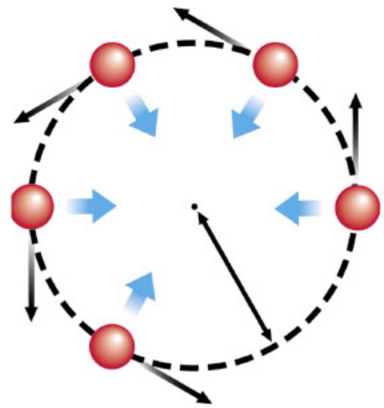
Welcome back to Physics 215

Today's agenda:

- *Rotations*
- *What's on the exam?*
- *Relative motion*



Midterm 1: in less than 2 weeks! (9/24)

- In Phys 208 (here!) at the usual lecture time
- Material covered:
  - **Textbook** chapters 1 – 4
  - **Lectures** up through next Tuesday (slides online)
  - **Wed/Fri recitation activities**
  - **Homework assignments**
- You will be given a **formula sheet** at the exam. A copy of this sheet will be available on the course website
- You should bring a **calculator**, but you must bring your own, and it can not be a phone. You may not store any equations in memory, and midterm proctors may request to see your calculator during the exam.
- Exam accommodations: must take exam at ODS
  - I need the request form by NEXT TUESDAY

How should I study?

- Gather a study group!!!!
- Attend the study session Thursday, Sept 19 from 6-8pm in Physics 204 with society of physics students
- Work through the practice exam and check your answers against solutions
- Look over HW solutions
- Go to physics clinic
- Ask questions during your recitation section

Recall SG from last week: Two cars are moving at different constant speeds on a curved road. One after the other, they are passing the same point on the road: Car A at V_A mph; car B at (2 V_A) mph. If car A's acceleration is 2 m/s^2, car B's acceleration is:

A. 1 m/s^2
B. 2 m/s^2
C. 4 m/s^2
D. 8 m/s^2

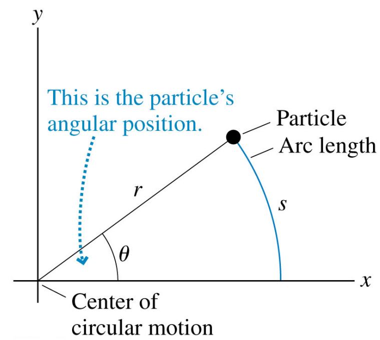
Angular Position

- The angle may be measured in degrees, revolutions (rev) or **radians** (rad), that are related by:

$$1 \text{ rev} = 360° = 2\pi \text{ rad}$$

- Radians are awesome! Because:

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



Angular velocity

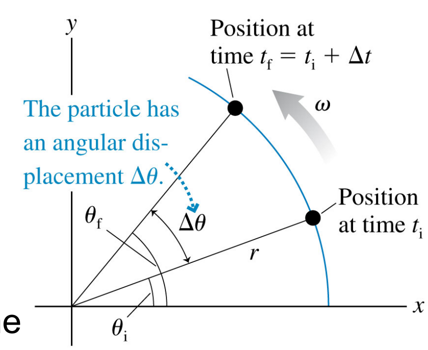
- $\Delta\theta = \theta_f - \theta_i$
  $\Delta t = t_f - t_i$.
- In analogy with linear motion, we define:

$\boldsymbol{\omega}_{\mathbf{avg}}$ **=**

- As the time interval Δt become arrive at the definition of instantaneous **angular velocity**.

ω =

- Counterclockwise is ________________



Units of angle are a pain!

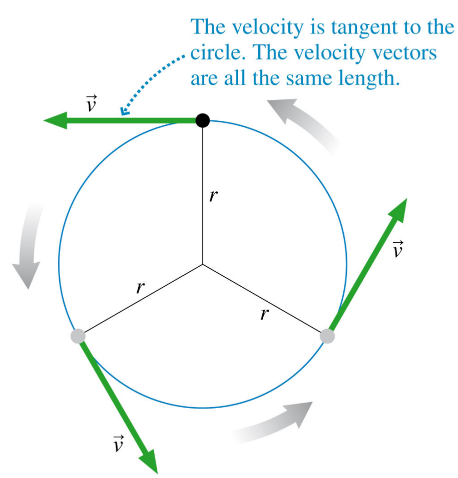
- Note that the radian is a ratio between two lengths, which makes it a *pure number*
- The units of angles are just a NAME to remind us we are dealing with an angle
- Angular velocities can be given in
  - rev/min, rad/s, degrees/hour, etc.
  - Just figure out what you need for a given problem
  - Practice problems help!

Angular velocity and linear velocity:

- The time interval to complete one revolution is called the period, T.
- The rate of revolution (i.e. rpm, rph) is ___
- The period T is related to the speed v:

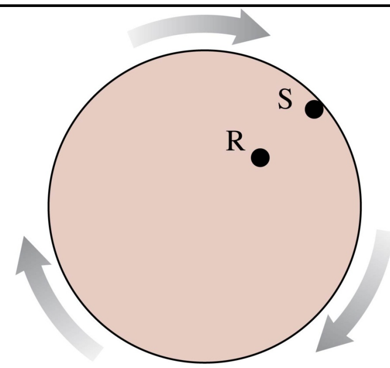
$$v = \frac{1 \text{ circumference}}{1 \text{ period}} = \frac{2\pi r}{T}$$

- ω r =



Small group

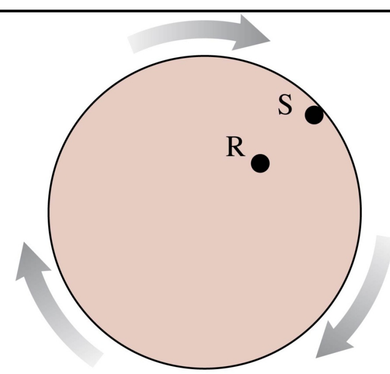
Rasheed and Sofia are riding a merry-go-round that is spinning steadily. Sofia is twice as far from the axis as is Rasheed. Sofia's angular velocity is ______ that of Rasheed.



A. half
B. the same as
C. twice
D. four times
E. We can't say without knowing their radii.

Individual

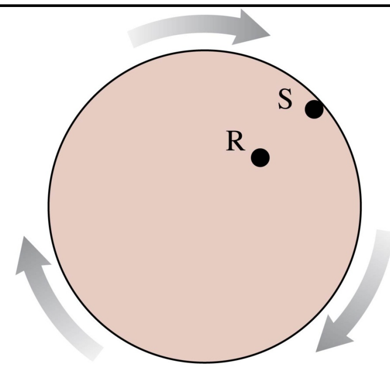
Rasheed and Sofia are riding a merry-go-round that is spinning steadily. Sofia is twice as far from the axis as is Rasheed. Sofia's speed is ______ that of Rasheed.



A. half
B. the same as
C. twice
D. four times
E. We can't say without knowing their radii.

Small group

Rasheed and Sofia are riding a merry-go-round that is spinning steadily. Sofia is twice as far from the axis as is Rasheed. Sofia's acceleration is ______ that of Rasheed.



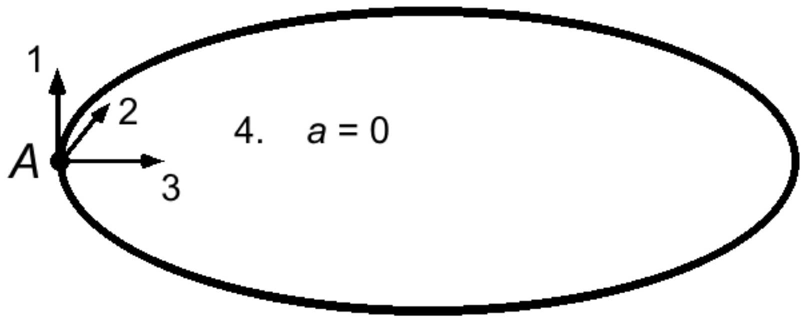
A. half
B. the same as
C. twice
D. four times
E. We can't say without knowing their radii.

Section 10.1 and 10.2 in Open Stax

But what if the speed is changing?

All those equations were for circular motion under constant speed

SG: What is the acceleration vector for object speeding up from rest at point *A* ?



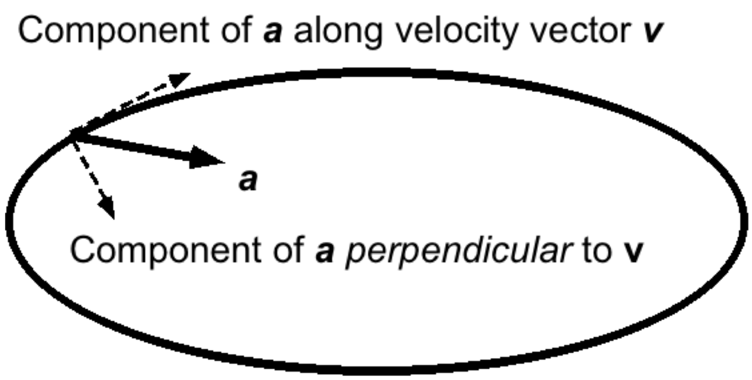
What if the speed is changing?

- Consider acceleration for object on curved path *starting from rest*
- Initially, $v^2/r = 0$, so no radial acceleration
- But a is not zero! It must be **parallel** to velocity

Acceleration vectors for object speeding up:

Tangential and radial components

(or parallel and perpendicular)



Summary

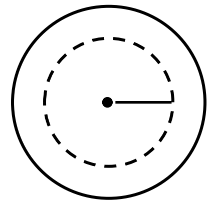
Components of acceleration vector:

- Parallel to direction of velocity:
  (Tangential acceleration)
  - "How much does speed of the object increase?"

- Perpendicular to direction of velocity:
  (Radial acceleration)
  - "How quickly does the object turn?"

Relating linear and angular kinematics

- Linear speed: $v = (2\pi r)/T = \omega r$
- Radial acceleration: $a_{rad} = v^2/r = \omega^2 r$
- Tangential acceleration: $a_{tan} = r\alpha$



$$\omega = \omega_0 + \alpha t$$

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$$

Demo: Loop-de-Loop

First draw the velocity vector at the sides and top of the loop-de-loop

Next draw the components of the acceleration vector at the sides and top of the loop-de-loop

Sample problem

A small steel roulette ball rolls around inside of a 30-cm diameter roulette wheel. It is spun at 150 rpm, but it slows down to 60 rpm over an interval of 5.0s. Assume constant angular acceleration. How many revolutions does the ball make during these 5.0s?

Frame of reference

- Consider 1D motion of some object
- Observer at origin of coordinate system measures pair of numbers (x, t)
  - (observer) + coordinate system + clock called ***frame of reference***
- But … we could change the origin and still get the same answer
  - Because observables depend only on Δ**x**

Inertial Frames of Reference

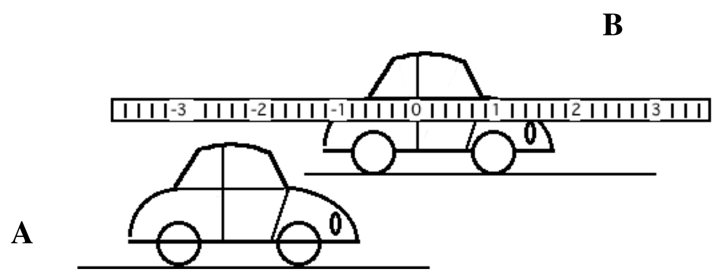
- Any system moving at a **constant velocity** has a nice "inertial frame of reference"
  - different frames will perceive velocities differently...
  - But accelerations are still the same
  - That's why things are still "nice"

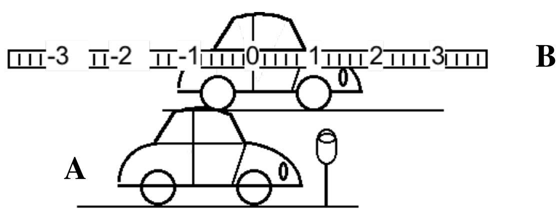
Why bother?

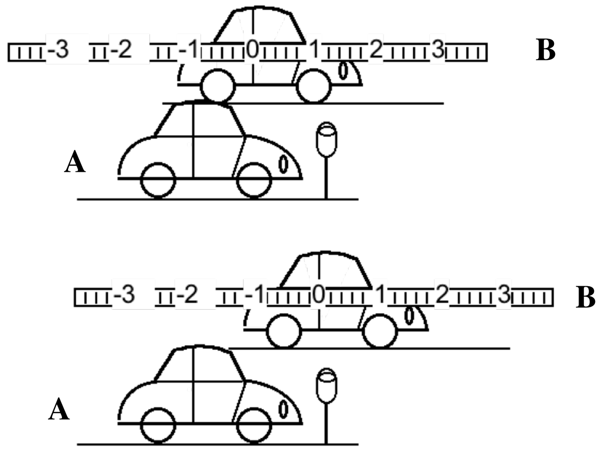
- Why would we want to use moving frames?
  - *Answer:* can **simplify** our analysis of the motion
- Have **no way in principle** of knowing whether any given frame is **at rest**
  - Physics building is NOT at rest (as we have been assuming!)

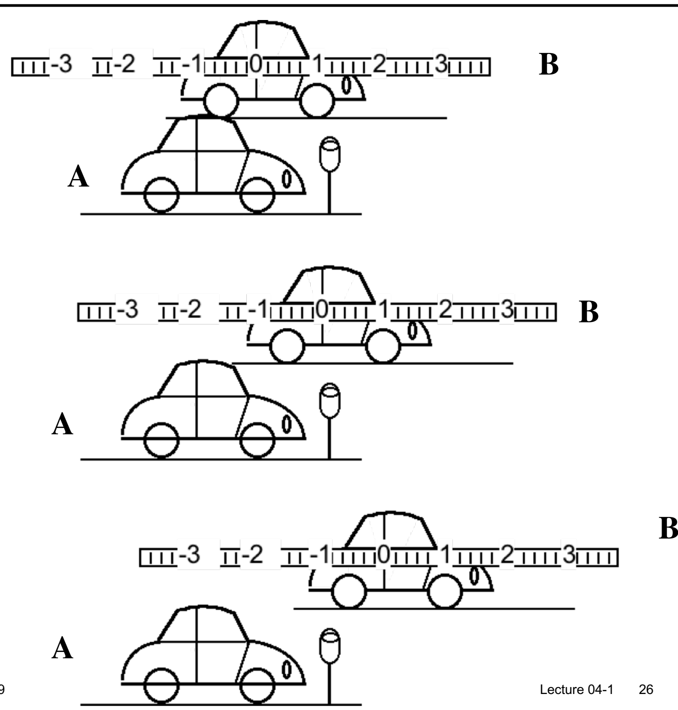
Reference frame

(clock, meterstick) carried along by moving object






-3 -2 -1 0 1 2 3
B
A
-3 -2 -1 0 1 2 3
B
A


-3 -2 -1 0 1 2 3
B
A
-3 -2 -1 0 1 2 3
B
A
B
-3 -2 -1 0 1 2 3
A

Discussion

- A says: car B moves to right. v_{BA} is the velocity of B relative to A is. So $v_{BA} > 0$
- B says: car A moves to left. So, $v_{AB} < 0$
- In general, can see that

$$v_{AB} = -v_{BA}$$

General formula for relative motion

sg: Otto is in one car, a cameraman is in another. Both cars are going 0.5 m/s to the right. How fast is Otto moving in the camera's frame of reference? (Right is positive!)

A. 0.5 m/s
B. 0 m/s
C. -0.5 m/s
D. 1 m/s
E. None of the above

sg: Otto is in one car, a cameraman is in another. Otto is going 0.5 m/s to the right. The cameraman is going 1.0 m/s to the right. How fast is Otto moving in the camera's frame of reference? (Right is positive!)

A. 0.5 m/s
B. 0 m/s
C. -0.5 m/s
D. 1 m/s
E. None of the above

sg: Otto is in one car, a cameraman is in another. Otto is going 0.5 m/s to the right. The cameraman is going 0.5 m/s to the left. How fast is Otto moving in the camera's frame of reference? (Right is positive!)

A. -1.0 m/s

B. 0 m/s

C. -0.5 m/s

D. 1.0 m/s

E. None of the above

What's more …

- Einstein developed **Special theory of relativity** to cover situations when velocities approach the speed of light
- **(more on Thursday!)**

sg: You are driving East on I-90 at a constant 65 miles per hour. You are passing another car that is going at a constant 60 miles per hour. In your frame of reference (*i.e.,* as measured relative to your car), is the other car

A. going East at constant speed

B. going West at constant speed,

C. going East and slowing down,

D. going West and speeding up.

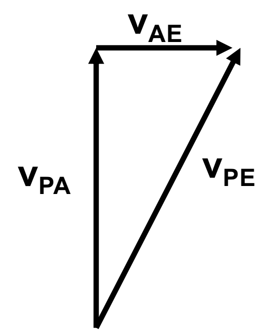
Conclusion

- If we want to use (inertial) moving frames of reference, then velocities are **not** the same in different frames
- However **constant velocity** motions are always seen as **constant velocity**
- There is a simple way to relate velocities measured by different frames.

Relative Motion in 2D

- Consider airplane flying in a crosswind
  - velocity of plane relative to air, $\mathbf{v_{PA}}$ = 240 km/h N
  - wind velocity, air relative to earth, $\mathbf{v_{AE}}$ = 100 km/h E
  - what is velocity of plane relative to earth, $\mathbf{v_{PE}}$?

$$\mathbf{v_{PE} = v_{PA} + v_{AE}}$$



Acceleration is same for all inertial FOR!

- We have:

$$v_{PA} = v_{PB} + v_{BA}$$

- For velocity of P measured in frame A in terms of velocity measured in B

→$\Delta v_{PA}/\Delta t = \Delta v_{PB}/\Delta t$ since v_{BA} is *constant*

→Thus acceleration measured in frame A or frame B is same!

Relative Motion in 2D

- Motion may look quite different in different inertial frames, e.g., ejecting ball from moving cart