Physics 211

Sections 1 & 70

Dr. Geoffrey Lovelace

Fall 2012

Lecture 22 (11/27/12)

Lecture 22 outline

- Announcements
- Exam followup
- Introduction to rigid body motion
  - Rigid bodies
  - Rolling without slipping
  - Torque
  - Equilibrium

Announcements

- Homework #10: assigned today
  - Due in 1 week at 11:59PM
  - Homework #11: last homework
- Course schedule updated: see piazza.com
- Reading: Continue chapter 8
- Office hours: 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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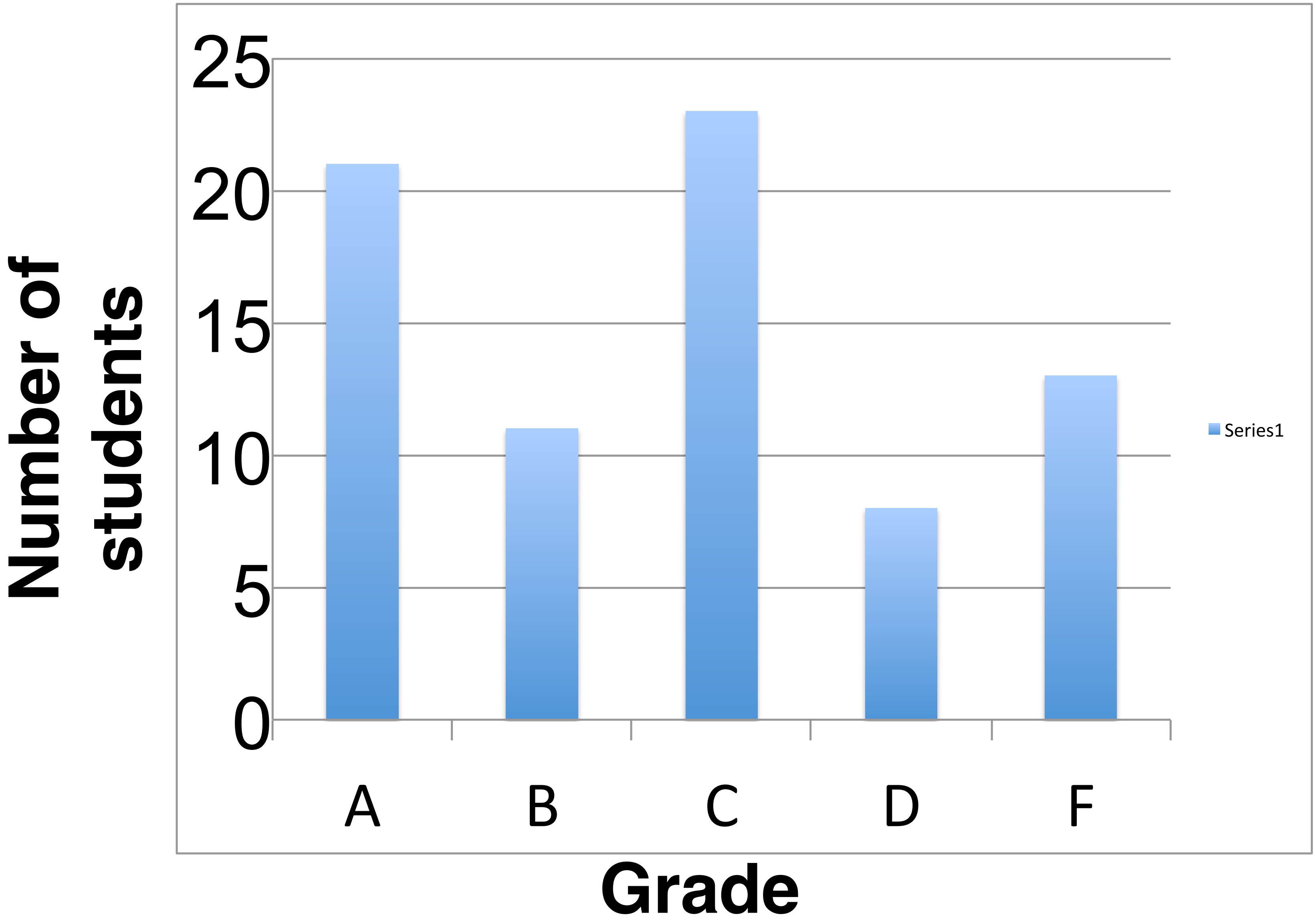
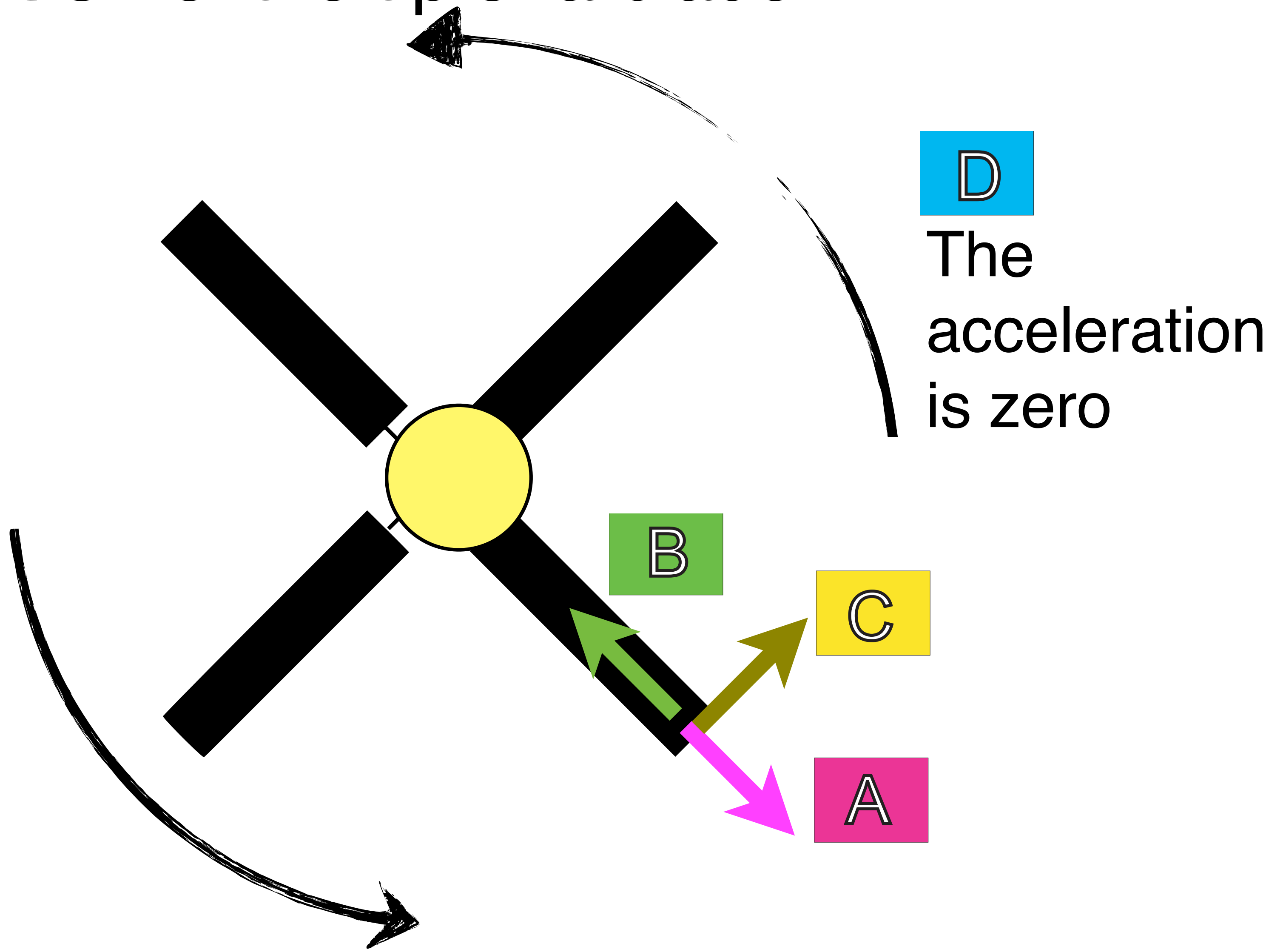
Exam followup



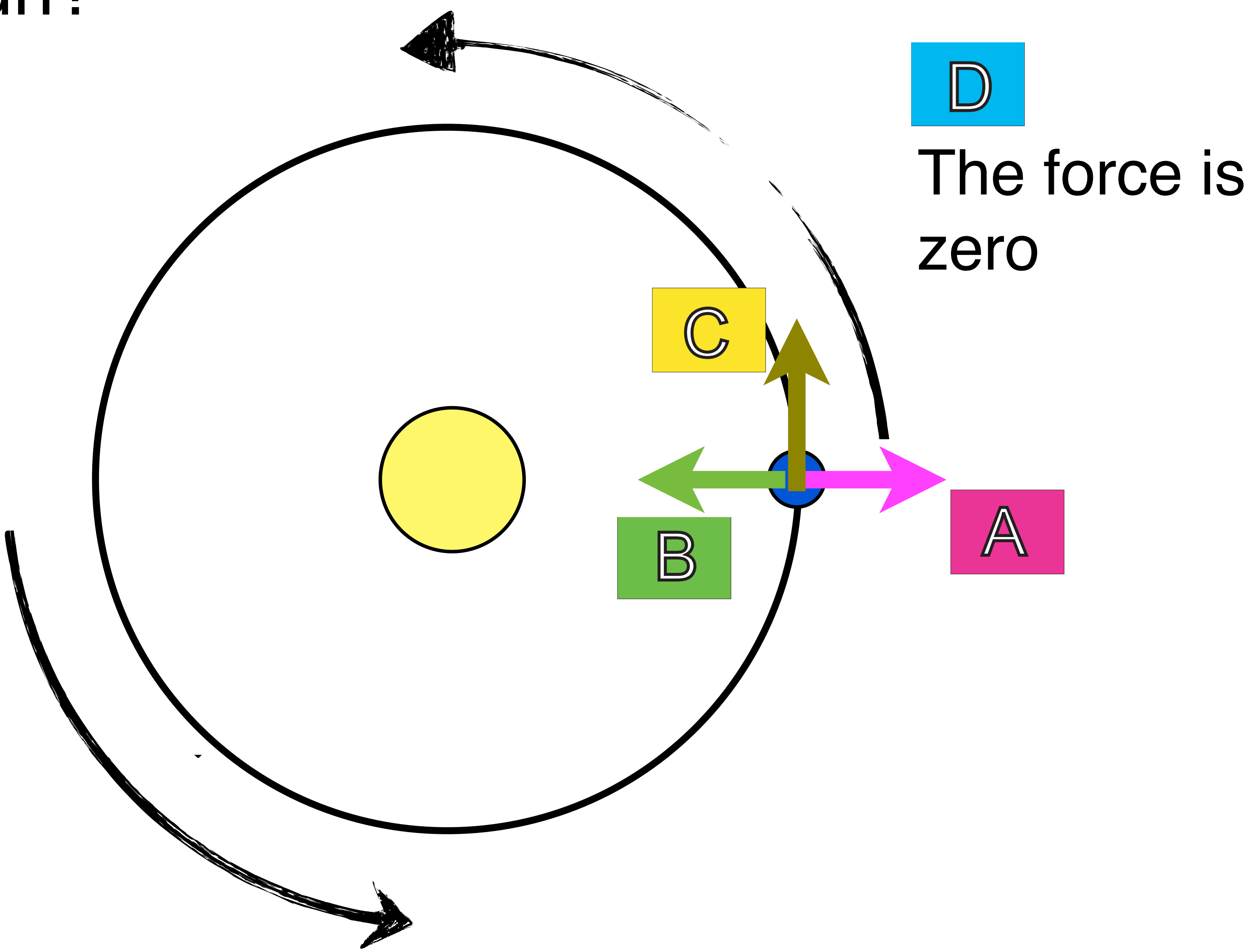
Clicker question #100

- What is the direction of the **instantaneous acceleration** of the tip of a blade?



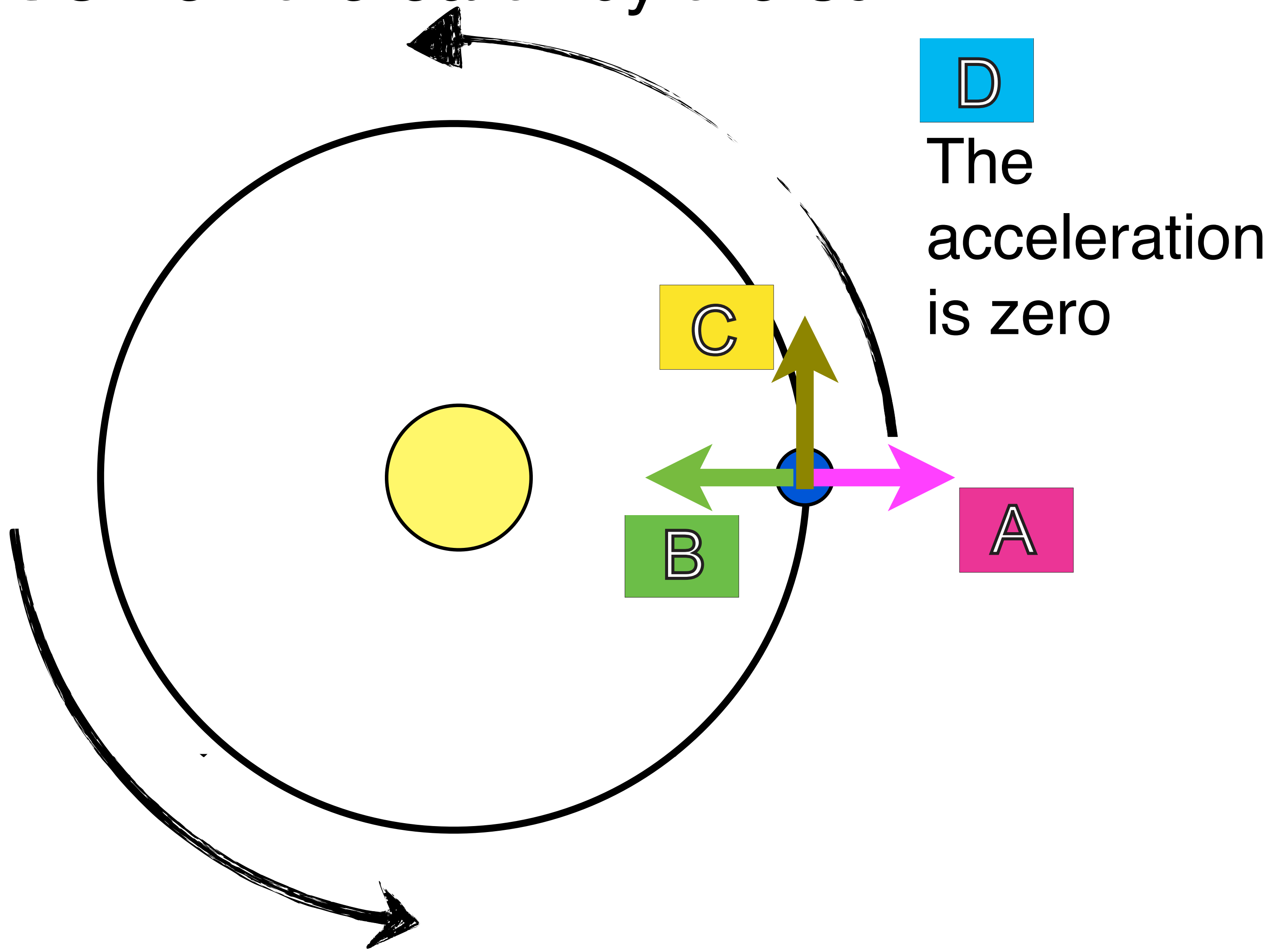
Clicker question #98

- What is the direction of the **force** on the earth by the sun?



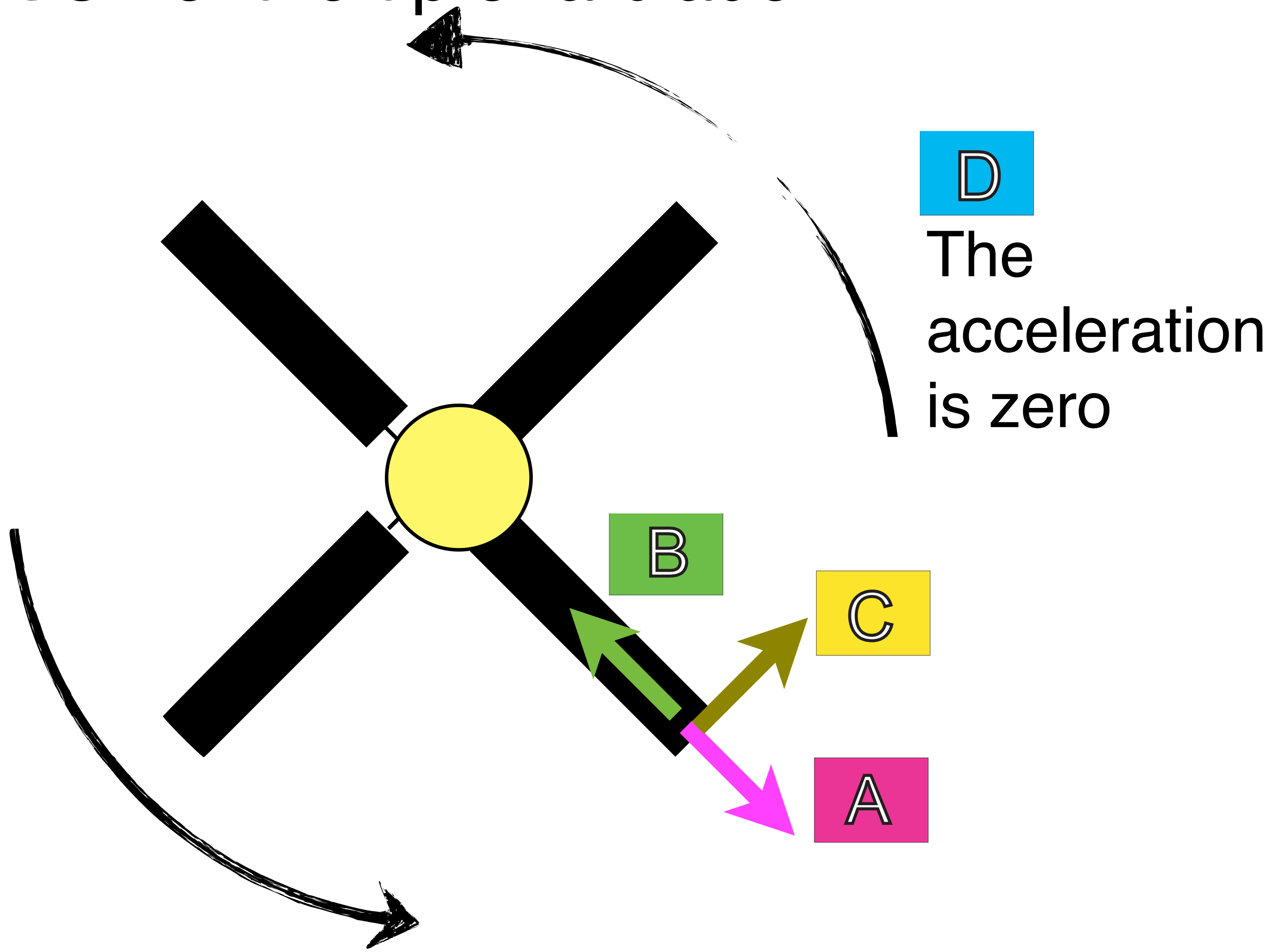
Clicker question #99

- What is the direction of the **instantaneous acceleration** on the earth by the sun?



Clicker question #100

- What is the direction of the **instantaneous acceleration** of the tip of a blade?



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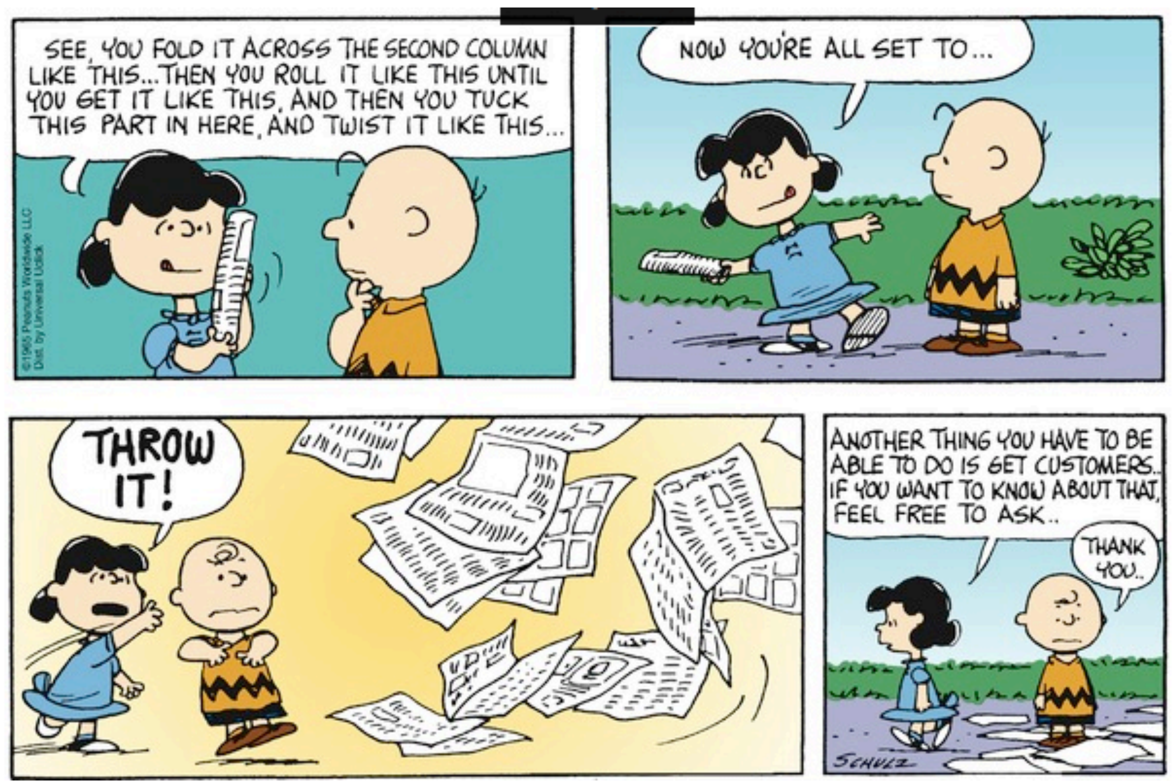
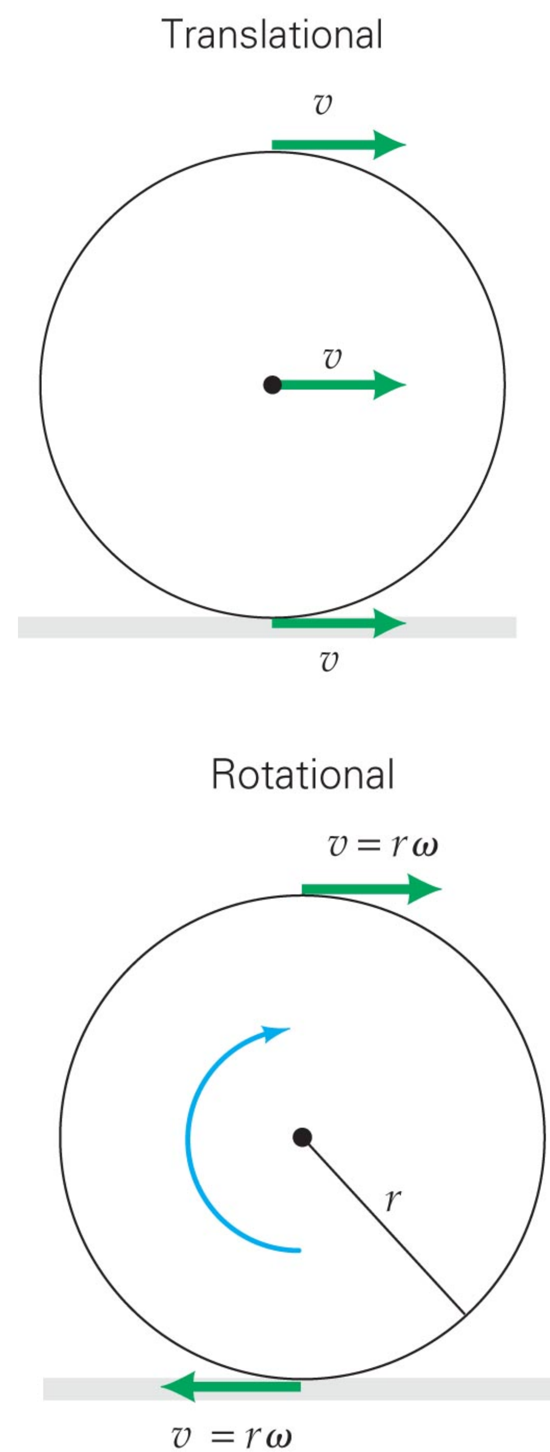
Rigid bodies

- Rigid body:
  - Solid extended object, distance between particles fixed
  - Neglect any deformations
- Examples: marker, iPhone
- Counter-examples: newspaper (not properly folded), beanbag



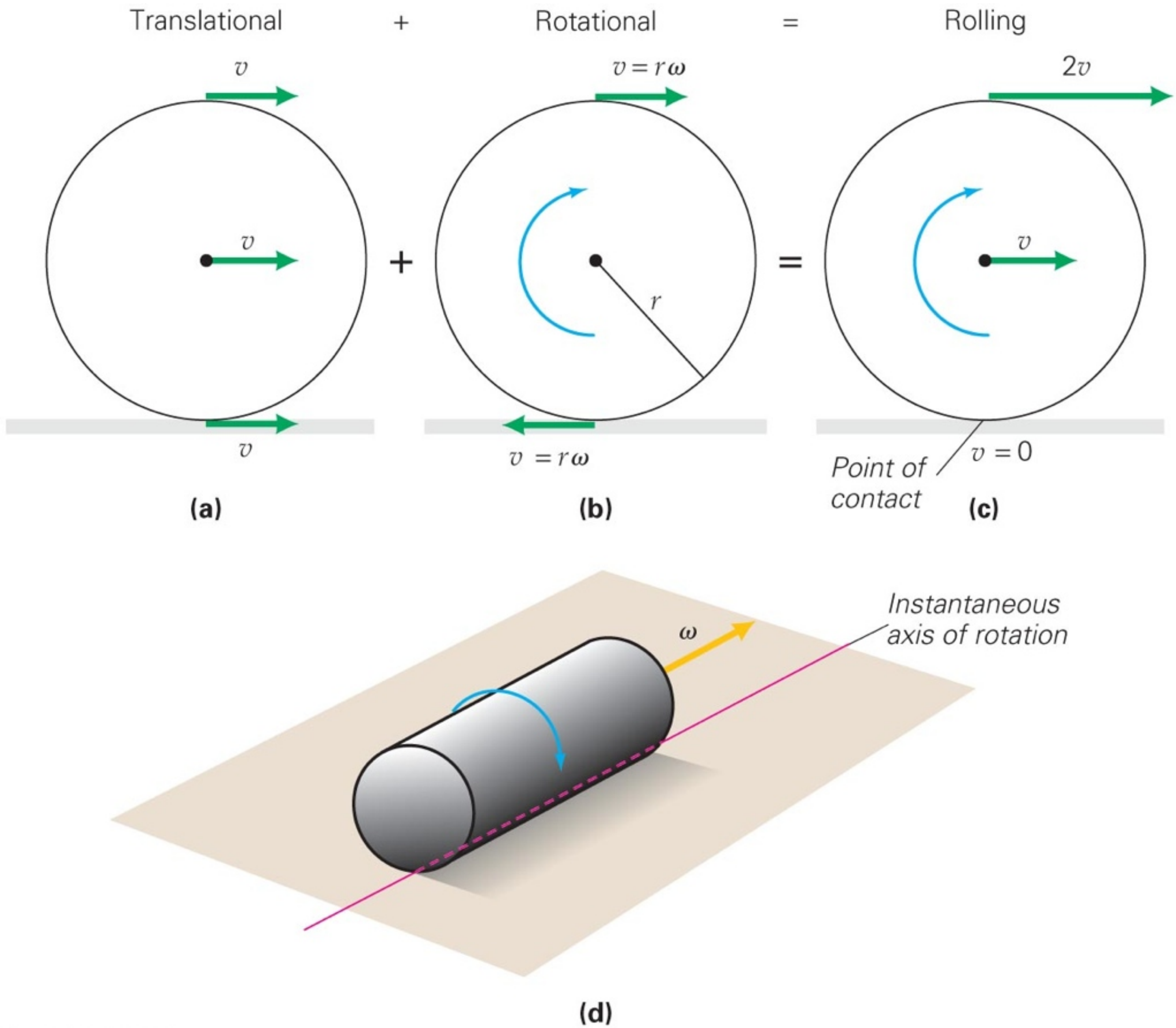
Translation & rotation

- Kinds of motion
  - Translational
    - All particles have equal instantaneous velocities
    - Treat as point particle
  - Rotational
    - All particles have equal instantaneous angular velocity about fixed axis of rotation
  - Example: video games http://www.play.vg/games/4-Asteroids.html



Rolling

- Translational + rotational motion



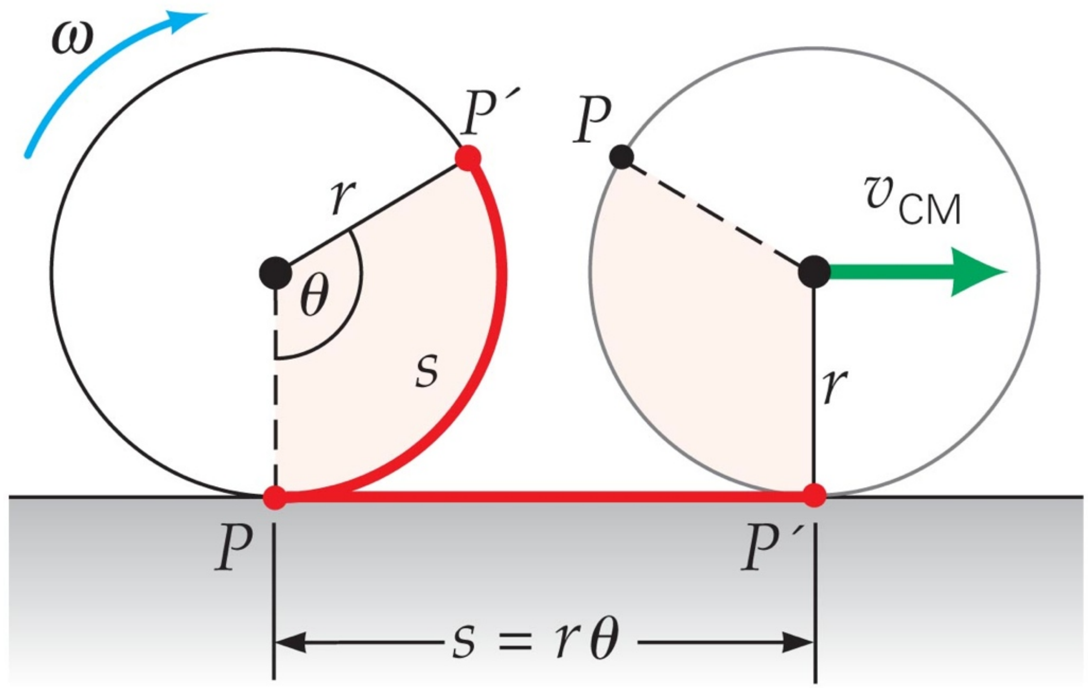
Rolling without slipping

- Static friction enough to prevent slipping
  - Counter example: drive on ice or in mud
- Relations

$$v_{CM} = r\omega$$

$$s = r\theta$$
$$v_{CM} = r\omega$$
$$a_{CM} = r\alpha$$

r = radius of roller
v = velocity
a = acceleration
CM = center of mass
θ = angular displacement
ω = angular vel.
α = angular accel.



Clicker question #101

Question 8.2 Truck Speedometer

Suppose that the speedometer of a truck is set to read the linear speed of the truck but uses a device that actually measures the angular speed of the tires. If larger diameter tires are mounted on the truck instead of normal tires, how will that affect the speedometer reading as compared to the true linear speed of the truck?

- **A** speedometer reads a higher speed than the true linear speed
- **B** speedometer reads a lower speed than the true linear speed
- **C** speedometer still reads the true linear speed

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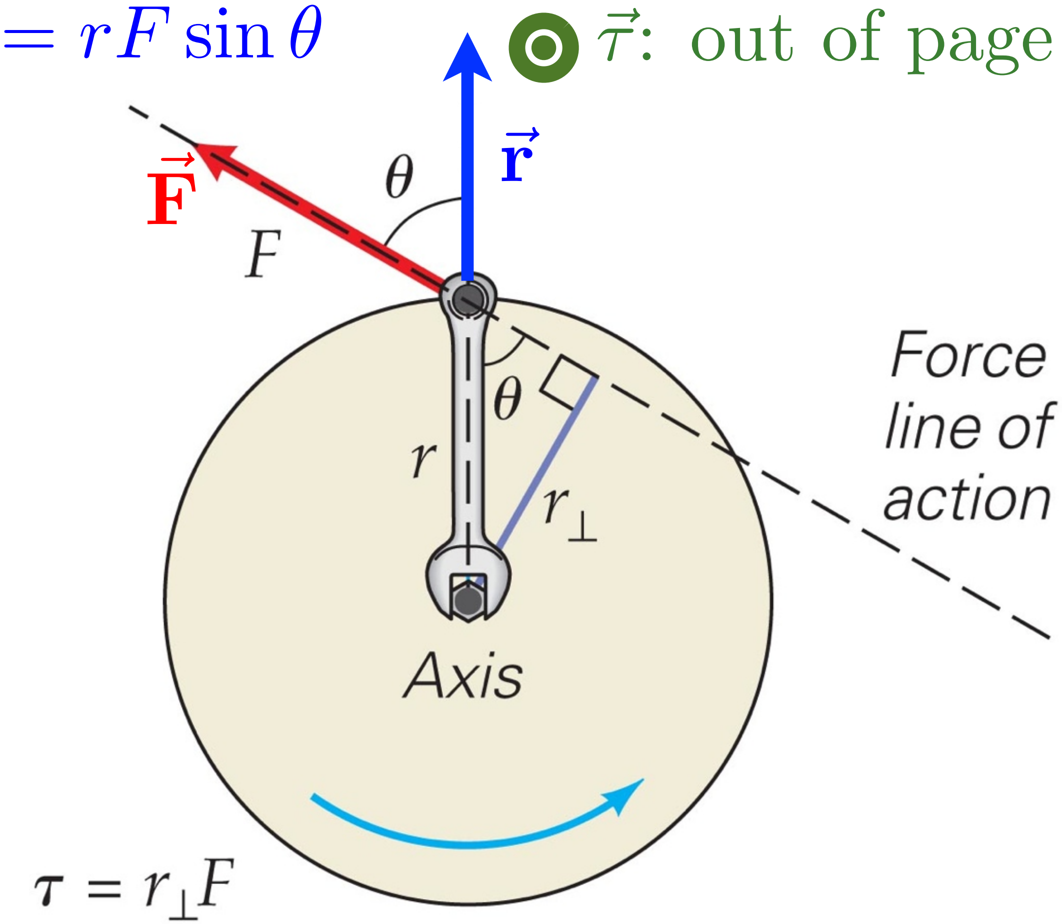
Torque

- Torque = τ = rotational analog of force
  - Zero torque = zero angular accel.

$r_\perp =$ lever arm

$\theta =$ angle between $\vec{\mathbf{r}}$ and $\vec{\mathbf{F}}$

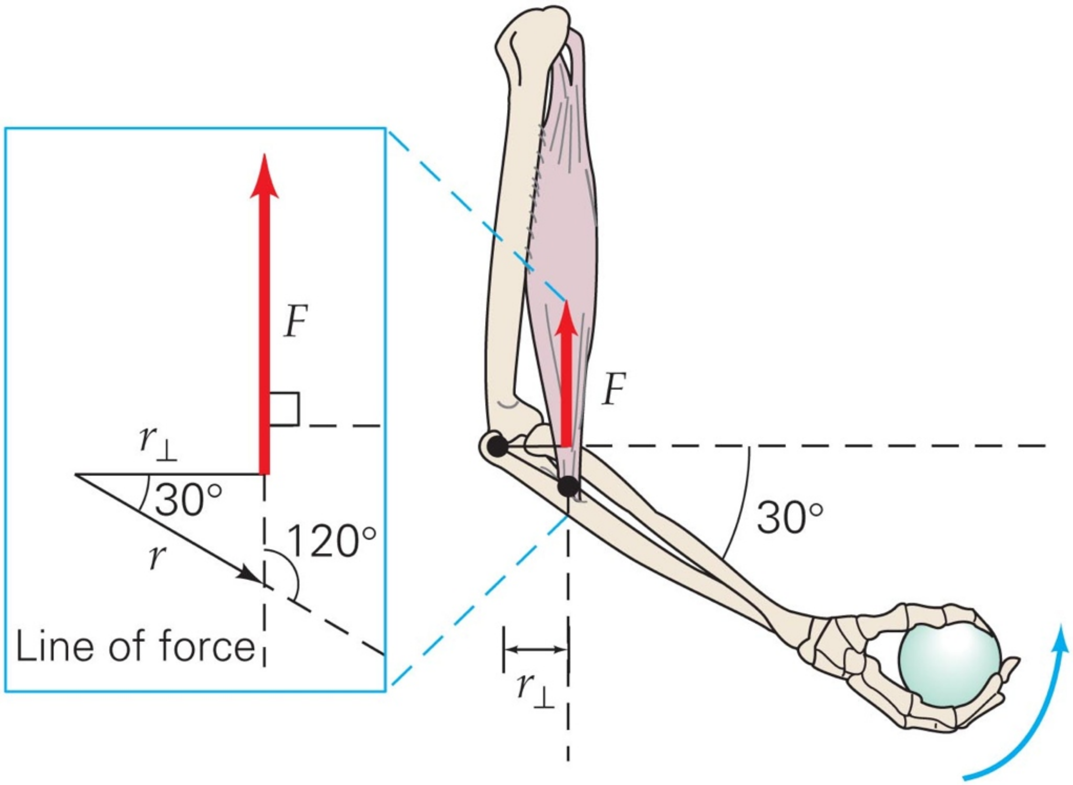
- Vector
  - Magnitude: $\tau \equiv r_\perp F = rF\sin\theta$
  - Direction: right-hand rule
  - Units: m•N [NOT N•m, not J; torque is not energy!]



Torque examples

- Tools: screwdrivers and wrenches
- Knobs & handles
- Larger knobs for arthritis

Ex. 8.2: lifting



(a) Starting to lift

Given:

$$F = 600\ \mathrm{N}$$
$$r = 4\ \mathrm{cm}$$
$$\theta = 120^\circ$$

Goal:

$$\vec{\tau}$$

$$\tau = rF\sin\theta = (4\ \mathrm{cm})\,(600\ \mathrm{N})\sin 120^\circ = 21\ \mathrm{m}\cdot\mathrm{N}$$

Clicker question #102

Question 8.5 Two Forces

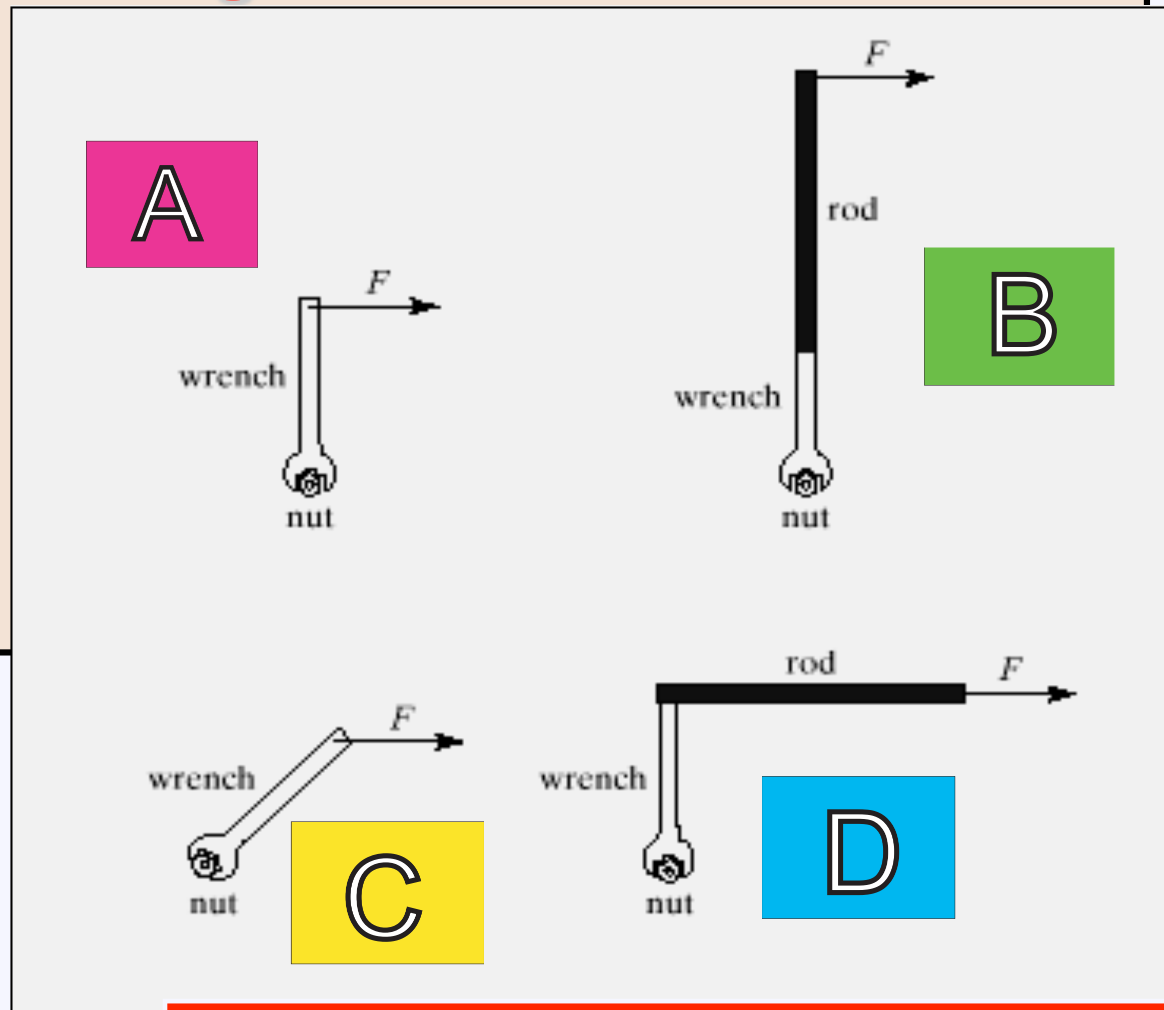
Two forces produce the same torque. Does it follow that they have the same magnitude?

- A) yes
- B) no
- C) it depends

Clicker question #103

Question 8.4 Using a Wrench

You are using a wrench to loosen a rusty nut. Which arrangement will be the most effective in loosening the nut?



E: all are equally effective

Clicker question #104

- Where should the outside doorknob on Bilbo's door be to make the door easiest to open?

D

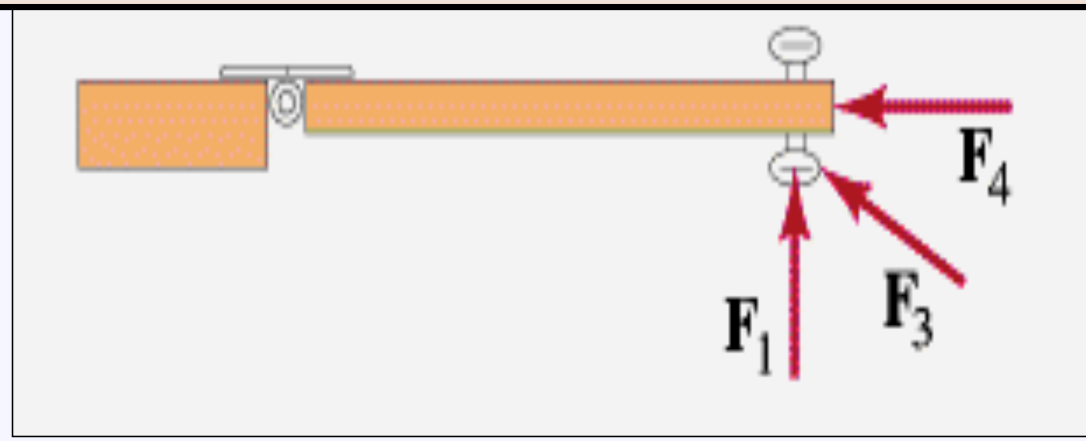
ABC equally easily open the door

Clicker question #105

Question 8.6 Closing a Door

In which of the cases shown below is the torque provided by the applied force about the rotation axis biggest? For all cases the magnitude of the applied force is the same.

- A F_1
- B F_3
- C F_4
- D all of them
- none of them



Equilibrium

- Mechanical equilibrium implies **both**
  - **Translational** equilibrium:
    no acceleration

$$\vec{\mathbf{F}}_{\mathrm{net}} = \sum \vec{\mathbf{F}}_i = \mathbf{0}$$

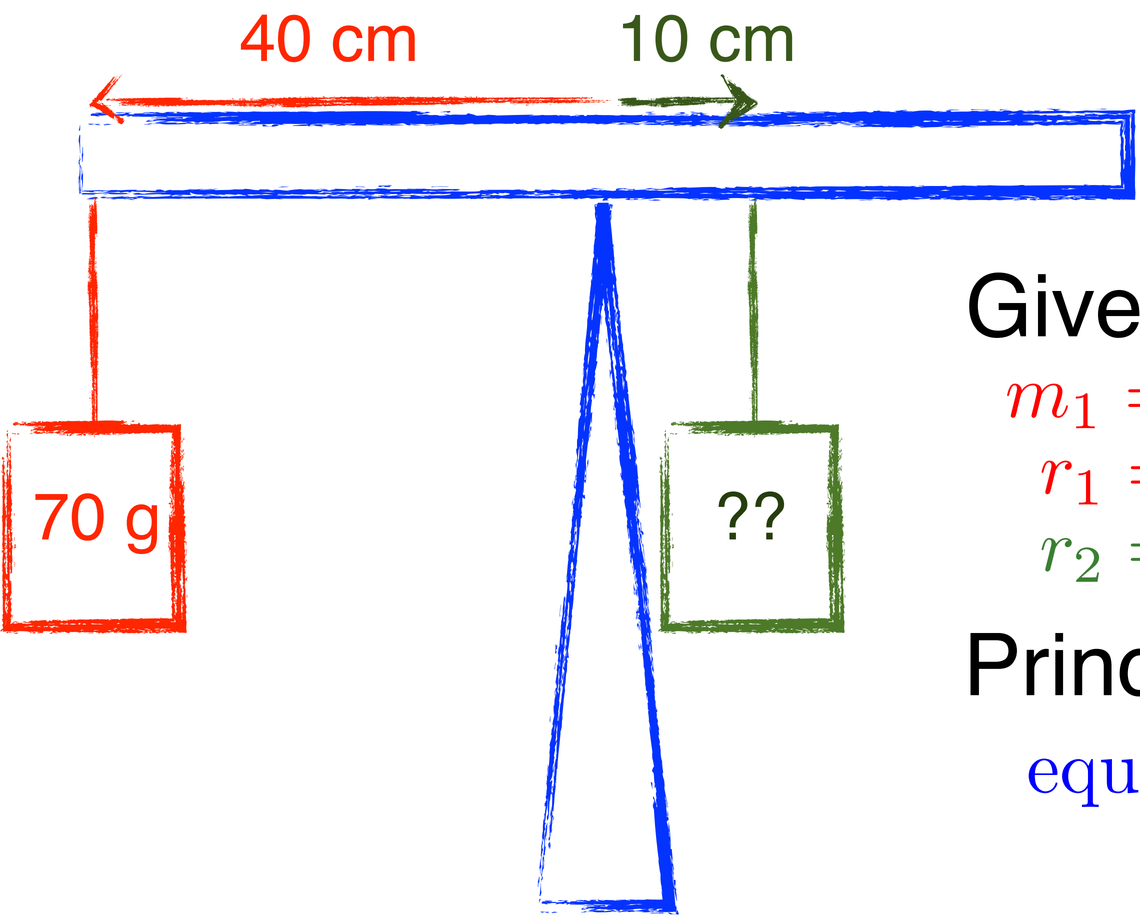
  - **Rotational** equilibrium:
    no *angular* acceleration

$$\vec{\tau}_{\mathrm{net}} = \sum \vec{\tau}_i = \mathbf{0}$$

    - If angular velocity = 0, choose rotation axis where most convenient

Demo & example

- A mass (70 g) is hung on a balancing meter stick 40 cm left of the axis of rotation. A second mass is hung 10 cm right of the axis of rotation. What is the second mass so that the system is in mechanical equilibrium?



Given:

$m_1 = 70\text{ g}$

$r_1 = 40\text{ cm}$

$r_2 = 10\text{ cm}$

Goal:

$m_2 = ?$

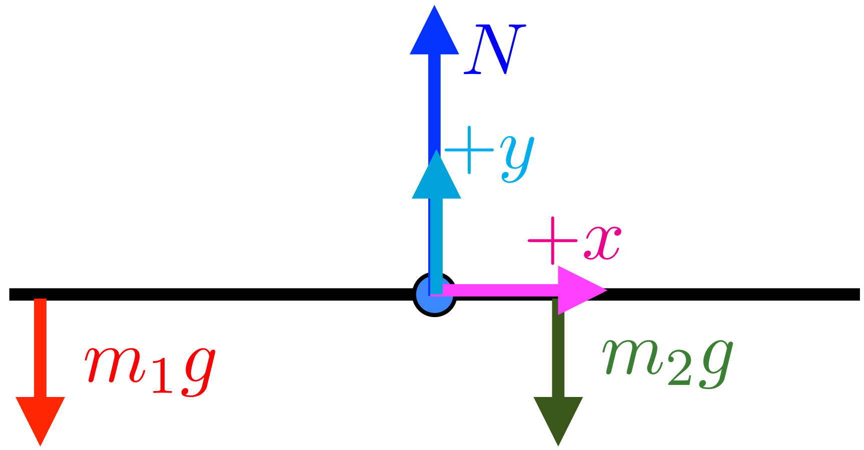
Principles & equations:

equilibrium $\sum \vec{\tau}_i = 0$

$\sum \vec{\mathbf{F}}_i = 0$

Demo & example

Free body diagram:



$$\sum \vec{\mathbf{F}}_i = 0$$

$$N - m_1 g - m_2 g = 0$$

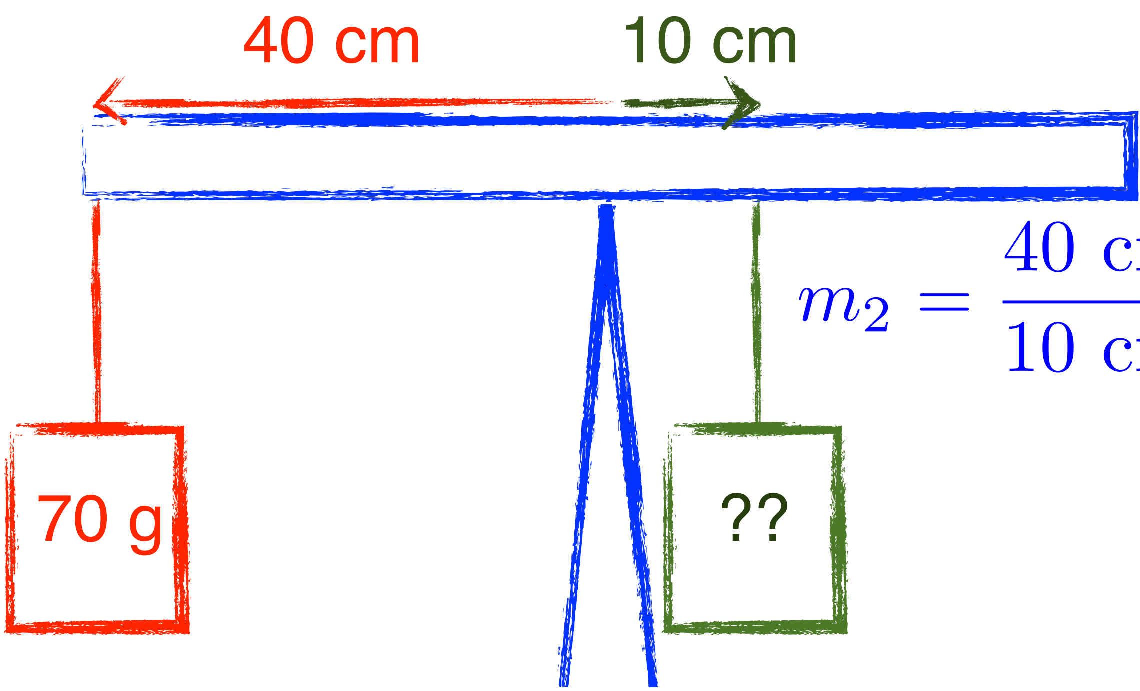
$$N = (m_1 + m_2)\, g$$

$$\sum \vec{\tau}_i = 0$$

$$r_{\perp 1} m_1 g + r_{\perp 2} m_2 g = 0$$

$$-r_1 m_1 g + r_2 m_2 g = 0$$

$$m_2 = \frac{r_1}{r_2} m_1$$



$$m_2 = \frac{40 \text{ cm}}{10 \text{ cm}} (70 \text{ g}) = 280 \text{ g} = 0.280 \text{ kg}$$

Class participation #21

- 0. Full name
- 1. What direction is the angular velocity?
- 2. If the fan is speeding up, what direction is the angular acceleration?
- 3. If the fan is speeding up, what direction is the torque?