Welcome back to Physics 211

Today's agenda:

- *Circular Motion*

Exam 1: Next Tuesday (9/23/14)

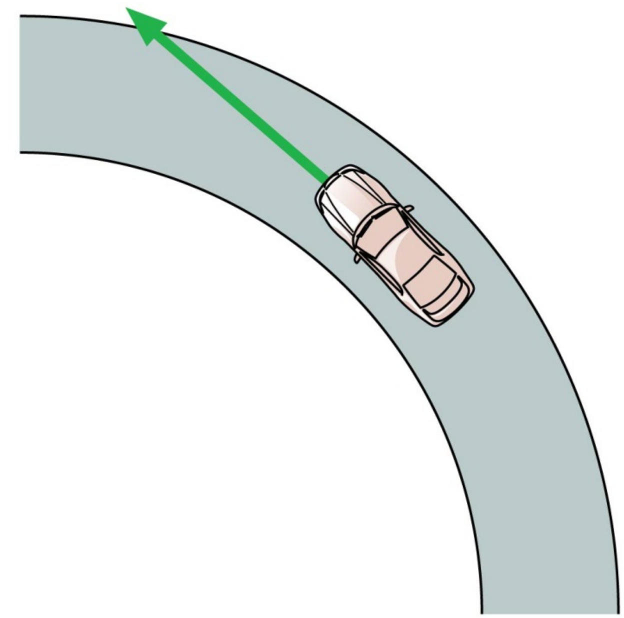
- In Stolkin (here!) at the usual lecture time
- Material covered:
  - **Textbook** chapters 1 – 4.3
  - **Lectures** up through 9/16 (Through projectile motion)
  - **Wed/Fri Workshop activities**
  - **Homework assignments**

- *Work through practice exam problems (posted on website and distributed in recitation).*

Assignments:

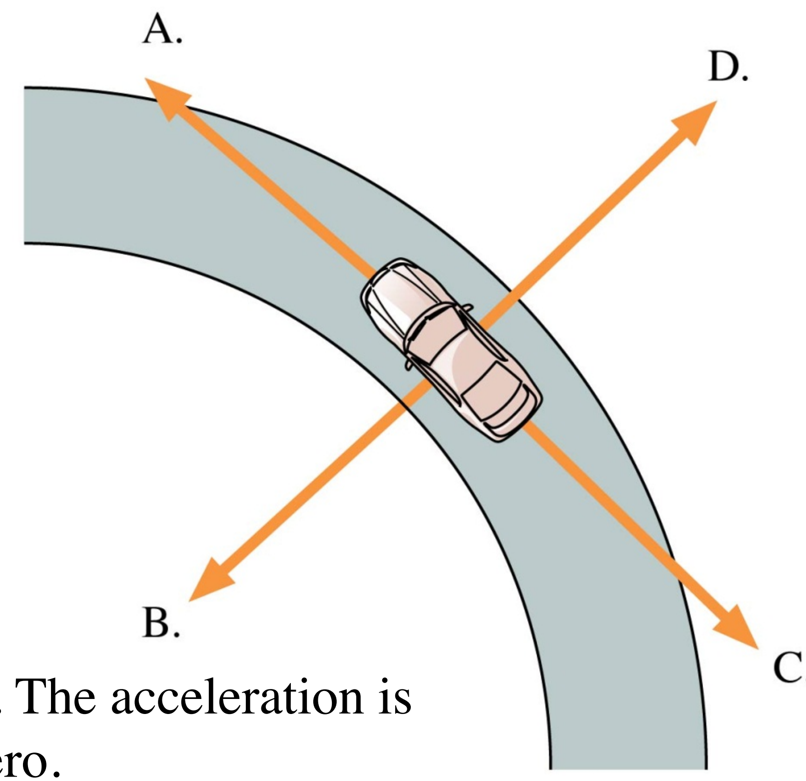
- HW#4 Due Friday at 5pm
- STUDY FOR MIDTERM!
- Extra Office Hours : Friday 3:30-4:30 pm 373 Physics (Laiho)

Clicker 4-2.1: A car is traveling around a curve at a steady 45 mph. Is the car accelerating?



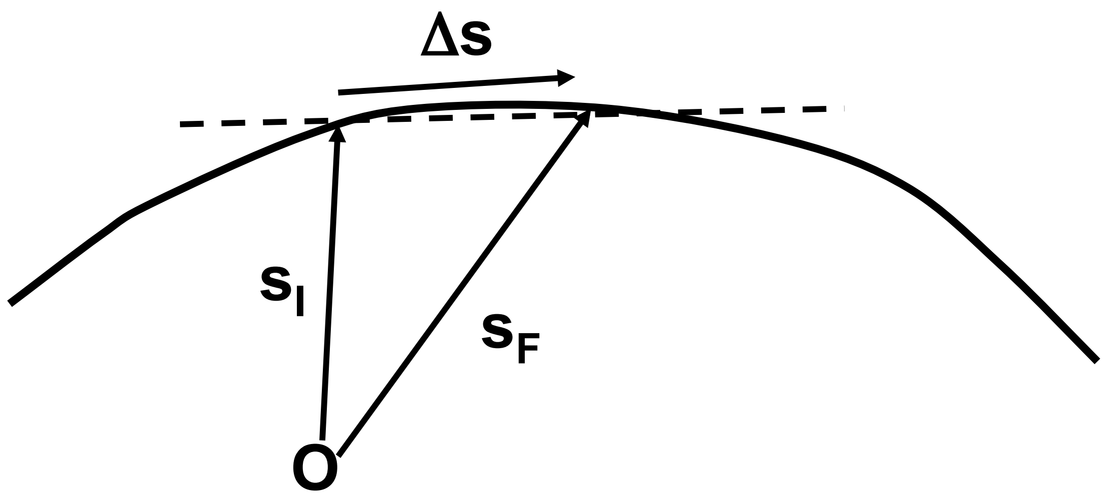
1. Yes
2. No

4-2.2: A car is traveling around a curve at a steady 45 mph. Which vector shows the direction of the car's acceleration?



E. The acceleration is zero.

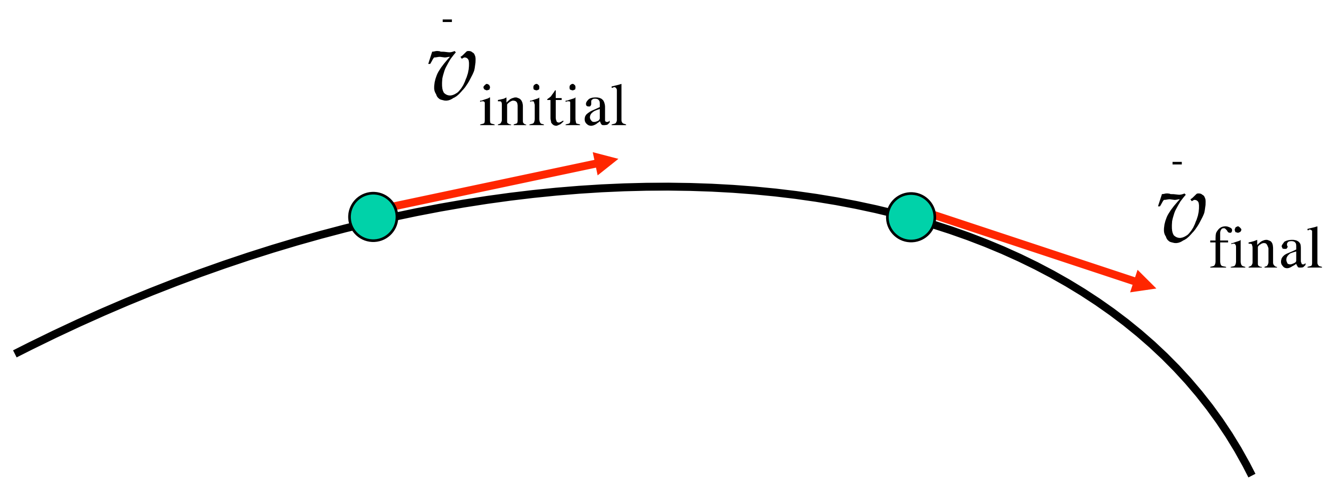
Velocity is tangent to path



v = Δs/Δt lies along dotted line. As Δt → 0 direction of v is tangent to path

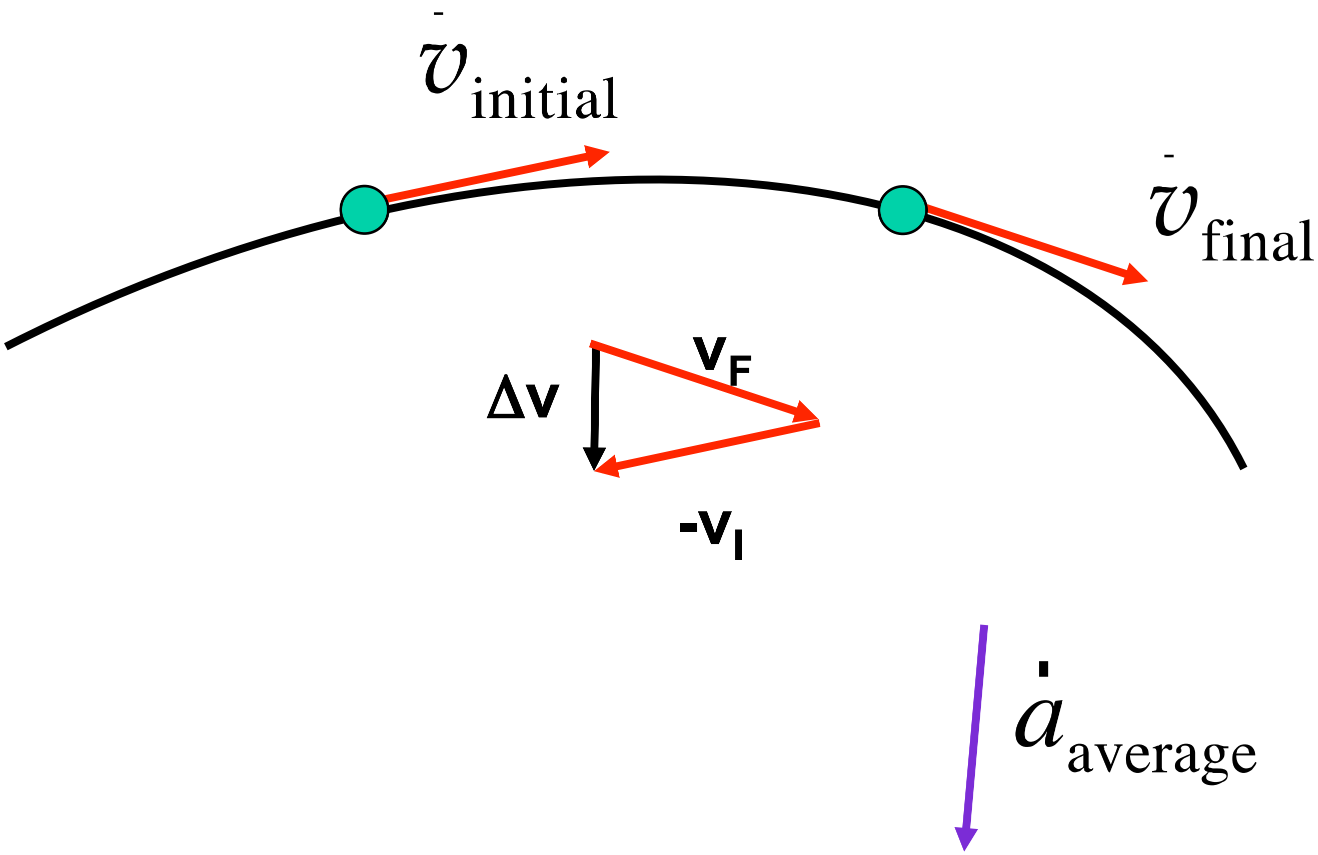
Dog on a string demo

Motion on a curved path at constant speed

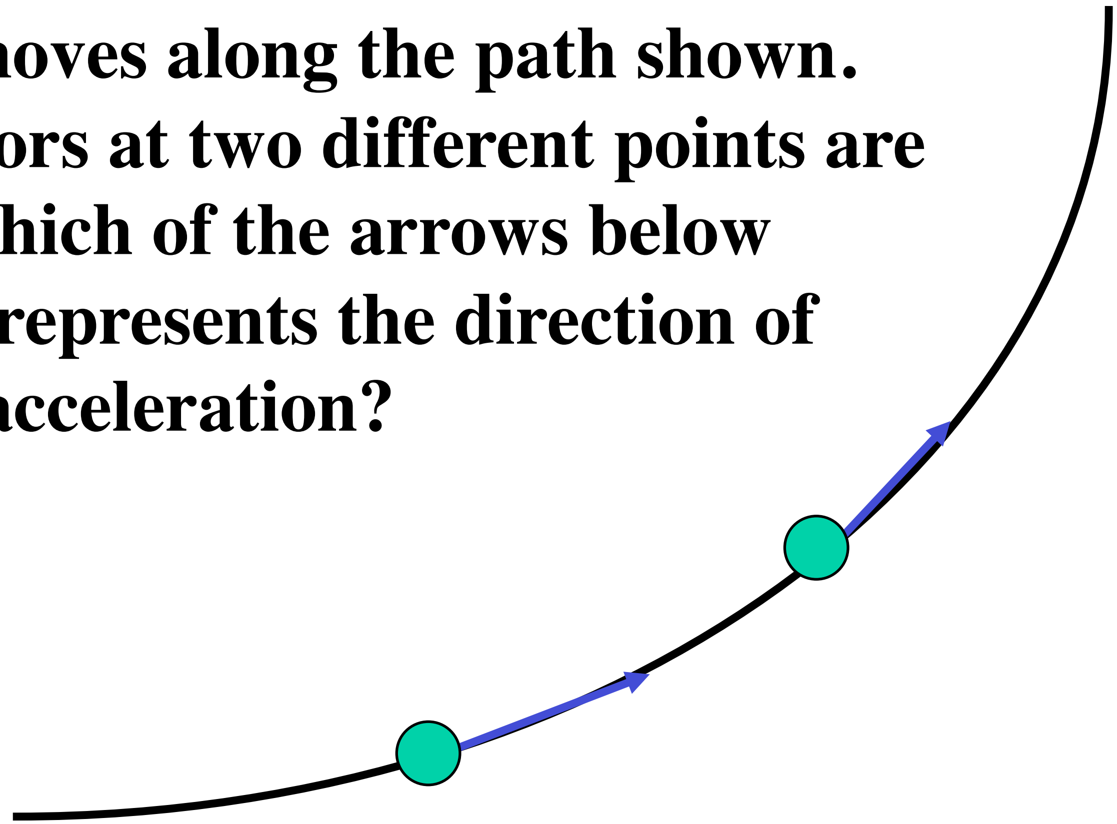


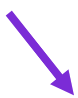
Is the acceleration of the object equal to zero?

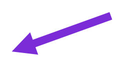
Motion on a curved path at constant speed

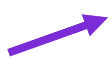


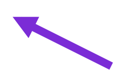
4-2. 3 A car moves along the path shown. Velocity vectors at two different points are sketched. Which of the arrows below most closely represents the direction of the average acceleration?



1. 

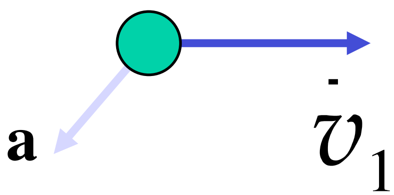
2. 

3. 

4. 

4-2.4 A child is riding a bicycle on a level street. The velocity and acceleration vectors of the child at a given time are shown.

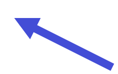
Which of the following velocity vectors may represent the velocity at a later time?



A.

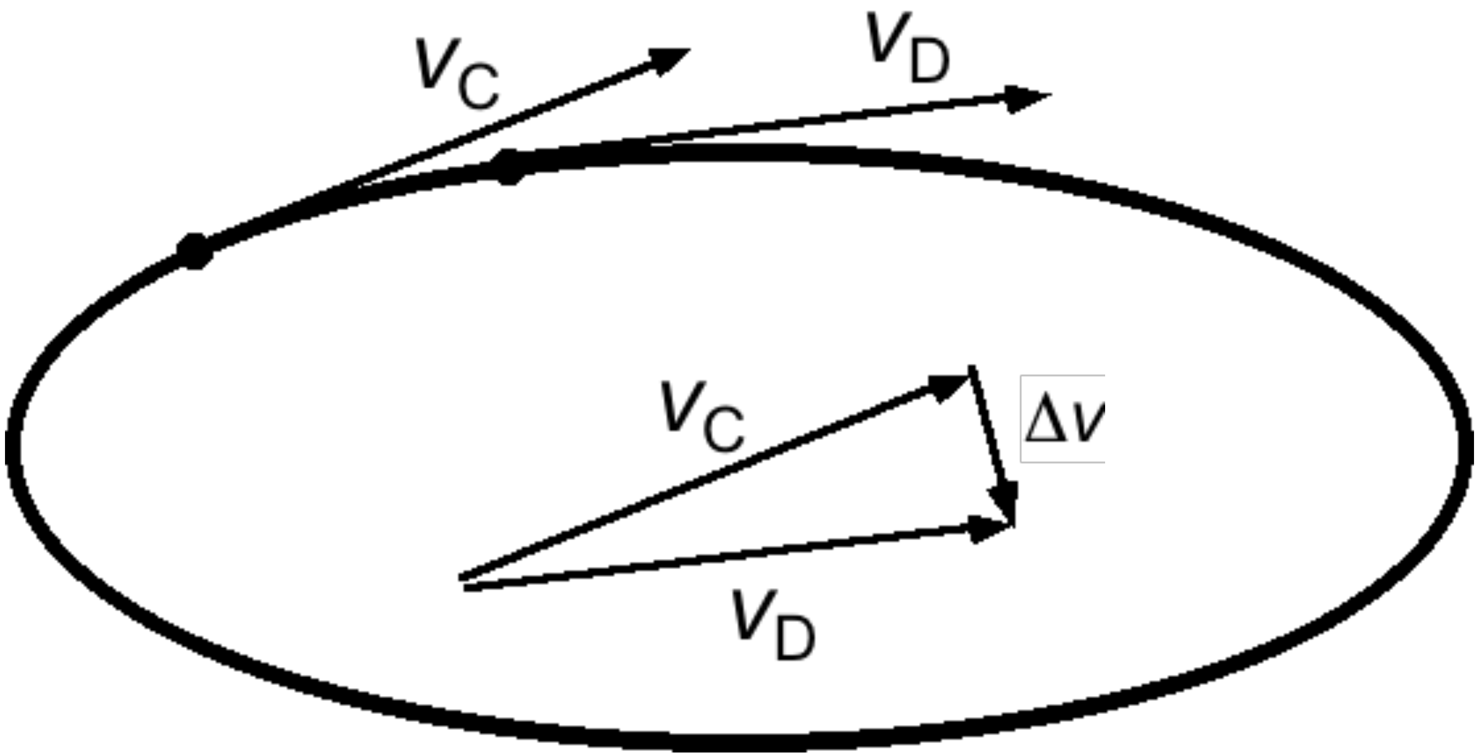
B.

C.



D.

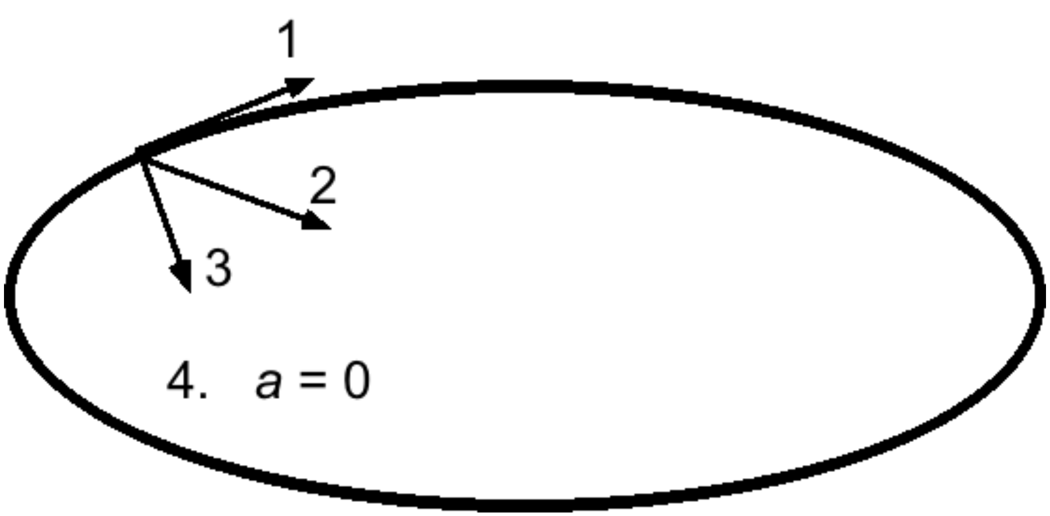
Biker moving around oval at *constant* speed



As point D *is moved closer to* C, *angle approaches 90°.*

4-2. 5 A biker is riding at constant speed clockwise on the oval track shown below.

Which vector correctly describes the *acceleration* at the point indicated?



Summary

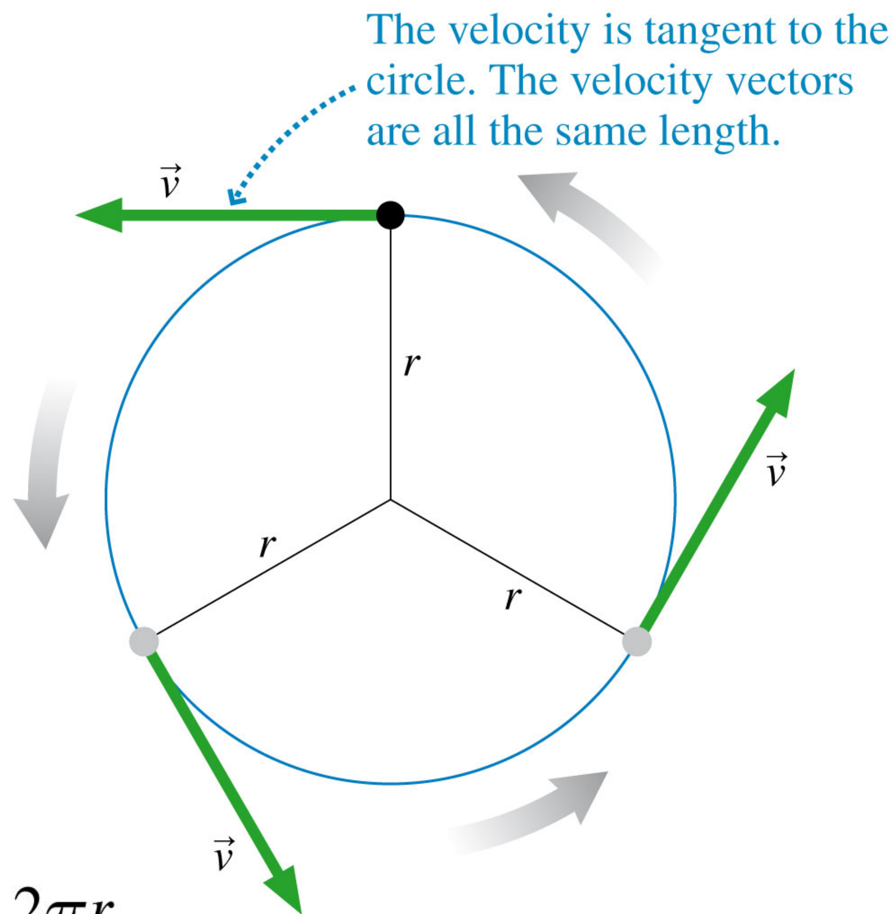
- For motion at constant speed, instantaneous acceleration vector is perpendicular to velocity vector
- Points ``inward’’
- What is the **magnitude** of the acceleration vector?

Circular Motion

- Consider a ball on a roulette wheel.
- It moves along a circular path of radius r.
- Other examples of circular motion are a satellite in an orbit or a ball on the end of a string.
- Circular motion is an example of two-dimensional motion in a plane.

Uniform Circular Motion

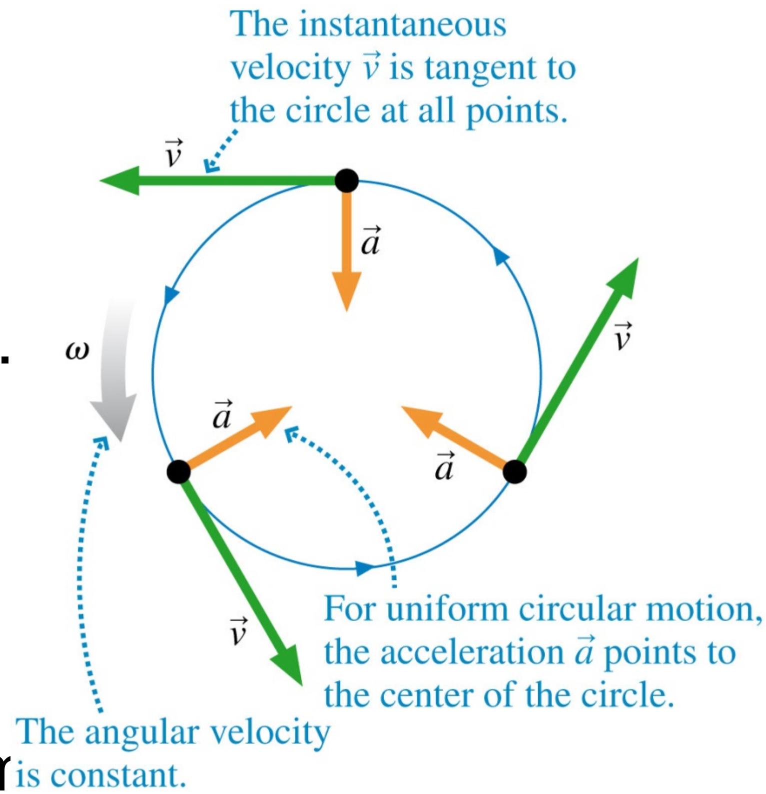
- particle that moves at *constant speed* around a circle of radius r.
- The time interval to complete one revolution is called the period, T.
- The period T is related to the speed v:



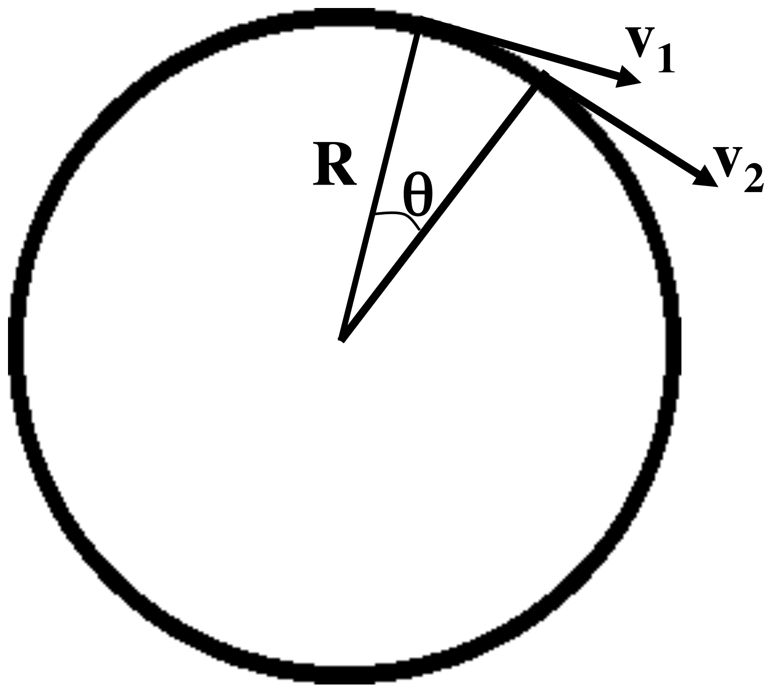
$$v = \frac{1 \text{ circumference}}{1 \text{ period}} = \frac{2\pi r}{T}$$

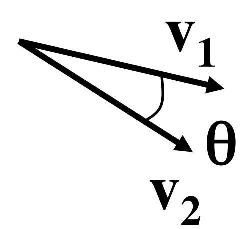
Centripetal Acceleration

- In uniform circular motion, although the speed is constant, there is a centripetal acceleration because the *direction* of the velocity vector is always changing.
- The direction of the centripetal acceleration is toward the center of the circle.
- The magnitude of the centripetal acceleration is constant for uniform circular motion.



Acceleration vectors for ball swung in a horizontal circle at *constant* speed v



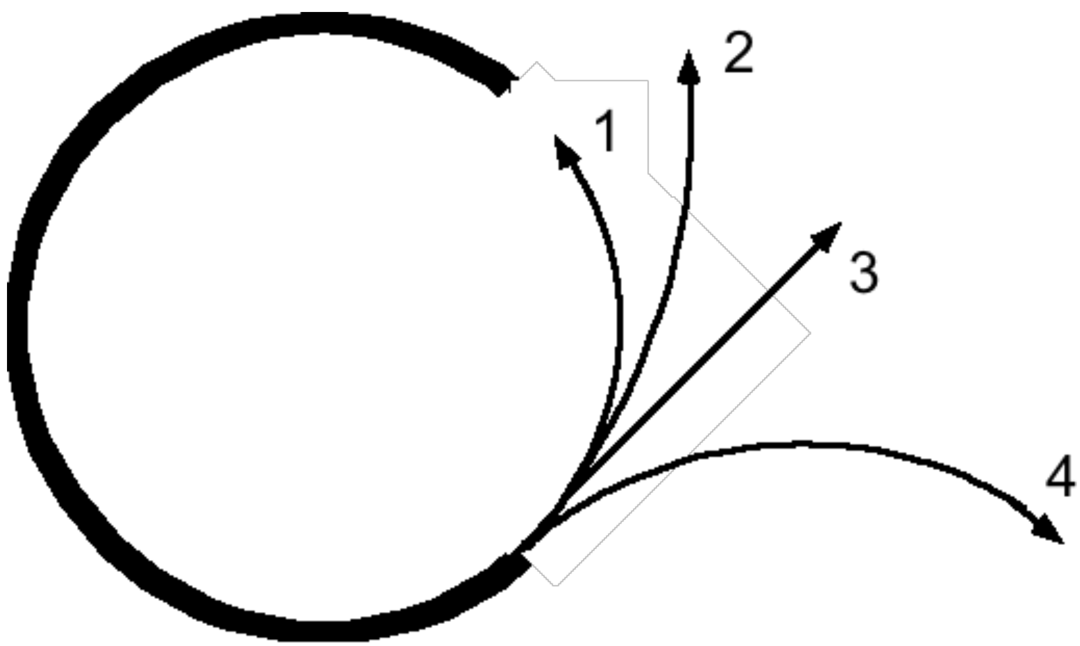


What is the magnitude of the acceleration?

$$|a| = v^2/R$$

4-2.6 A ball is rolling counter-clockwise at constant speed on a circular track. One quarter of the track is removed.

What path will the ball follow after reaching the end of the track?



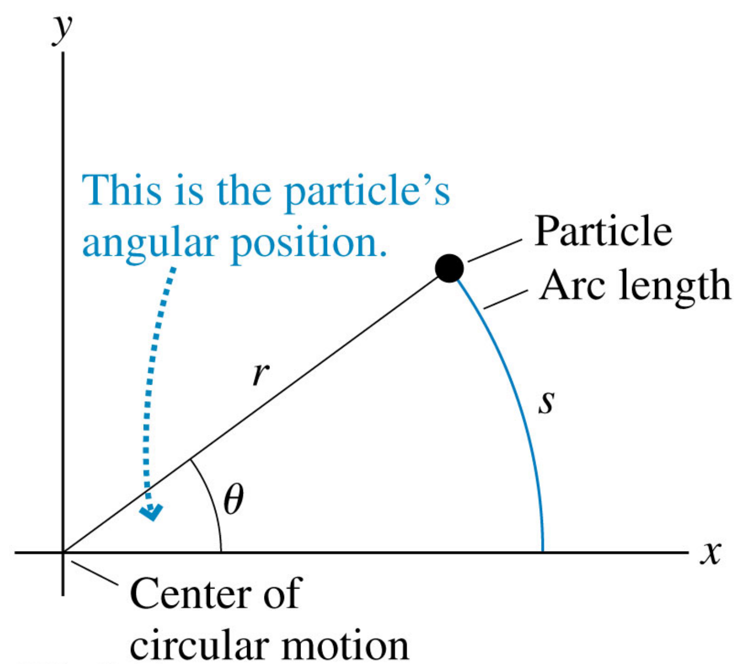
Angular Position

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

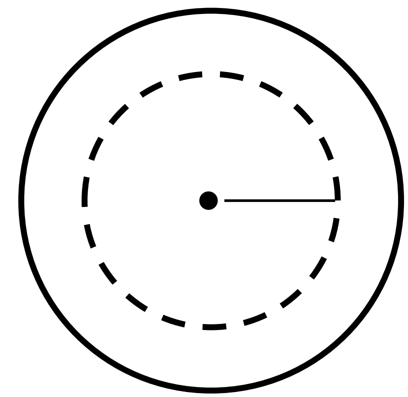
- Radians are the best! Because:

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

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



Rotations about fixed axis



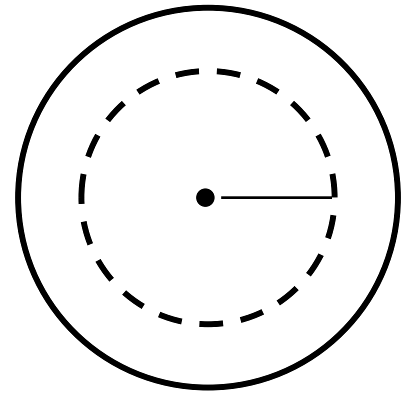
- Linear speed: $v = (2\pi r)/T = \omega\ r$. Quantity ω is called ***angular velocity***

- ω is a vector! Use right hand rule to find direction of ω.

- Angular acceleration $\alpha = \Delta\omega/\Delta t$ is also a vector!
  - ω and α *parallel* $\rightarrow$ angular speed increasing
  - ω and α *antiparallel* $\rightarrow$ angular speed decreasing

Relating linear and angular kinematics

- Linear speed: $v = (2\pi r)/T = \omega r$



- Tangential acceleration: $a_{tan} = r\alpha$
- Radial acceleration: $a_{rad} = v^2/r = \omega^2 r$

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

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

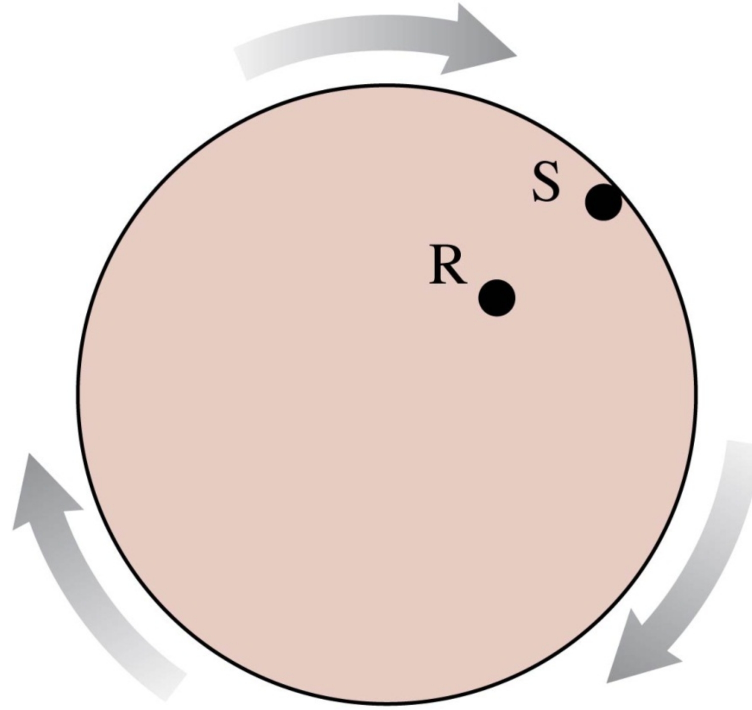
$$\omega^2 = \omega_0^2 + 2\alpha\Delta\theta$$

Sample problem

Taken directly from DIYelectriccar.com: I want to build an electric car that can go 60 mph. (This means that you want the edge of the tire to go 60 mph.) If my tires are 15” in diameter, how many rpms (revolutions per minute) must the motor be able to produce on the tire axels?

Clicker 4-2.7

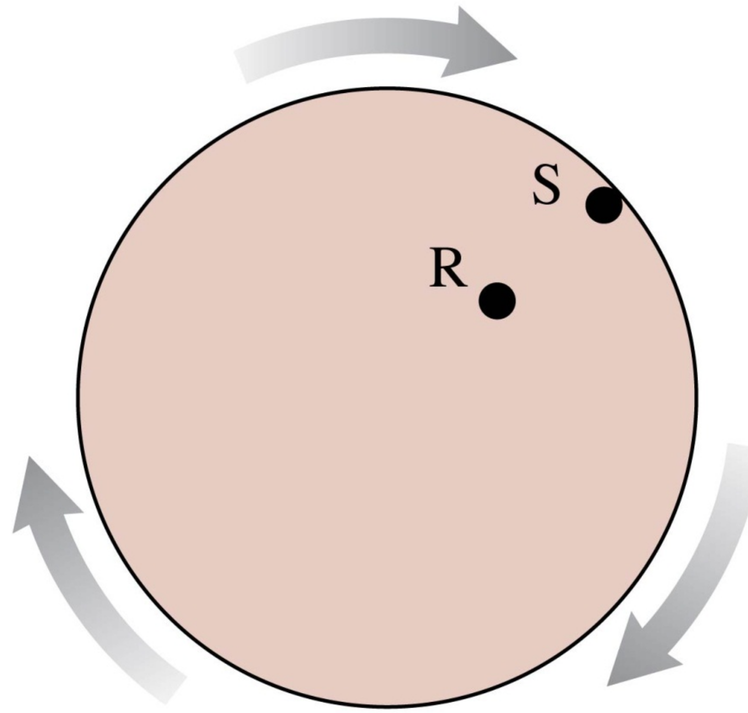
Rasheed and Sofia are riding a merry-go-round that is spinning steadily. Sofia is twice as far from the axis as is Rasheed. Sofia's angular velocity is ______ that of Rasheed.



1. half
2. the same as
3. twice
4. four times
5. We can't say without knowing their radii.

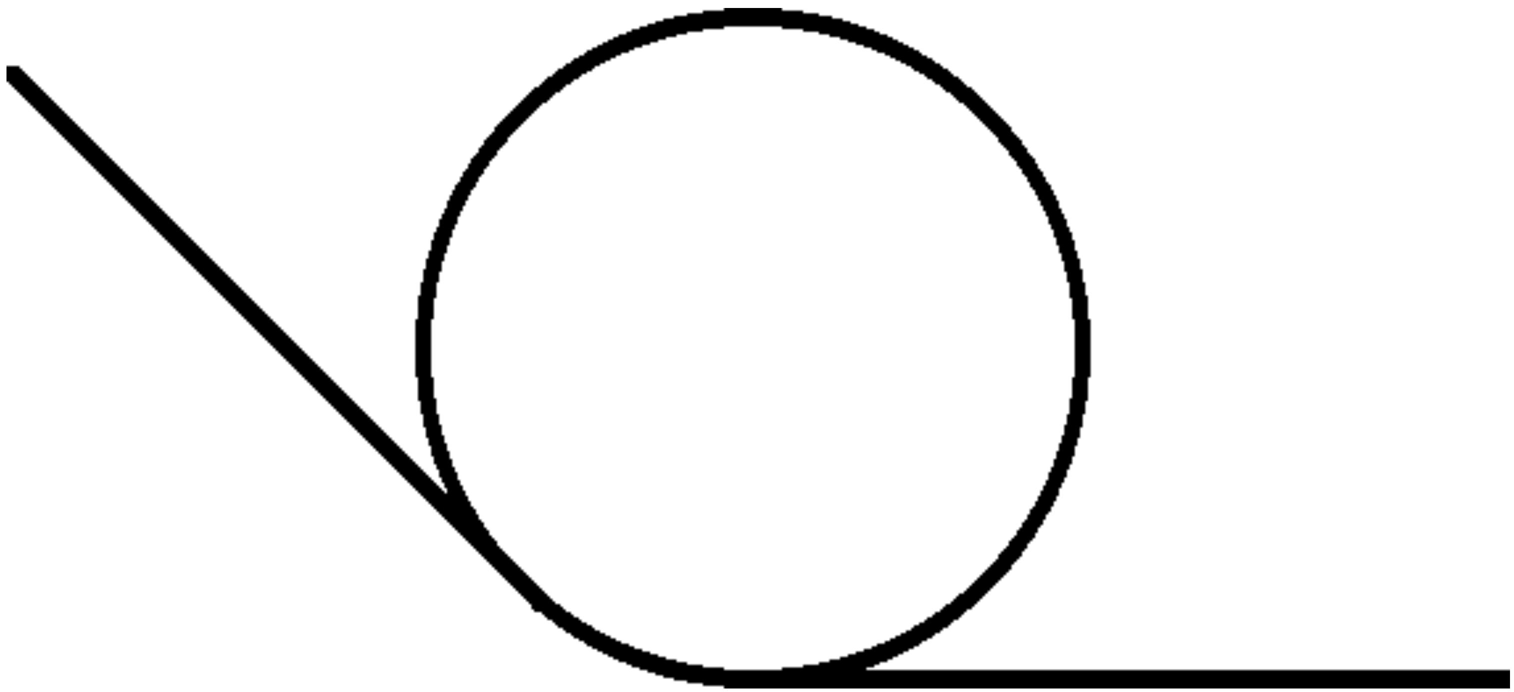
Clicker 4-2.8

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 velocity is ______ that of Rasheed.

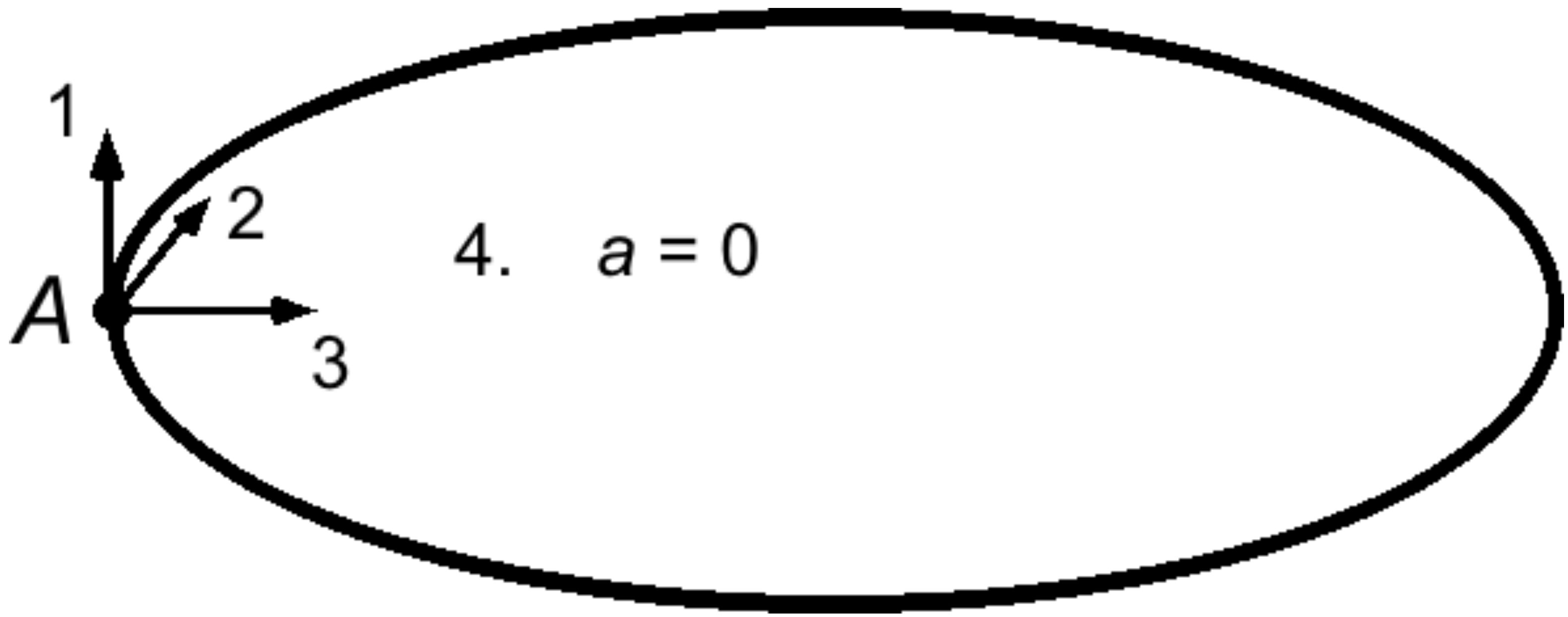


1. half
2. the same as
3. twice
4. four times
5. We can't say without knowing their radii.

Ball going through loop-the-loop



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*

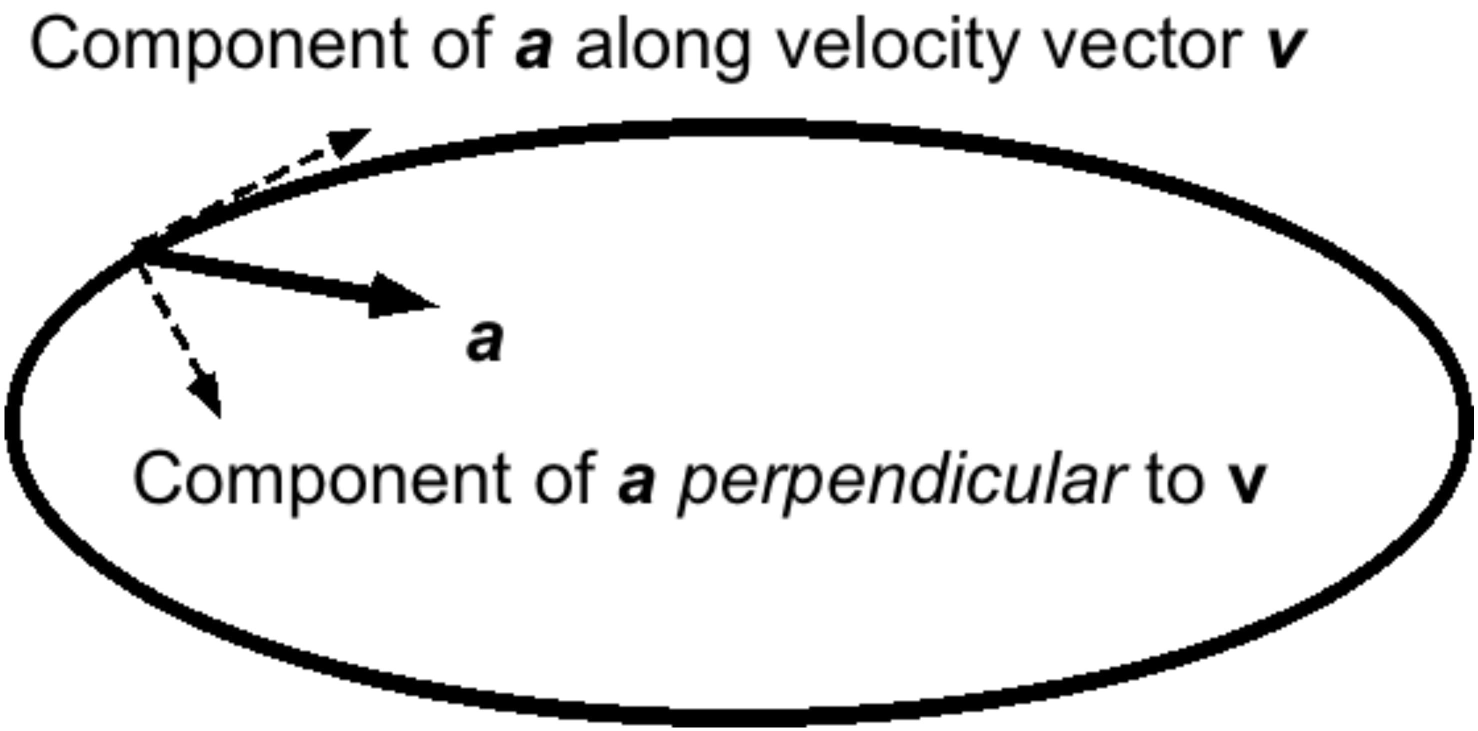
- Initially, $v^2/r = 0$, so no radial acceleration

- But a is not zero! It must be **parallel** to velocity

Acceleration vectors for object speeding up:

Tangential and radial components

(<u>or</u> parallel and perpendicular)



Sample problem

A Ferris wheel with diameter 14.0 m, which rotates counter-clockwise, is just starting up. At a given instant, a passenger on the rim of the wheel and passing through the lowest point of his circular motion is moving at 3.00 m/s and is gaining speed at a rate of 0.500 m/s^2. (a) Find the magnitude and the direction of the passenger's acceleration at this instant. (b) Sketch the Ferris wheel and passenger showing his velocity and acceleration vectors.

What is the magnitude of the acceleration of an object moving at *constant speed* if the path is curved but *not* a circle?

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

***"r"* is the *radius of curvature* of the path at a given point**

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?"

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 $\Delta \mathbf{x}$

Inertial Frames of Reference

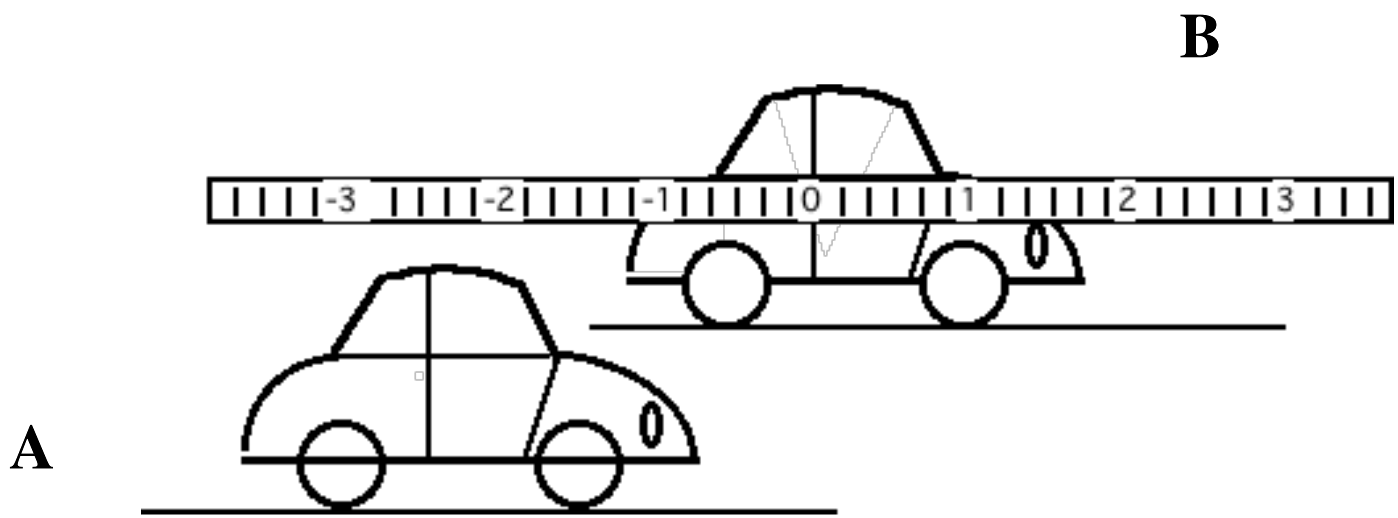
- Any system moving at a **constant velocity** has a nice "inertial frame of reference"
  - different frames will perceive velocities differently...
  - But accelerations are still the same
  - That's why things are still "nice"

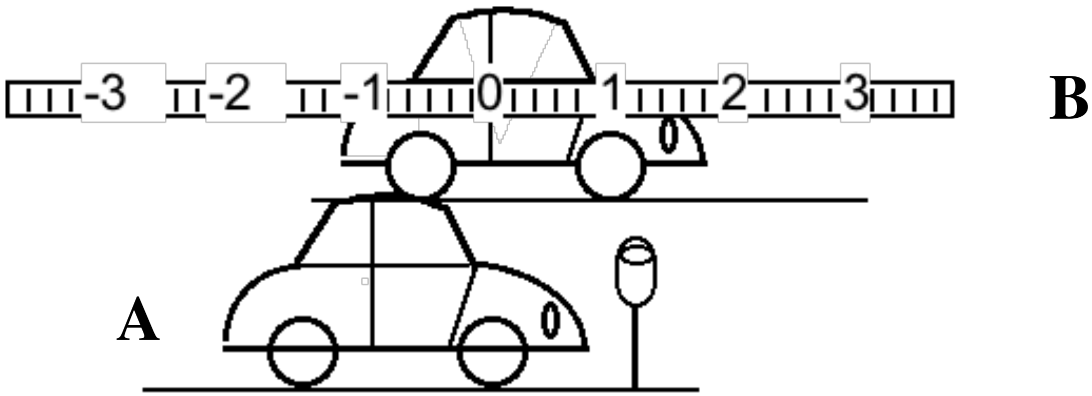
Why bother?

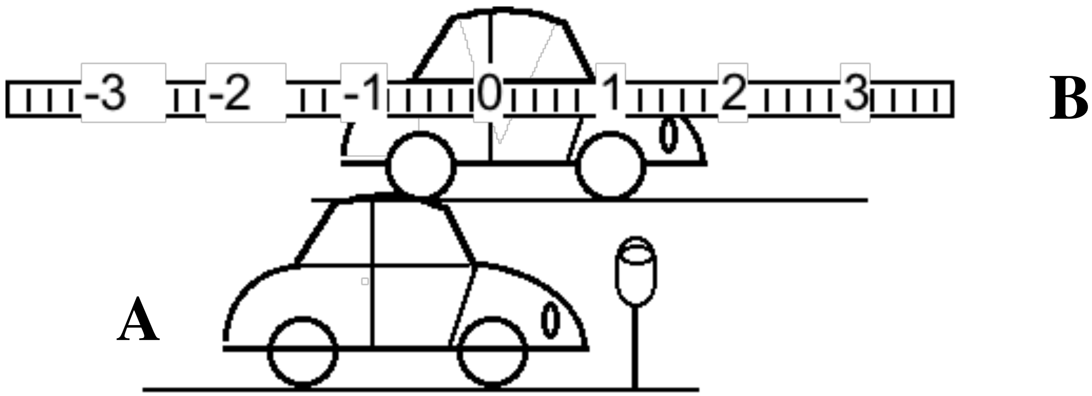
- Why would we want to use moving frames?
  - *Answer:* can **simplify** our analysis of the motion
- Have **no way in principle** of knowing whether any given frame is **at rest**
  - Stolkin is NOT at rest (as we have been assuming!)

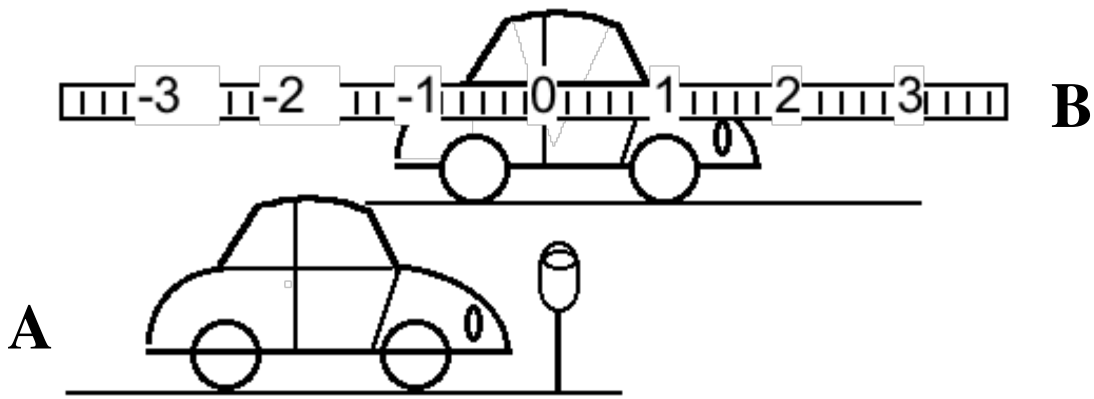
Reference frame

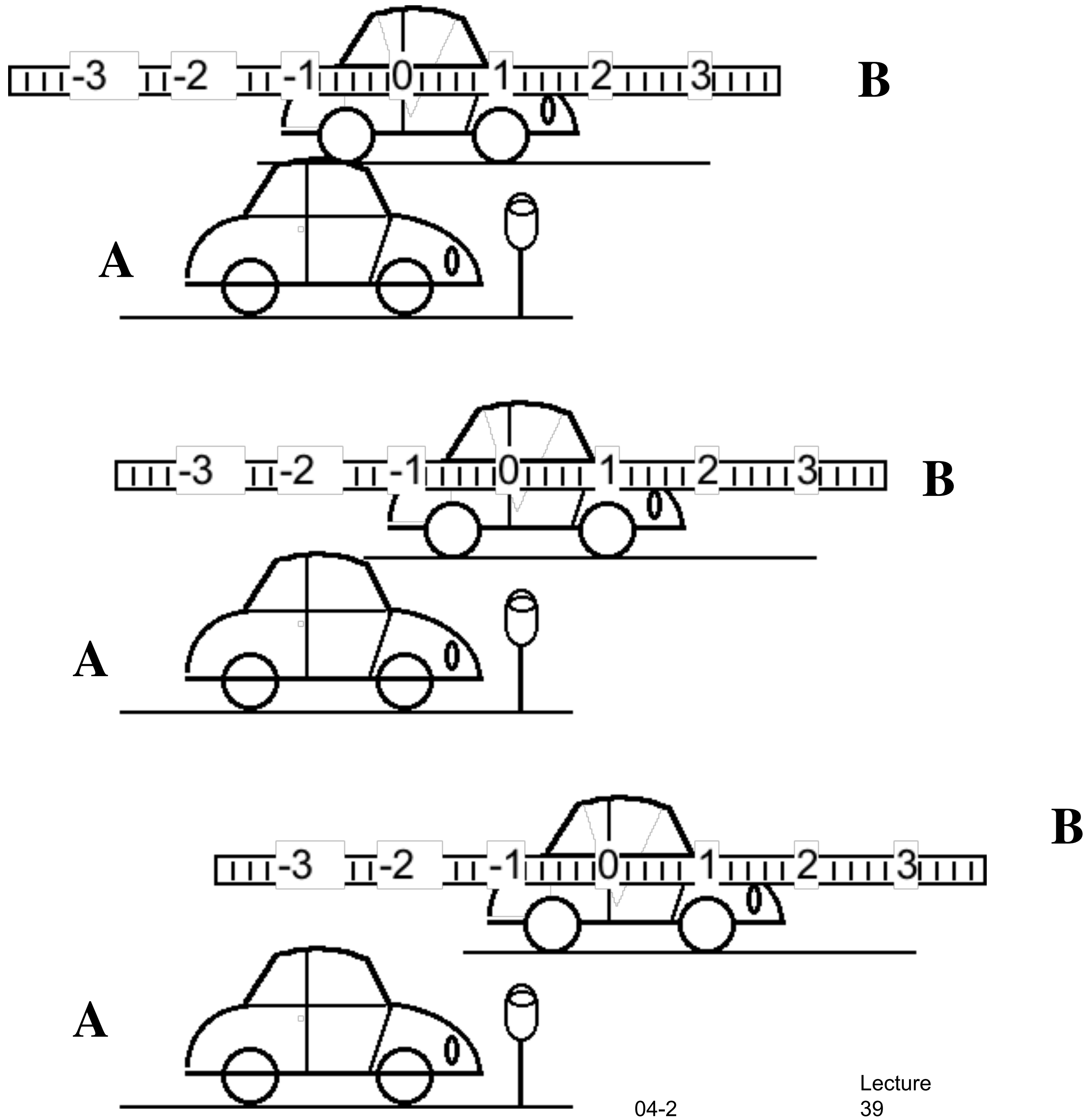
(clock, meterstick) carried along by moving object




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

Discussion

- A says: car B moves to right. v_{BA} is the velocity of B relative to A. So $v_{BA} > 0$

- B says: car A moves to left. So, $v_{AB} < 0$

- In general, can see that

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

Clicker 4-2.4: 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!)

1. 0.5 m/s
2. 0 m/s
3. -0.5 m/s
4. 1 m/s
5. None of the above

Clicker 4-2.5: 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!)

1. 0.5 m/s
2. 0 m/s
3. -0.5 m/s
4. 1 m/s
5. None of the above

Clicker 4-2.6: 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!)

1. -1.0 m/s
2. 0 m/s
3. -0.5 m/s
4. 1.0 m/s
5. None of the above

What’s more …

- Einstein developed **Special theory of relativity** to cover situations when velocities approach the speed of light

Clicker 4-2.7: 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

1. going East at constant speed
2. going West at constant speed,
3. going East and slowing down,
4. 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

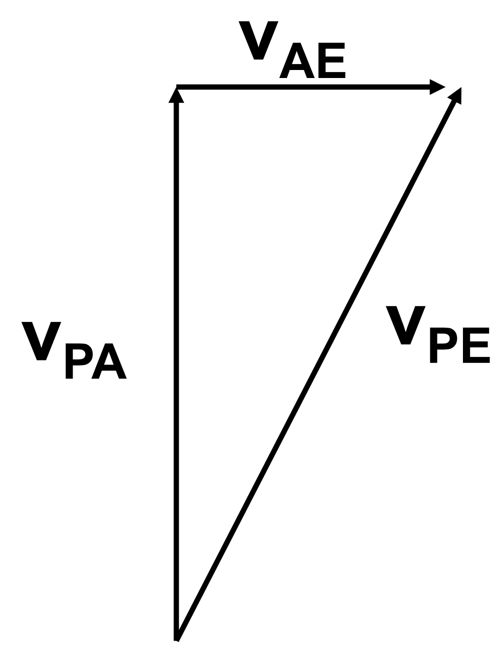
- However **constant velocity** motions are always seen as **constant velocity**

- 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, $\mathbf{v}_{PE}$?

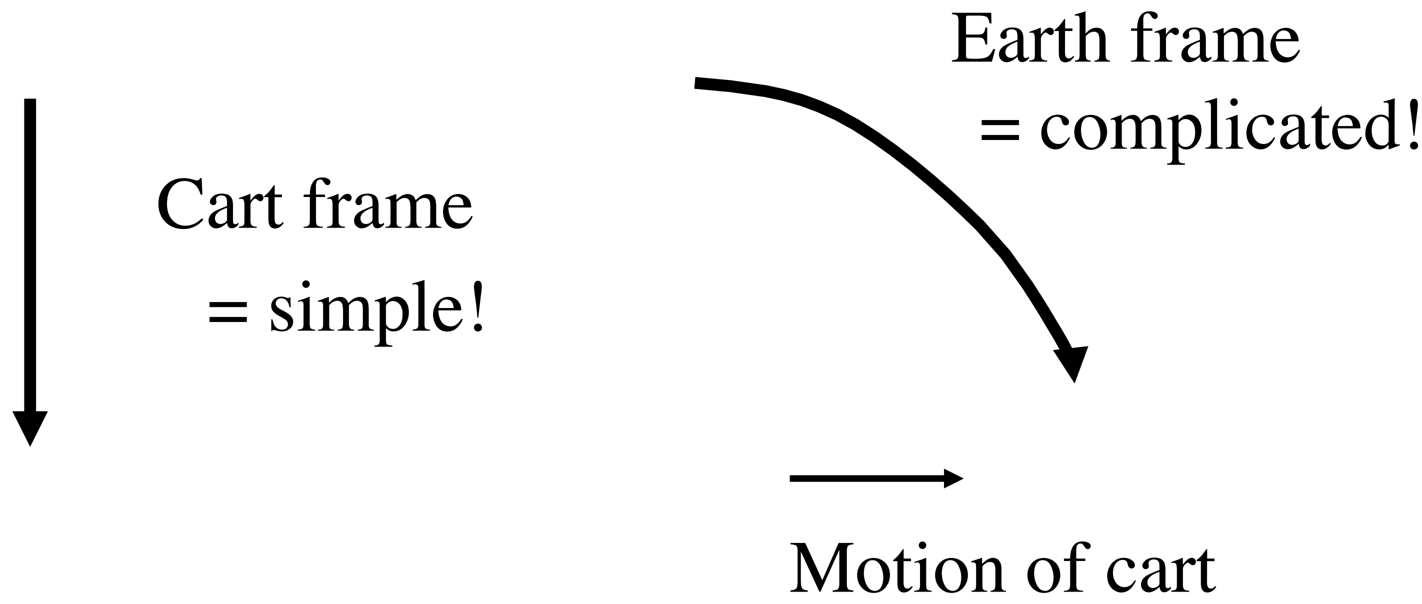
$$\mathbf{v}_{PE} = \mathbf{v}_{PA} + \mathbf{v}_{AE}$$



Sample Problem: While standing still, Otto shoots a basketball into the air at 4 m/s with a launch angle of 30 degrees. Just as he is shooting, a cameraman rolls by in a car moving at 2 m/s (along the x-axis). What is the apparent launch angle in the frame of the camera?

Relative Motion in 2D

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



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!

Physical Laws

- Since all FOR agree on the *acceleration* of object, they all agree on the *forces* that act on that object

- All such FOR are equally good for discovering the laws of mechanics

Forces

- are interactions between ***two*** objects (*i.e.,* a push or pull of one object on another)
- can be broadly categorized as *contact* or *non-contact* forces
- have a *direction* and a *magnitude* -- **vectors**
- can be used to *predict* and *explain* the motion of objects
- described by *Newton's Laws of Motion*

Examples

- Pushing table
  - contact, magnitude, motion…
- Magnet on a pivot
  - non-contact
- Mass on a spring
  - dependence on displacement from eqm...
- Pulling heavy object with two ropes
  - force is vector …

Types of forces

<u>*Contact* forces</u>

- *normal*
- *frictional*
- *tension*

<u>*Non-contact* forces</u>

- gravitational
- *electric*
- *magnetic*

4-2.8: A hovercraft puck is a plastic disk with a built-in ventilator that blows air out of the bottom of the puck. The stream of air lifts up the puck and allows it to glide with negligible friction and at (almost) constant speed on any level surface.

After the puck has left the instructor's hands the *horizontal* forces on the puck are:

1. the force of the motion.
2. the force of inertia.
3. the force of the motion and the force of inertia.
4. Neglecting friction and air drag, there are no horizontal forces.

Newton's *First* law
(Law of inertia)

In the absence of a net external force, an object at rest remains at rest, and an object in motion continues in motion with constant velocity (i.e., constant speed and direction).

Remarks

- Compatible with principle of relativity
  - All FOR moving with constant velocity will agree that no forces act
- Since forces are vectors, this statement can be applied to any components -- *(x, y, z)* separately
- Only **net** force required to be zero…

4-2.9: A locomotive is pulling a long freight train at ***constant speed*** on straight tracks***.*** The horizontal forces on the train cars are as follows:

1. No horizontal forces at all.
2. Only a “pull” by the locomotive.
3. A “pull” by the locomotive and a friction force of equal magnitude and opposite direction.
4. A “pull” by the locomotive and a somewhat smaller friction force in the opposite direction.

Common forces
1. Weight

- Gravitational force (weight)
  – Universal force of attraction between 2 massive bodies

  – For object near earth's surface directed "downward" with magnitude mg

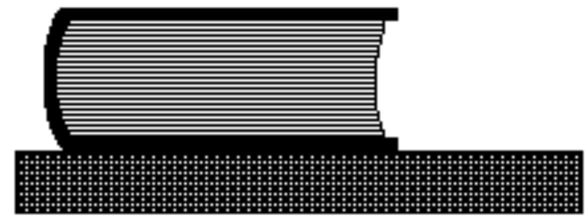
  – Notation: W_{BE}

Common forces
2. Normal forces

- Two objects A, B touch → exert a force at 90^o to surface of contact

- Notation: N_{AB} is normal force on A due to B

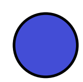
4-2.10 A book is at rest on a table. Which of the following statements is correct? The vertical forces exerted **on the book** (and their respective directions) are



1. A weight force (down) only.
2. A weight force (down) and another force (up).
3. A weight force (down) and two other forces (one up and one down).
4. There is no force exerted on the book; the book just exerts a force on the table (which is downward).

Free-body diagram for book on table

- To solve problem introduce idea of **free body diagram**
- Show all forces exerted ***on*** the book.
- Do ***not*** show forces exerted ***by*** the book on anything else.



Remarks on free-body diagram for book

- Use point to represent object
- On earth, there will always be weight force (downwards, magnitude = mg)
- Since **not** accelerating, must be upward force also – N_{BT} normal force on book due to table
- No net force → $|N_{BT}| = mg$

Newton's *Second Law*

Second Law:

$$\boldsymbol{F}_{\text{on object}} = m\, \boldsymbol{a}_{\text{of object}}$$

where $\boldsymbol{F}_{\text{net}}$ is the vector sum of all *external* forces on the object considered

- m = (inertial) mass
- Acceleration measured relative to inertial FOR.

Newton's *Third law*

- Forces always occur in relation to pairs of objects.

- If A exerts some force on B, then B will exert a force back on A which is equal in magnitude but opposite in direction

Notation

- Force on A due to B = $\mathbf{F}_{AB}$
- Force on B due to A = $\mathbf{F}_{BA}$
- 3rd law states:

$$\mathbf{F}_{AB} = -\mathbf{F}_{BA}$$

- $\mathbf{F}_{AB}$ and $\mathbf{F}_{BA}$ referred to as 3rd law pair