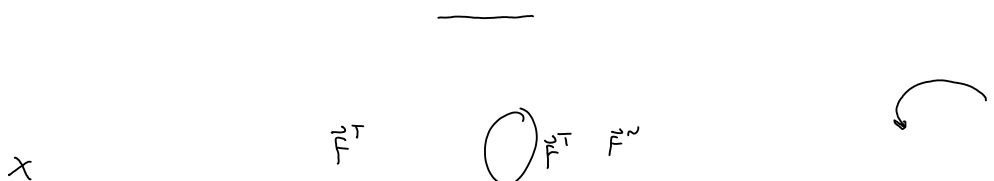
CONSTANT SPEED & RADIUS

Problem Statement: An air hockey puck attached to a string is traveling counter-clockwise in a circle at a constant speed (i.e. UCM).

- (a) Choose the pair of FBDs that correctly describe this scenario.

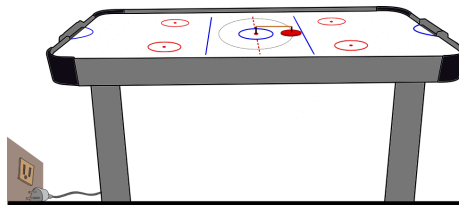
<p>Top-down view</p> <p>A</p>	<p>Top-down view</p> <p>B</p>
<p>Top-down view</p> <p>C</p>	<p>Top-down view</p> <p>D</p>





(b) The air is suddenly turned off causing the puck to slow down as it is traveling counter-clockwise around the circle. Choose the pair of FBDs that correctly describe this scenario.

<p>Top-down view</p>	<p>Side view</p>
<p>Top-down view</p>	<p>Side view</p>
<p>Top-down view</p>	<p>Side view</p>
<p>Top-down view</p>	<p>Side view</p>



**RK.2.L1-3:**

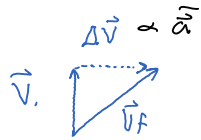
**Description:** Given initial and final velocity vectors, find direction of average acceleration. (3 minutes)

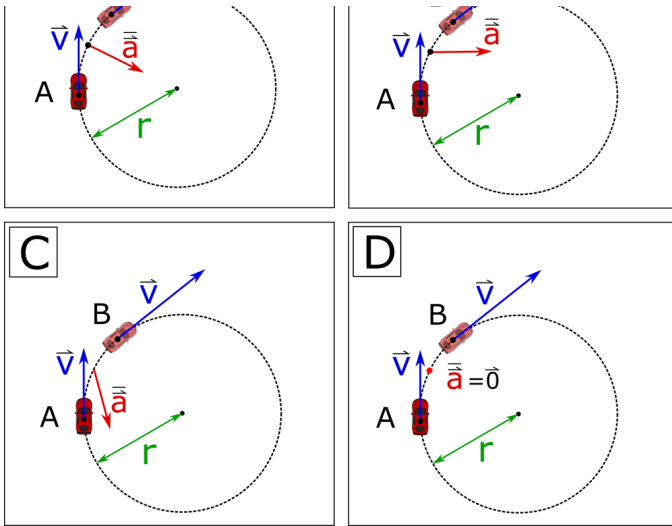
**Learning Objectives:** [1, 12, 13]

$$\bar{a} = \frac{\Delta v}{\Delta t}$$

**Problem Statement:** Consider a car speeding up as it travels in a circle. Two snapshots are taken at **A** and **B** with the car's velocity vector shown at each time. What is the direction of the change in velocity and thus the average acceleration of the car between **A** and **B**?

<p><b>A</b></p>	<p><b>B</b></p>
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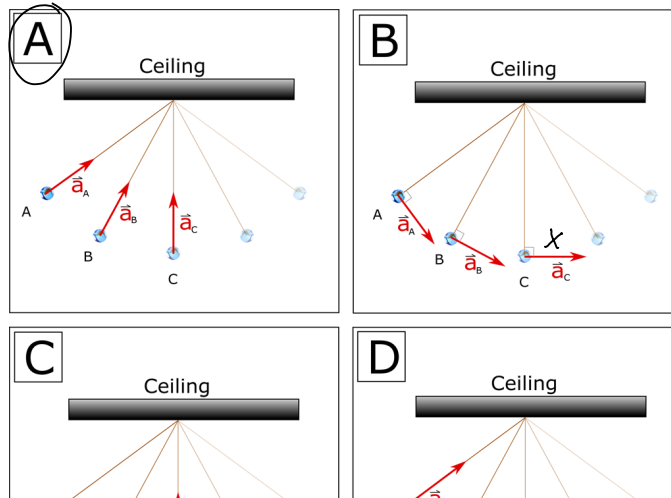
**RK.2.L1-4:**

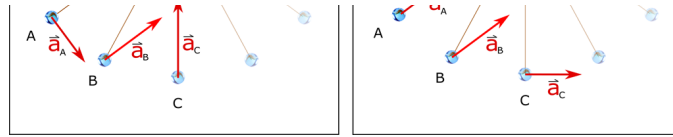
**Description:** Choose the correct acceleration vectors for a pendulum. (4 minutes)

**Learning Objectives:** [1, 12, 13]

**Problem Statement:** A pendulum is released from rest at snapshot A. The pendulum speeds up at a decreasing rate reaching its maximum speed at location C. Which of the following set of acceleration vectors correctly describe this scenario.

\*NOTE...  
 ...THE FASTER AN OBJECT SPEEDS UP AROUND A CIRCLE, THE MORE TANGENT  $\vec{a}$  IS TO THE CIRCULAR PATH





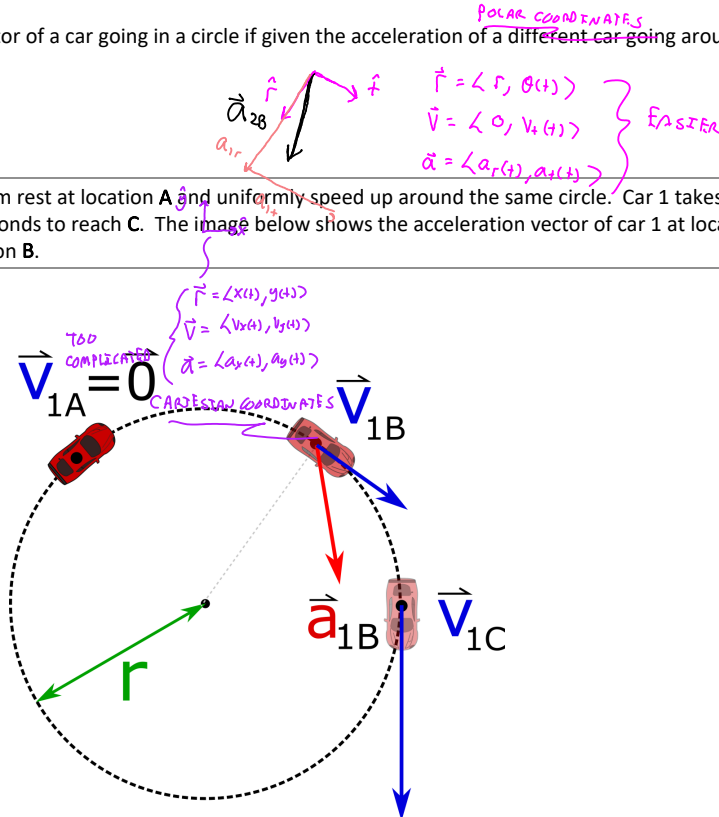
**RK.2.1** ~~ONE~~ DIST

Description: Sketch the acceleration vector of a car going in a circle if given the acceleration of a different car going around the same circle. (4 minutes)

Learning Objectives: [9, 12, 13]

THUS  $\vec{a}_{1B}$  IS MORE TANGENT

**Problem Statement:** Two cars starts from rest at location A and uniformly speed up around the same circle. Car 1 takes 5 seconds to reach location C while car 2 takes 15 seconds to reach C. The image below shows the acceleration vector of car 1 at location B. Sketch the acceleration vector of car 2 at location B.



**Act II: Average quantities**

**RK.2.L1-6:**

$$\Delta\theta \longleftrightarrow \Delta x$$

**Description:** Match the form like mathematical representations for average quantities. (2 minutes)

$$\omega \longleftrightarrow v_x$$

**Learning Objectives:** [1, 12, 13]

$$\alpha \longleftrightarrow a_x$$

**Problem Statement:** Below there are 8 mathematical representations, 4 are linear forms and 4 are rotational forms. Match each rotational mathematical representation with the linear analog.

(a)  $\theta$

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

(b)  $\Delta\theta = \theta_f - \theta_i$

$$x$$

(c)  $\omega = \frac{\Delta\theta}{\Delta t}$

$$a_x = \frac{\Delta v_x}{\Delta t}$$

(d)  $\alpha = \frac{\Delta\omega}{\Delta t}$

$$\Delta x = x_f - x_i$$

$$1 \text{ RAD} \times \frac{360^\circ}{2\pi \text{ RAD}} \approx \boxed{57.3^\circ}$$

**RK.2.L1-7:**

$$45^\circ \times \frac{2\pi \text{ RAD}}{360^\circ} \approx \boxed{0.785 \text{ RAD}}$$

**Description:** Convert degrees and revolutions to radians and radians to degrees. (2 minutes + 2 minutes + 2 minutes)

**Learning Objectives:** [1, 12, 13]

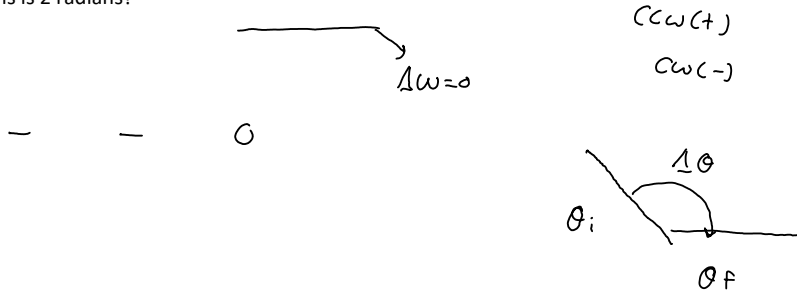
**Problem Statement:** What is a radian?

$$2 \text{ RAD} \times \frac{1 \text{ REV}}{2\pi \text{ RAD}} = \boxed{0.318 \text{ REV}}$$

(a) How many degrees is 1 radian?

(b) How many radians is 45 degrees?

(c) How many revolutions is 2 radians?



**RK.2.L1-8:**

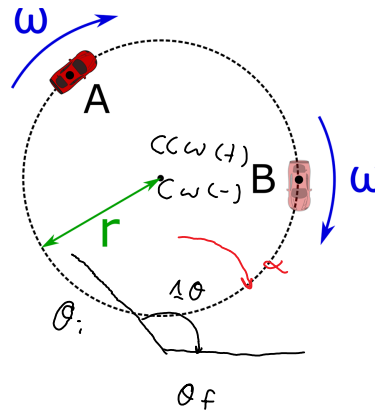
**Description:** Determine the sign of angular kinematic quantities. (3 minutes + 3 minutes + 3 minutes)

**Learning Objectives:** [1, 12, 13]

**Problem Statement:** Fill in each table with the sign (+, -, or 0) for each quantities given the situations described below.

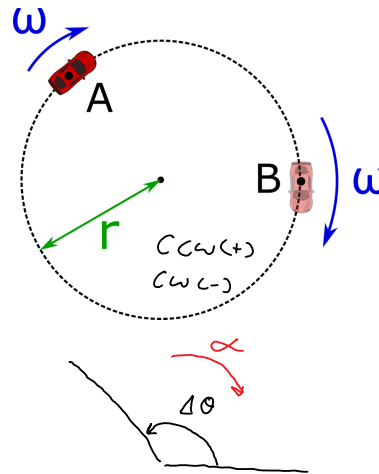
(a) A car is traveling clockwise around a circle at a constant speed.

$\Delta\theta$	$\omega$	$\alpha$
-	-	-



(b) A car is traveling clockwise around a circle and speeding up.

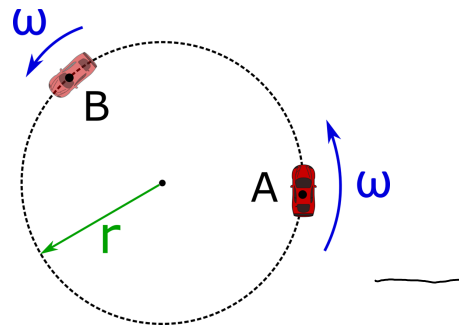
$\Delta\theta$	$\omega$	[Equation]



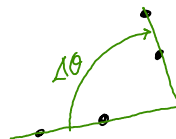
+ + -

(c) A car is traveling counter-clockwise around a circle and slowing down.

[Equation]	[Equation]	[Equation]



O



$$|\omega| = \left| \frac{\Delta\theta}{\Delta t} \right|$$

SAME  $\Delta\theta$   
SAME  $\Delta t$

**RK.2.L1-9:**

**Description:** Compare angular velocity of two objects going around the same circle. (3 minutes)

**Learning Objectives:** [1, 12, 13]

**Problem Statement:** A ladybug sits at the outer edge of a record player which is spinning clockwise, and a gentleman bug sits halfway between her and the axis of rotation. The record player makes  $33 \frac{1}{3}$  revolutions every 1 minute. The gentleman bug's angular speed is

- (1) half the ladybug's.
- (2) the same as the ladybug's.
- (3) twice the ladybug's.
- (4) impossible to determine without radius and angular speed.



$$\frac{1 \text{ MIN}}{33 \frac{1}{3} \text{ REV}} = \boxed{0.03 \frac{\text{MIN}}{\text{REV}}} \times \frac{60 \text{ SEC}}{1 \text{ MIN}} = \boxed{1.8 \frac{\text{SEC}}{\text{REV}}}$$

$T = 1.8 \text{ SEC.}$

$$f = \frac{1}{T} = \frac{1}{1.8 \text{ SEC}} = \boxed{0.556 \frac{1}{\text{SEC}}} = \boxed{0.556 \text{ Hz}}$$

**RK.2.L1-10:**

**Description:** Convert frequency to period and angular velocity. (3 minutes)

**Learning Objectives:** [1, 12, 13]

$$\omega = 2\pi f = \boxed{\pm 3.49 \frac{\text{RAD}}{\text{SEC}}}$$

SPINNER'S CW OR CCW?

**Problem Statement:** A standard record player record player makes  $33 \frac{1}{3}$  revolutions every 1 minute.

(a) How much time in seconds does it take for the record player to make one full revolution (i.e. what is the period)?

(b) What is the frequency of the record player in SI units?

(c) What is the angular velocity of the record player in SI units?

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### Conceptual questions for discussion

1. Do you agree with the following statement: the frequency of a cd disk at the outer edge is larger than the frequency at the inner edge?
2. Imagine driving along a straight level horizontal road with the cruise control on (i.e. at a constant speed). Is it possible to accelerate the car without stepping on the gas or brake pedal?
3. Sketch the acceleration vector at the three other snapshots of the pendulum as it swings backup to its maximum height in problem RK.2.L1-4.
4. Consider a pendulum like in problem RK.2.L1-4. Is it possible to break the string without pulling vertically down on the pendulum bob? If so, explain the physics behind the mechanism for the string breaking. If not, explain why you must only pull downwards to break the string.
5. \*Beyond the scope of this class but fun: The vector nature of these rotational quantities can be found by using your right hand; if you align your fingers so that they can curl in the CW or CCW direction then your thumb points in the direction of that rotational vector quantity. What is the direction of the angular velocity vector for the car at location **B** in problem RK.2.L1-8 part c? Also, what is the direction of the angular acceleration vector?
  - i. Straight into the page
  - ii. Straight out of the page
  - iii. Horizontally to the left
  - iv. Horizontally to the right
  - v. Vertically up on the paper
  - vi. Vertically down on the paper

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### Hints

**RK.2.L1-1:** Recall that average acceleration is the change in velocity divided by change in time. Also, a change in a vector quantity can be found by placing the initial and final vectors tail to tail, with the change pointing from the initial to the final.

**RK.2.L1-2:** Recall that the net external force causes an acceleration of the center of mass of the object, thus first determine which direction the acceleration of the puck is.

**RK.2.L1-3:** Use a vector operation diagram to help determine the direction of the average acceleration.

**RK.2.L1-4:** If an object is speeding up and moving in a circle, there must be a component of acceleration in the tangential direction. Discuss with your neighbors what "speeding up at a decreasing rate" means with regards to tangential acceleration.

**RK.2.L1-5:** No hints.

**RK.2.L1-6:** No hints.

**RK.2.L1-7:** No hints.

**RK.2.L1-8:** No hints.

**RK.2.L1-9:** No hints.

**RK.2.L1-10:** No hints.

## (RK.L1.3) Practice Stage

Thursday, March 29, 2018 8:34 PM

### Rotational Kinematics (RK): Angular Position, Velocity, and Acceleration for Non-uniform Circular Motion

#### Practice Stage:

##### Post-lecture 1: Angular Position, Velocity, and Acceleration for Non-Uniform Circular Motion

###### Reading

1. none

###### Lecture Videos

1. none

###### Example Problems

1. none

###### Simulations

1. none

###### Other Suggested Content

1. none

###### Practice

1. none

###### Homework

###### **RK.L1.3-01**

**Description:** Features of non-uniform circular motion

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Which of the following statements are true regarding an object undergoing non-uniform circular motion? (Choose all that apply)

- |   |
|---|
| (1) The object has a constant velocity.             |
| (2) The object has a constant speed.                |
| (3) The object has a time-varying speed.            |
| (4) The object has a constant angular velocity.     |
| (5) The object has a time-varying angular velocity. |
| (6) The object has a constant acceleration.         |
| (7) The object has a constant angular acceleration. |

**Answer:** (3), (5), (7)

### RK.L1.3-02

**Description:** Direction of acceleration in non-uniform circular motion

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** An object is slowing down while travelling clock-wise around a circle of constant radius. Which of the following statements are true regarding this situation?

- |   |
|---|
| (1) The object's acceleration vector points directly towards the center of the circle.  |
| (2) The object's acceleration vector has a component that points towards the center of the circle.                                  |
| (3) The object's acceleration vector has a component that points radially outward.  |
| (4) The object's acceleration vector has a component that points tangent to the circle and in the direction of its motion.          |
| (5) The object's acceleration vector has a component that points tangent to the circle and in the opposite direction of its motion. |
| (6) The object's angular acceleration is positive.  |

(7) The object's angular acceleration is negative.

**Answer:** (2), (5), (6)

**RK.L1.3-01**

**Description:** Compare angular acceleration of two objects on the same turntable.

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** A ladybug sits at the outer edge of a record player which is spinning clockwise, and a gentleman bug sits halfway between her and the axis of rotation. The record player makes  $33 \frac{1}{3}$  revolutions every 1 minute. The gentleman bug's angular acceleration is



(1) half the ladybug's.

(2) the same as the ladybug's.

(3) twice the ladybug's.

(4) impossible to determine without knowing radius and angular speed.

**Answer:** (2)

**RK.L1.3-01**

**Description:** Non-UCM kinematics of a grinding wheel

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** A machinist turns the power on to a grinding wheel, at rest, at time  $t = 0$  s. The wheel accelerates uniformly for 10 s and reaches the operating angular velocity of  $+38$  rad/s. The wheel is run at that angular velocity for 30 s and then power is shut off. The wheel slows down uniformly at a rate of  $2.1$  rad/s<sup>2</sup> until the wheel stops.

(a) In this situation, the change in angular position between 0 and 10 s is:

- |                             |
|-----------------------------|
| (1) Positive                |
| (2) Negative                |
| (3) Impossible to determine |

**Answer:** (1) Positive

(b) In this situation, the change in angular position between 40 s and the time it comes to rest is:

- |                             |
|-----------------------------|
| (1) Positive                |
| (2) Negative                |
| (3) Impossible to determine |

**Answer:** (1) Positive

(c) In this situation, the angular acceleration of the wheel between  $t = 0$  s and  $t = 10$  s is closest to:

- |                            |
|----------------------------|
| (1) 3.8 rad/s <sup>2</sup> |
| (2) 4.6 rad/s <sup>2</sup> |
| (3) 5.3 rad/s <sup>2</sup> |
| (4) 6.1 rad/s <sup>2</sup> |
| (5) 6.8 rad/s <sup>2</sup> |

**Answer:** (1) 3.8 rad/s<sup>2</sup>

(d) In this situation, at what time relative to when the wheel started accelerating ( $t = 0$  s), does it come to rest?

- |          |
|----------|
| (1) 18 s |
| (2) 33 s |
| (3) 42 s |
| (4) 50 s |
| (5) 58 s |

**Answer:** (5) 58 s

**RK.L1.3-01**

**Description:** Period and frequency from distance and time

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** The Large Hadron Collider (LHC) is a particle accelerator in Europe that uses electric and magnetic fields to speed particles up along a circular track. They then smash the particles together at incredible speeds to see what smaller pieces they break up into. The track has a radius of 2.71 km and in one such experiment they have accelerated the particles up to a constant speed of 10% the speed of light ( $c = 3 \times 10^8$  m/s).

(a) What is the circumference of the LHC track?

(1) 5.42 km

(2) 6.80 km

(3) 17.0 km

(4) 36.3 km

(5) 2,710 km

**Answer: (3)**

(b) What is the period of the particle's motion?

(1)  $5.60 \times 10^{-7}$  s

(2)  $6.73 \times 10^{-5}$  s

(3)  $6.73 \times 10^{-4}$  s

(4)  $5.67 \times 10^{-4}$  s

(5) 0.45 s

(6) 3.02 s

**Answer: (4)**

(c) What is the frequency of the particle's motion?

- |                           |
|---------------------------|
| (1) 12.5 Hz               |
| (2) 1,760 Hz              |
| (3) 32,100 Hz             |
| (4) $4.56 \times 10^7$ Hz |
| (5) $6.73 \times 10^8$ Hz |

**Answer:** (2)

**RK.L1.3-01**

**Description:** One (or two) sentence quick description of the problem

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Write the problem statement here

**Answer:** x

**RK.L1.3-01**

**Description:** One (or two) sentence quick description of the problem

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Write the problem statement here

**Answer:** x

**RK.L1.3-01**

**Description:** One (or two) sentence quick description of the problem

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Write the problem statement here

**Answer:** x

**RK.L1.3-01**

**Description:** One (or two) sentence quick description of the problem

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Write the problem statement here

**Answer:** x

**RK.L1.3-01**

**Description:** One (or two) sentence quick description of the problem

**Learning Objectives:** [x,xx,...] Put the learning objective numbers here

**Problem Statement:** Write the problem statement here

**Answer:** x



































