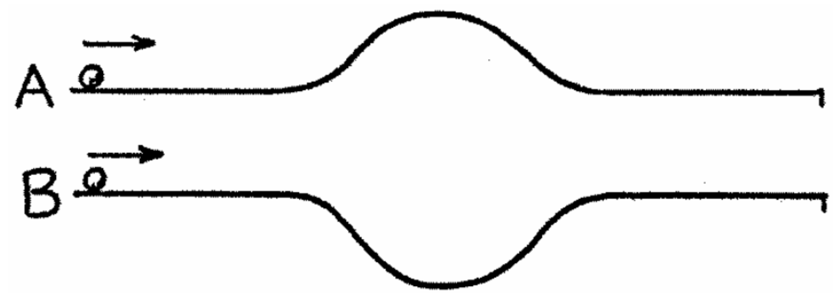
EXAM 1, Friday, February 28

- Review class, this Friday (2/21)
- Partial Exam questions posted on course website this coming weekend
- Special office hours, Mon., 2/24, 11:00 – 12:30

  Tu., 2/25, 4:00 – 5:30 pm

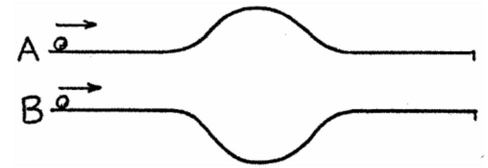
  Room 1220N



Two smooth tracks of equal length have "bumps"—A up, and B down, both of the same curvature. If the initial speed = 2 m/s, and the speed of the ball at the bottom of the curve on Track B is 3 m/s, then the speed of the ball at the top of the curve on Track A is

1. 1 m/s. 2. > 1 m/s. 3. < 1m/s.

Answer: < 1m/s



Two smooth tracks of equal length have "bumps"—A up, and B down, both of the same curvature. If the initial speed = 2 m/s, and the speed of the ball at the bottom of the curve on Track B is 3 m/s, then the speed of the ball at the top of the curve on Track A is

1. 1 m/s. 2. > 1 m/s. ✔**3. < 1m/s.**

The change in the speed in either track comes from change in the kinetic energy that happens because potential energy changes (change in height) while total energy remains constant.

For track B, at the bottom, gain in KE = mgh = ½ $m(3^2 - 2^2)$ = ½ $m(5)$.

This means for track A, loss in KE = ½ $m(5)$ at the top – but this is *greater* than the initial KE ½ $m(2)^2$ = ½ $m(4)$. So the ball actually never makes it to the top of A's curve!

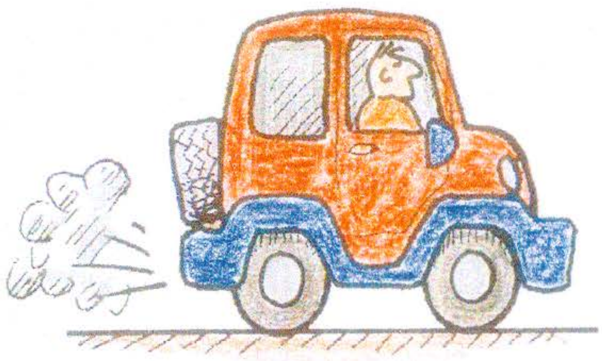
NEXT-TIME QUESTION

A typical car weighs about 1.5 tons, and the weight of carbon in a gallon of gasoline is about 5 lb. The CO_2 that's emitted by a typical car in a year weighs

a) much less than the car.

b) about as much as the car.

c) much more than the car.



thanks to Art Hobson

Hewitt Drew it!

NEXT-TIME QUESTION

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c) much more than the car.

Answer: c

Typical cars in the U.S. get about 25 miles per gallon and are driven about 15,000 miles per year. So a typical car consumes about (15,000 mi/yr)/(25 mi/gal) = 600 gal/yr. Multiply by 5 lb C/gal to get 3000 lb C/yr, or 1.5 tons C/yr. An oxygen atom weighs more than a carbon atom so the mass of a CO_2 is more than 3 times greater. So a typical car emits about 5 tons of CO_2 per year—more than 3 times the weight of the car!

Per capita emission of CO_2 in the U.S. is about 22 tons per year — about twice as much as other industrialized nations such as Germany, Great Britain, and Japan. About one-third of this 22 tons comes from transportation, much of it from automobiles. Try estimating how much comes from your own use of an automobile.

If you want your car to emit only its own weight of CO_2 in a year, make it a hybrid and drive it less than 10,000 miles.

Chapter 8: Rotational Motion

If you ride near the outside of a merry-go-round, do you go faster or slower than if you ride near the middle?

It depends on whether "faster" means

-a faster **linear speed (= speed)**, ie more *distance* covered per second,

or

- a faster **rotational speed (=angular speed, ω),** i.e. more *rotations or revolutions* per second.

• The linear speed of a rotating object is greater on the outside, further from the axis (center), but the rotational speed is the same for any point on the object – all parts make the same # of rotations in the same time interval.

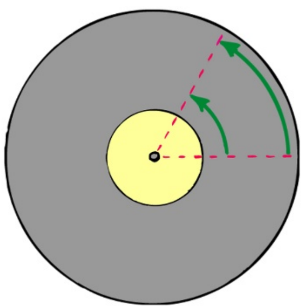
Note that for motion in a circle, linear speed is often called **tangential speed**

More on rotational vs tangential speed

– The faster the ω, the faster the *v* in the same way (e.g. merry-go-round), i.e. $v \sim \omega$.

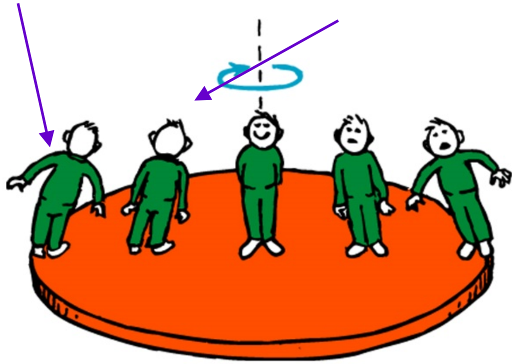
– ω doesn't depend on where you are on the merry-go-round, but v does: i.e. $v \sim r$

directly proportional to



He's got twice the linear speed than this guy.

Same RPM (ω) for all these people, but different tangential speeds.



Merrygoround flashvideo

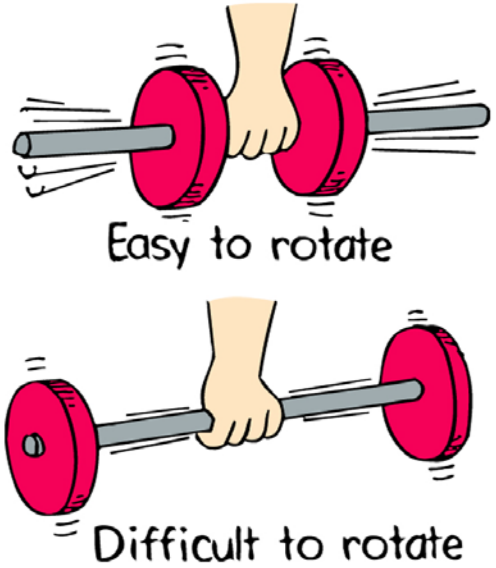
Rotational Inertia

- An object rotating about an axis tends to remain rotating about the same axis, unless an external influence (*torque*, see soon) is acting. (c.f. 1st law)

- The property to resist changes in rotational state of motion is called **rotational inertia**, or **moment of inertia, *I* .**

- Depends on **mass**, as well as the **distribution of the mass relative to axis of rotation –** largest if the mass is <u>further away</u> from the axis

Eg. DEMO: Spinning a pencil with globs of play-doh on it – if the globs are near the ends of the pencil, it is harder to spin, than if the globs are nearer the middle.



Eg. Tight-rope walker carries a pole to increase his rotational inertia - if he starts to wobble, the pole starts to rotate but its inertia resists this, so the tight-rope walker has time to adjust balance and not rotate and fall.

Better balance (more rotational inertia) if pole is longer and has weights at the ends.

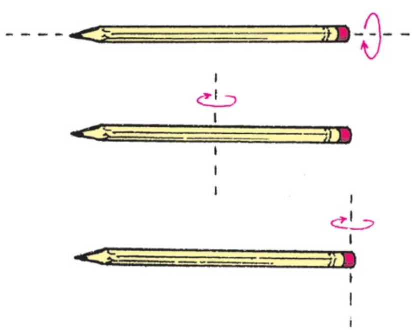
• Rotational inertia depends on the axis around which it rotates:

Eg With a pencil:

Easiest to spin here (smallest I)

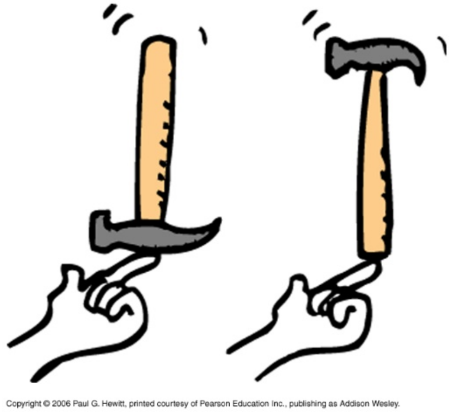
Harder here

Even harder here



Questions

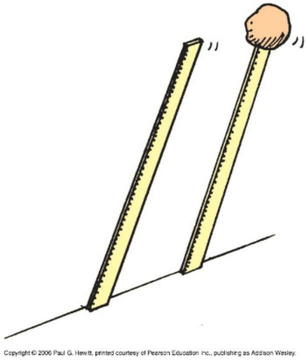
(1) Consider balancing a hammer upright on the tip of your finger. Would it be easier to balance in the left-hand picture or the right-hand picture, and why?



Easier on the right, because it has more rotational inertia (heavy part further away from your finger), so is more resistant to a rotational change.

Hammer balance movie

(2) Consider the meter sticks shown, one with a glob of clay at the top end. If released from upright position, which reaches the ground first?



The one without the clay! Try it! Because the stick-with-clay has more rotational inertia, so resists rotation to ground more.

(Also, experiences more torque…see later)

Hammer Balance

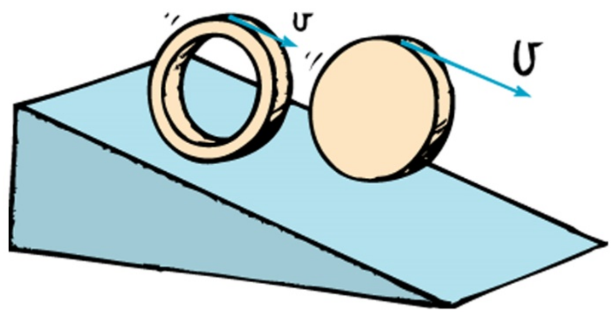
More about rotational inertia: rolling objects down a hill…

- Which rolls to the bottom of an incline first, a solid ball, a solid cylinder or a ring?

First ask: which has smallest rotational inertia? – since this will resist rolling the least, so will reach the bottom first.

The shape which has most of its mass closest to the center has least rotational inertia, i.e. first is ball, second is cylinder, and last is the ring.

(In fact this is independent of their size and mass, it just depends on their shape!)



- Fig 8.15 in your text illustrates some rotational inertia values of various objects – you don't need to learn these, but do try to understand why the bigger ones are bigger from considering mass distribution.

Demo- rolling down plane

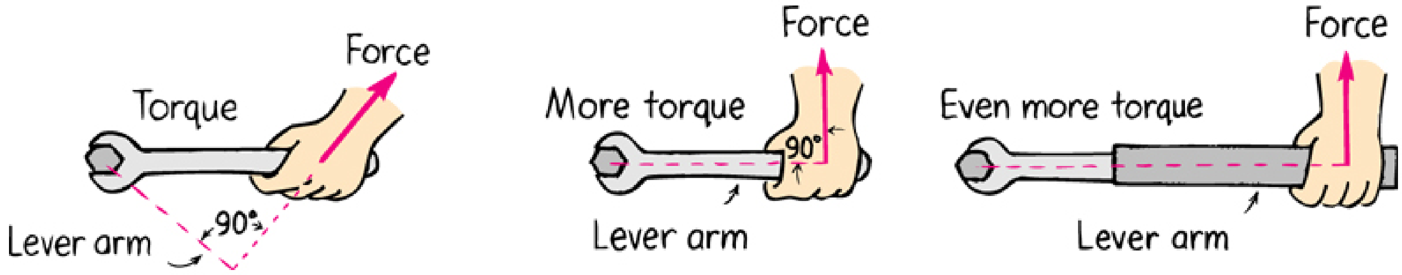
Torque

- Rotational analog of force – i.e. causes changes in rotations of objects.

Torque = lever arm x force

lever arm = the perpendicular distance from the axis of rotation to the line along which the force acts.

Eg. Turning a bolt

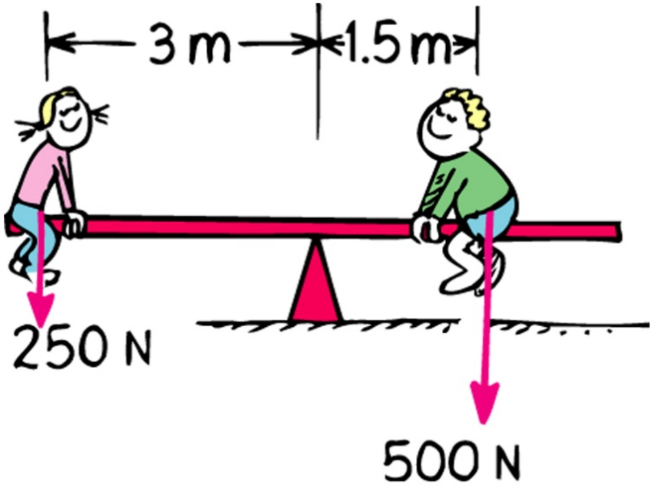


Torque flashvideo

- Eg. See-saws.

  The dependence of the torque on the lever arm is why kids can balance see-saws even when they have different weights – The heavier one sits closer to the center :

  Larger F x Smaller lever-arm = Smaller F x Larger lever-arm.



- Mechanical equilibrium:

  not only Σ F = 0 (chap 2) but also Σ torques = net torque = 0

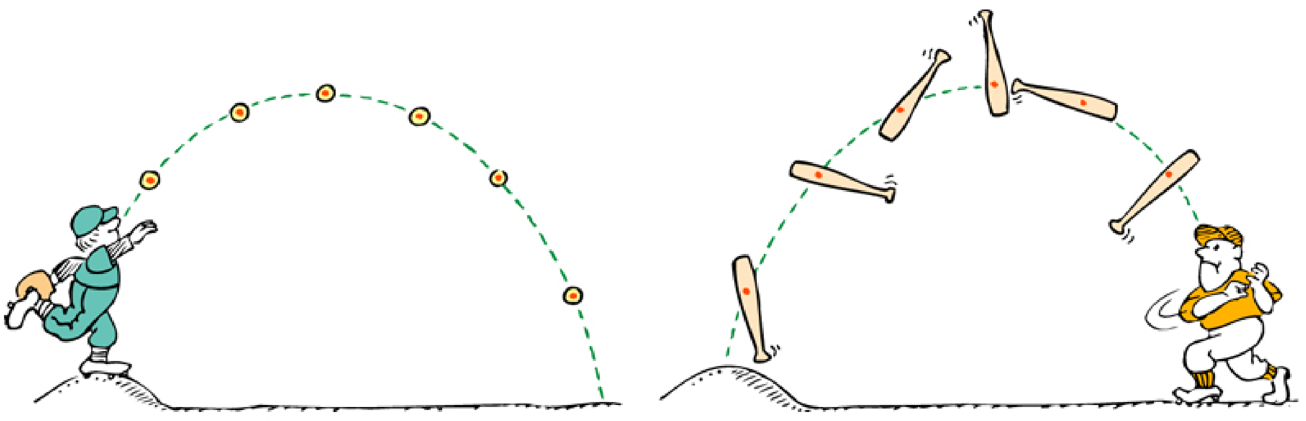
see-saw interactive and demo- equal arm balance

Center of mass/Center of gravity

- Center of mass (CM) = average position of all the mass that makes up the object.
- Center of gravity (CG) = average position of weight distribution
  - So CM = CG for objects on earth. We'll use CM and CG interchangeably.

- Often, motion of a body is complex, but CM motion is very simple:

Eg. Any shaped object thrown in the air may spin in a complicated way as it falls, but the CM always follows a parabola (as if it were a point object, or ball, thrown)

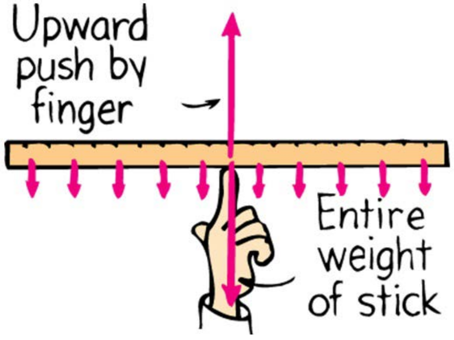


Locating the CM

- When object is symmetric, it’s simple eg. For a meter stick, CM is at the center. It acts as if all the mass is concentrated there.

All the small arrows indicate gravity along

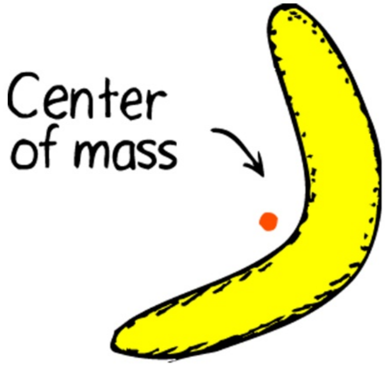
the stick – can combine to single large arrow acting downward through CM.



- If freely suspend an object from any point, the CM lies somewhere along the line vertically down from it. So, to determine exactly where, suspend it freely from some other point on the object, let it adjust, draw again the vertical line: the intersection of the two lines gives CM.

- Sometimes, the CM is outside of the object.

Eg. A hollow ring, CM in the center, Or banana:



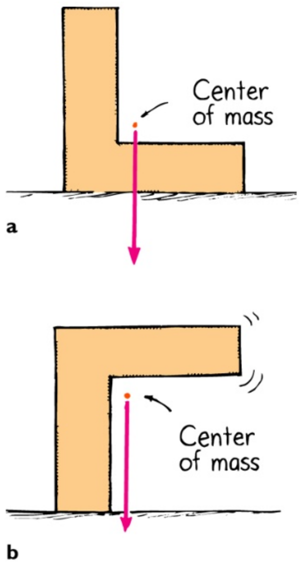
Demo – forks’n corks

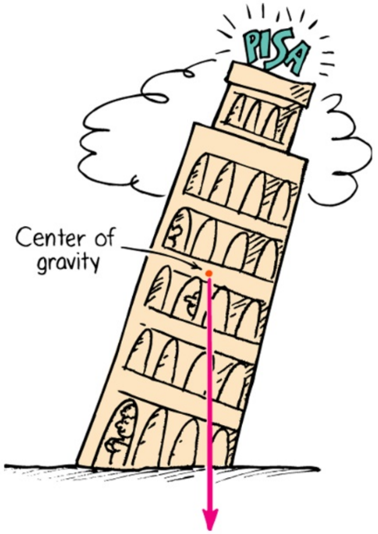
Stability

- Stable equilibrium – if vertical line down from CM falls inside the base of object.

stable

unstable





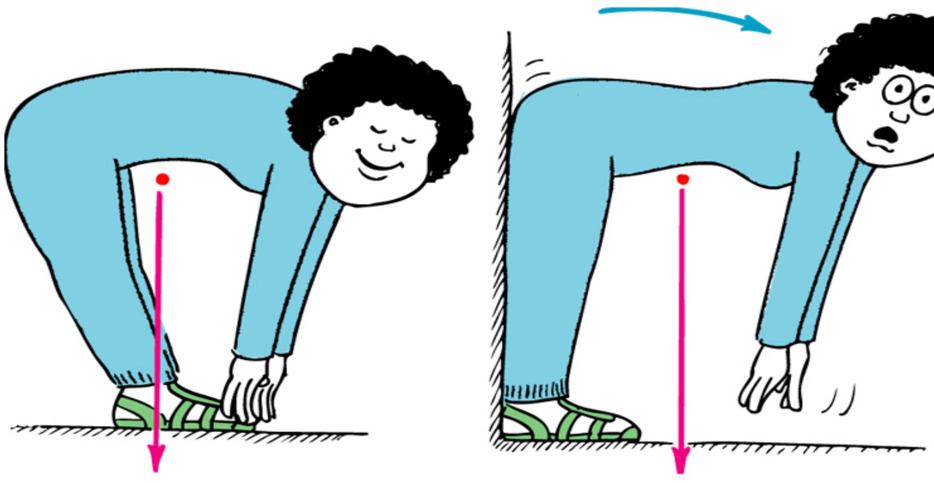
So often design objects with a wide base and lower CM.

This is why its dangerous if you leave the top drawers of a heavy cabinet open – CM may extend beyond support base and so tip…

Example

- Why is not possible for a flexible person to bend down and touch her toes keeping legs straight, while standing with her back against a wall? *(Try this!!)*

Hint: Deduce first the CM of the person, approximating her as an L-shape (see last slide).



If she leans back, the CM is above the base (her feet) - stable

If she can't lean back, CM is no longer above her feet- unstable

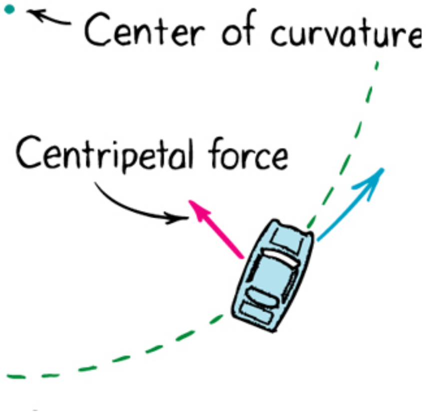
The torque from gravity acting on the upper half of the body is larger in the RH case because the lever arm is longer.

Related problem: Try getting up from a chair without putting your feet under your chair.

Centripetal Force

- Is *any* force that is **directed toward a fixed center**.
- Often leads to motion in a circle – then, force is inwards, towards center of circle

Examples	Centripetal force
Moon orbiting earth	Gravitational force
Electrons orbiting nucleus in atom	Electrical force
Whirling object at end of a string	Tension in the string
Car rounding a bend	Friction between tires and road



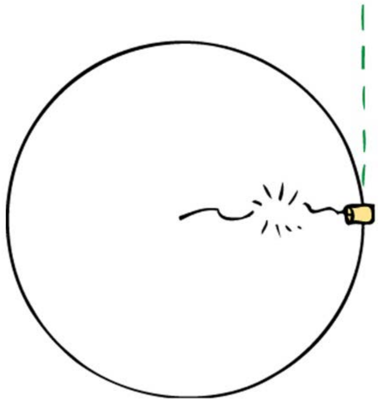
Centrifugal force

- When *you* are the object moving in a circle, you feel an ***outward* force** – called centrifugal force. It is a type of "inertial" force , as it is a result of rotation.

- First, consider again whirling can on end of string:

Common misconception: to say centrifugal force pulls outward on the can – wrong!

If the string breaks, the can goes off in a straight line because no force acts on it. It is the inward-directed centripetal force of the string that keeps it in a circle before string breaks.



Then why, if we were the can whirling around in a circle, would we feel we are being pushed out, rather than the inward directed centripetal force?

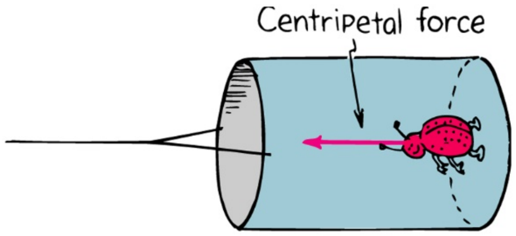
Centrifugal force continued..

…why, if we were the can, would we feel we are being pushed out rather than the inward directed centripetal force?

It's to do with the **frame of reference:** a rotating frame is a "non-inertial" frame, unlike inertial (non-accelerating) frames. **Only in inertial frames do Newton's laws strictly hold.**

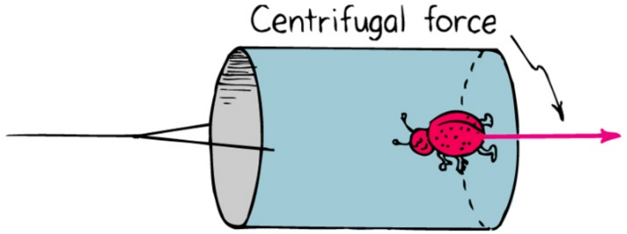
Consider a ladybug inside the can from the point of view of someone outside watching it (i.e. in an inertial frame).

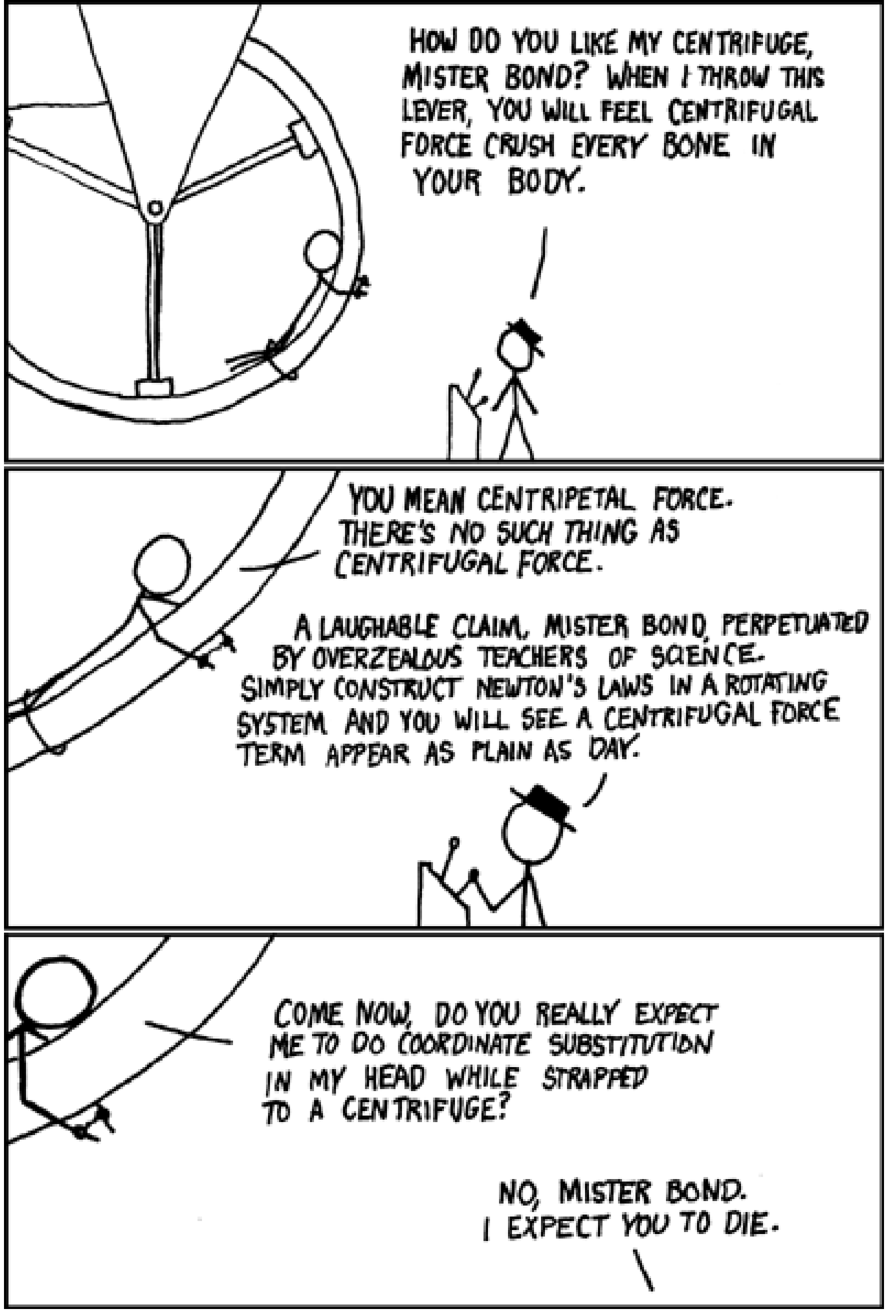
Then the only force acting on it is the walls of the can on her feet, giving the inward directed centripetal force.



Now consider from the ladybug' s rotating frame.

In her own frame, she is at rest. So there must be a force to cancel the wall inwardly pushing - this is the centrifugal force directed outward.





Centrifugal force: a pseudoforce

http://xkcd.com/123/

Angular momentum

- "Inertia of rotation" *(c.f. momentum = linear momentum of Ch.6)*

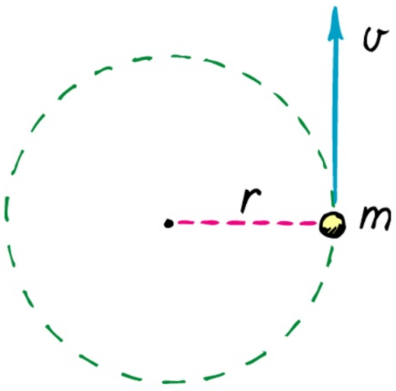
Angular Momentum = rotational inertia x rotational velocity

$= I\,\omega$

For an object rotating around a circular path at const speed :

ang mom. = $m\,v\,r$

Eg. a whirling tin can

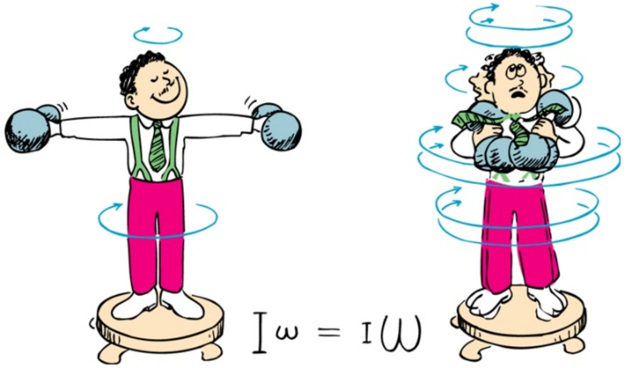


Angular momentum is a vector quantity, but in this course, we won't deal with the (many interesting) consequences of its vector nature (eg gyroscopes). Come ask me later if you'd like to learn more about this!

Conservation of Angular Momentum

An object or system of objects will maintain its angular momentum unless acted upon by an unbalanced external torque.

- So, if there is no net torque, ang mom is conserved.
- DEMO: Sit on a rotating stool, holding weights away from you. Then pull the weights in – you go much faster! Your ***I*** decreases when you pull in the masses, and your ω compensates, to keep ***I*** ω constant.

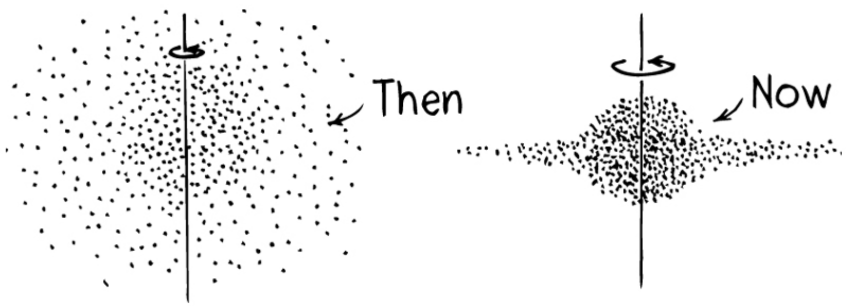


This principle is often used by a figure skater, drawing arms and legs in to spin faster.

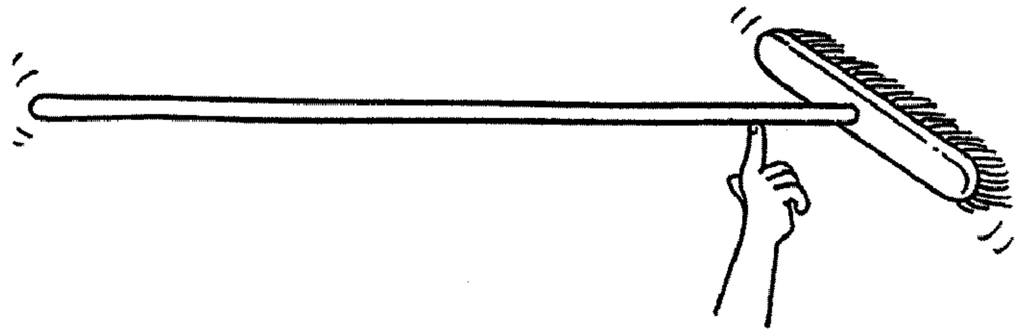
Skaterspin flashvideo **Demo - volunteer needed** **Demo - gyro**

- Another place where ang mom conservation plays big role, is in understanding motion of planets, and galaxy shapes.

e.g. we believe originally our galaxy was a huge spherical cloud of gas, rotating very slowly. Gravitational attraction between particles pulled the cloud together, so giving it a smaller radius. By ang mom cons, this means faster rotation; some stars being spun out…

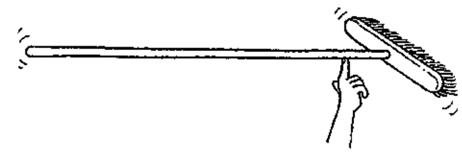


• Read in your book about how the moon is gradually getting further away from us because earth's ang mom is decreasing from ocean-water friction, and so the moon's must increase to compensate.



The broom balances at its center of gravity. If you saw the broom into two parts through the center of gravity and then weigh each part on a scale, which part will weigh more?

1. Short broom part
2. Long broom part

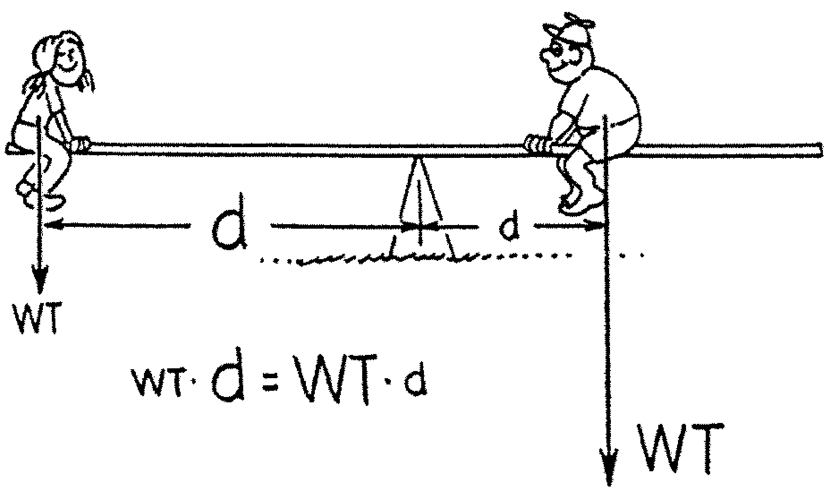


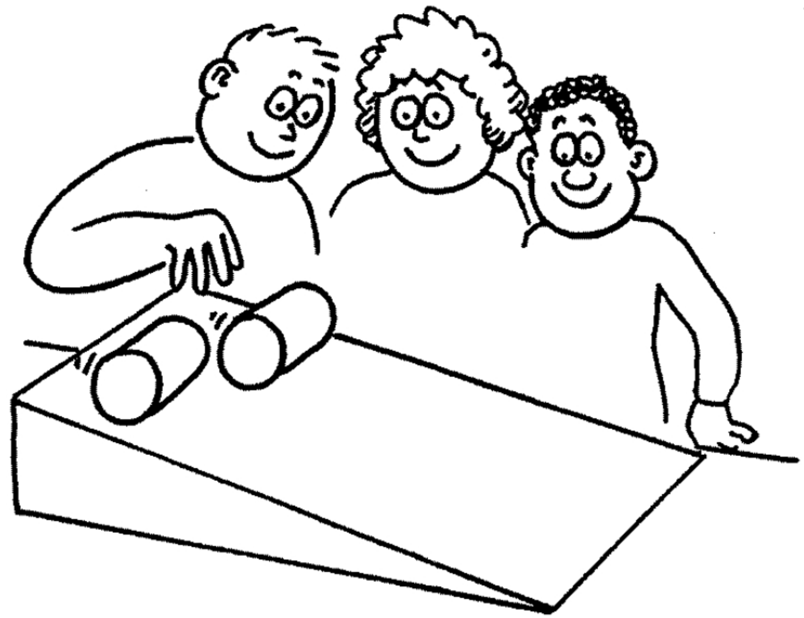
The broom balances at its center of gravity. If you saw the broom into two parts through the center of gravity and then weigh each part on a scale, which part will weigh more?

✔**1. Short broom part**
2. Long broom part

Answer:1. short broom part.

The short broom part balances the long handle just as kids of unequal weights can balance on a seesaw when the heavier kid sits closer to the fulcrum. Both the balanced broom and seesaw are evidence of equal and opposite torques—not equal weights.



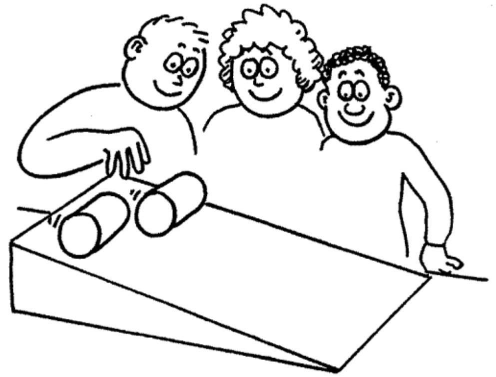


Which will roll down a hill faster, a can of regular fruit juice or a can of frozen fruit juice?

1. Regular fruit juice
2. Frozen fruit juice
3. Depends on the relative sizes and weights of the cans

Hint: Note that the regular juice is a liquid and so is not forced to roll with the can i.e. much of it slides. The frozen juice must roll with the can. So which has less rotational inertia?

Answer: 1. Regular fruit juice



Which will roll down a hill faster, a can of regular fruit juice or a can of frozen fruit juice?

✔ **1. Regular fruit juice**
2. Frozen fruit juice
3. Depends on the relative sizes and weights of the cans

The regular fruit juice has an appreciably greater acceleration down an incline than the can of frozen juice: Because the regular juice is a liquid and is not made to roll with the can, as the solid juice does. Most of the liquid effectively slides down the incline inside the rolling can. The can of liquid therefore has very little rotational inertia compared to its mass.
The solid juice, on the other hand, is made to rotate, giving the can more rotational inertia.