L-11 (M-10) Rotational Inertia and Conservation of rotational momentum

- Why does a wheel keep spinning?
- Spinning ice skater Video
- Why is a bicycle stable when it is moving, but falls over when it stops?
- Why is it difficult to change the orientation of the axis of a spinning wheel?

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Rotational inertia → symbol I

- 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 axis of rotation
- the rotational inertia is bigger, if more mass is located *farther* from the axis.

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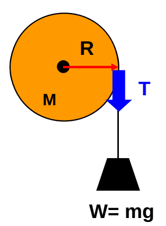
Rotational inertia and torque

- To start an object spinning, a torque must be applied to it
- The amount of torque required depends on the rotational inertia (I) of the object
- The rotational inertia (I) depends on the mass of the object, its shape, *and on how the mass is distributed.* I is larger if more mass is further from the center.
- The larger the rotation inertia, the more torque that is required to make an object spin



Torque = T · R

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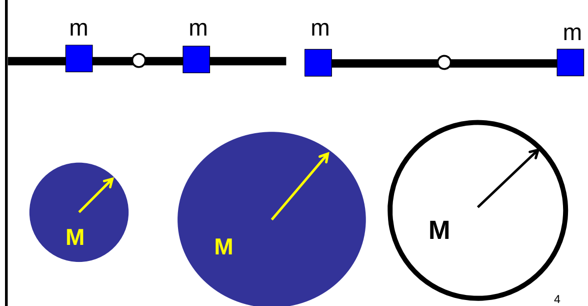
rotational inertia examples

small rotational inertia → large rotational inertia



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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

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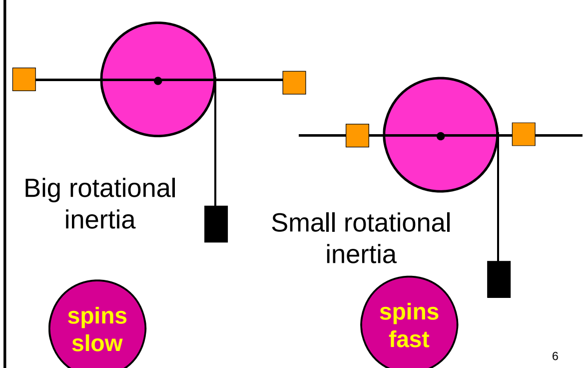
Same torque, different rotational inertia



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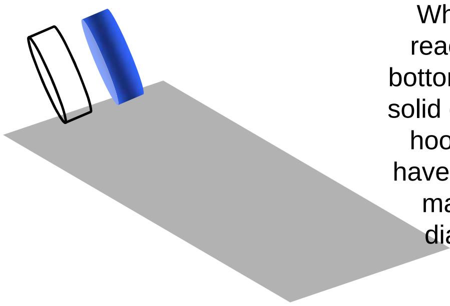
Rolling down the incline



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

The solid disk gets to the bottom faster because it has a *smaller* rotational inertia

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Speed of rotation

- For motion in a straight line velocity is simply how far you travel in a certain time (meters per second)
- How do we quantify how fast an object 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; the rotational speed of the earth around the sun is 1 revolution per year.
- Another way to quantify rotational velocity is by the angular displacement of the object in degrees per second

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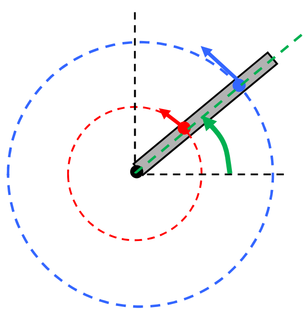
Ordinary (linear) speed vs. rotational speed



every point on the green dashed 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 – every point moves through the same angle in the same time
- However, the red point in the middle has only half the linear speed as the blue point on the end.

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Ice Capades

Skaters farther from center must skate faster

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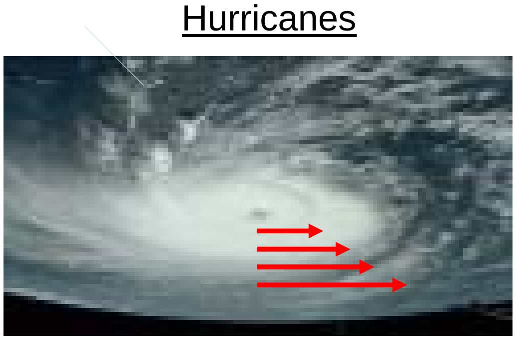
Hurricanes



The winds are higher as you get farther from the eye of a hurricane.

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Rotational (angular) momentum

- Rotational, or angular momentum is a measure of the amount of rotation an object has, taking into account its mass, shape and speed.
- It is a law of nature that the total rotational (angular) momentum of an isolated system (no external torques) is constant.

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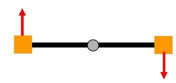
Rotational (angular) momentum

- A spinning object has rotational momentum
- Rotational momentum depends on
  - the mass of the spinning object
  - where the mass is located
  - how fast it is spinning
- If the rotational inertia is larger, the rotational momentum is larger
- If the rotational velocity is larger, the rotational momentum is larger

Conservation of rotational momentum

- If no outside torques disturb a spinning object, it rotational momentum is conserved
- The rotating masses on the rod form a system and keep spinning until the friction in the bearing slows brings it to rest.
- Without friction in the axle, the system would keep spinning indefinitely.
- Note that the total *linear* momentum is zero.



Rotational momentum

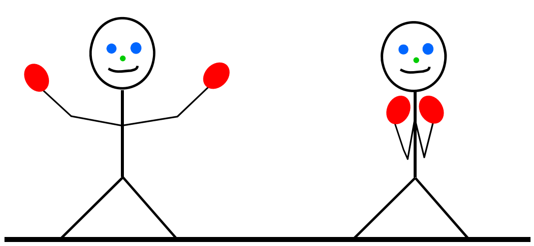
- The rotational momentum of a spinning object depends on both its rotational inertia and its rotational velocity (how fast it is spinning)
- If either the rotational inertia or rotational velocity changes, the other parameter must also change to keep the rotational momentum constant
- if the rotational inertia changes, the rotational velocity must also change
- If the rotational inertia increases, then the rotational velocity must decrease
- if the rotational inertia decreases, then the rotational velocity must increases

Conservation of Rotational momentum demonstrations

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

Slow spin Fast spin

You can change your rotational inertia



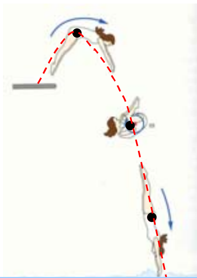
Big rotational inertia

Small rotational inertia

Spinning faster or slower

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

Divers use rotational momentum conservation to spin faster



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

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Example

Question: A figure skater with her arms outstretched spins at the rate of 1 revolution per sec. By pulling her arms and legs in, she reduces her rotational inertia to one-half its value when her arms and legs were outstretched.
→ What is her final rotational velocity?

Solution: Her angular momentum is conserved. If her rotational inertia is *reduced* by a factor of 2, her rotational velocity must *increase* by a factor of 2.

➔ *Her final rotational velocity is 2 rev/sec.*

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Tornadoes (Cyclones)

- Technical term is mesocyclone
- Intense updrafts stretch the mesocyclone vertically
- As it is stretched upward it gets increasingly narrower
- As it gets narrower, its rotation speed increases
- This is similar to the ice skater who pulls hers arms in

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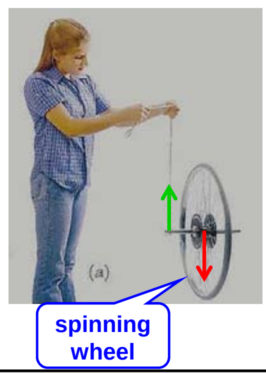
Spinning wheel defies gravity!



- An object that can rotate about any axis is called a gyroscope
- 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

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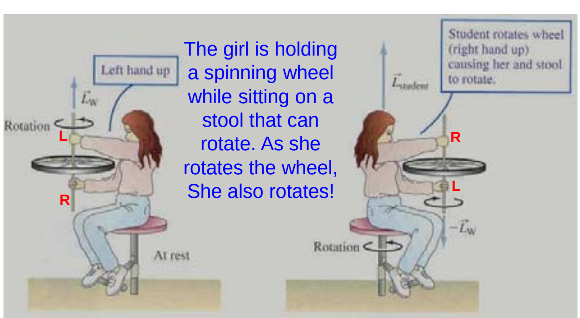
Falling off the stool!



http://www.youtube.com/watch?v=V3UsrfHa4MQ

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