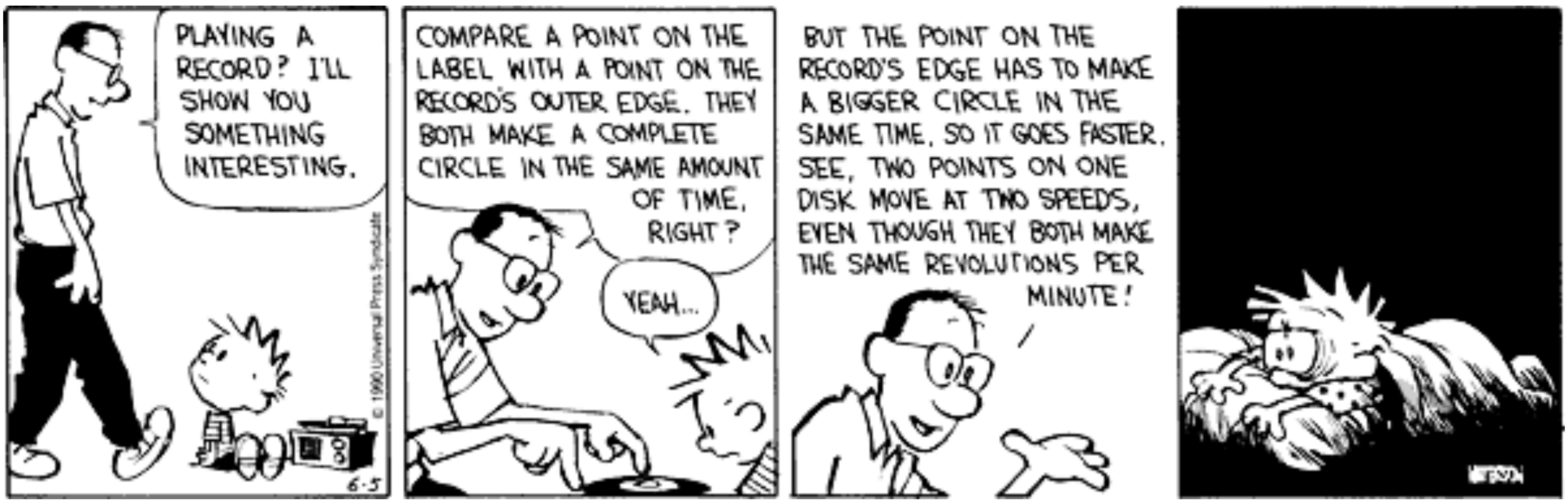
Physics 211

Sections 1 & 70
Dr. Geoffrey Lovelace
Fall 2012
Lecture 19 (11/6/12)



Announcements

- Homework
  - Homework #9: out today, due in 1 week
- Exams: grades posted
- Reading: For Thursday: finish chapter 7
- Office hours: 4PM-5PM today
  - McCarthy Hall room 601B
  - Feel free to just come & work on the homework
- Exam #3: 1 week from Thursday

Lecture 19 outline

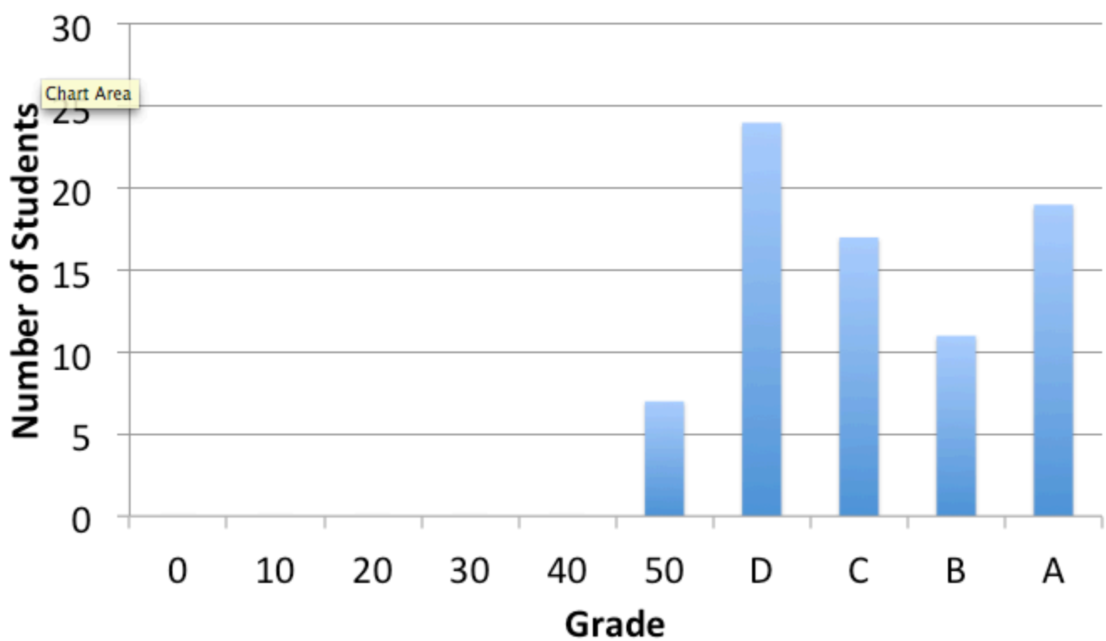
- Announcements
- Exam #3 followup
- Angular motion
  - Arc length, radians & degrees, small angles
  - Angular displacement
  - Angular & tangential velocity
- Circular motion
  - Period & frequency
  - Centripetal acceleration
  - Examples & demos

Today →

Oct 23	**Exam 2**
Oct 25	Linear momentum, conservation of linear momentum
Oct 30	Conservation of linear momentum, collisions
Nov 1	Center of mass, rockets, *HW #8 due*
Nov 6	Circular motion, gravitation
Nov 8	Gravitation, Kepler's laws
Nov 13	Special feature: temperature, heat, entropy *HW #9 due*
Nov 15	**Exam 3**
Nov 20	*Fall Recess — No class*
Nov 22	*Fall Recess — No class*
Nov 27	Rigid body rotation, torque, rotational dynamics
Nov 29	Rotational dynamics, rotational energy, *HW #10 due*
Dec 4	Angular momentum, conservation of angular momentur
Dec 6	Harmonic motion, *HW #11 due*
Dec 11	Harmonic motion & waves
Dec 13	Gravitational waves, harmonic motion, black holes, *HW*
Dec 20	**Final exam 9:30AM–11:20AM**

Exam followup

- Distribution (after +3 bonus)



- Most-missed
  - Moving bus, you move forward as the bus comes to an immediate stop. What force caused you to move? **Newton's first law.**

Clicker question #33

Question 4.1c Newton's First Law III

You put your book on the bus seat next to you. When the bus stops suddenly, the book slides forward off the seat. Why?

- A. a net force acted on it
- B. no net force acted on it
- C. it remained at rest
- D. it did not move, but only seemed to
- gravity briefly stopped acting on it

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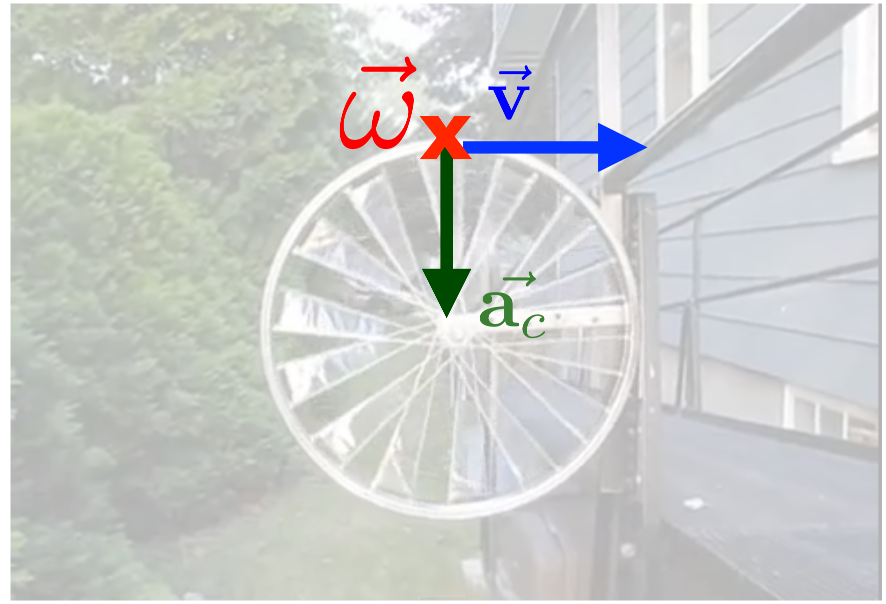
Example: wheel & record

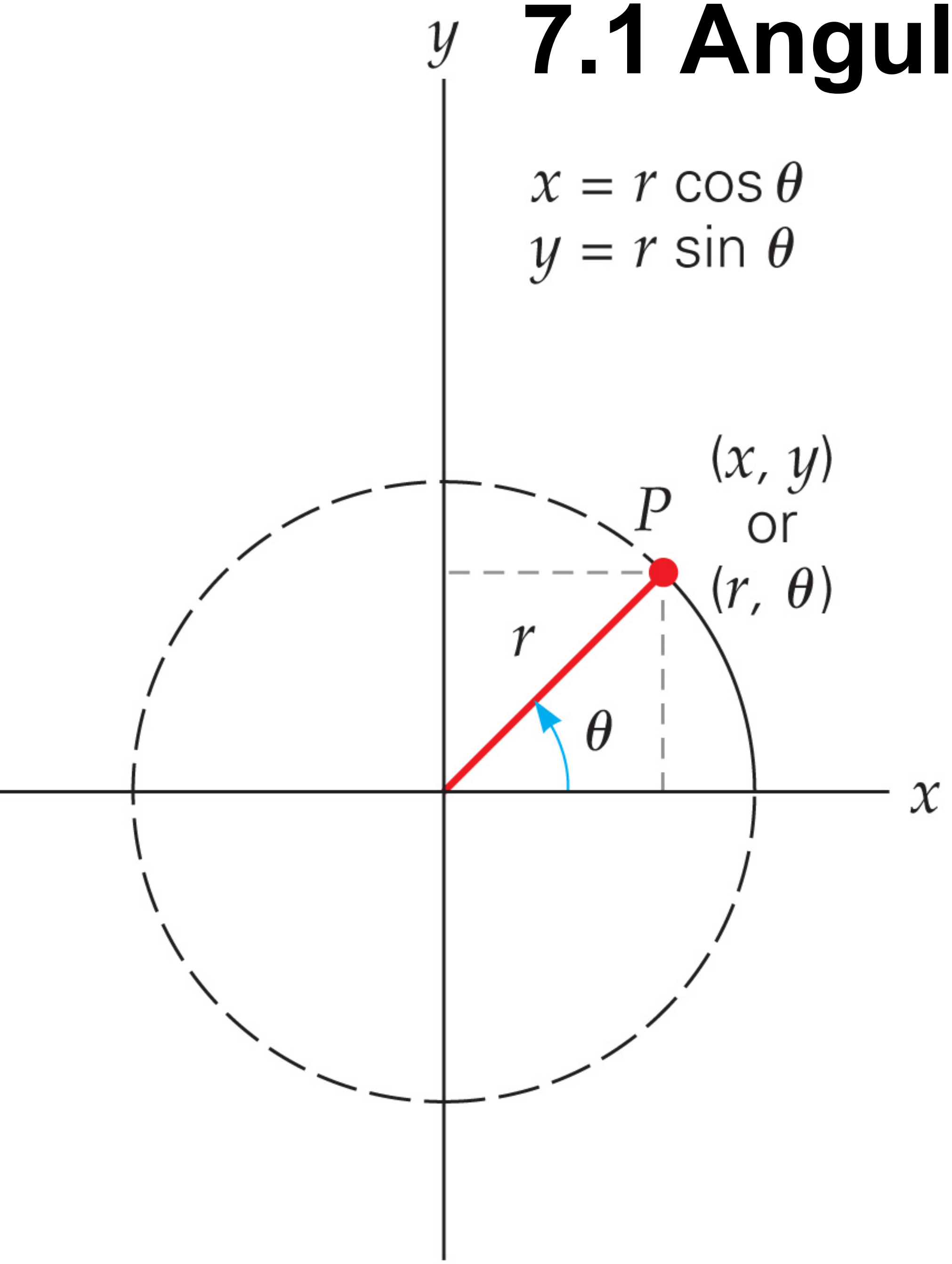
- Windmill



- Record on record player

http://www.youtube.com/watch?v=jtF-oL_m2QY

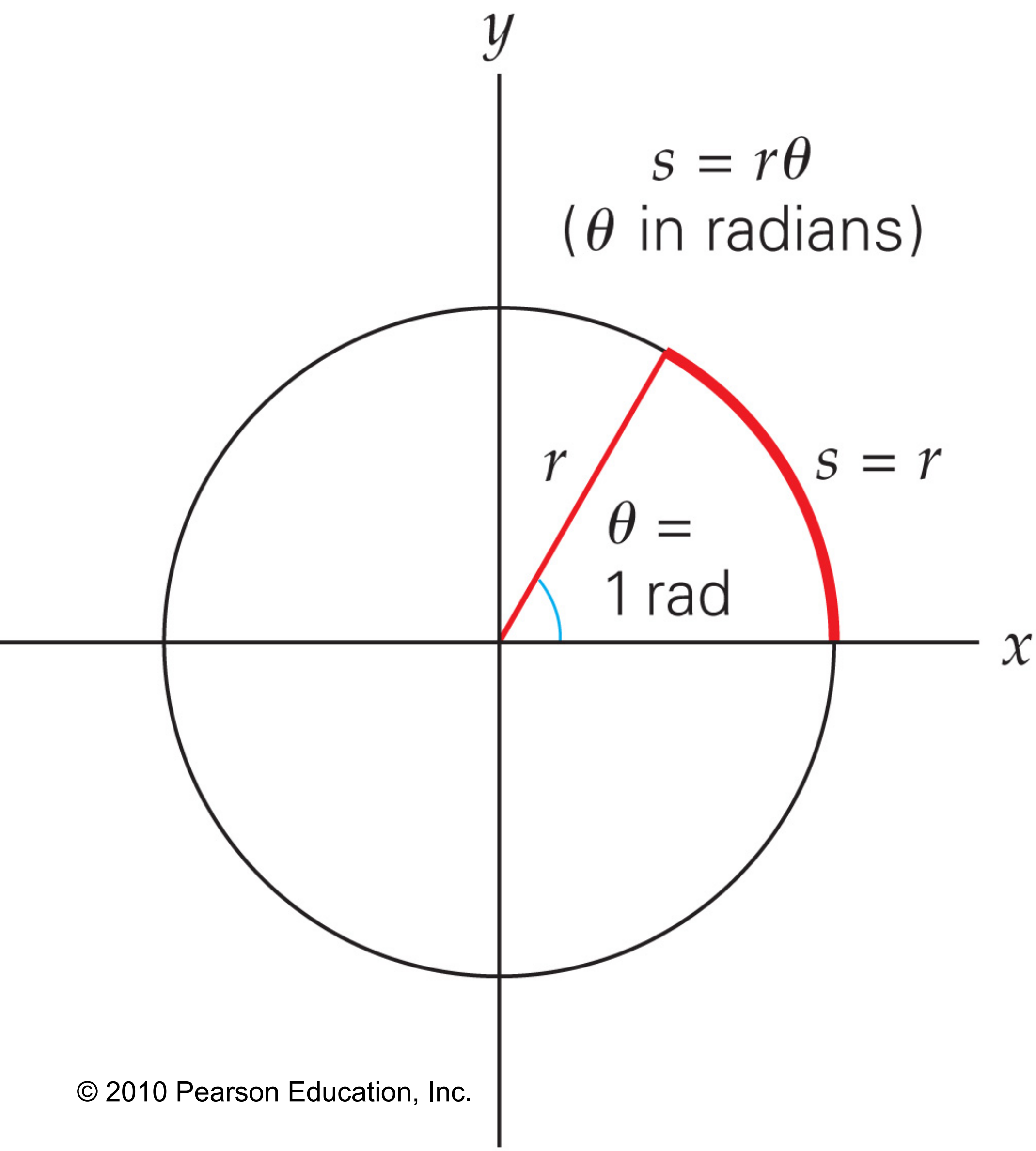
7.1 Angular Measure



The position of an object can be described using polar coordinates—*r* and θ—rather than *x* and *y*. The figure at left gives the conversion between the two descriptions.

7.1 Angular Measure

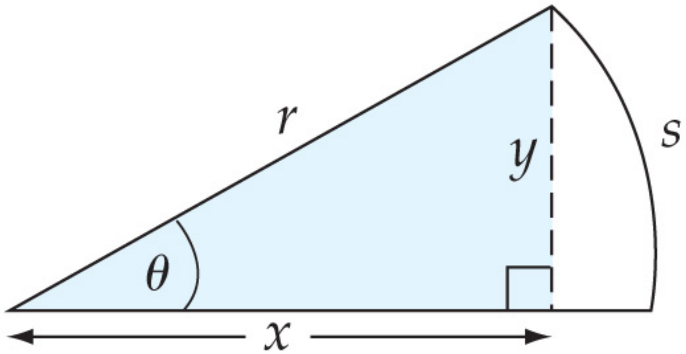
It is most convenient to measure the angle θ in radians, since then arc length $s = r\theta$



$$1 = \frac{2\pi \text{ rad}}{360^\circ}$$

$$1 = \frac{360^\circ}{2\pi \text{ rad}}$$

7.1 Angular Measure



θ *not* small:

$$\theta\ (\text{in rad}) = \frac{s}{r}$$

$$\sin\theta = \frac{y}{r} \qquad \tan\theta = \frac{y}{x}$$

θ small:

$$y \approx s$$
$$x \approx r$$

$$\theta\ (\text{in rad}) = \frac{s}{r} \approx \frac{y}{r} \approx \frac{y}{x}$$

$$\theta\ (\text{in rad}) \approx \sin\theta \approx \tan\theta$$

The small-angle approximation is very useful, as it allows the substitution of θ for sin θ when the angle is sufficiently small.

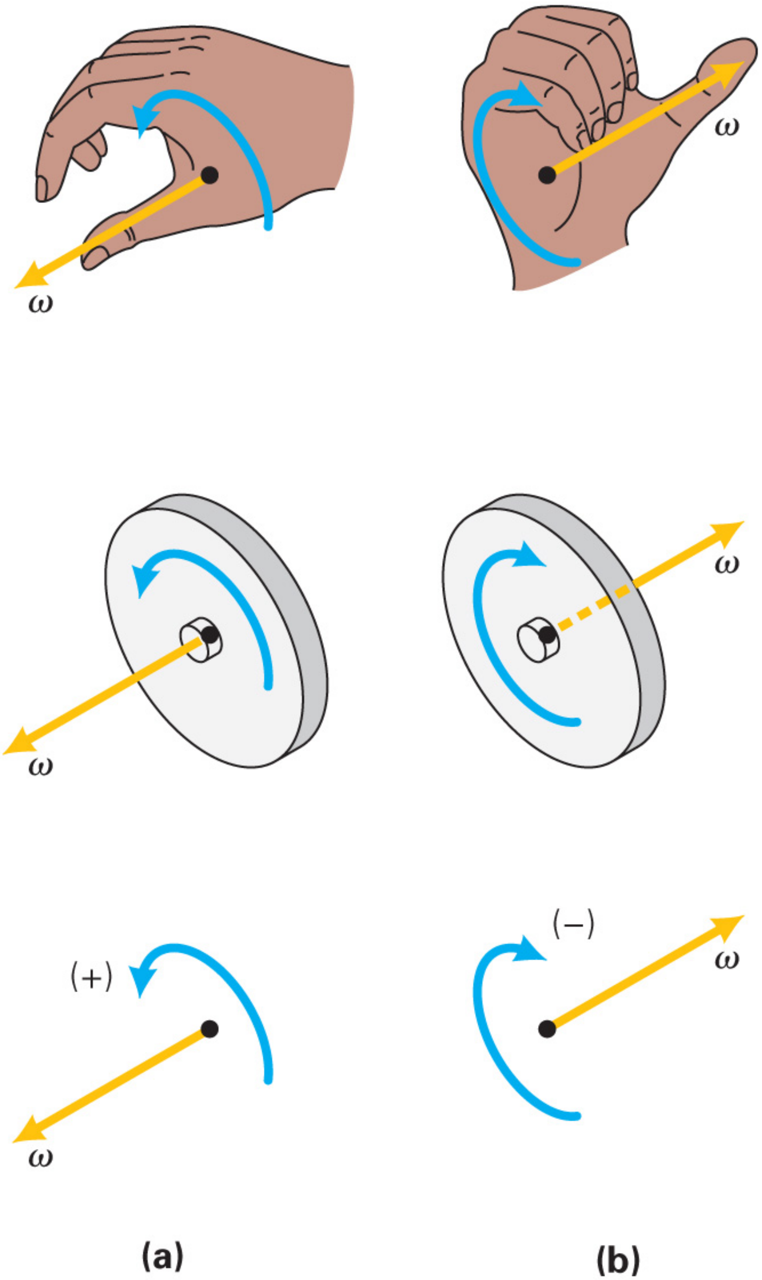
7.2 Angular Speed and Velocity

In analogy to the linear case, we define the average and instantaneous angular speed:

$$\bar{\omega} = \frac{\Delta\theta}{\Delta t} = \frac{\theta - \theta_o}{t - t_o}$$

$$\omega = \frac{\theta}{t} \quad \text{or} \quad \theta = \omega t$$

7.2 Angular Speed and Velocity



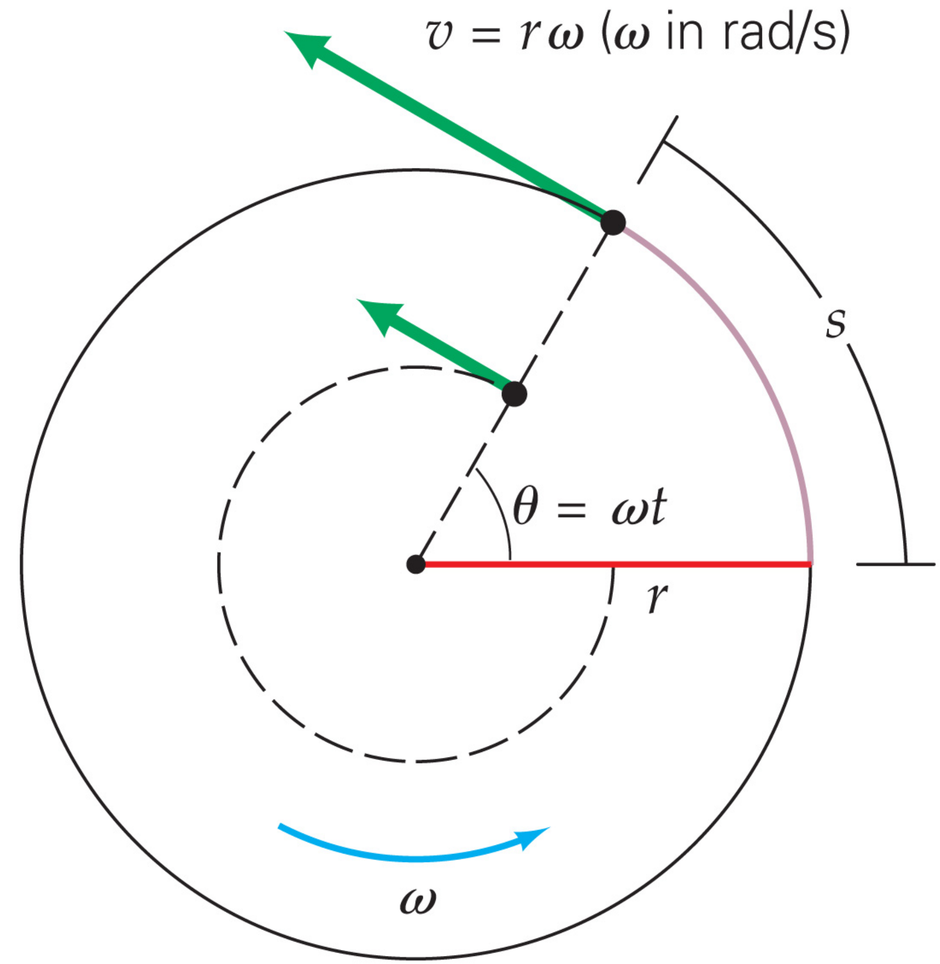
The direction of the angular velocity is along the axis of rotation, and is given by a right-hand rule.

Important:
Don’t use your left hand for the right-hand rule!

7.2 Angular Speed and Velocity

Relationship between tangential and angular speeds:

$$v = r\omega$$



This means that parts of a rotating object farther from the axis of rotation move faster.

7.2 Angular Speed and Velocity

The period is the time it takes for one rotation; the frequency is the number of rotations per second.

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

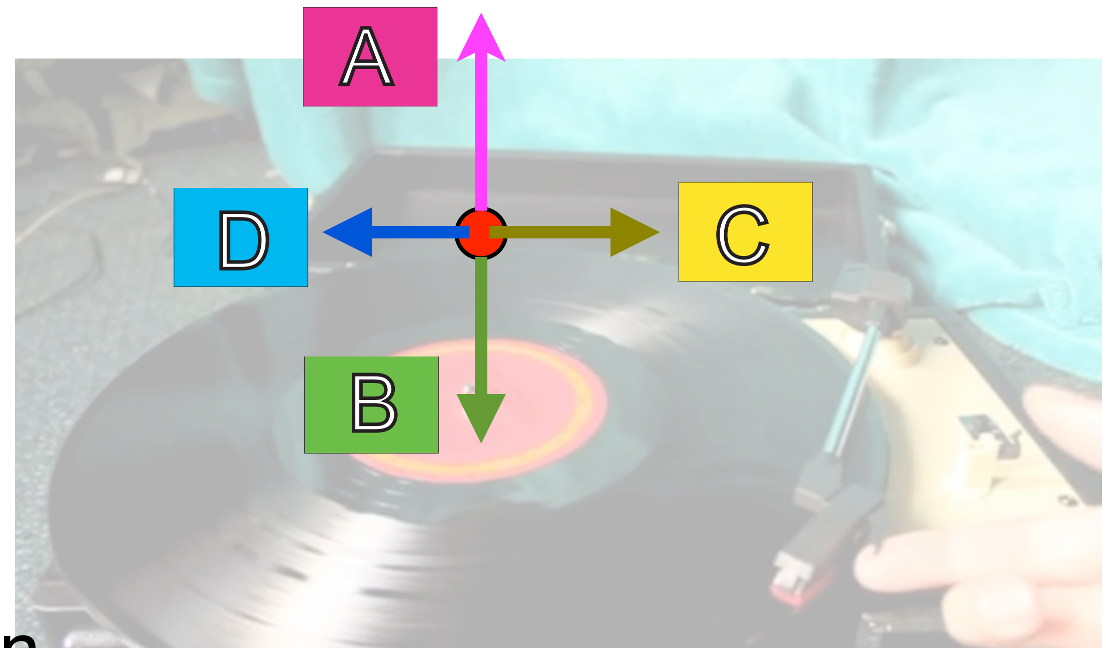
The relation of the frequency to the angular speed:

$$\omega = \frac{2\pi}{T} = 2\pi f$$

Clicker question #84

The record rotates **clockwise**. What is the **angular velocity direction** at the red dot?

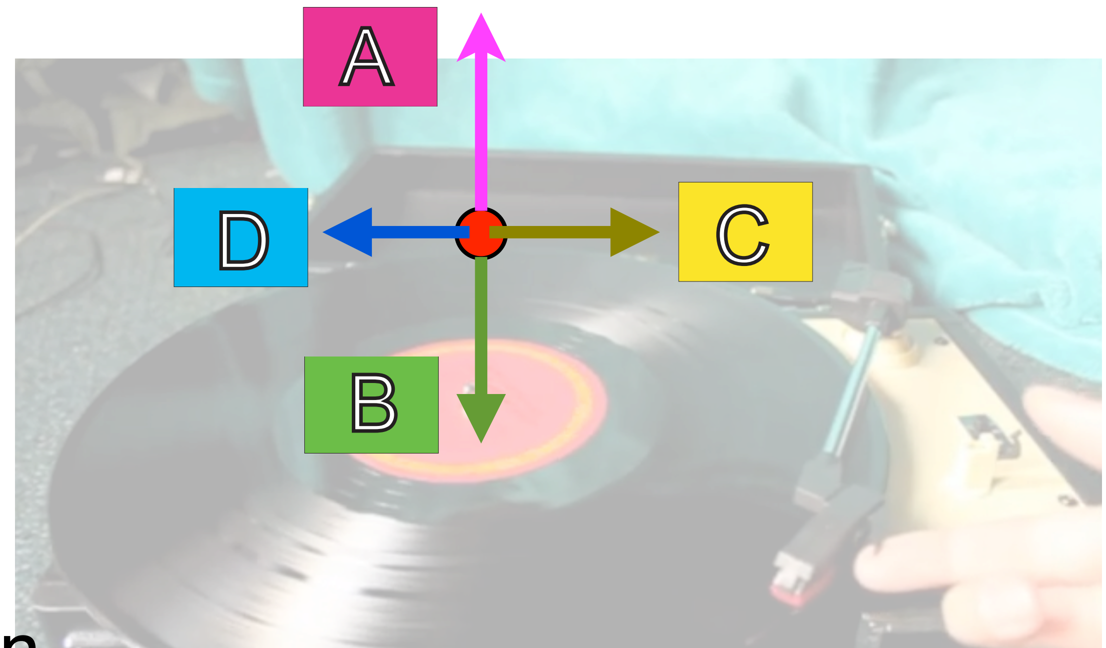
- A — Up along the axle
- B — Down along the axle
- C — To the right
- D — To the left
- ☐ — Angular velocity doesn't have a direction



Clicker question #85

The record rotates **clockwise**. What is the **tangential velocity direction** at the red dot?

- A — Up along the axle
- B — Down along the axle
- C — To the right
- D — To the left
- ☐ — Tangential velocity doesn’t have a direction



Clicker question #86

The record rotates **clockwise**. How are the **angular speeds** related at points x and o?

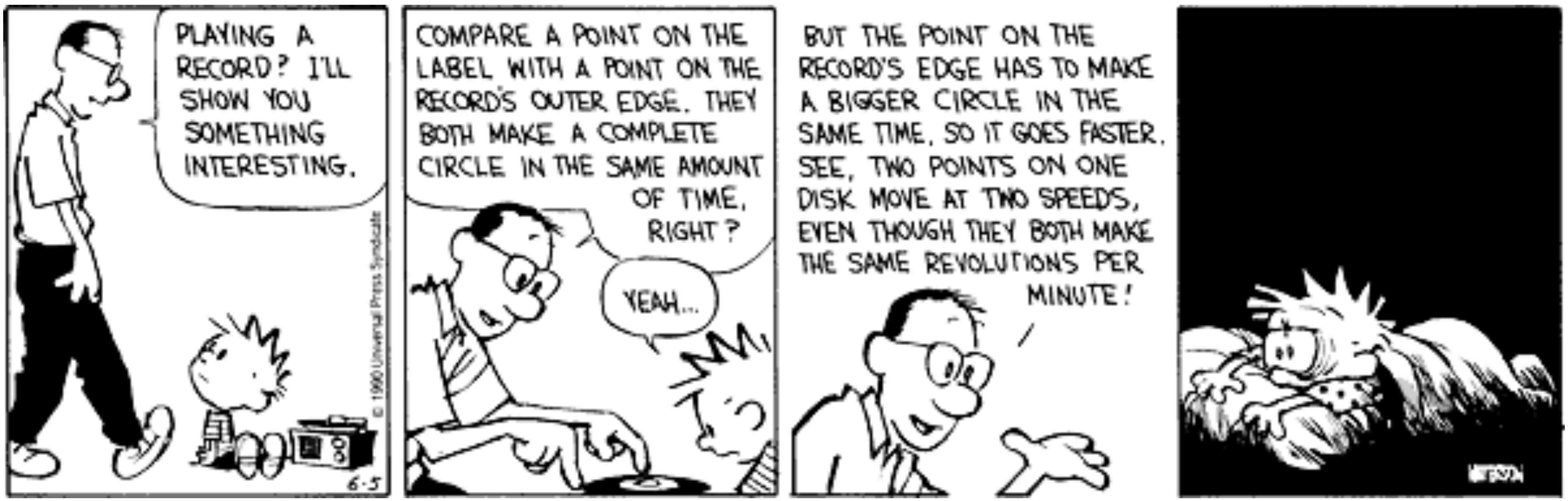
- A largest at x
- B largest at o
- C equal at x and o
- D Depends on how fast the record spins

Clicker question #87

The record rotates **clockwise**. Which point has a faster **tangential speed**?

- A largest at x
- B largest at o
- C equal at x and o
- D Depends on how fast the record spins

Example: record player



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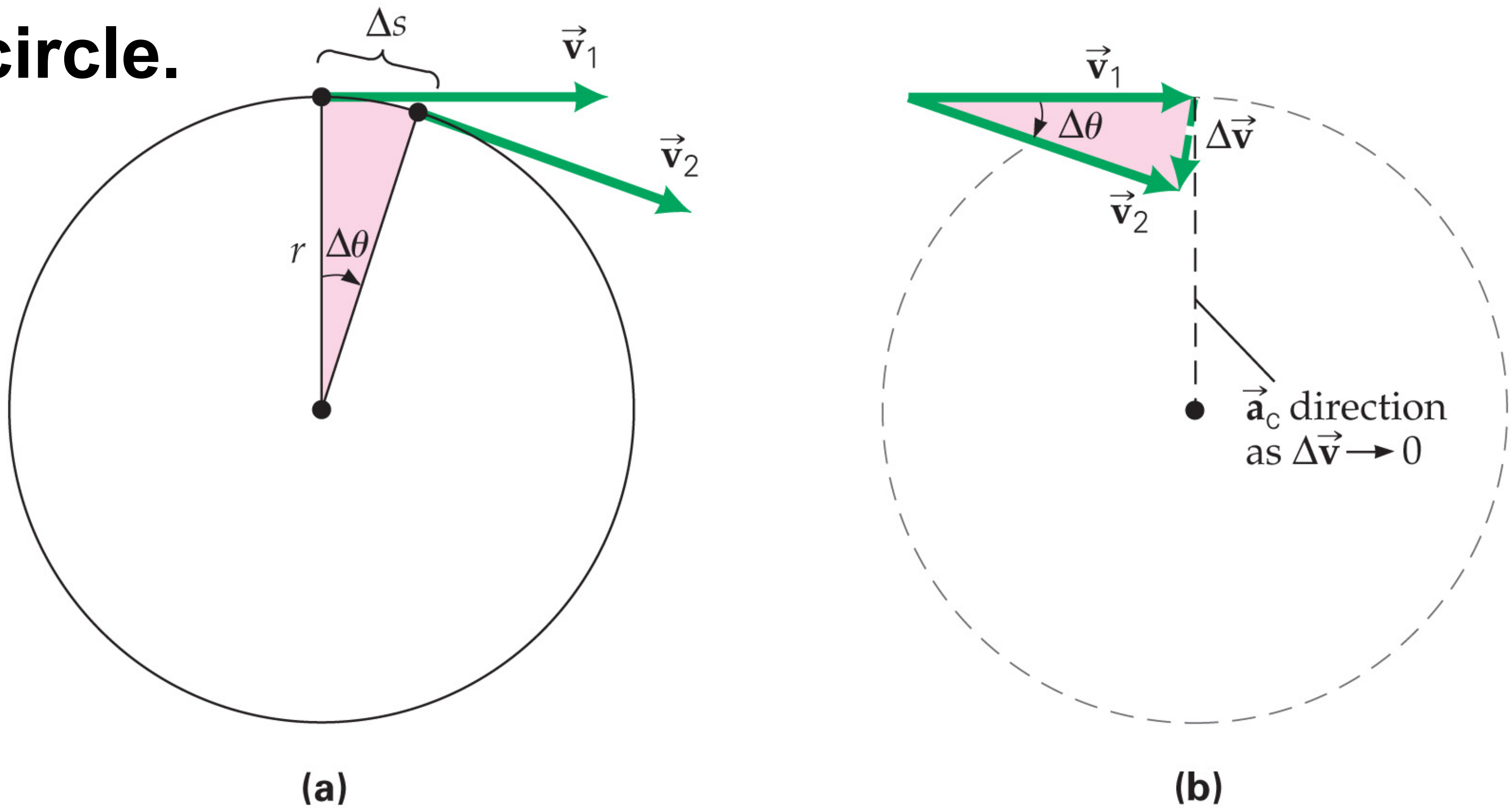
7.3 Uniform Circular Motion and Centripetal Acceleration

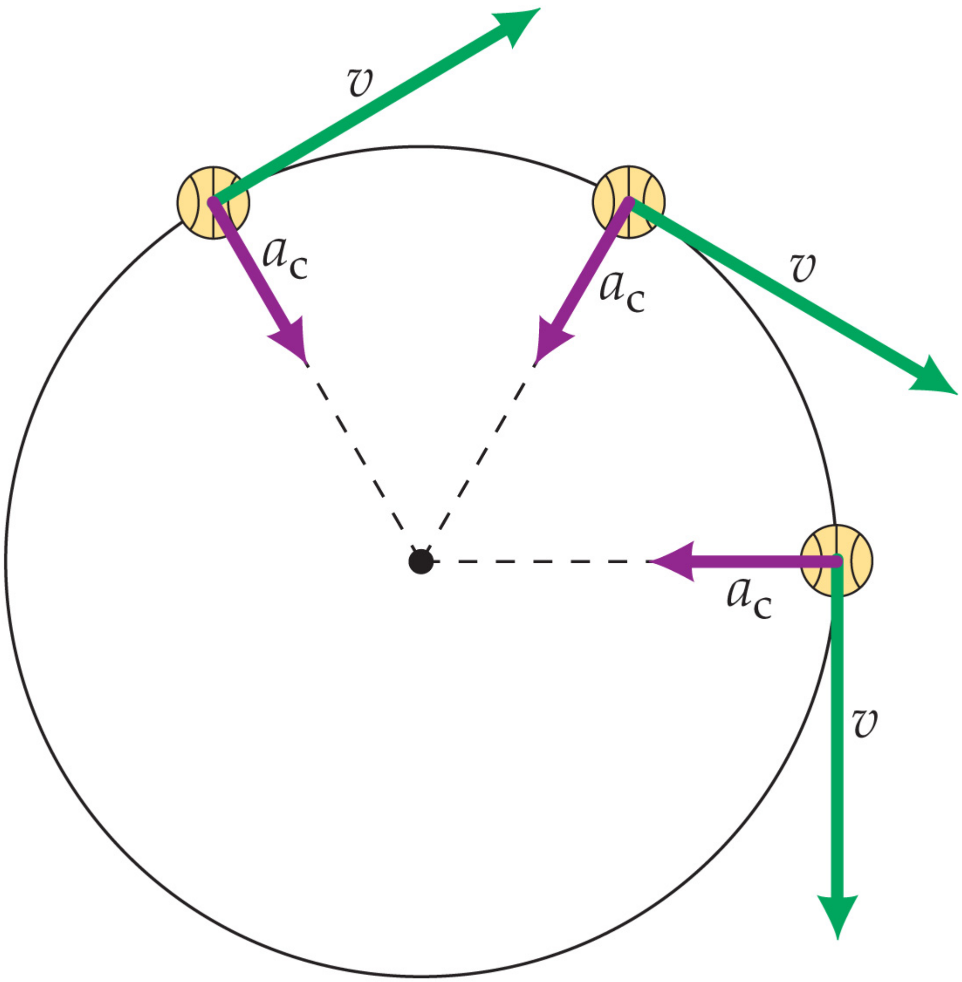
A careful look at the change in the velocity vector of an object moving in a circle at constant speed shows that the acceleration is toward the center of the circle.



$\vec{v}_2 = \vec{v}_1 + \Delta\vec{v}$ or

$\vec{v}_2 - \vec{v}_1 = \Delta\vec{v}$

7.3 Uniform Circular Motion and Centripetal Acceleration



The same analysis shows that the centripetal acceleration is given by:

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

$$a_c = \frac{v^2}{r} = \frac{(r\omega)^2}{r} = r\omega^2$$

7.3 Uniform Circular Motion and Centripetal Acceleration

The centripetal force is the mass multiplied by the centripetal acceleration.

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

This force is the net force on the object. As the force is always perpendicular to the velocity, it does no work.

Circular motion examples

- Circular motion
  - Tetherball
    http://www.youtube.com/watch?v=MGx_xxn2l0w
  - Centrifuge
    http://www.youtube.com/watch?v=FACvmZJpRLs

  - Exoplanets

Clicker question #88

Question 7.1 Tetherball

In the game of tetherball, the struck ball whirls around a pole. In what direction does the **net force** on the ball point?

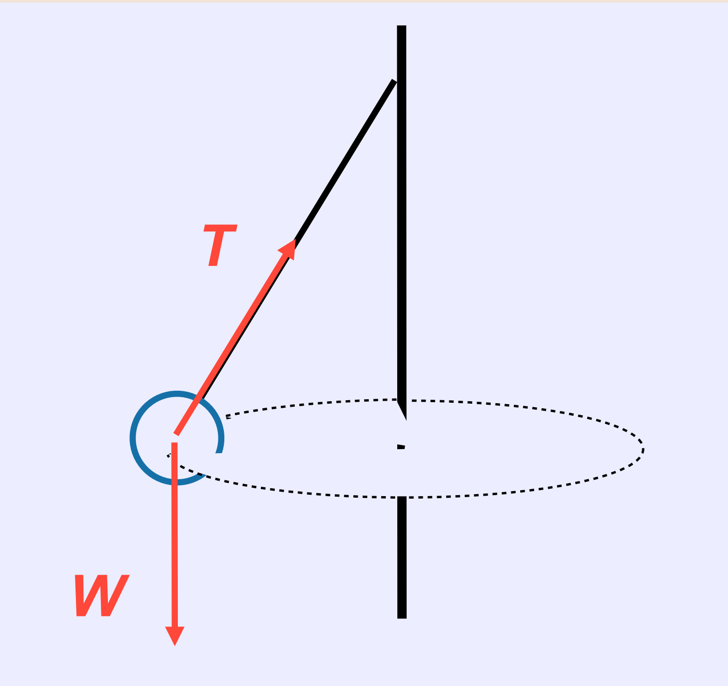
A. toward the top of the pole

B. toward the ground

C. along the horizontal component of the tension force

D. along the vertical component of the tension force

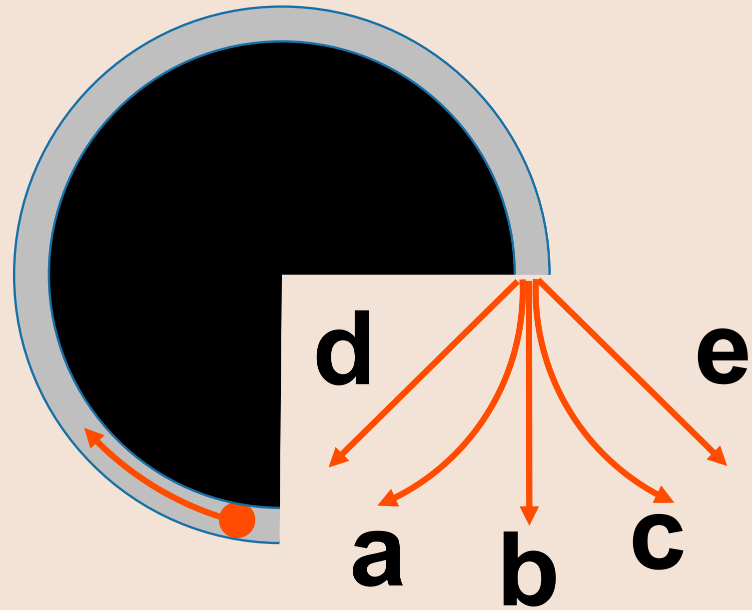
E. tangential to the circle



Clicker question #89

Question 7.3 **Missing Link**

A Ping-Pong ball is shot into a circular tube that is lying flat (horizontal) on a tabletop. When the Ping-Pong ball leaves the track, which path will it follow?



Clicker question #90

Question 7.6a Going in Circles I

You're on a Ferris wheel moving in a vertical circle. When the Ferris wheel is at rest, the normal force *N* exerted by your seat is equal to your weight *mg*. How does *N* change at the top of the Ferris wheel when you are in motion?

a) *N* remains equal to *mg*

b) *N* is smaller than *mg*

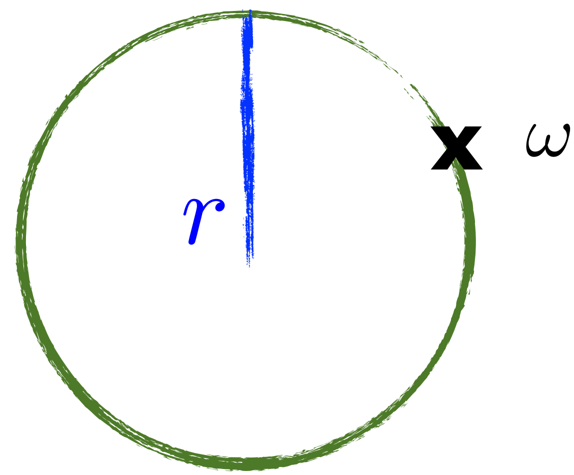
c) *N* is larger than *mg*

d) none of the above

Ex. 7.5

1. Read carefully
2. Draw a sketch
3. Given? Goal?
4. Principles & equations?
5. Calculate
6. Plug in numbers
7. Is answer reasonable?

Lab centrifuge operates at 12000 revolutions per minute (rpm). Centripetal accel. of red blood cell that is 8.0 cm from center?



Given: angular velocity ω

radius r

Goal: centripetal accel. a_c

Principle: centripetal accel.

$$a_c = \omega^2 r$$

$$a_c = \left(1.2 \times 10^4 \frac{\text{rev}}{\text{min}} \frac{2\pi \text{ rad}}{\text{rev}} \frac{1 \text{ min}}{60 \text{ s}}\right)^2 (0.08\text{m})$$

$$a_c = 1.3 \times 10^5 \text{m} = 1.3 \times 10^4 g$$

Class participation

- 0. Name
- 1. What is its angular velocity?
- 2. The earth is 1.5×10^{11} m from the sun. What is the earth's tangential velocity?

(Formula sheet:)

$$\omega = \frac{2\pi}{T} = 2\pi f$$

$$v = r\omega$$