Note on Posted Slides

- These are the slides that I intended to show in class on Mon. Jan. 28, 2013.
- They contain important ideas and questions from your reading.
- Due to time constraints, I was probably not able to show all the slides during class.
- They are all posted here for completeness.

PHY205H1S
Physics of Everyday Life
Class 7: **Rotation**

- Circular Motion
- Rotational Inertia
- Torque
- Centre of Mass and Centre of Gravity
- Centripetal Force
- Centrifugal Force
- Angular Momentum

Chapter 8. Pre-Class Reading Question

- The rotational speed on the outer edge of a rotating roulette wheel is

A. less than toward the centre.
B. the same as toward the centre.
C. greater than toward the centre.

Roulette wheel image from http://yourfamilyfinances.com/2012/09/01/payday-loans-debt-trap/]

Chapter 8. Pre-Class Reading Question

- The tangential speed on the outer edge of a rotating roulette wheel is

A. less than toward the centre.
B. the same as toward the centre.
C. greater than toward the centre.

Roulette wheel image from http://yourfamilyfinances.com/2012/09/01/payday-loans-debt-trap/]

Circular Motion

- When an object turns about an internal axis, it is undergoing circular motion or rotation.

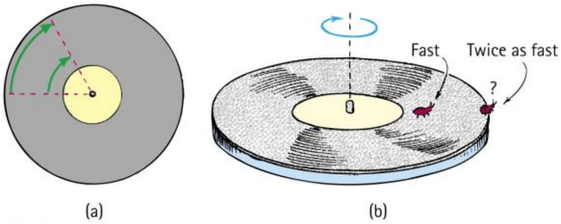
- Circular Motion is characterized by two kinds of speeds:
  - tangential speed, v in m/s.
  - rotational speed, ω in radians / s.
- 1 radian ≈ 57°, and is a unit of angle.

[Image from http://www.coolgraphic.org/festival-graphics/earth-day/earth-rotating-earth-day/]

Circular Motion—Tangential Speed

The distance traveled by a point on the rotating object divided by the time taken to travel that distance is called its *tangential* speed, v.

- Points closer to the circumference have a higher tangential speed that points closer to the centre.



Circular Motion – Rotational Speed

- Rotational (angular) speed is the *number of radians of angle per unit of time* (symbol ω).
  - All parts of a rigid merry-go-round or turntable turn about the axis of rotation in the same amount of time.
  - So, all parts have the same rotational speed.

Tangential speed

= Radial Distance × Rotational Speed

$$v = r\omega$$

Rolling Without Slipping

- Under normal driving conditions, the portion of the rolling wheel that contacts the surface is *stationary*, not sliding
- In this case the speed of the centre of the wheel is:

$$v = \frac{C}{T}$$

where C = circumference [m] and T = Period [s]

- If your car is accelerating or decelerating or turning, it is *static friction* of the road on the wheels that provides the net force which accelerates the car

Discussion Question

- The circumference of the tires on your car is 0.9 m.
- The onboard computer in your car measures that your tires rotate 10 times per second.
- What is the speed as displayed on your speedometer?

A. 0.09 m/s
B. 0.11 m/s
C. 0.9 m/s
D. 1.1 m/s
E. 9 m/s

Rotational Inertia

- An object rotating about an axis tends to remain rotating about the same axis at the same rotational speed unless interfered with by some external influence.

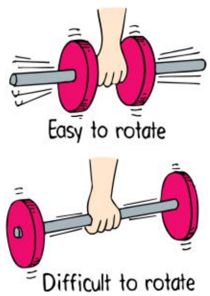
- The property of an object to resist changes in its rotational state of motion is called **rotational inertia (symbol *I*).**

[Image downloaded Jan.10, 2013 from http://images.yourdictionary.com/grindstone]

Rotational Inertia

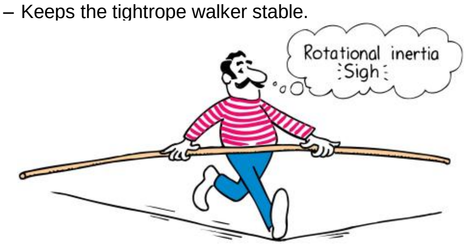
Depends upon:

- mass of object.
- distribution of mass around axis of rotation.
  – The greater the distance between an object's mass concentration and the axis, the greater the rotational inertia.



Rotational Inertia

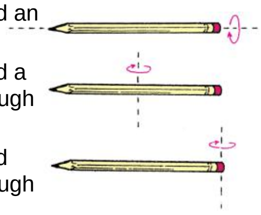
- The greater the rotational inertia, the harder it is to change its rotational state.
  – A tightrope walker carries a long pole that has a high rotational inertia, so it does not easily rotate.
  – Keeps the tightrope walker stable.



Rotational Inertia

Which pencil has the largest rotational inertia?

A. The pencil rotated around an axis passing through it.
B. The pencil rotated around a vertical axis passing through centre.
C. The pencil rotated around vertical axis passing through the end.



Torque

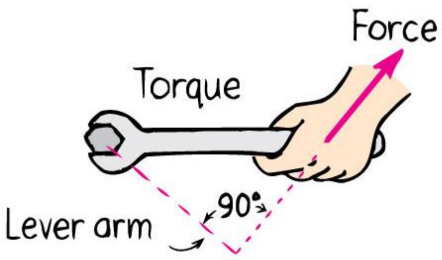
- The tendency of a force to cause rotation is called **torque.**

- Torque depends upon three factors:
  – Magnitude of the force
  – The direction in which it acts
  – The point at which it is applied on the object

Image by John Zdralek, retrieved Jan.10 2013 from http://en.wikipedia.org/wiki/File:1980_c1980_Torque_wrench,_140ft-lbs_19.36m-kg,_nominally_14-20in,_.5in_socket_drive,_Craftsman_44641_WF,_Sears_dtl.jpg]

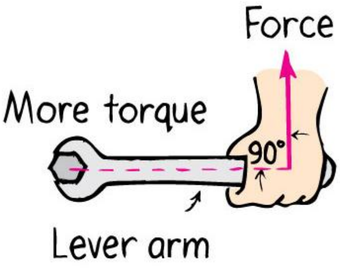
Torque—Example 1 of 3

- Lever arm is *less than* length of handle because of direction of force.



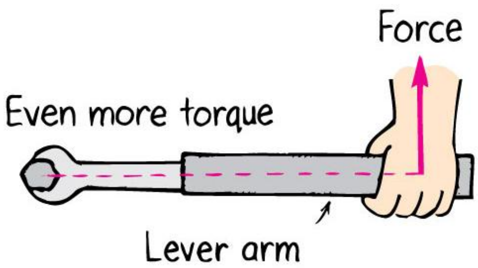
Torque—Example 2 of 3

- Lever arm is equal to length of handle.



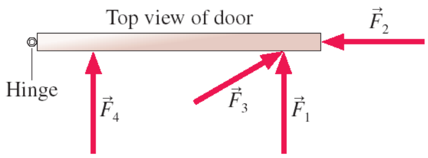
Torque—Example 3 of 3

- Lever arm is longer than length of handle.



Torque

Consider the common experience of pushing open a door. Shown is a top view of a door hinged on the left. Four pushing forces are shown, all of equal strength. Which of these will be most effective at opening the door?



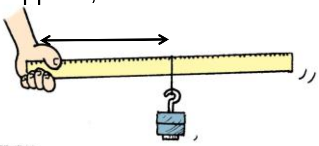
A. F_1
B. F_2
C. F_3
D. F_4

Torque

- The equation for Torque is

  Torque = lever arm × force

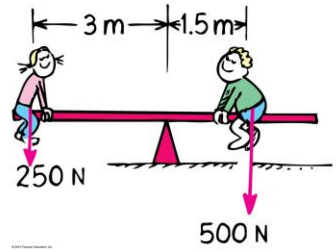
- The lever arm is the perpendicular distance between the line along which the force is applied, and the rotation axis.



Rotational Inertia
CHECK YOUR NEIGHBOR

Suppose the girl on the left suddenly is handed a bag of apples weighing 50 N. Where should she sit order to balance, assuming the boy does not move?

A. 1 m from pivot
B. 1.5 m from pivot
C. 2 m from pivot
D. 2.5 m from pivot



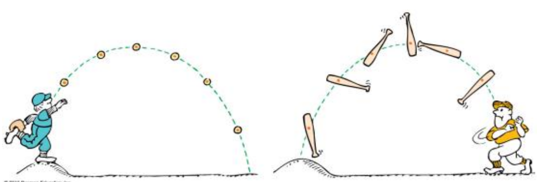
Test on Wednesday during class time

- **Location:** EX100, which is 255 McCaul St.
- Test will begin promptly at 10 minutes after the hour and will be 50 minutes long – if you can be there a bit early that would be great.
- Please bring a calculator, and, if you wish, a 3x5 notecard upon which you may write anything you wish on both sides
- Test will cover Hewitt chapters 2-8, and will include:
- 3 short-answer problems for which you must show your reasoning
- 12 multiple choice questions – you fill in a bubble sheet
- Questions will be similar in style and level to the Exercises and Problems at the end of the chapters in Hewitt

Tips for the 50 minute Test

- No phones / ipods etc allowed. You will need a regular calculator, and a watch could be handy as well!
- Time Management:
  - Skim over the entire test from front to back **before** you begin. Look for problems that you have confidence to solve first.
  - If you start a problem but can't finish it, leave it, make a mark on the edge of the paper beside it, and come back to it after you have solved all the easy problems.
- Bring your T-card or other photo ID, as we will be collecting signatures

- **Centre of mass** is the average position of all the mass that makes up the object.
- **Centre of gravity (CG)** is the average position of weight distribution.
  - Since weight and mass are proportional, centre of gravity and centre of mass usually refer to the same point of an object.

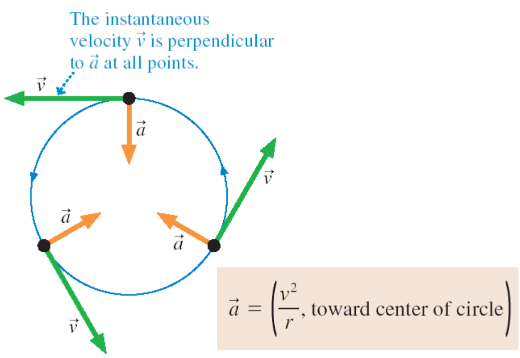


Centre of Gravity—Stability

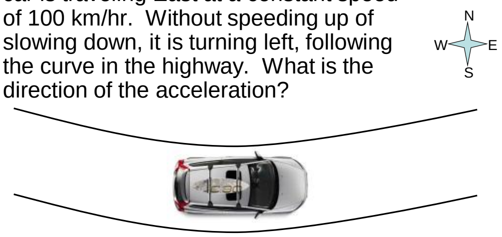
The location of the centre of gravity is important for stability.

- If we draw a line straight down from the centre of gravity and it falls inside the base of the object, it is in stable **equilibrium;** it will balance.
- If it falls outside the base, it is unstable.

Centripetal Acceleration



A car is traveling East at a constant speed of 100 km/hr. Without speeding up of slowing down, it is turning left, following the curve in the highway. What is the direction of the acceleration?



A. North
B. East
C. North-East
D. North-West
E. None; the acceleration is zero.

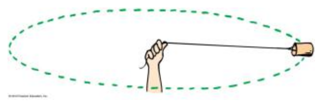
Centripetal Force

- Any force directed toward a fixed centre is called a **centripetal force.**
- *Centripetal* means "centre-seeking" or "toward the centre."

Example: To whirl a tin can at the end of a string, you pull the string toward the centre and exert a centripetal force to keep the can moving in a circle.

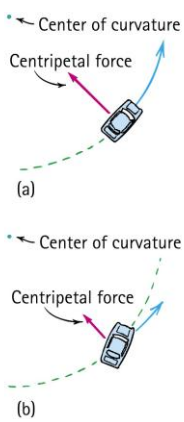
Centripetal Force

- Depends upon
  - mass of object, *m*.
  - tangential speed of the object, *v*.
  - radius of the circle, *r*.
- In equation form: $F = \dfrac{mv^2}{r}$



Centripetal Force Example

- When a car rounds a curve, the centripetal force prevents it from skidding off the road.
- If the road is wet, or if the car is going too fast, the centripetal force is insufficient to prevent skidding off the road.



Centripetal Force
CHECK YOUR NEIGHBOR

Suppose you double the speed at which you round a bend in the curve, by what factor must the centripetal force change to prevent you from skidding?

A. Double
B. Four times
C. Half
D. One-quarter

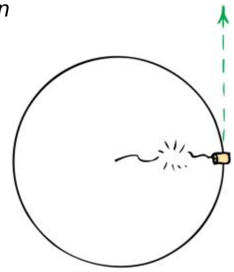
Centrifugal Force

- Although centripetal force is centre directed, an occupant inside a rotating system seems to experience an outward force.
- This apparent outward force is called **centrifugal force.**
- *Centrifugal* means "centre-fleeing" or "away from the centre."

[Image downloaded Jan.10 2013 from http://www.et.byu.edu/~wanderto/homealgaeproject/Harvesting%20Algae.html]

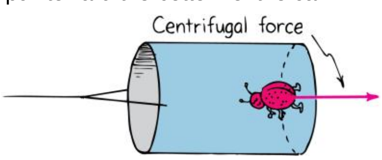
Centrifugal Force – *A Common Misconception*

- It is a *common misconception* that a *centrifugal force pulls **outward*** on an object.
- Example:
  - If the string breaks, the object *doesn't move radially outward*.
  - It continues along its tangent straight-line path—because *no* force acts on it. (Newton's first law)



Rotating Reference Frames

- Centrifugal force *in a rotating reference frame* is a force in its own right – feels as real as any other force, e.g. gravity.
- Example:
  - The bug at the bottom of the can experiences a pull toward the bottom of the can.



Angular Momentum

- The "inertia of rotation" of rotating objects is called **angular momentum.**
  - This is analogous to "inertia of motion", which was momentum.
- Angular momentum
  = rotational inertia × rotational velocity

$$L = I\omega$$

  - This is analogous to
    Linear momentum = mass × velocity

$$p = mv$$

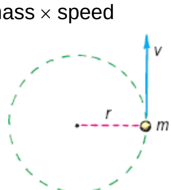
Angular Momentum

- For an object that is small compared with the radial distance to its axis, magnitude of

Angular momentum = mass x tangential speed × radius

  - This is analogous to magnitude of
    Linear momentum = mass × speed

- Examples:
  - Whirling ball at the end of a long string
  - Planet going around the Sun



- An external net torque is required to change the angular momentum of an object.
- Rotational version of Newton's first law:
  - **An object or system of objects will maintain its angular momentum unless acted upon by an external net torque.**

Conservation of Angular Momentum

The **law of conservation of angular momentum** states:

If **no external net torque** acts on a rotating system, the **angular momentum of that system remains constant**.

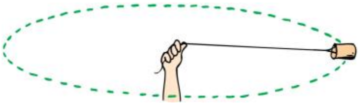
Analogous to the law of conservation of linear momentum:

If **no external force** acts on a system, the total **linear momentum** of that system remains constant.

Angular Momentum
CHECK YOUR NEIGHBOR

Suppose you are swirling a can around and suddenly decide to pull the rope in *half*way; by what factor would the speed of the can change?

A. Double
B. Four times
C. Half
D. One-quarter



Angular Momentum
CHECK YOUR NEIGHBOR

Your professor is rotating at some rotational speed ω with some rotational inertia set partly by the fact that he is holding masses in his outstretched arms.

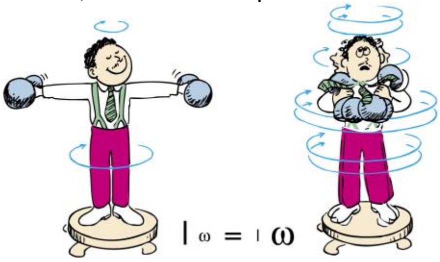
Suppose by pulling the weights inward, the rotational inertia of the professor reduces to half its original value. By what factor would his rotational speed change?

A. Double
B. Three times
C. Half
D. One-quarter

Conservation of Angular Momentum

Example:

- When the professor pulls the weights inward, his rotational speed increases!



Before Class 8 on Monday

- Please read Chapter 12, or at least watch the 10-minute pre-class video for class 8
  - We are now done the “Mechanics” part of the course, and will be starting next on solids, liquids, gases, and thermal physics.
  - Something to think about over the weekend:
  - Which has the greater surface area to volume ratio: an ant or an elephant?