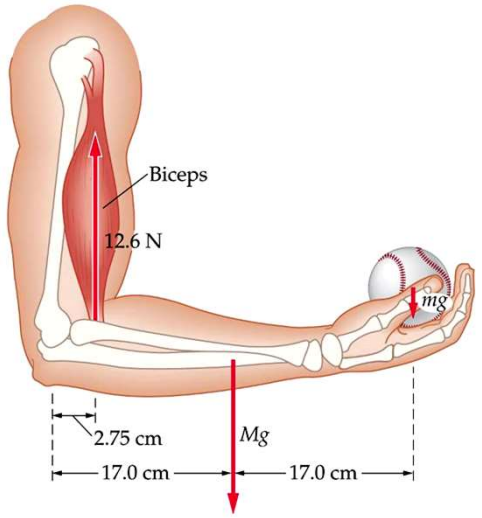
How do we rotate things?

To think about this, you can rotate your pencils or notebooks on your desk.

Main Ideas in Class Today

After today, you should be able to:

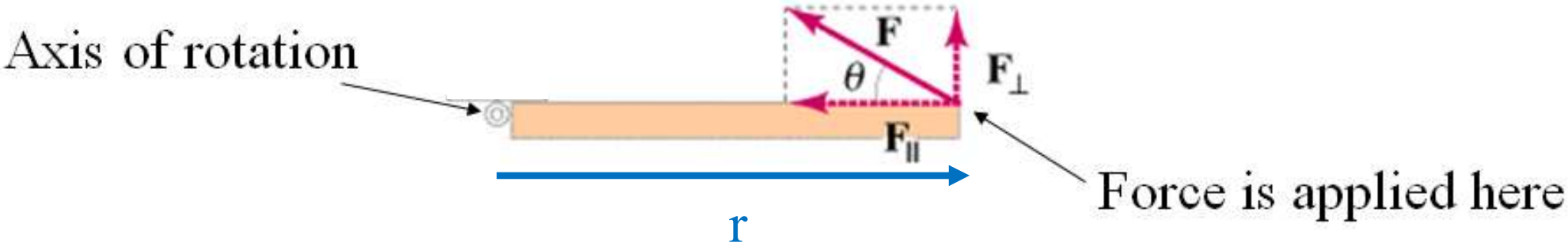
- Calculate the torque on an object
- Determine when an object is in "equilibrium"
- Find the center of gravity



Extra Practice: 8.1, 8.3, 8.5, 8.7, 8.11, 8.25

Main Topic Today: Torque

- Torque is the ability of a force to rotate an object about some axis

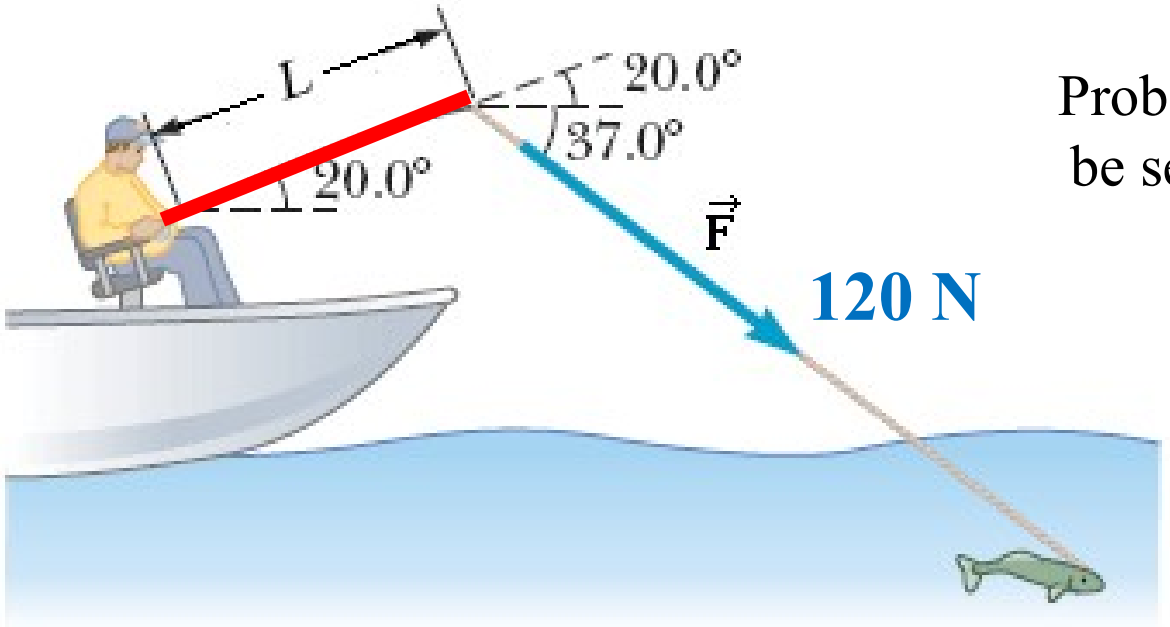


- Only component of **F** perpendicular to **r** can cause rotation about axis of rotation
  - We define **r** as a vector starting from axis of rotation pointing **to** **where force is applied**

$$\tau = rF_{\perp}$$

In drawing above, $\tau = rF\sin\theta$

Units: N m

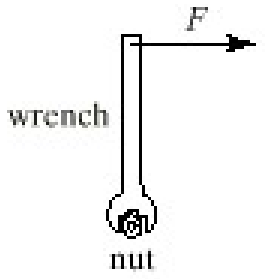


Problems won't always be set up in the easiest way to see

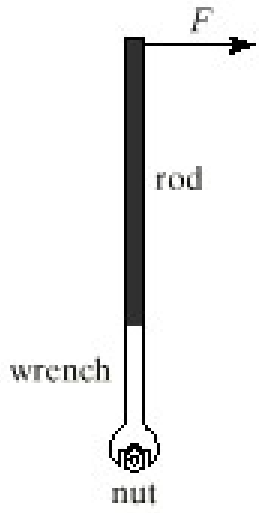
The red fishing pole in the figure makes an angle of 20.0° with the horizontal. What is the magnitude of the **torque** exerted by the fish about an axis through the angler's hand if the fish pulls on the fishing line with a force of 120 N at an angle 37.0° below the horizontal? The force is applied at a point with distance $L = 2$ m from the angler's hands.

You are using a wrench and trying to loosen a rusty nut. Which of the arrangements shown is most effective in loosening the nut?

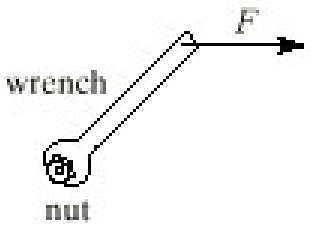
$$\tau = rF_{\perp}$$



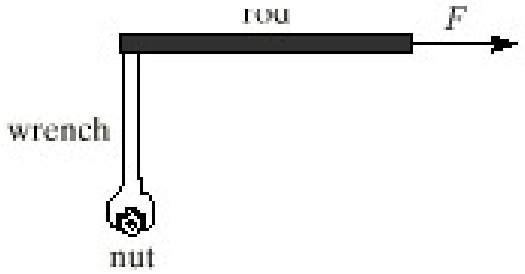
A.



B.



C.



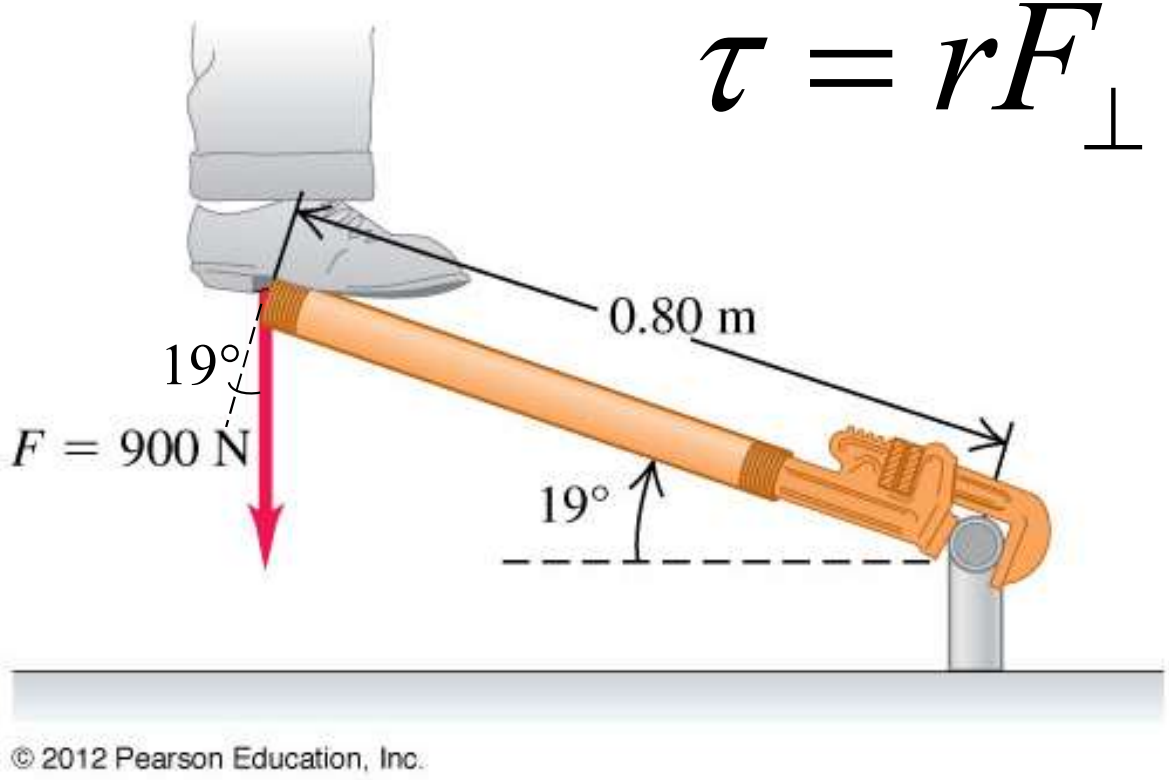
D.

E. There are 2 best ones (equal torque)

Q104

Joe the plumber pushes straight down on the end of a long wrench as shown. What is the magnitude of the torque Joe applies about the pipe at the moment shown in this picture?

$$\tau = rF_{\perp}$$



A. (0.80 m)(900 N) sin 19°

B. (0.80 m)(900 N) cos 19°

C. (0.80 m)(900 N) tan 19°

D. (0.80 m)(900 N)

E. None of the above

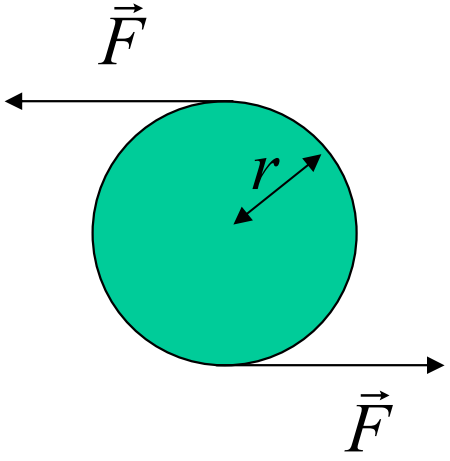
Q105

Torque

$+\tau$

- Notes:
  - Sign of torque (convention): If torque tends to make object spin counterclockwise, torque is positive.
  - We can add torques (just like forces).
  - Net torque: an object can have a net torque acting on it even though the net force is zero.

Ex: wheel with two forces acting on it



$$\vec{F}_{net} = \vec{F} - \vec{F} = 0$$

$$\tau_{net} = rF + rF = 2rF$$

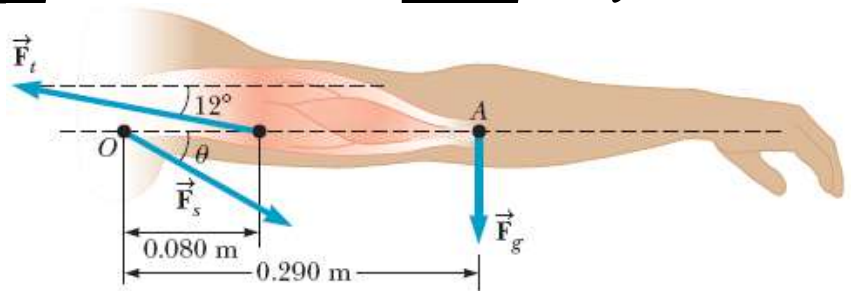
Definition: Equilibrium

- Object in equilibrium - the object is at rest and not rotating
- At rest means net force on object is zero
- Not rotating means net torque on object is zero (doesn't matter where axis is selected, which will be a convenient trick for us later)

Mathematical condition for equilibrium:

$$\sum \vec{F} = 0 \quad \left(\sum F_x = 0, \sum F_y = 0\right)$$

$$\sum \tau = 0$$



Sammy is on Top Chef and Padma tells him to hold a 2.00 kg carton of milk at arm's length. What force F_B must be exerted by the biceps muscle?

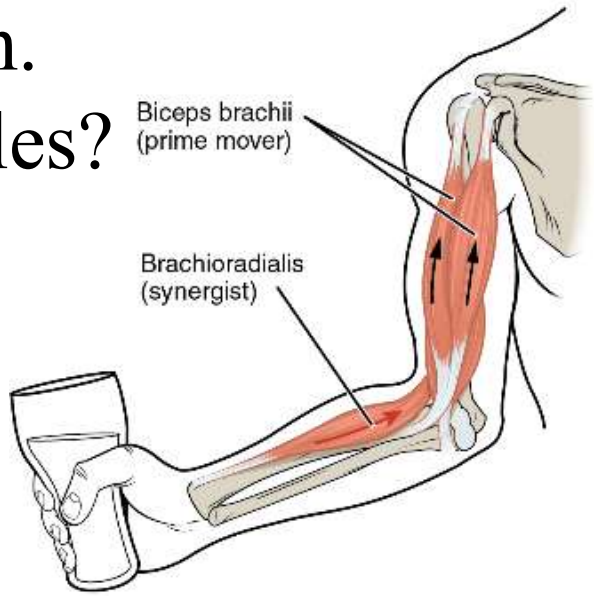
What does this have to do with torque or equilibrium?

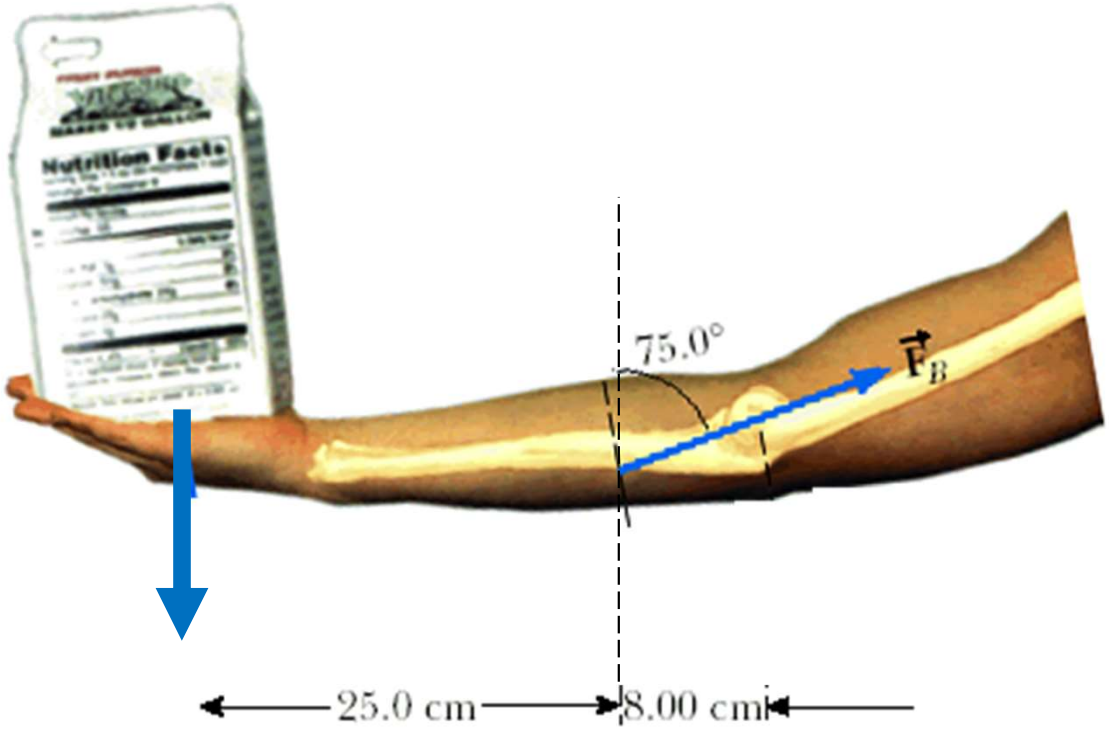
Everyone stand up. Grab something heavy. Is it harder to hold it straight out or with your elbows bent?

A. Straight out
B. With elbows bent
C. Same for both

Q106

Sammy is on Top Chef and Padma tells him to hold a 2.00 kg carton of milk at arm's length. What force F_B must be exerted by the muscles? (Ignore the weight of the forearm.)



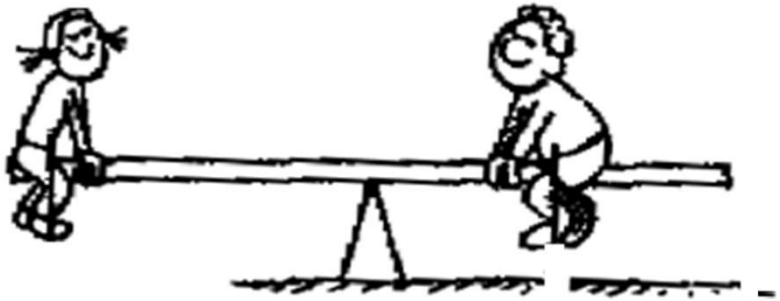


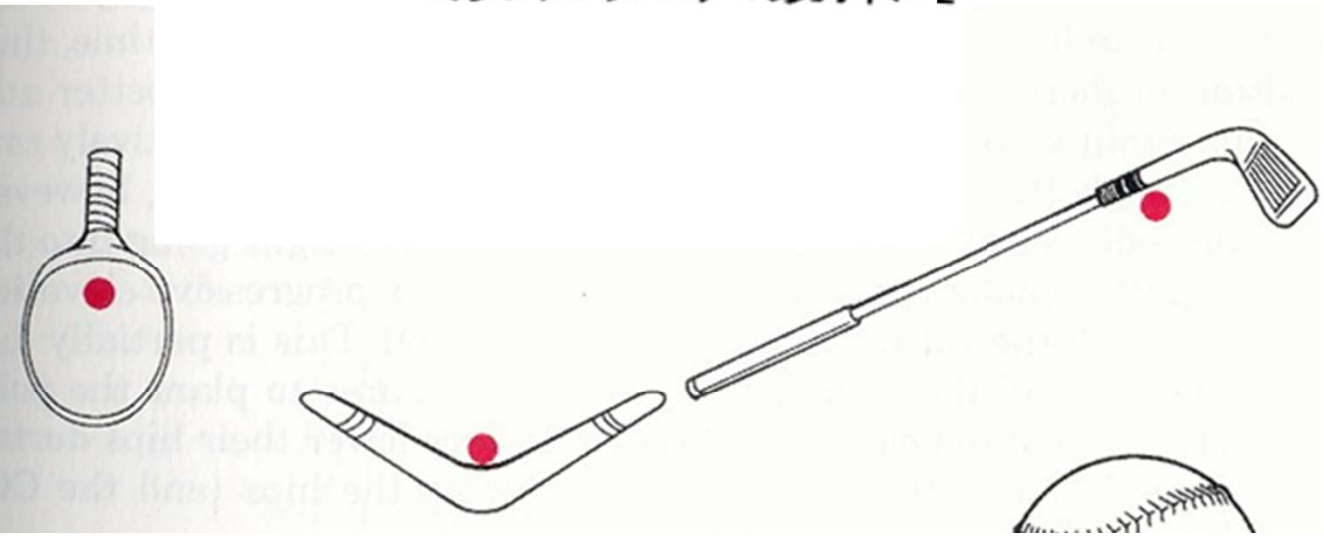
How will this change if we don't ignore the weight of the forearm?

The **center of gravity** of a solid object is the point where its entire weight can be considered to act when calculating the torque due to the weight of the object.

Center of Gravity/Mass

Find the center of gravity of the system of two blocks above if they are 50 m apart.



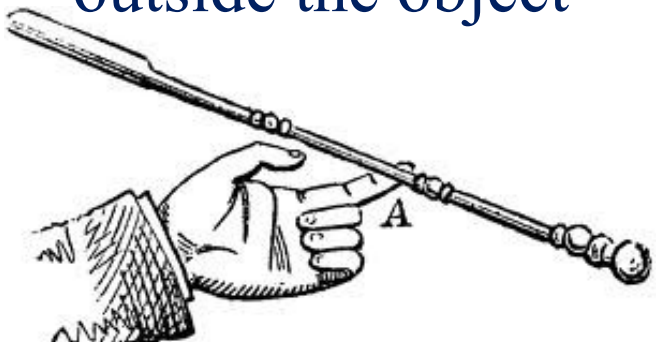


$$x_{cg} = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3 + \cdots}{m_1 + m_2 + m_3 + \cdots} = \frac{\Sigma m_i x_i}{\Sigma m_i}$$

The center of gravity is the point around which a body's mass is equally distributed in all directions.

In a uniform object, at its mid point

Center of gravity can be outside the object



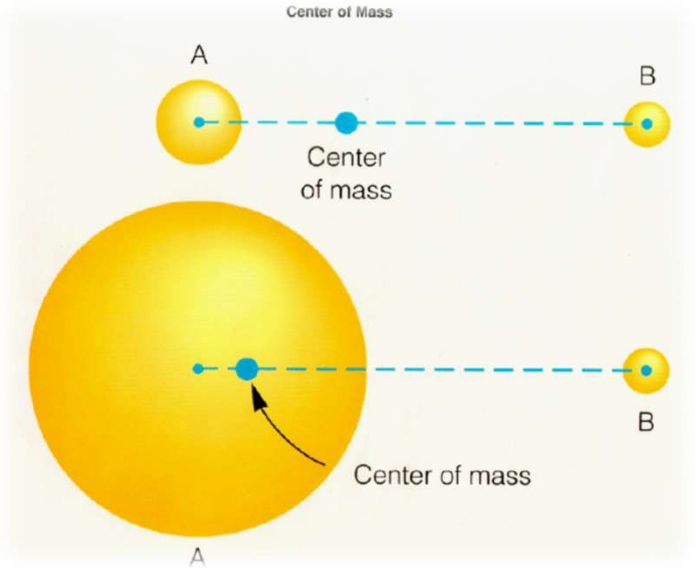
Center of Mass in Astrophysics

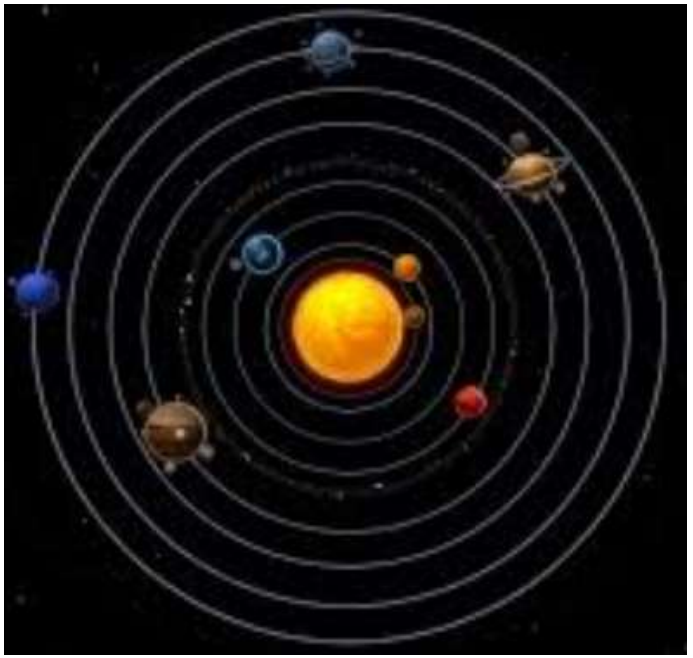
Even star/planet systems rotate about center of mass

Center of mass of solar system is not in the center of the star, causing the star to wobble a little

Astronomers search for wobbling stars to find planets

As of March 2, 2022, 4980 extrasolar planets have been confirmed.



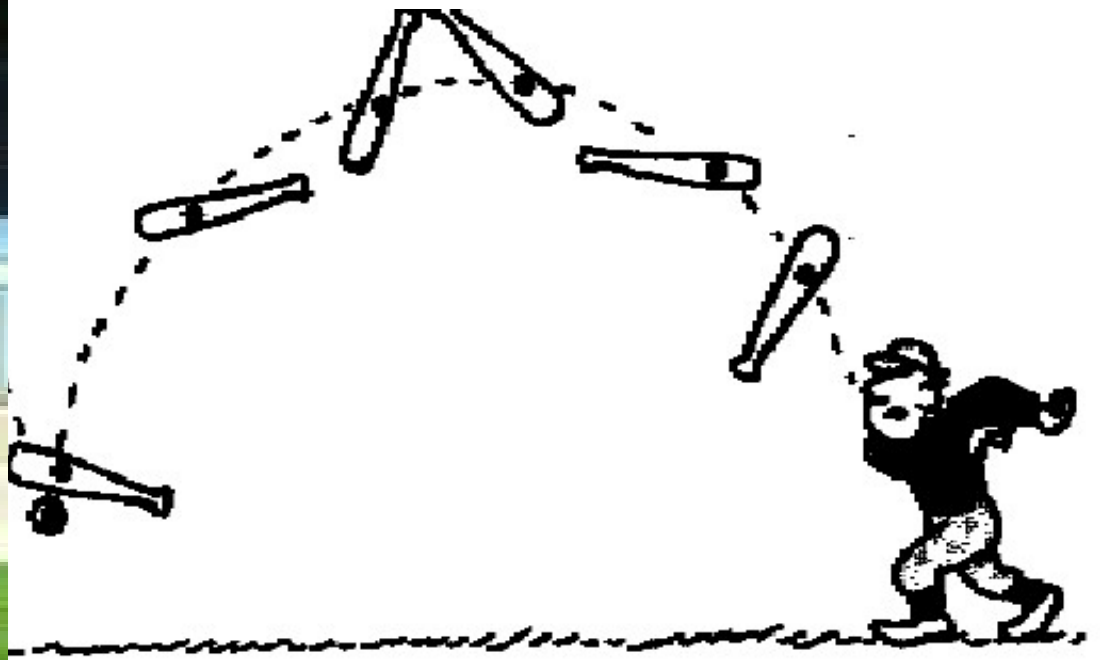


Center of Gravity

Point of Rotation of Projectiles

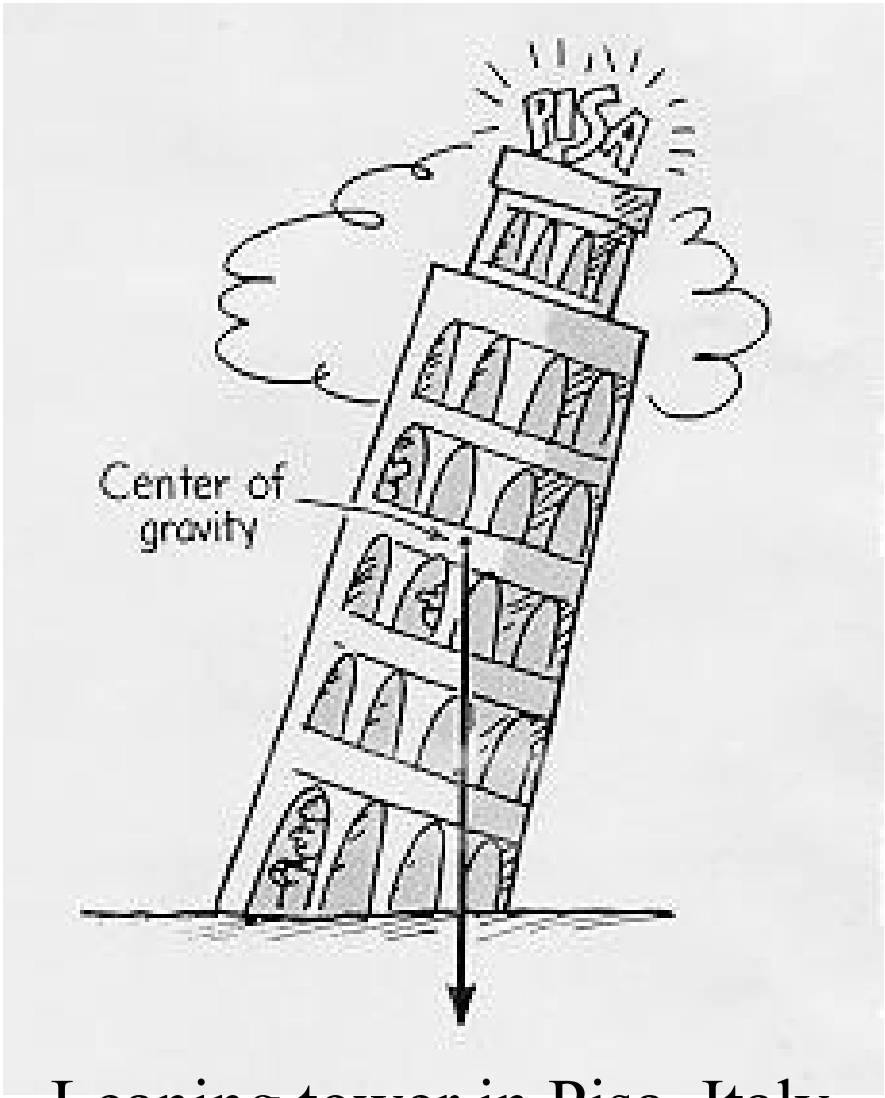
One point in the ball or bat follows the projectile path

Center of gravity is this point



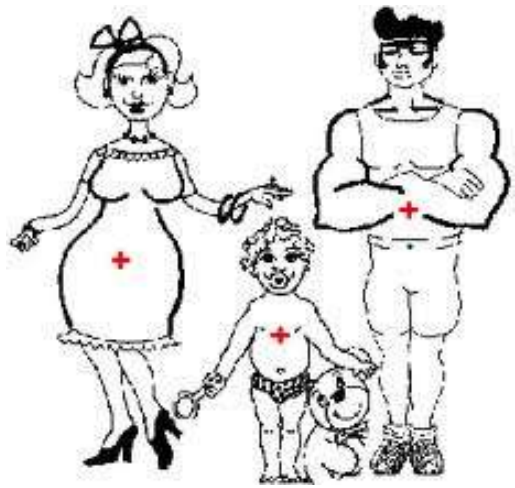
Toppling Rule of Thumb

- If the CG of the object is above the area of support, the object will remain upright.
- If the CG is outside the area of support the object will topple.



Leaning tower in Pisa, Italy

Human Center of Gravity When Standing Straight



Within the body near the navel

Higher in men than women

Higher in children than adults (relatively)

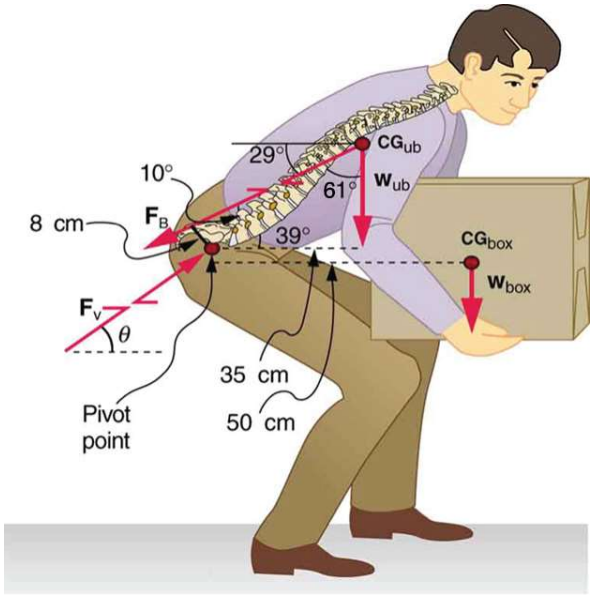
To avoid toppling - stand so that your center of gravity is above area enclosed by your feet

Lift With Your Legs

https://opentextbc.ca/openstaxcollegephysics/chapter/forces-and-torques-in-muscles-and-joints/

You have probably been warned against lifting objects with your back. This action, even more than bad posture, can cause muscle strain and damage discs and vertebrae.

What variable would you want to calculate here?

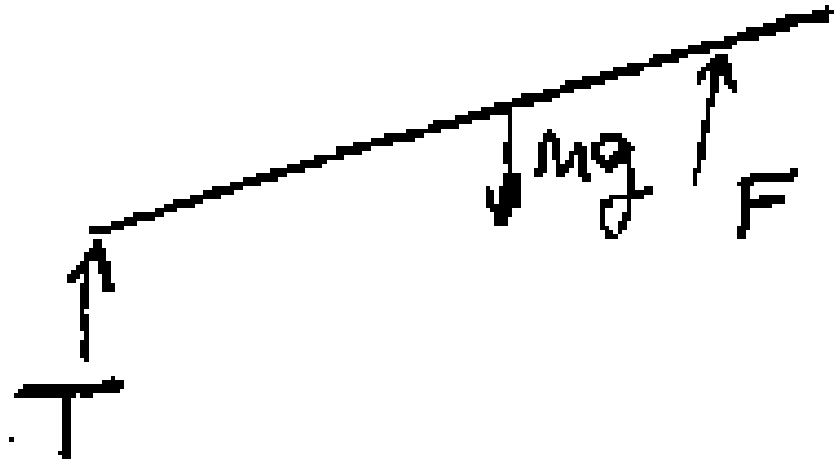


Proper lifting, performed with the back erect and using the legs to raise the body and load, creates much smaller forces in the back—in this case, about 5.6 times smaller.

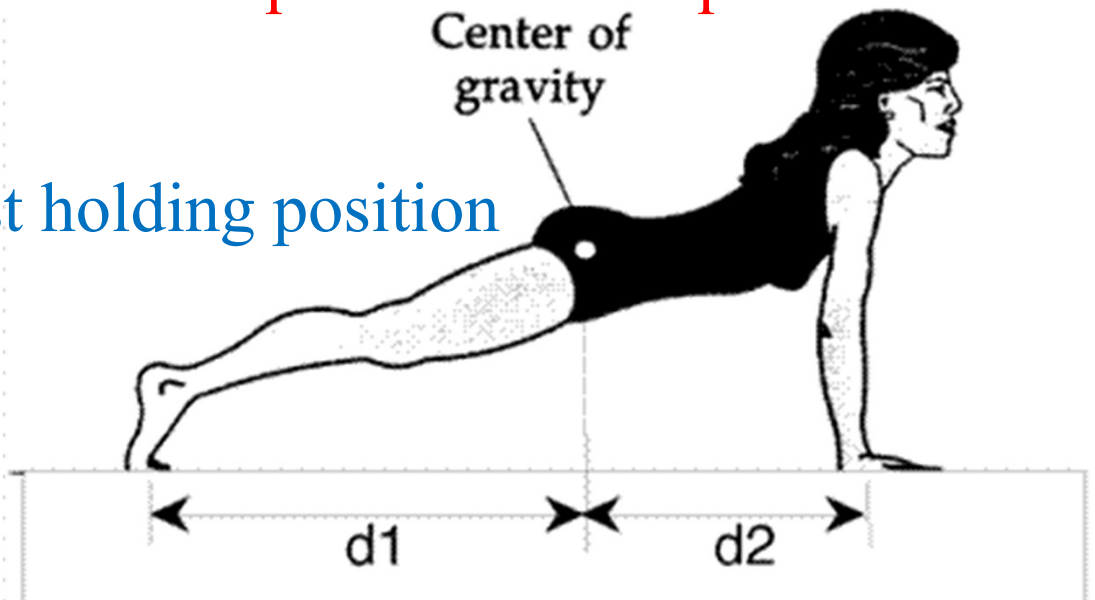
Force needed to do a pushup

Mary is about to do a push-up. Her center of gravity lies directly above a point on the floor which is d_1=1.0 *m* from her feet and d_2=0.7 *m* from her hands. If her mass is 50 *kg*, what is the force exerted by the floor on her hands, assuming that she holds this position? What is the force exerted by the floor on her feet?

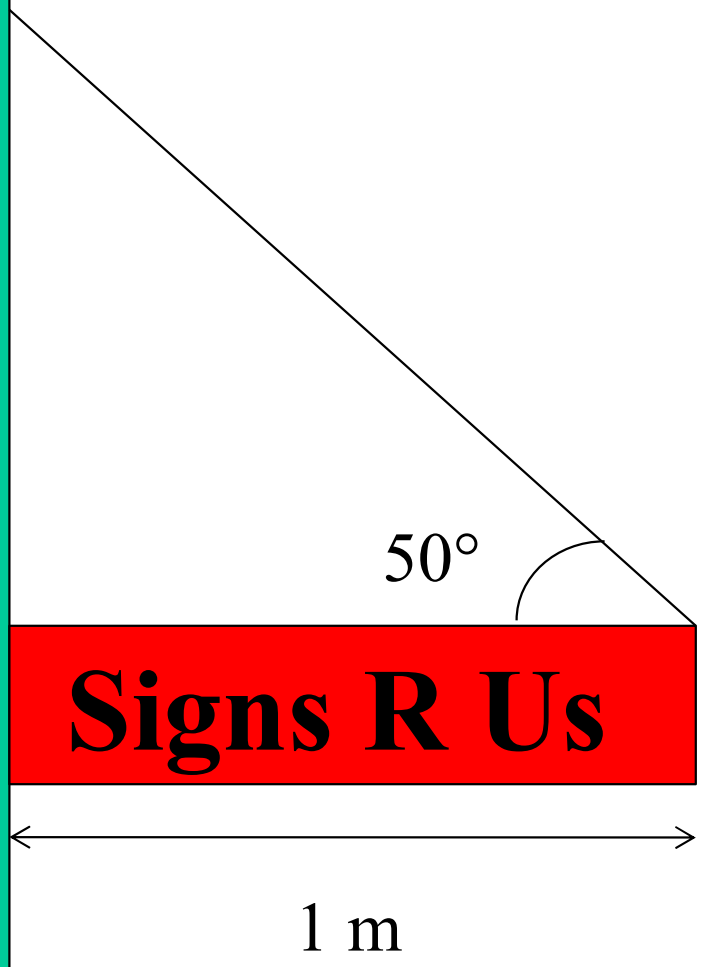
If an object is in equilibrium (she is), you can take the axis of rotation to be anywhere. The trick here is to take it at her toes so you don't need to know that force. Then sum the torques which is equal to 0.



Just holding position

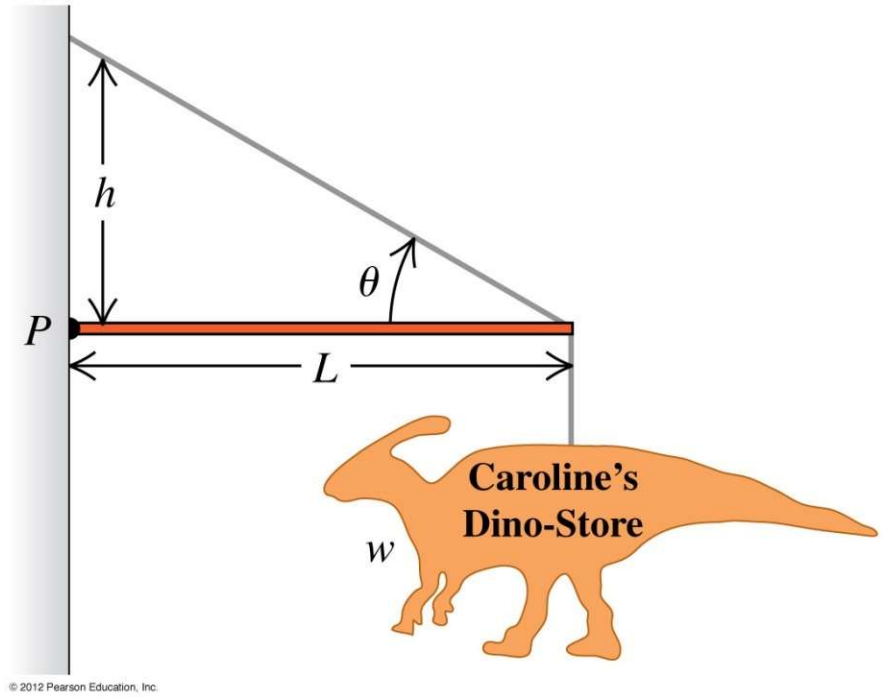


Signs in Equilibrium



What tension will be needed in the rope to support the sign's 15 kg weight and keep it from falling off the wall?

A metal advertising sign (weight w) is suspended from the end of a massless rod of length L. The rod is supported at one end by a hinge at point P and at the other end by a cable at an angle θ from the horizontal.



What is the tension in the cable?

A. $T = w \sin \theta$

B. $T = w \cos \theta$

C. $T = w/(\sin \theta)$

D. $T = w/(\cos \theta)$

E. none of the above

Q107

Questions to Ponder

- How does your stability change with the use of crutches? How does the CoG change?
- Using concepts from this lecture, which hand would you recommend that a person put a cane in, given that his right knee is injured and needs a break.

  (Google it to verify)