Physics 211

Sections 1 & 70

Dr. Geoffrey Lovelace

Fall 2012

Lecture 23 (11/29/12)

Lecture 23 outline

- Announcements
- Class participation followup
- Rigid body motion
  - Stable equilibrium
  - Rotational dynamics
    - Moment of inertia
    - Example: opening a door
  - Rotational work and kinetic energy
    - Automotive torque & power

Announcements

- Homework #10: due Tuesday at 11:59PM
  - Homework #11: last homework
- Course schedule updated, slides posted at piazza.com
- Reading: Finish chapter 8
- Office hours: 10AM-11AM, 4PM-5PM today
  - McCarthy Hall room 601B
- Final exam December 20, 9:30AM-11:20AM
  - Planning to skip the final exam? See me in office hours or by appointment!

Today →

Date	Event
Nov 15	**Exam 3**
Nov 20	*Fall Recess — No class*
Nov 22	*Fall Recess — No class*
Nov 27	Rigid body rotation, torque
Nov 29	Rotational dynamics, rotational energy
Dec 4	Angular momentum, rigid body wrap-up *HW #10 due*
Dec 6	Harmonic motion
Dec 11	Harmonic motion & waves
Dec 13	Gravitational waves, harmonic motion, black holes, *HW #11 due*
Dec 20	**Final exam 9:30AM–11:20AM**

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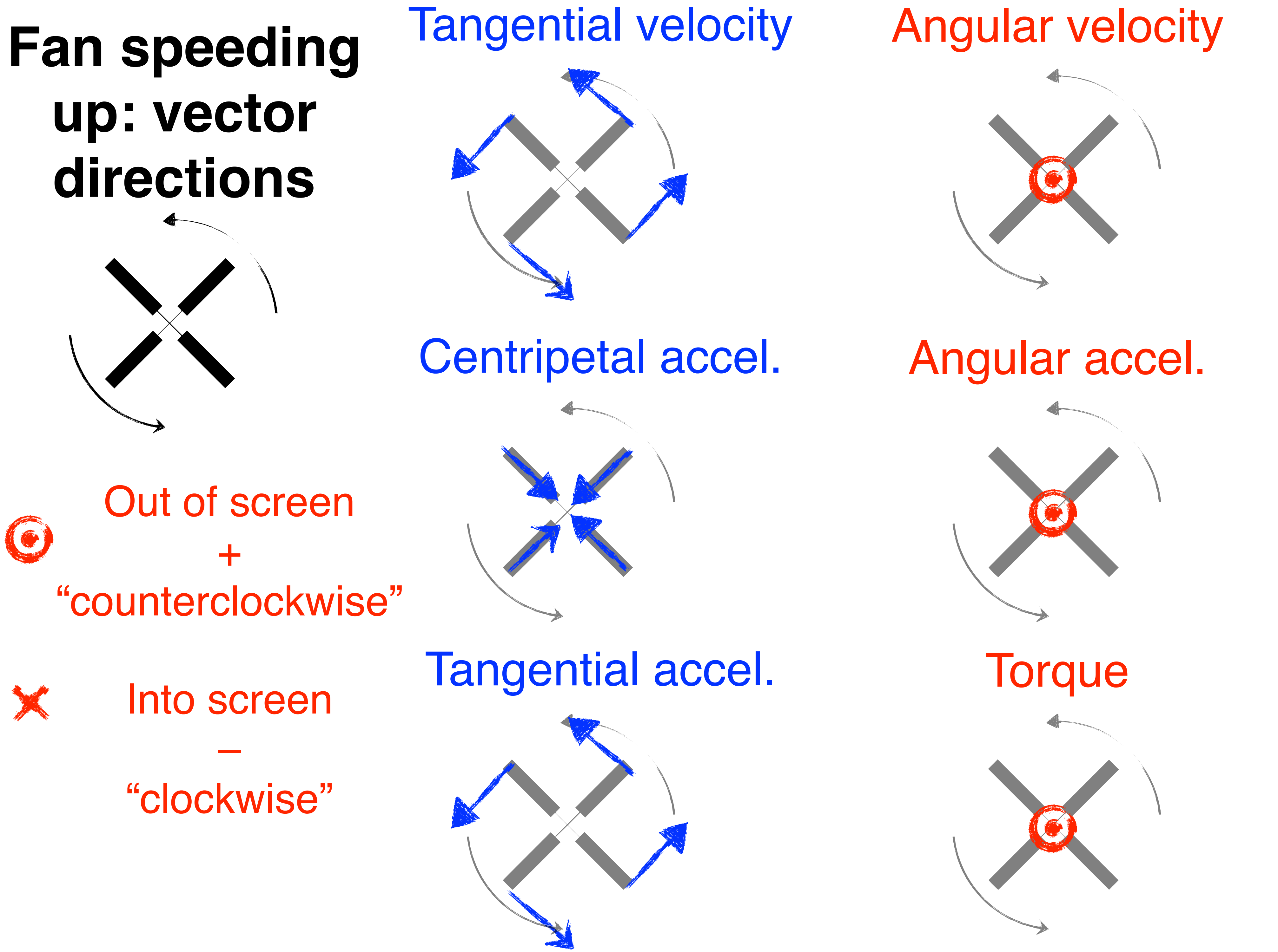
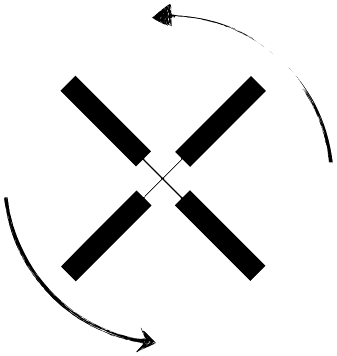

Fan speeding up: vector directions
Tangential velocity
Angular velocity
Centripetal accel.
Angular accel.
Tangential accel.
Torque
Out of screen
+
"counterclockwise"
Into screen
–
"clockwise"

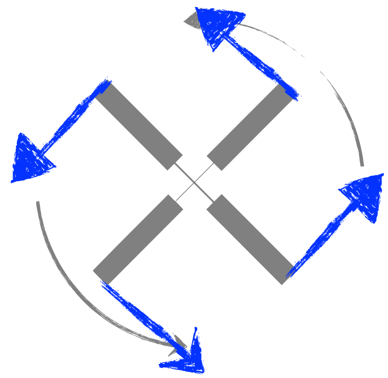
Fan slowing down: vector directions



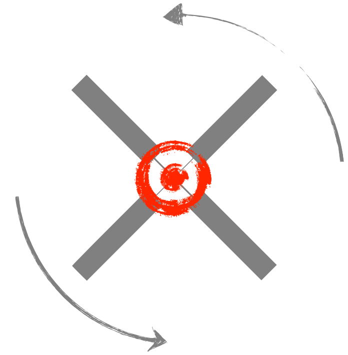
Out of screen
+
"counterclockwise"

Into screen
–
"clockwise"

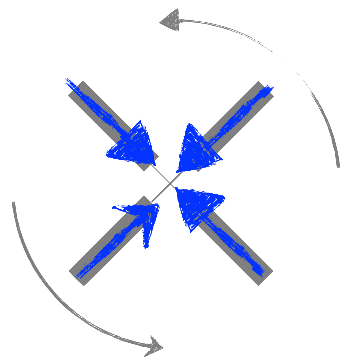
Tangential velocity



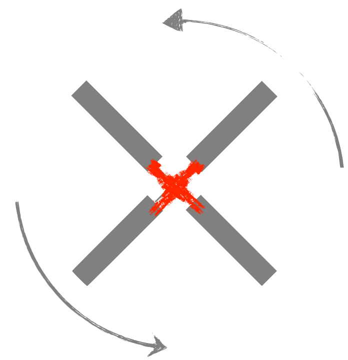
Angular velocity



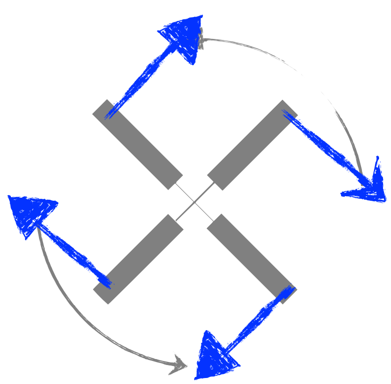
Centripetal accel.



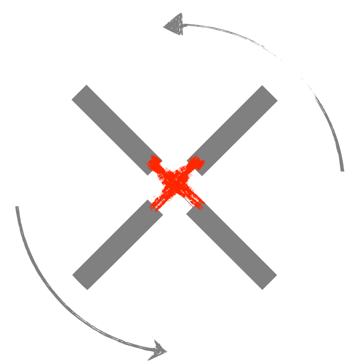
Angular accel.



Tangential accel.

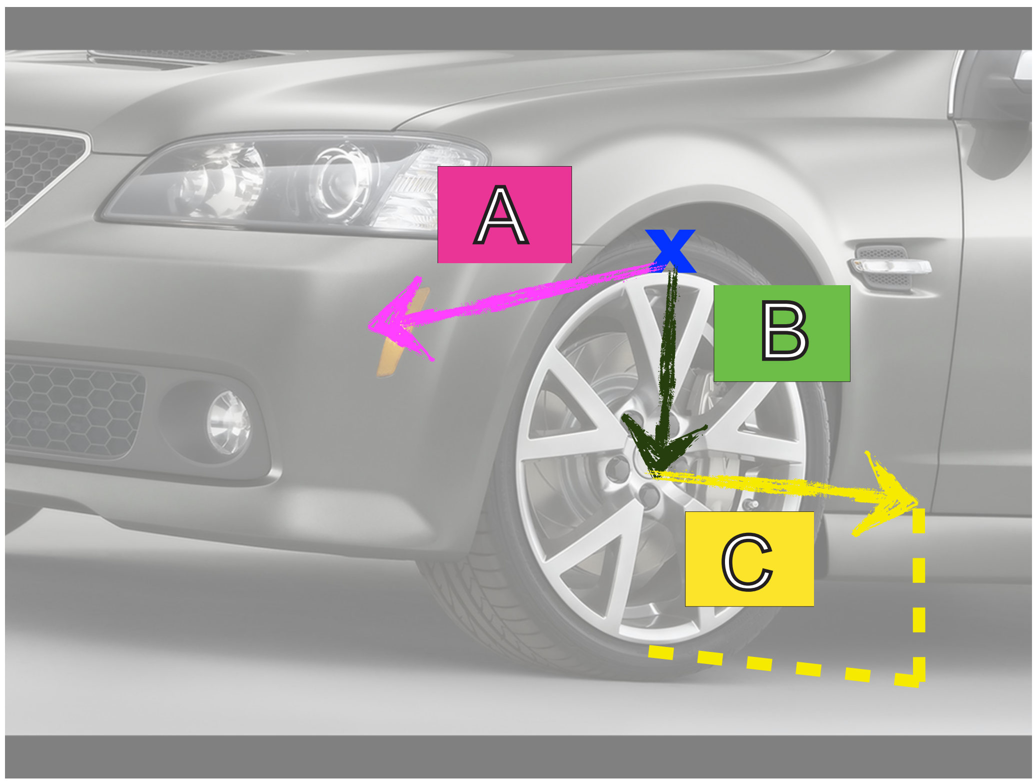


Torque



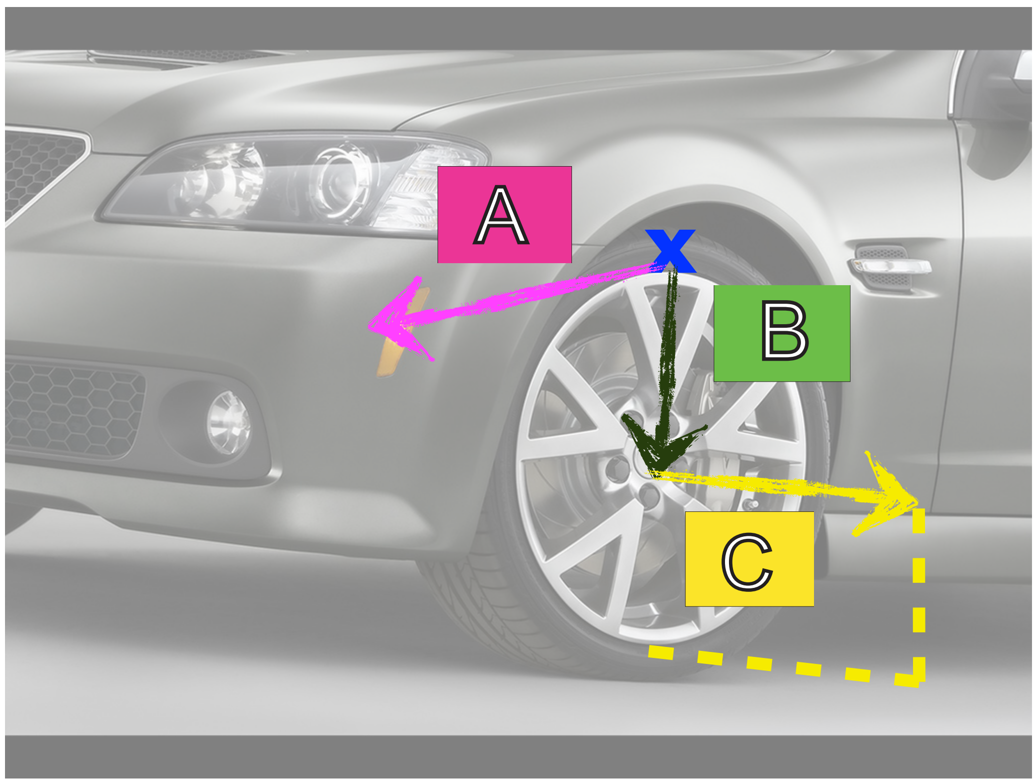
Clicker question #111a

- If the car shown below accelerates forward to a speed of 20 mi/hr, what is the direction of the **tangential acceleration** of point **x**?



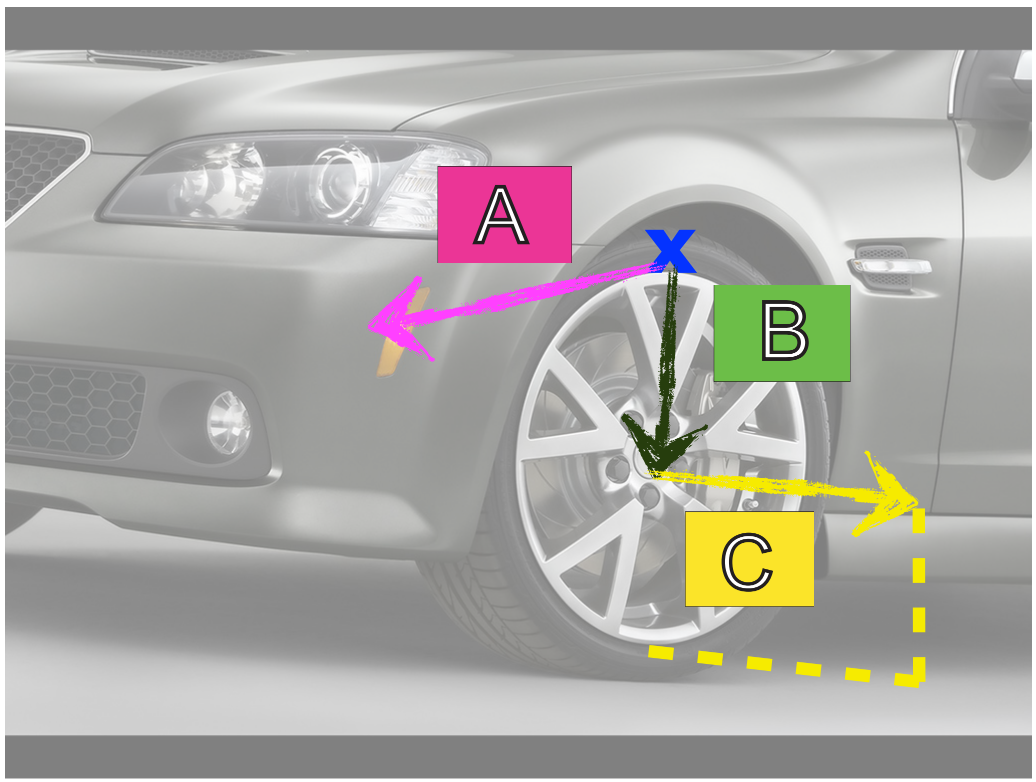
Clicker question #111b

- If the car shown below accelerates forward to a speed of 20 mi/hr, what is the direction of the **centripetal acceleration** of point **x**?



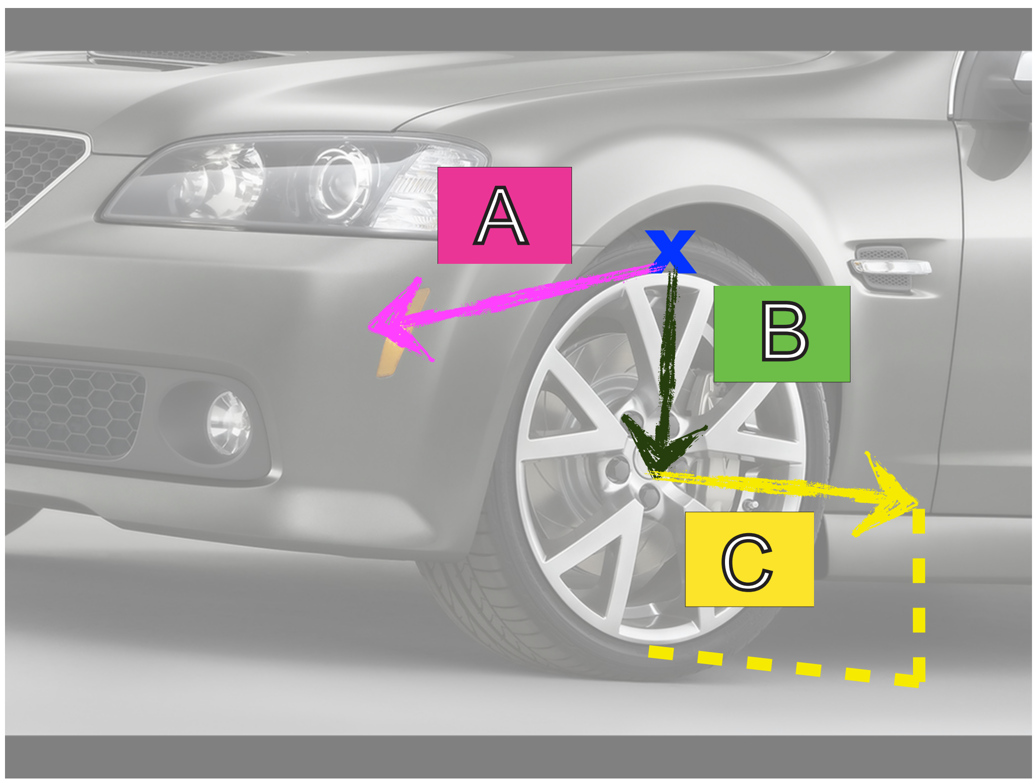
Clicker question #111c

- If the car shown below accelerates forward to a speed of 20 mi/hr, what is the direction of the final **angular velocity** of point **x**?



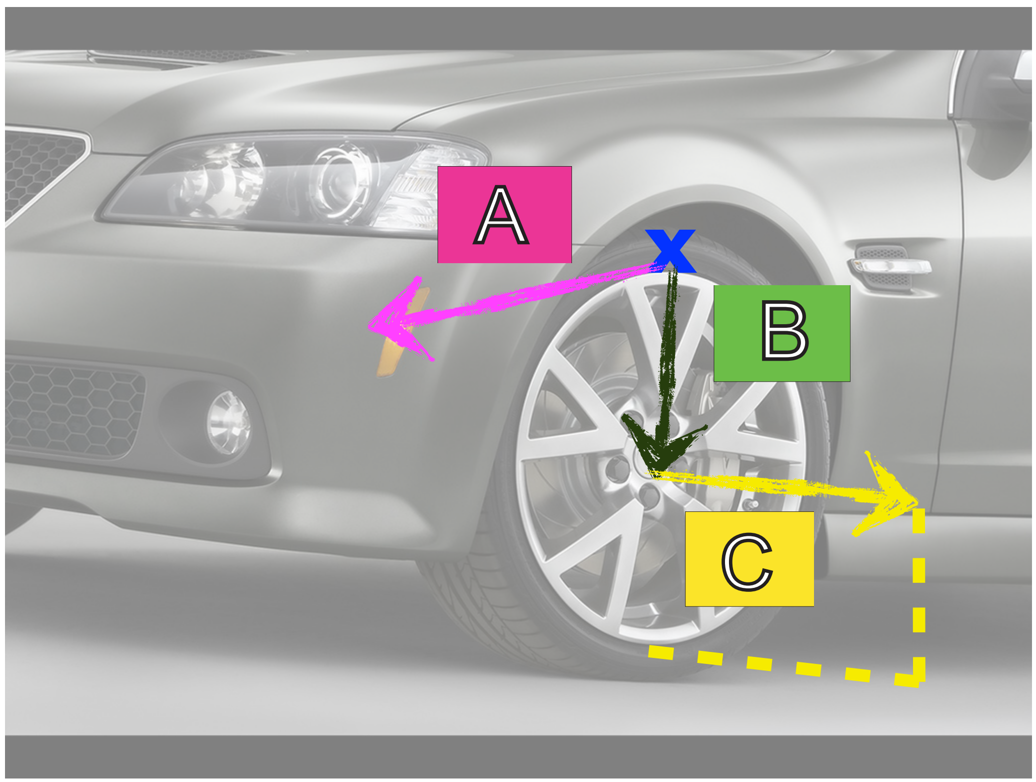
Clicker question #111d

- If the car shown below accelerates forward to a speed of 20 mi/hr, what is the direction of the **angular acceleration** of point **x**?



Clicker question #111e

- If the car shown below accelerates forward to a speed of 20 mi/hr, what is the direction of the **torque** of point **x**?



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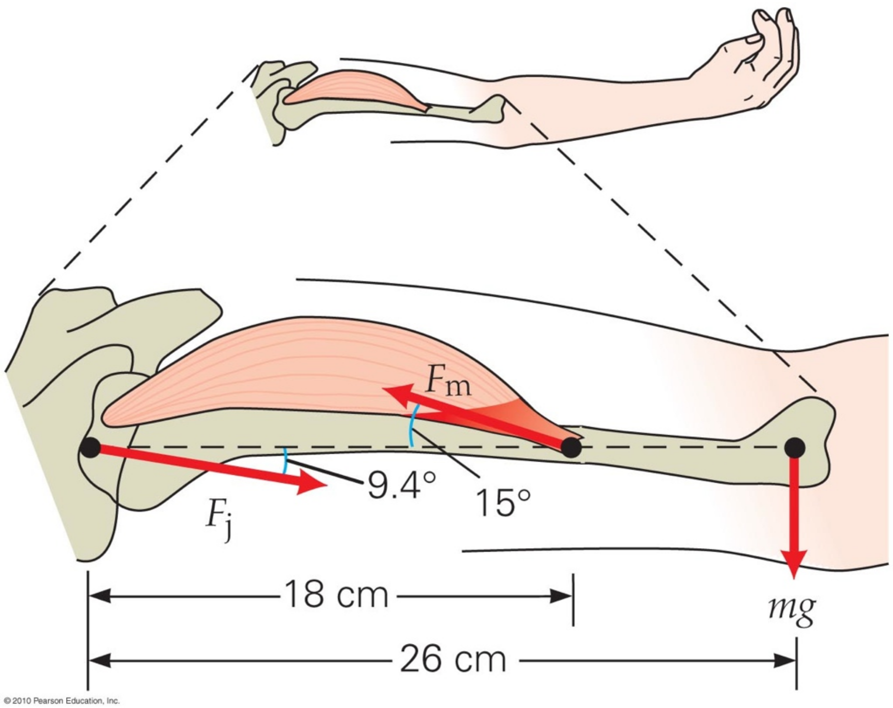
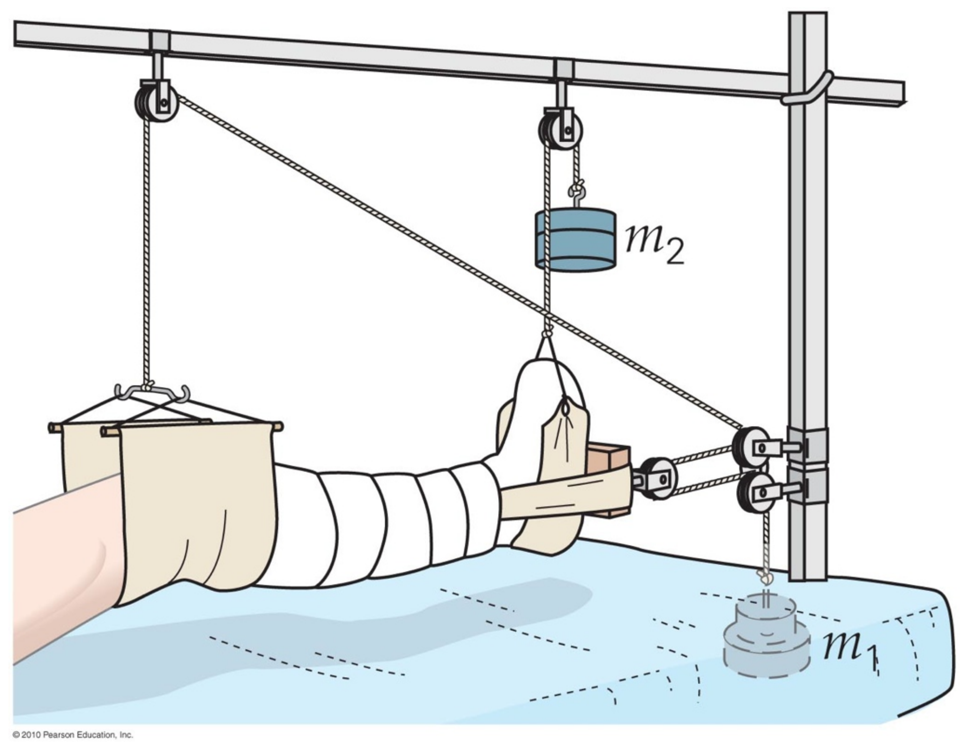
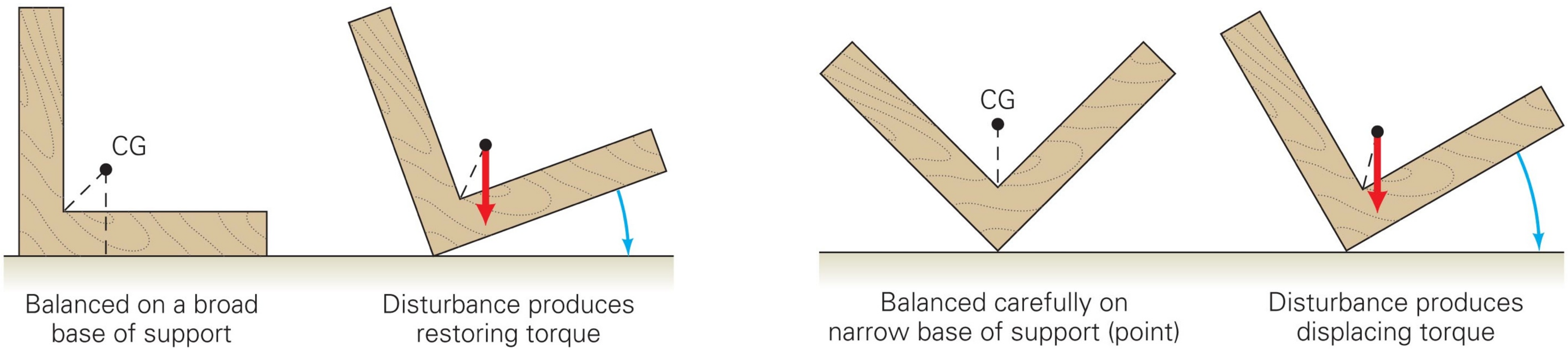
Example of equilibrium: humans





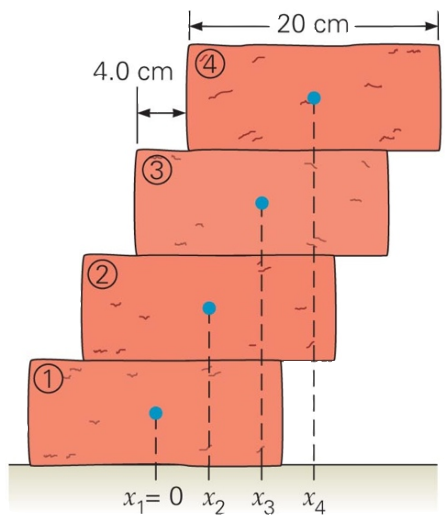
Stable equilibrium

- Condition for stable equilibrium: center of mass is above base of support



(a) Stable Equilibrium

(b) Unstable Equilibrium



Clicker question #108

Question 8.15b Tipping Over II

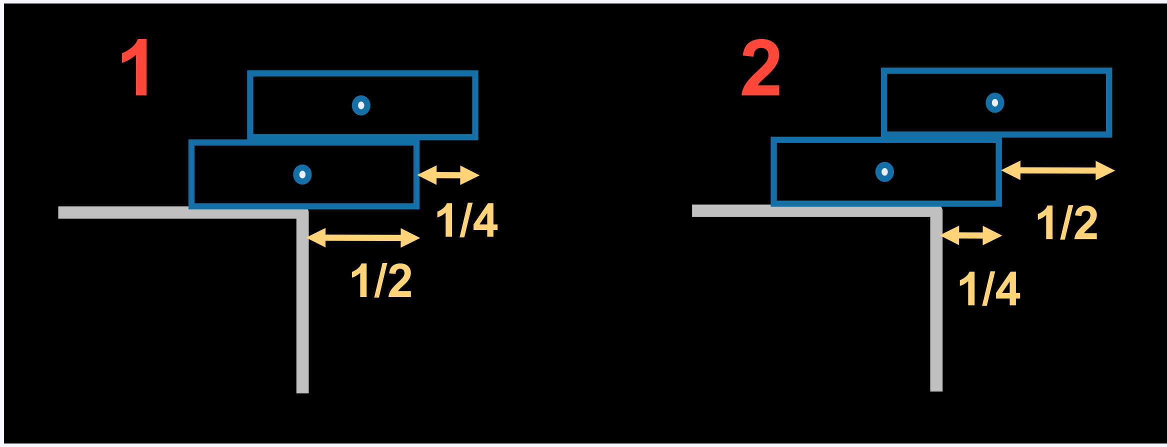
Consider the two configurations of books shown below. Which of the following is true?

A case 1 will tip

B case 2 will tip

C both will tip

D neither will tip



Lecture 23 outline

- Announcements
- Class participation followup
- Rigid body motion
  - Equilibrium examples: brick stacking, traction
  - Rotational dynamics
    - Moment of inertia
    - Example: opening a door
  - Rotational work and kinetic energy
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Moment of inertia

- Rotational analog of mass
  - I.e. a measure of rotational inertia
- Newton's second law

$$\vec{\mathbf{F}}_{\text{net}} = m\vec{\mathbf{a}}$$

$\vec{\mathbf{F}}_{\text{net}} = \text{net force}$

$m = \text{mass} \quad \vec{\mathbf{a}} = \text{accel.}$

Describes motion of center of mass

$$\vec{\tau}_{\text{net}} = I\vec{\alpha}$$

$\vec{\tau}_{\text{net}} = \text{torque} \quad \vec{\alpha} = \text{angular accel.}$

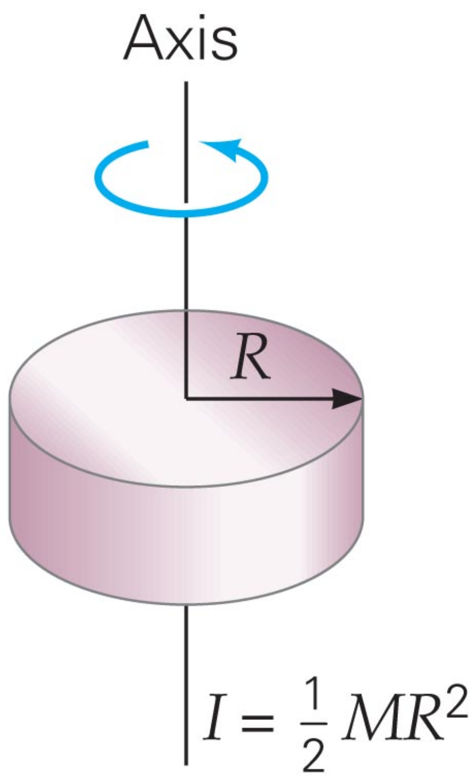
$I = \text{Moment of inertia}$

Describes rotational motion

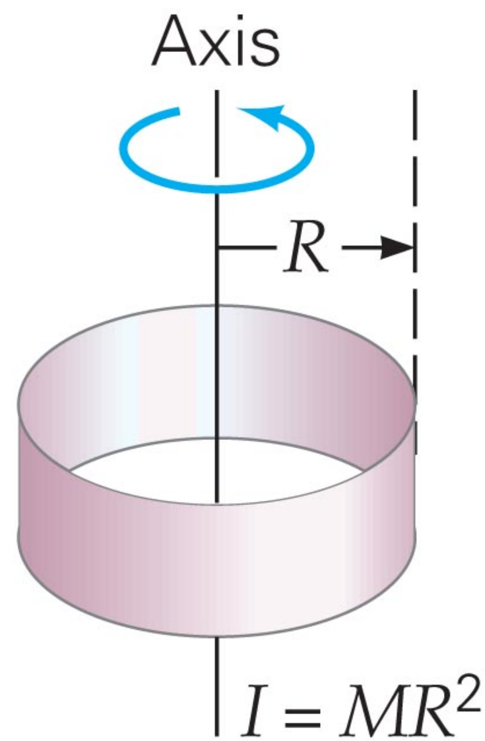
- Computing moment of inertia
  - Depends on mass distribution
  - System of individual particles $I = \sum m_i r_i^2$
  - Continuous object: derive with calculus

Moment of inertia

- Examples



(e) Solid cylinder or disk



(d) Thin cylindrical shell, hoop, or ring

Clicker question #106

Question 8.9 Moment of Inertia

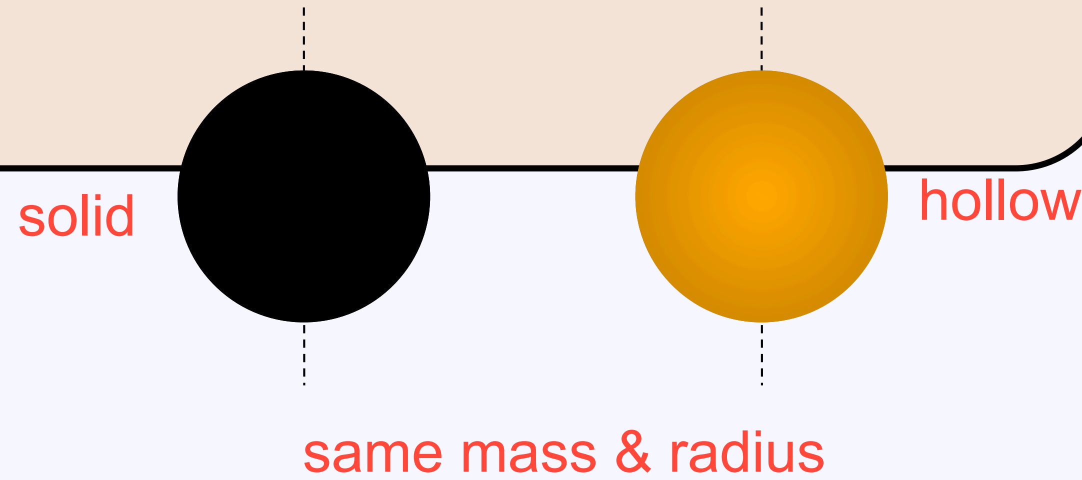
Two spheres have the same radius and equal masses. One is made of solid aluminum, and the other is made from a hollow shell of gold.

Which one has the bigger moment of inertia about an axis through its center?

A. **solid aluminum**

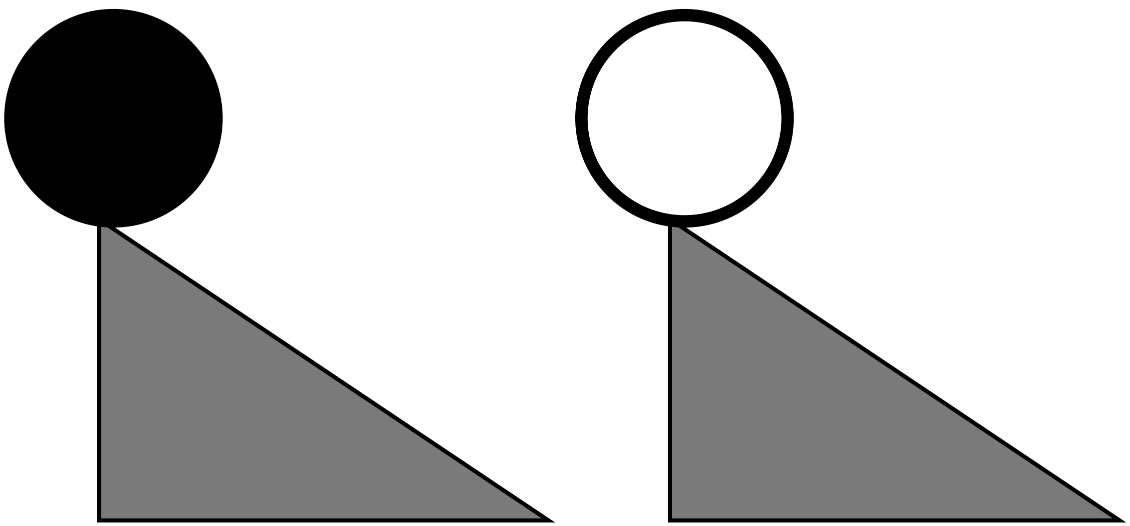
B. **hollow gold**

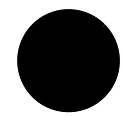
C. **same**

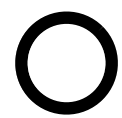


Clicker question #107

- A disk and ring (equal mass) start from rest at the same time down identical ramps. Which reaches the bottom of the ramp **first**?



A  first

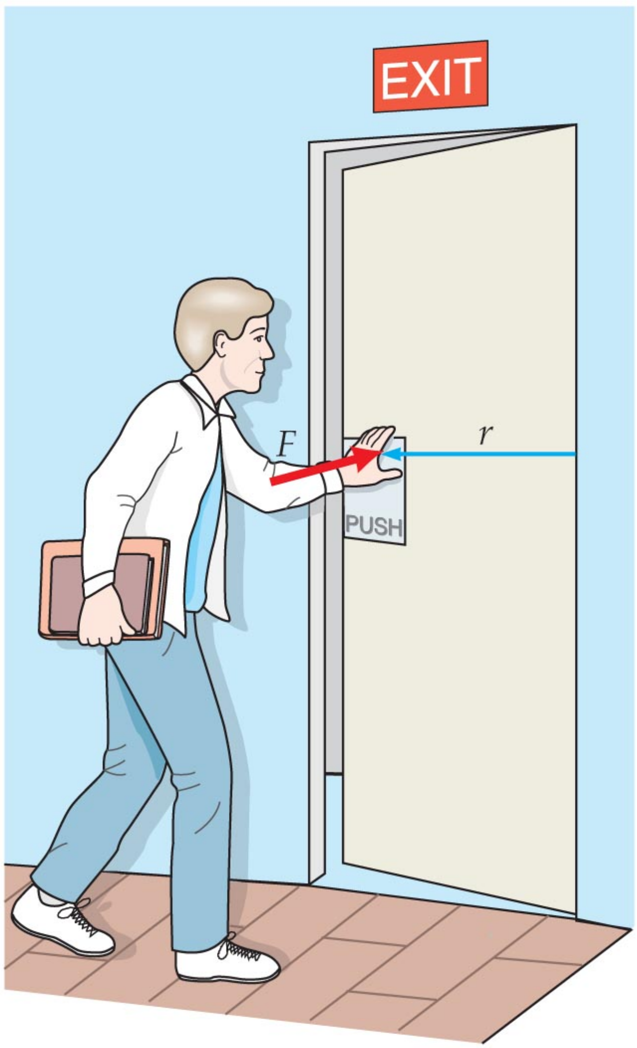
B  first

C Both arrive at the same time

D Not enough information to know

Ex. 8.12

- A student opens a 12 kg door by applying a force of 40 N at a perpendicular distance 0.90m from the hinges. If the door is 1.0m wide, what is the angular acceleration?



Given:

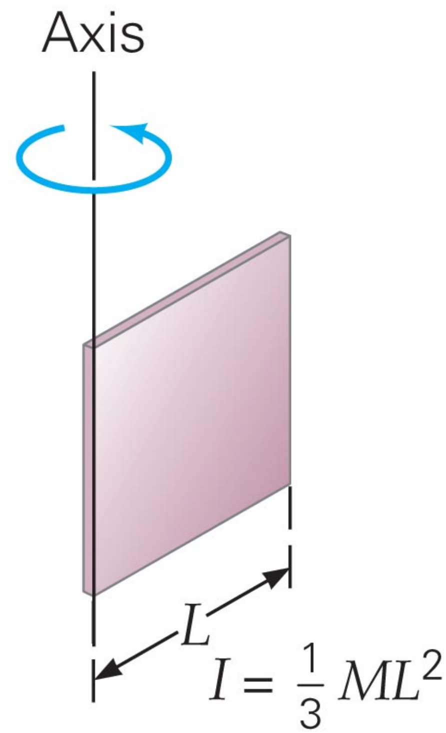
$$r_\perp = 0.90 \text{ m}$$
$$F = 40 \text{ N}$$
$$L = 1.0 \text{ m}$$
$$M = 12 \text{ kg}$$

Goal:

$$\alpha = ?$$

Principles & eqns.:

$$\vec{\tau} = I\vec{\alpha}$$



(k) Thin rectangular sheet

Ex. 8.12

Given:

$$r_\perp = 0.90 \text{ m}$$
$$F = 40 \text{ N}$$
$$L = 1.0 \text{ m}$$
$$M = 12 \text{ kg}$$

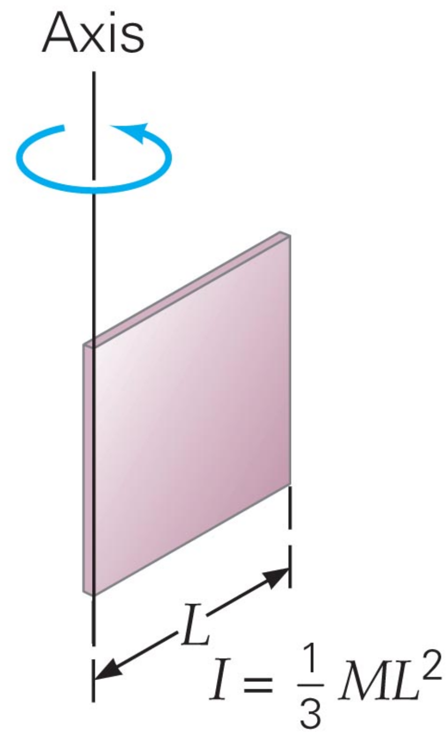
Goal:

$$\alpha = ?$$

Equation:

$$\vec{\tau} = I\vec{\alpha}$$

$$\alpha = \frac{\tau}{I} = \frac{r_\perp F}{\frac{1}{3}ML^2} = \frac{3(0.90 \text{ m})(40 \text{ N})}{(12 \text{ kg})(1.0 \text{ m}^2)} = 9.0 \text{rad/s}^2$$



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Rotational energy

- Rotational work for a single force

$$W = \tau\theta$$

Sign: + if $\vec{\tau}$ points along $\vec{\omega}$,
– if $\vec{\tau}$ points opposite $\vec{\omega}$

$$W = Fd$$

- Rotational power

$$P = \tau\omega$$

Sign: + if $\vec{\tau}$ points along $\vec{\omega}$,
– if $\vec{\tau}$ points opposite $\vec{\omega}$

$$P = Fv$$

- Rotational kinetic energy

$$K = \frac{1}{2}I\omega^2$$

$$K = \frac{1}{2}mv^2$$

Clicker question #108

Question 8.8a Dumbbell I

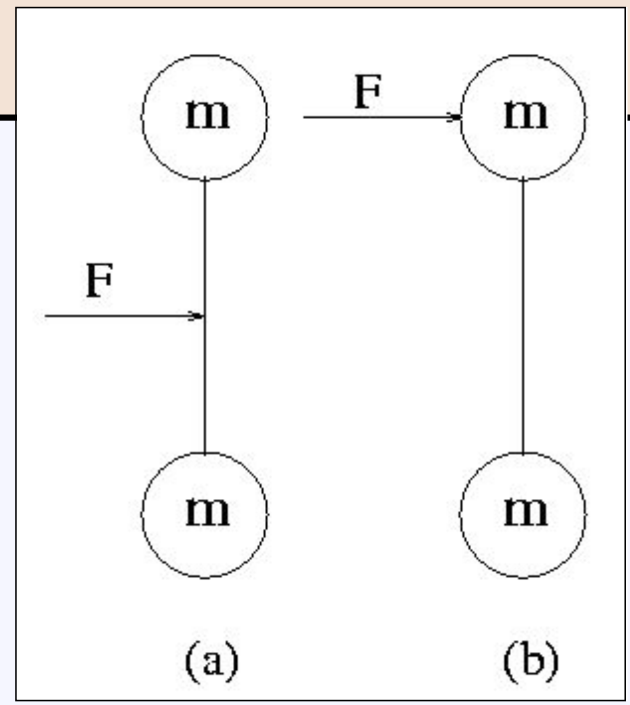
A force is applied to a dumbbell for a certain period of time, first as in (a) and then as in (b). In which case does the dumbbell acquire the greater center-of-mass speed ?

A case (a)

B case (b)

C no difference

D it depends on the rotational inertia of the dumbbell



Clicker question #109

Question 8.8b Dumbbell II

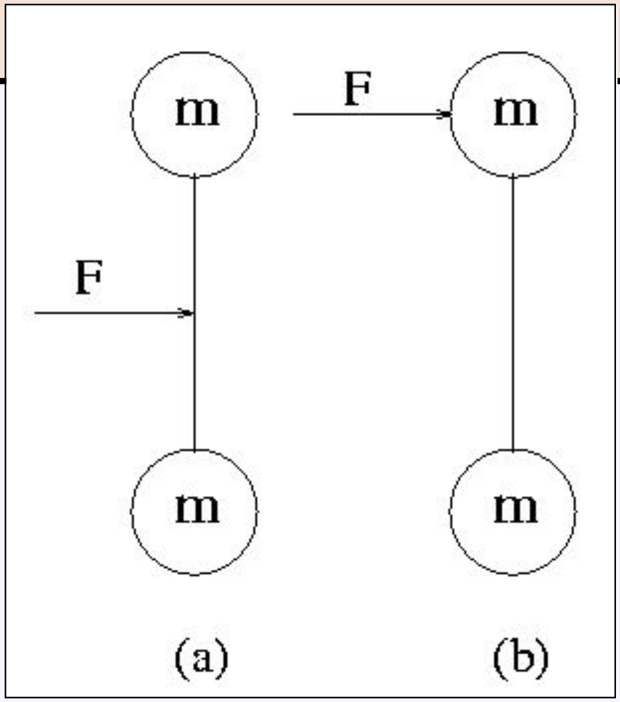
A force is applied to a dumbbell for a certain period of time, first as in (a) and then as in (b). In which case does the dumbbell acquire the greater energy ?

A. case (a)

B. case (b)

C. no difference

D. it depends on the rotational inertia of the dumbbell



Ex. 8.16

- A ring is released from rest and rolls down the ramp without slipping, and no energy is lost to friction. What is the linear speed of the ring's center of mass when it reaches the bottom?

Given: $h = 0.25\ \mathrm{m}$ $\quad v_0 = 0$

$I = MR^2 \quad \omega_0 = 0$

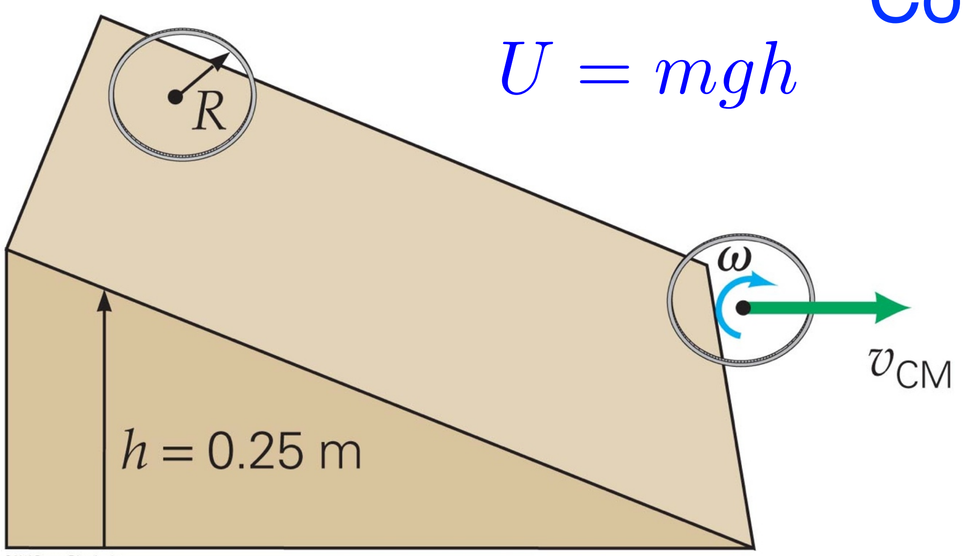
Goal: v_{CM}

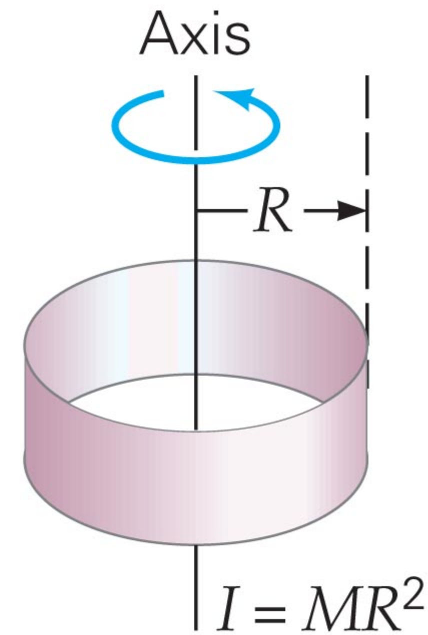
Principles & eqns.:

$$K = \frac{1}{2}I\omega^2 + \frac{1}{2}mv^2 \qquad v = r\omega$$

$$U = mgh$$

Conservation of energy





(d) Thin cylindrical shell, hoop, or ring

Ex. 8.16

Given: $h = 0.25\ \mathrm{m}$ $\quad v_0 = 0$
$I = MR^2$ $\quad \omega_0 = 0$

Goal: v_{CM}

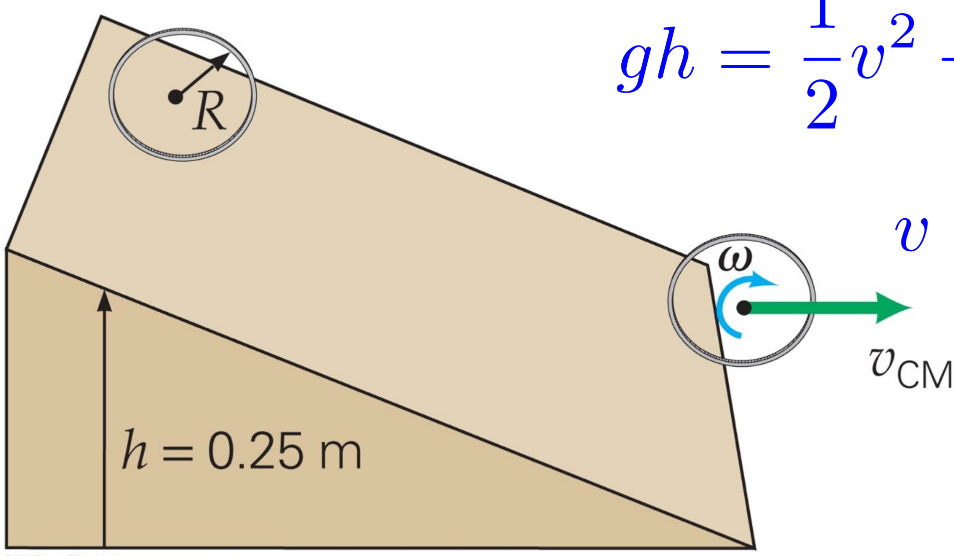
Principles & eqns.:

$$K = \frac{1}{2}I\omega^2 + \frac{1}{2}mv^2 \qquad v = r\omega \qquad U = mgh$$

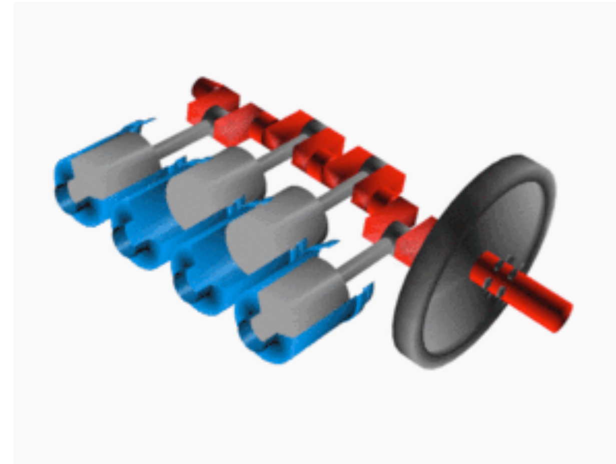
$$mgh = \frac{1}{2}I\omega^2 + \frac{1}{2}mv^2 = \frac{1}{2}mR^2\frac{v^2}{R^2} + \frac{1}{2}mv^2$$

$$gh = \frac{1}{2}v^2 + \frac{1}{2}v^2 \qquad v = \sqrt{gh}$$

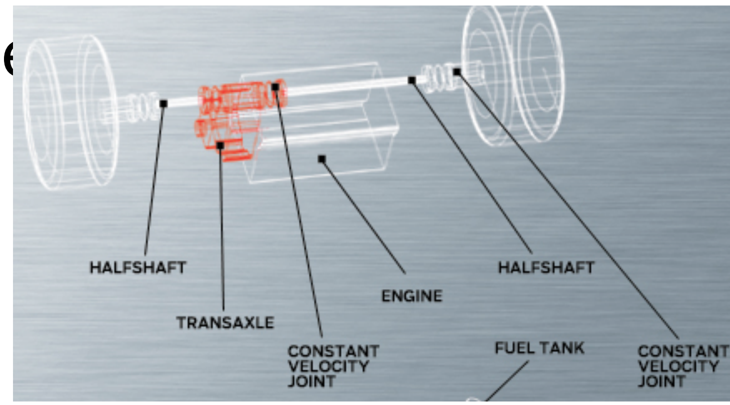
$$v = \sqrt{(0.25\ \mathrm{m})(9.8\ \mathrm{m/s^2})} = 1.6\ \mathrm{m/s}$$



Example: car

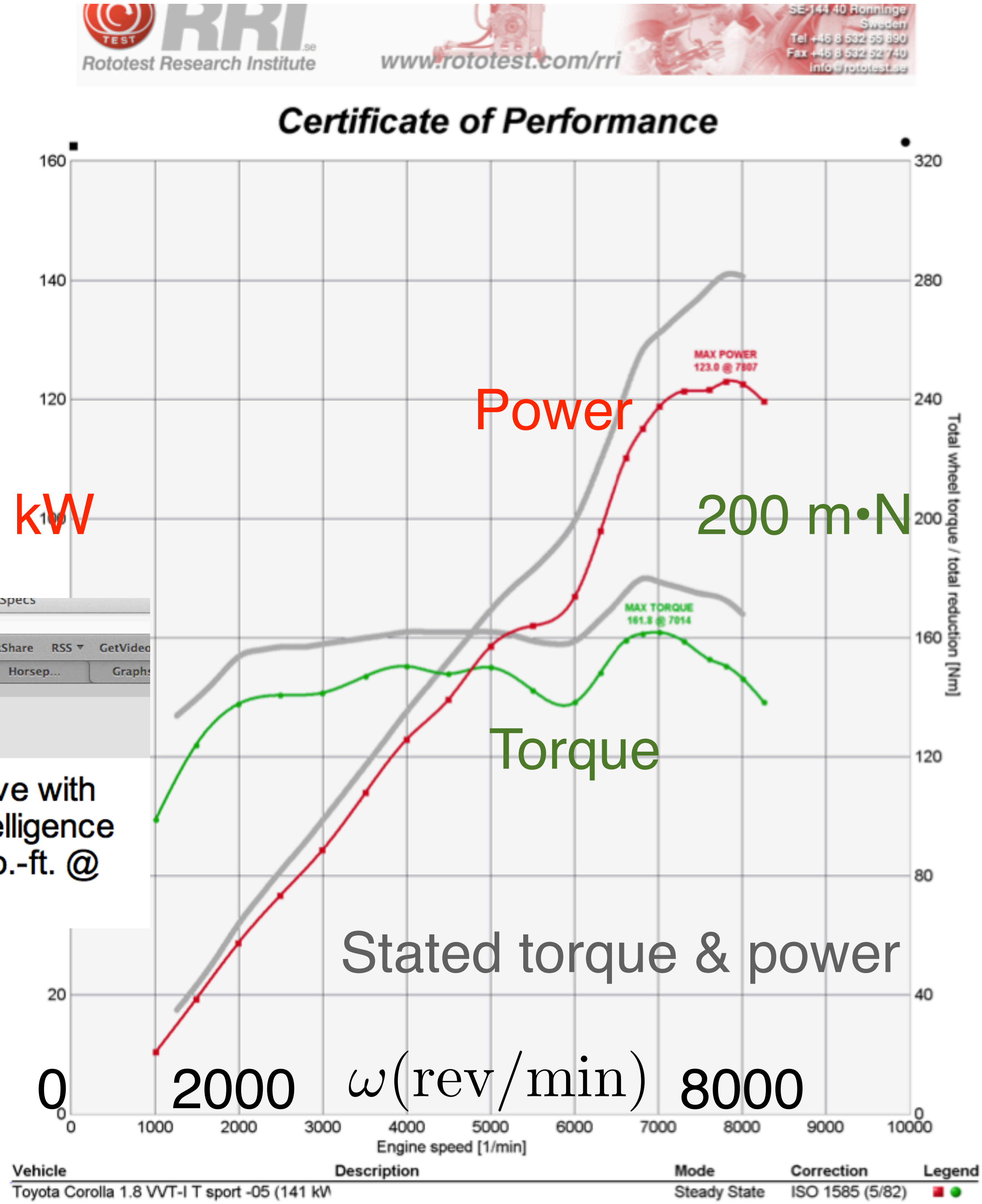


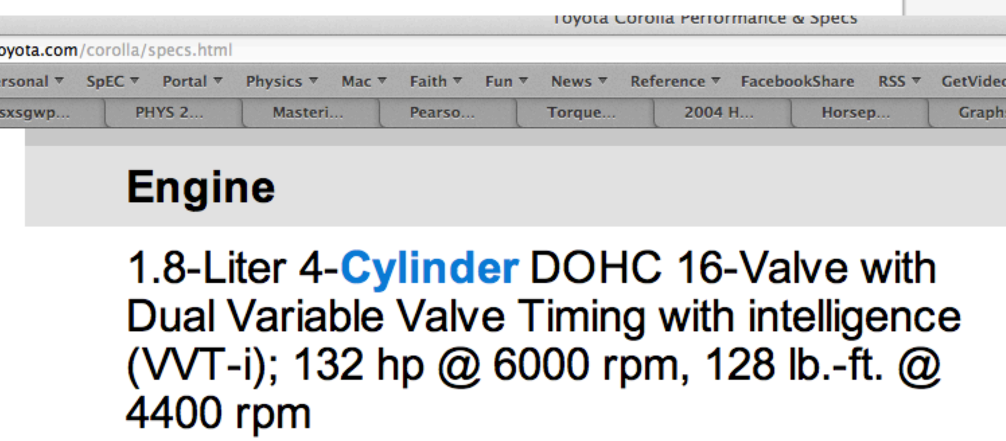
- Basic idea
  - Engine: gives angular acceleration to a flywheel
  - Transmission: connect flywheel to axle
    - Uses gears: wheels have lower angular speed
- Engine ratings
  - Torque: determines how much angular acceleration engine can give to flywheel
  - Power: rotational power output of engine $P = \tau\omega$
  - Dealers quote max torque, max power "King of torque" http://www.youtube.com/watch?v=JR3nQf79gtc



Car spec

- Torque roughly constant at all angular velocities
- Power roughly linear in angular velocity





Toyota Corolla Performance & Specs

Engine

1.8-Liter 4-Cylinder DOHC 16-Valve with Dual Variable Valve Timing with intelligence (VVT-i); 132 hp @ 6000 rpm, 128 lb.-ft. @ 4400 rpm

Class participation #22

- 0. Full name
- 1. I would most like to see another in-class worked example about…
  - Center of mass
  - Torque
  - Rotational dynamics
  - Trans./rot. equilibrium & free-body diagrams
  - Rotational energy/power/work