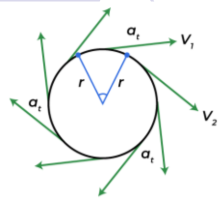
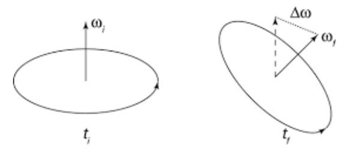
3 Types of Acceleration

- **Tc = tangential acceleration**
  - $a_T = r\alpha$
  - Units – m/s^2



- **α = angular acceleration**
  - $\alpha = \frac{\Delta\omega}{\Delta t}$
  - Units – rad/s^2

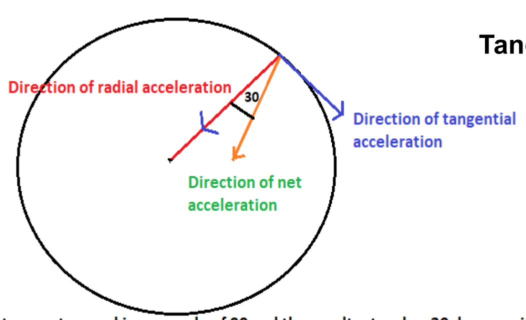


$$\alpha = \frac{\omega_f - \omega_i}{t_f - t_i} = \frac{\Delta\omega}{\Delta t}$$

- **a_c = Centripetal acceleration**
  - $a_c = \frac{v^2}{r} = r\omega^2$
  - Units – m/s^2

Tangential Acceleration

- **Tangential acceleration, a_T**
  - Results from changing the speed of rotation
  - The linear and tangential accelerations are the same but in the tangential direction, which leads to the circular motion.



Tangential Velocity

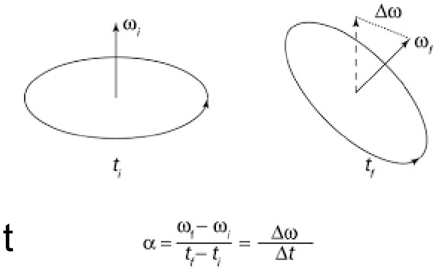
$$V_T = \frac{\Delta s}{\Delta t} = \frac{r\Delta\emptyset}{\Delta t} = r\,\omega$$

Units – rpm or m/s

So,we have two vectors,making an angle of 90 and the resultant makes 30 degree with one of them.

Angular acceleration, **α**

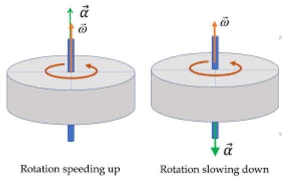
- Also called rotational acceleration
- the change in angular velocity that a spinning object undergoes per unit time

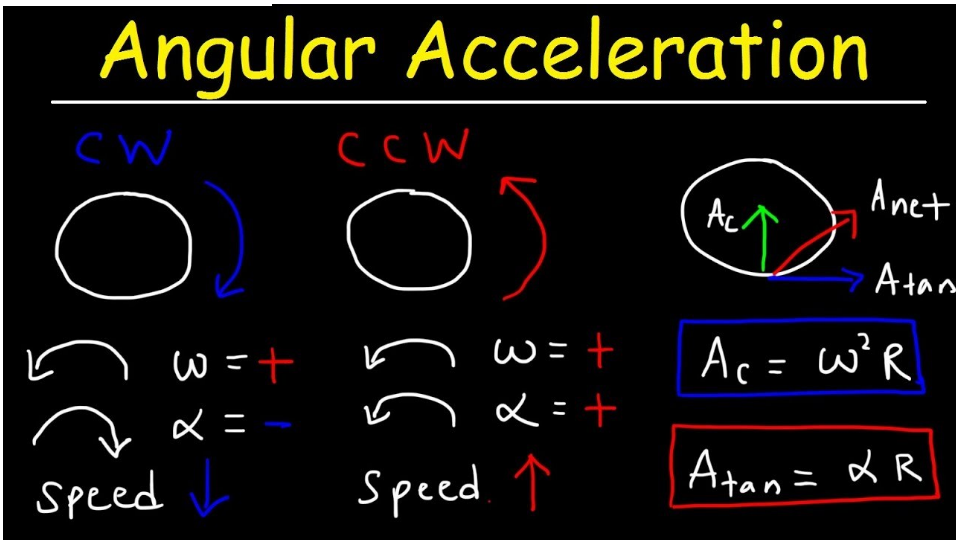


- **α = angular acceleration**
  - $\alpha = \frac{\Delta\omega}{\Delta t}$
  - Units – rad/s^2

Angular Acceleration - Examples

- Angular velocity is not constant when a skater pulls in her arms, when a child starts up a merry-go-round from rest, or when a computer's hard disk slows to a halt when switched off.
- In all these cases, there is an ***angular acceleration***, in which ω changes. The faster the change occurs, the greater the angular acceleration.





Angular vs Tangential acceleration

- **Angular acceleration, α**, is the change in angular velocity divided by time $\alpha = \frac{\Delta\omega}{\Delta t}$
- While **Tangential acceleration** is the change in linear velocity divided by time.
- **Angular acceleration does not change with radius**, but **tangential acceleration does**.
- These equations mean that linear acceleration and angular acceleration are directly proportional. The greater the angular acceleration is, the larger the linear (tangential) acceleration is, and vice versa.

Centripetal Acceleration

CENTRIPETAL ACCELERATION

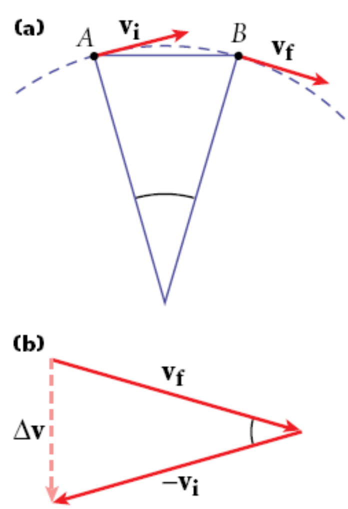
$$a_c = \frac{v_t^2}{r}$$

$$\text{centripetal acceleration} = \frac{(\text{tangential speed})^2}{\text{radius of circular path}}$$

- An object, in circular motion, with a constant speed, will there be acceleration?
  - Yes: acceleration is vector (both magnitude and direction) and the direction is constantly changing
- An acceleration of this nature is called **centripetal acceleration**
  - **Term that describes a change in speed of an object in circular motion**
  - Which results from change in direction
  - Example: car on circular track, constant speed, but changing direction = centripetal acceleration

Centripetal acceleration - Cont

- (a) As the particle moves from *A* to *B*, the direction of the particle's velocity vector changes.
- (b) For short time intervals, **Δv is directed toward the center of the circle.**
- **Centripetal acceleration is always directed toward the center of a circle.**



Centripetal acceleration - Cont

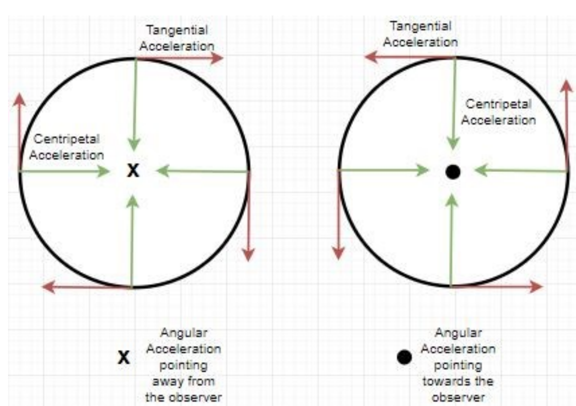
- You have seen that **centripetal acceleration** results from a **change in direction.**

- In circular motion, an acceleration due to a **change in speed** is called **tangential acceleration.**

- To understand the difference between centripetal and tangential acceleration, consider a car traveling in a circular track.
  - Because the car is moving in a circle, the car has a **centripetal** component of acceleration.
  - If the car's speed changes, the car also has a **tangential** component of acceleration.

Tangential vs Centripetal Acceleration

- One of the key differences between centripetal acceleration and tangential acceleration:
- **Centripetal acceleration** is the radial component of the net acceleration
- **tangential acceleration** is the tangential component of the net acceleration acting on the object moving in a circular direction.



Angular vs Centripetal Acceleration

- Is angular acceleration same as centripetal acceleration?
  - They cannot be the same thing because they have different units.
  - Centripetal acceleration $a_c = v^2/R = \omega^2 R$
    - units of m/s^2,
  - while angular acceleration $\alpha = \frac{\Delta\omega}{\Delta t}$
    - units of radian/s^2

What is the *minimum* centripetal acceleration the coaster needs *(at the top)* so that people don't fall out?

9.8 m/s^2

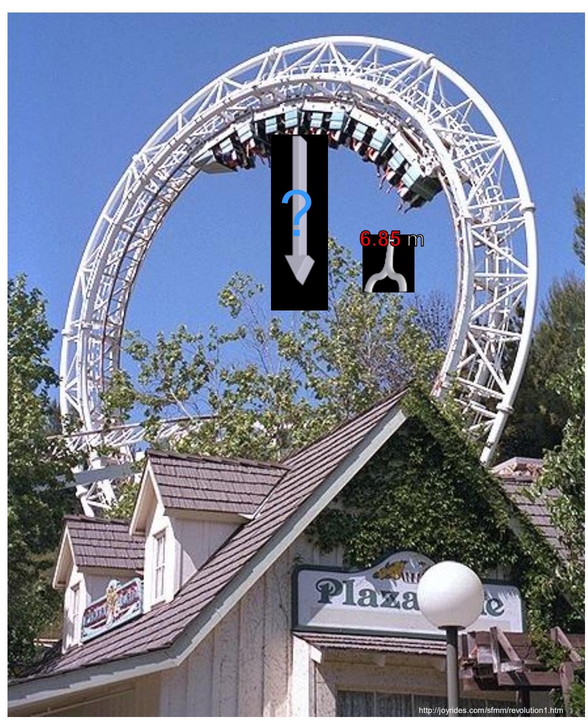
What is the minimum tangential velocity?

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

$$9.8 = \frac{v^2}{6.85}$$

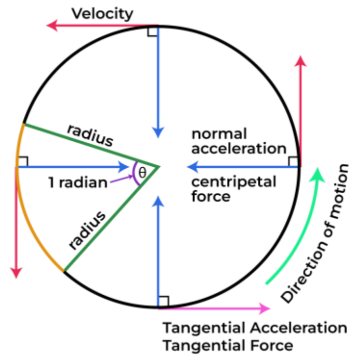
$$v = 8.2\ m/s$$

$$v = 18\, mi/hr$$



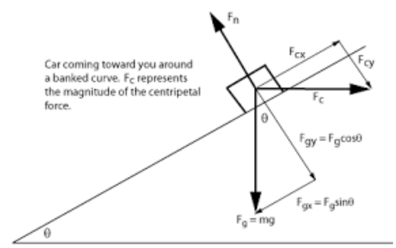
Centripetal Force

- **Centripetal force (F_c)** is a force that makes a body follow a curved path
  - Without a centripetal force, an object in motion continues along a straight-line path.
  - With a centripetal force, an object in motion will be accelerated and change its direction



- Centripetal force is directed **toward the center** of the circle

- Centripetal force is simply the name given to the **net force** on an object in uniform circular motion

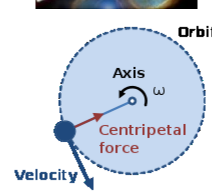


Centripetal Force

- Any type of force or combination of forces can provide this Centripetal force (net force)
  - **Example:** **Friction** between a race car's tires and circular track is a centripetal force that keeps the car in a circular path

  - **Example:** **Gravitational force** is a centripetal force that keeps the moon in its orbit

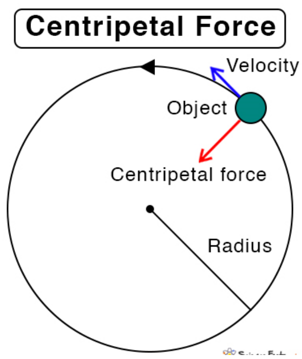
  - **Example:** A mass on a **string** being whirled in a horizontal circular path. The string is the centripetal force



Analyzing motion in a circle

Centripetal Force

“Centripetal” means “toward the center” - centripetal force and centripetal acceleration are a necessary part of circular motion



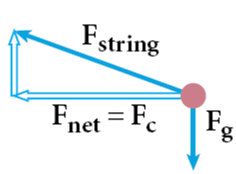
Many things people see or experience as “centrifugal force” are **inertia** - and a centripetal force that isn’t big enough to create uniform circular motion

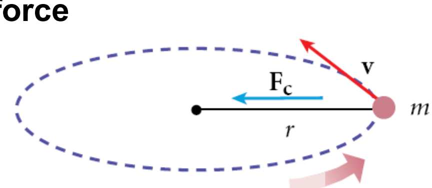
For example, when turning in your car you slide on your seat toward the outside of the curve - there’s no force toward the outside - there just isn’t enough frictional force to give you the same centripetal acceleration that the car has

Definition:
Centripetal – Center seeking
Centrifugal – Misconception “center fleeing” - Centrifugal is a fictious acceleration present in a rotating frame of reference

Centripetal Forces

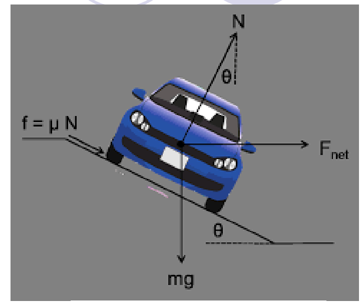
- Consider a ball of **mass *m*** that is being whirled in a horizontal circular path of **radius *r*** with constant speed
- The force exerted by the string has horizontal and vertical components. The **vertical** component is equal and opposite to the **gravitational force**. Thus, the **horizontal component** is the **net force.**
- This net force, which is is directed toward the center of the circle, is a **centripetal force**

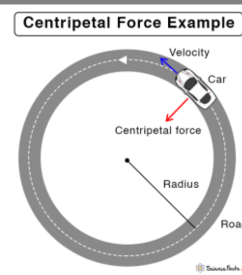




Centripetal Forces continued

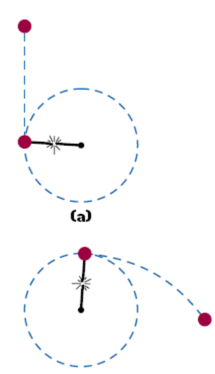
- **Centripetal force** is simply the name given to the **net force** on an object in uniform circular motion.
- **Any type of force or combination of forces can provide this net force.**
  - For example, **friction** between a race car's tires and a circular track is a centripetal force that keeps the car in a circular path.
  - As another example, **gravitational force** is a centripetal force that keeps the moon in its orbit.





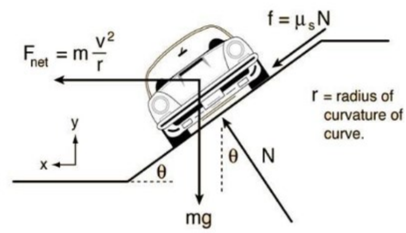
Centripetal Forces continued

- If the centripetal force vanishes, the object stops moving in a circular path.
- A ball that is on the end of a string is whirled in a vertical circular path.
  - *If the string breaks at the position shown in **(a)**, the ball will move vertically upward in free fall.*
  - *If the string breaks at the top of the ball's path, as in **(b)**, the ball will move along a parabolic path.*



Centripetal Forces continued

- Newton's second law can be combined with the equation for centripetal acceleration to derive an equation for centripetal force:



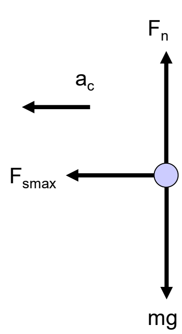
$$a_c = \frac{v_t^2}{r}$$

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

$$\text{centripetal force} = \frac{\text{mass} \times (\text{tangential speed})^2}{\text{radius of circular path}}$$

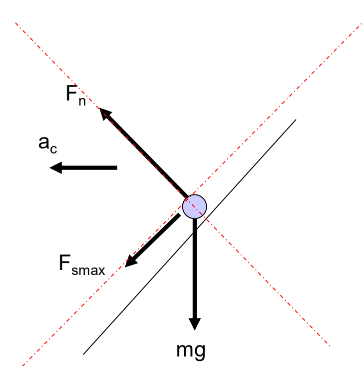
2 Types of Car problems – Fs usually used to find max V_t

- On a flat curve
  - F_{smax} keeps car from sliding off road

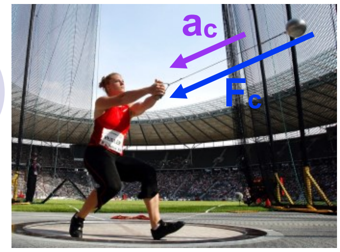


What force keeps the car in the curve without slipping? **Static Friction**

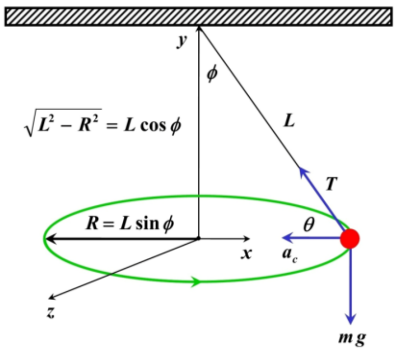
- On a banked curve



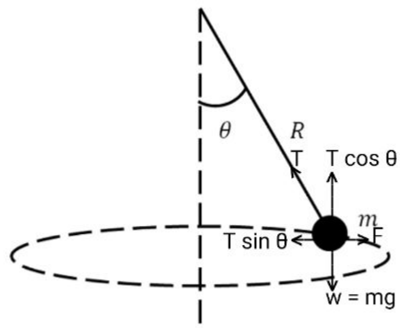
What keeps the car in the curve in this diagram? **both static friction <u>and</u> the normal force**



- **Centripetal Force**
  - **F = ma**
    - $a_c = \frac{v_t^2}{r} = r\omega^2$
  - **F = m** $\frac{v_t^2}{r}$
  - **F= m** $r\omega^2$



Conical Pendulum =>Tetherball



Forces causing circular motion (centripetal force)

Newton's 2nd Law tells us that all accelerations must be caused by a net force

If an object is in uniform circular motion, it has a centripetal acceleration, which must be caused by a net force.

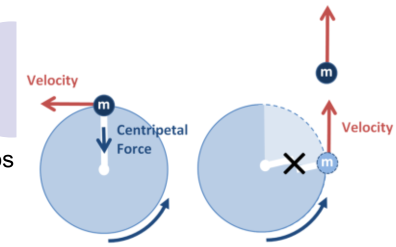
In circular motion, we call this net force "centripetal force". Using Newton's 2nd Law:

$$F_c = ma_c = mv^2/r$$

It's important to remember that "Centripetal force" isn't a new force - it's a title that we give to whatever creates the net force that causes circular motion.

For instance, orbits are caused by gravity - the centripetal force on the moon is caused by the force of gravity between the moon and the Earth

Centripetal Force



- If the centripetal force vanishes, the object stops moving in a circular path
  - Inertia will cause the object to move in a direction tangent to the path

- Newton's 2[nd] law combined with centripetal acceleration forms an equation for **centripetal force**

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

$$F = \frac{mv^2}{r} = m\omega^2 r$$

$$\text{centripetal force} = \frac{\text{mass} \times (\text{tangential speed})^2}{\text{radius of circular path}}$$

Find the Tension in the cable.

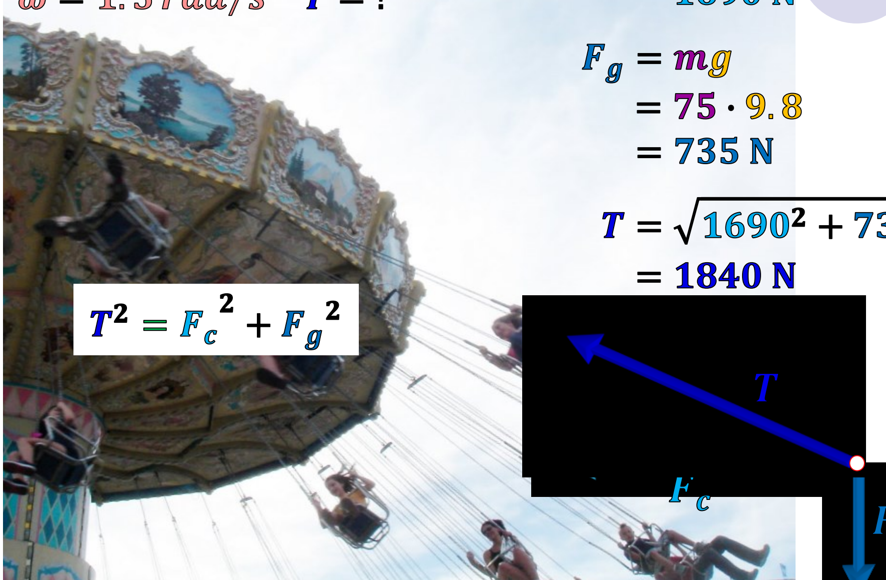
$r = 10.0\ m$ $\quad m = 75\ kg$

$\omega = 1.5\ rad/s$ $\quad T = ?$

$$F_c = mr\omega^2 = 75 \cdot 10.0 \cdot 1.5^2 = 1690\ \text{N}$$

$$F_g = mg = 75 \cdot 9.8 = 735\ \text{N}$$

$$T = \sqrt{1690^2 + 735^2} = 1840\ \text{N}$$



$$T^2 = F_c{}^2 + F_g{}^2$$