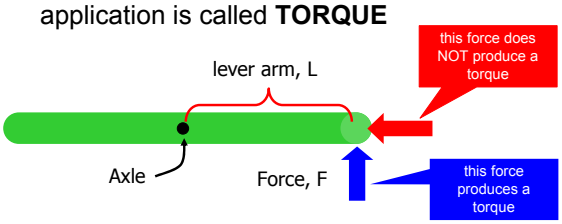
REVIEW: TORQUE

- To make an object rotate, a force must be applied in the right place.
- the combination of force and point of application is called **TORQUE**



TORQUE

- Torque = force times lever arm

$$\text{Torque} = F \times L$$

- To get an object spinning from rest a torque must be applied
- To make a spinning object spin faster a torque must be applied
- To slow down a spinning object a torque must be applied
- Torque *changes* the rotational speed of an object

L-11 Rotational Inertia and Momentum

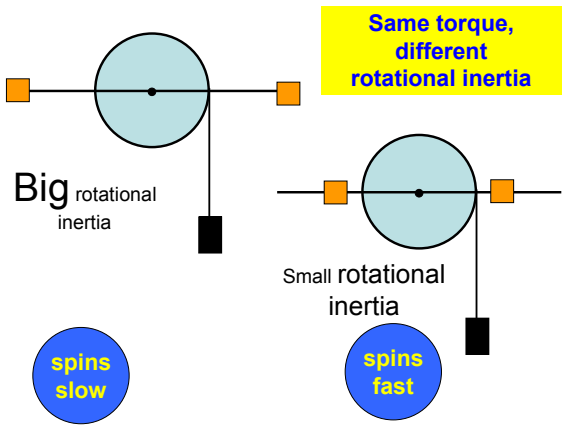
Why is a bicycle stable (it doesn't fall over) only when it is moving?

Rotational Inertia (moment of inertia)

- Rotational inertia is a parameter that is used to quantify how much torque it takes to get a particular object rotating
- it depends not only on the mass of the object, but where the mass is relative to the hinge or axis of rotation
- the rotational inertia is bigger, if more mass is located farther from the axis.

How fast does it spin?

- For spinning or rotational motion, the rotational inertia of an object plays the same role as ordinary mass for simple motion
- For a given amount of torque applied to an object, its rotational inertia determines its rotational acceleration → the smaller the rotational inertia, the bigger the rotational acceleration



rotational inertia - examples

Suppose we have a rod of mass 2 kg and length 1 meter with the axis through the center

Its moment of inertia is 2 units

Imagine now that we take the same rod and stretch it out to 2 meters; its mass is, of course, the same.

Its moment of inertia is 4 units

rotational inertia examples

Rods of equal mass and length

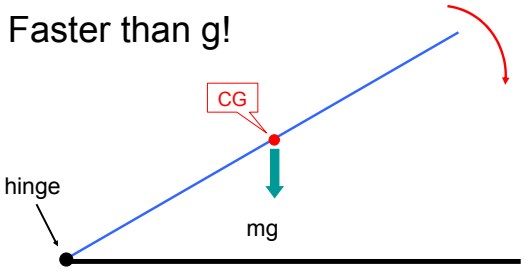
axes through center

Rotational inertia of 1 unit

axes through end

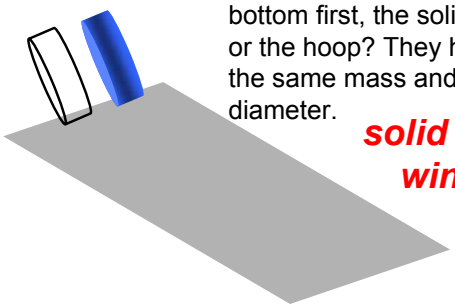
Rotational inertia of 4 units

Faster than g!



The acceleration of end of the hinged rod can be **greater** than g.

Place your bets!



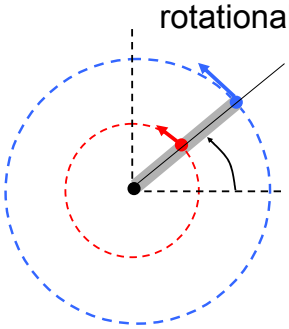
Which one reaches the bottom first, the solid disk or the hoop? They have the same mass and same diameter.

solid disk wins!

Speed of rotation

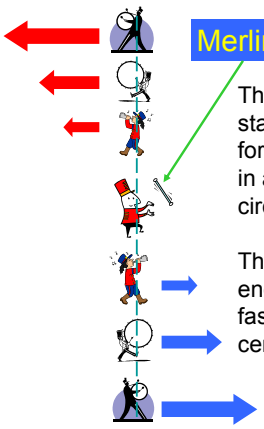
- For motion in a straight line we tell how fast you go by the velocity meters per second, miles per hour, etc.
- How do we indicate how fast something rotates?
- We use a parameter called **rotational velocity**, simply the number of revolutions per minute for example -- the number of times something spins say in a second or minute (rpm's- revs per min)
- for example the rotational speed of the earth spinning on it axis is 1 revolution per day or 1 revolution per 24 hours.

Ordinary (linear) speed and rotational speed



every point on the line moves through the same angle

- the rod is rotating around the circle in the counterclockwise direction
- ALL points on the rod have the **SAME** rotational speed
- The red point in the middle has only half the linear speed as the blue point on the end.



Merlino's marching band

The band is executing its state championship winning formation. They move in a big counterclockwise circle.

The band members at the end of the line must walk faster than those near the center of the line.

Rotational momentum

- an object of mass m moving with velocity v has a momentum m v
- A spinning object has **rotational momentum**
- **rotational momentum = moment of inertia *times* angular velocity**
- like momentum, once you get some angular momentum you tend to keep it!

Rotational momentum

- **rotational momentum = moment of inertia × angular velocity**
- since the rotational momentum can't change then if the moment of inertia changes, the rotational velocity must also change to keep the rotational momentum constant
- If the moment of inertia increases, then the rotational velocity must decrease
- if the moment of inertia decreases, then the rotational velocity must increases

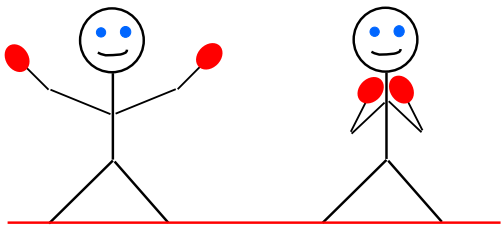
Rotational momentum demonstrations

- spinning ice skater
- divers
- Hobermann sphere
- bicycle wheel
- top
- tippy top
- gyroscope

http://www.youtube.com/watch?v=NtEnEnEyw_s&NR=1

Objects that have rotational momentum (SPIN) tend not to loose it easily → Bicycles

You can change your moment of inertia



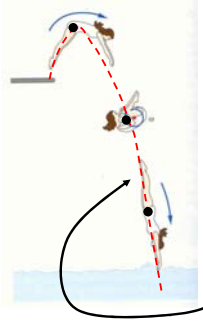
Big rotational inertia

small rotational inertia

Spinning faster or slower

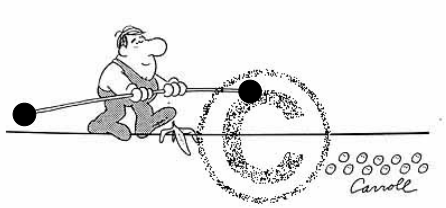
- When your arms are extended you have a big moment of inertia
- When you pull your arms in you make your moment of inertia smaller
- If you were spinning with your arms out, when you pull your arms in you will spin faster to keep your angular momentum constant
- This works in figure skating and diving

Divers use rotational momentum conservation to spin



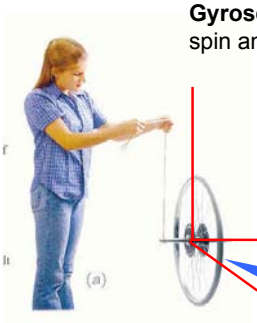
- the diver starts spinning when she jumps off the board
- when she pulls her arms and legs in she makes her moment of inertia smaller
- this makes her spin even faster!
- Her CG follows the same path as a projectile

Walking the tightrope



The acrobat carries a stick weighted at each end. By increasing his rotational inertia, the torque due to gravity is less likely to make him fall off the tightrope.

Spinning wheel defies gravity!



Gyroscope- an object that can spin and rotate about three axes

Once it starts spinning its axle wants to keep spinning in the same direction. It resists forces that try to change the direction of its spin axis.

spinning wheel

Don't fall off the stool!