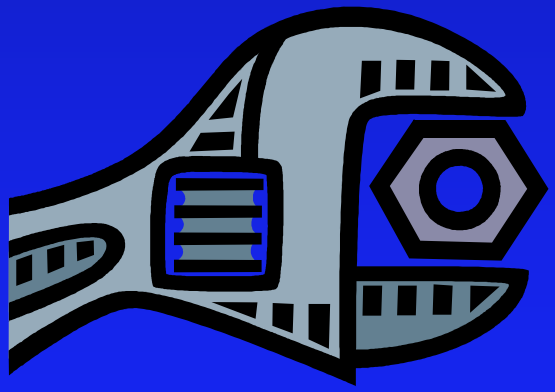
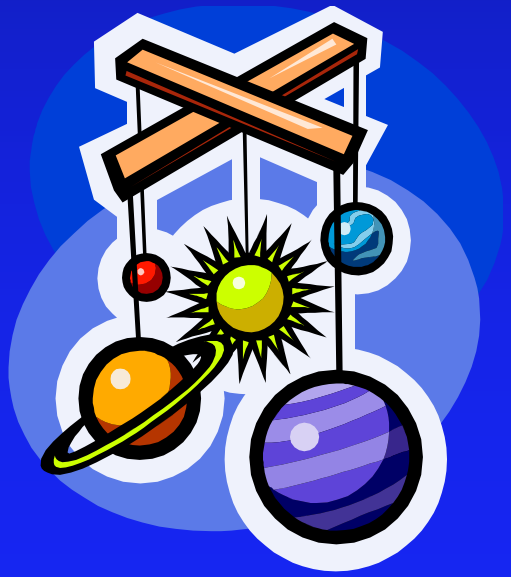
EXAM II

Physics 101: Lecture 14
Torque and Equilibrium

Today's lecture will cover Textbook Chapter 8.2-8.4





Review

- Rotational Kinetic Energy $K_{rot} = \frac{1}{2} I \omega^2$
- Rotational Inertia $I = \Sigma m_i r_i^2$
- Energy Still Conserved!

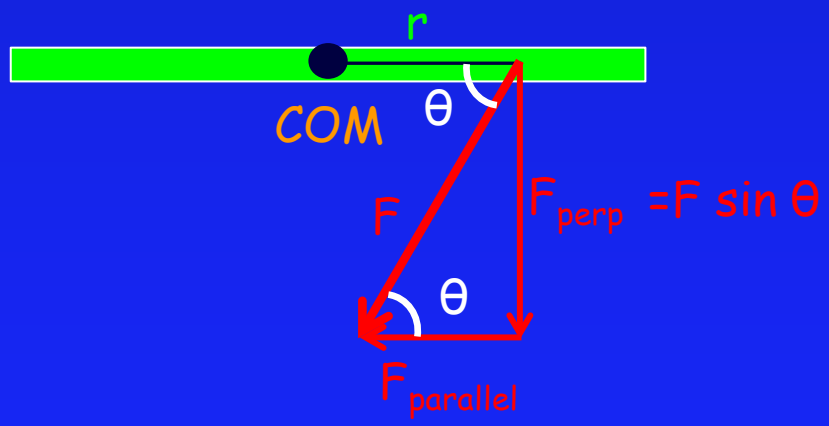
Today

- Torque!

Torque

- A TORQUE is a force that causes rotation. Tells how effective force is at twisting or rotating an object.

- $\tau = +\text{-}\ r\ F_{perpendicular} = r\ F \sin\theta$
  - ➔Units N m
  - ➔Sign: CCW rotation is positive

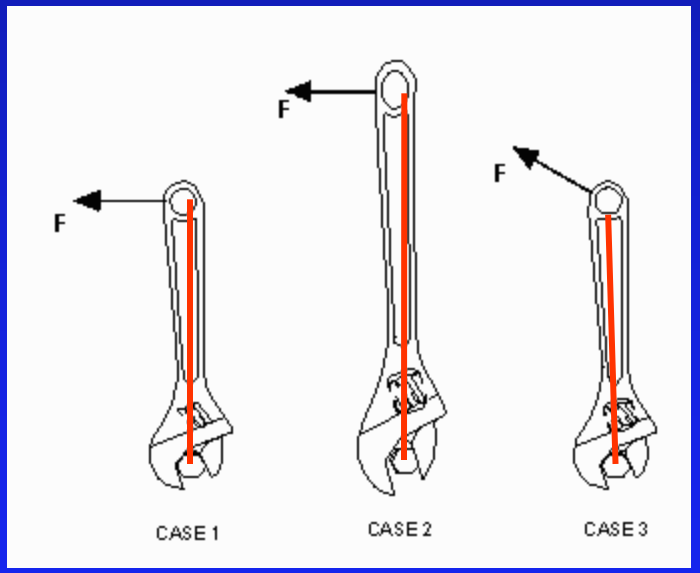


ACT

The picture below shows three different ways of using a wrench to loosen a stuck nut. Assume the applied force F is the same in each case.

In which of the cases is the torque on the nut the biggest?

A. Case 1
B. Case 2 ← CORRECT
C. Case 3

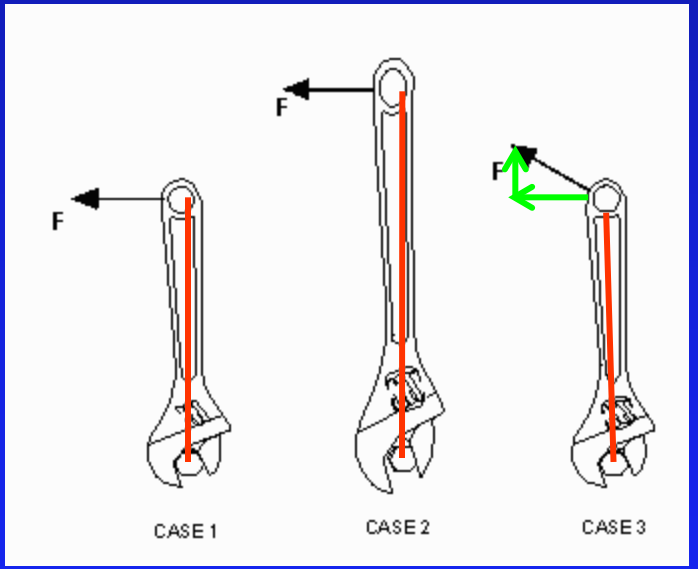


ACT 2

The picture below shows three different ways of using a wrench to loosen a stuck nut. Assume the applied force F is the same in each case.

In which of the cases is the torque on the nut the smallest?

A. Case 1
B. Case 2
C. Case 3 ← CORRECT



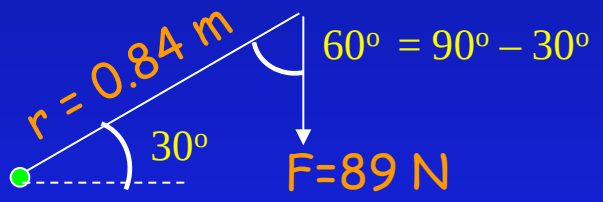
Torque Example and ACT

A person raises one leg to an angle of 30 degrees. An ankle weight (89 N) attached a distance of 0.84 m from her hip. What is the torque due to this weight?

1) Draw Diagram

2) $\tau = F\ r \sin\theta$

$= F\ r \sin(60) = 65$ N m

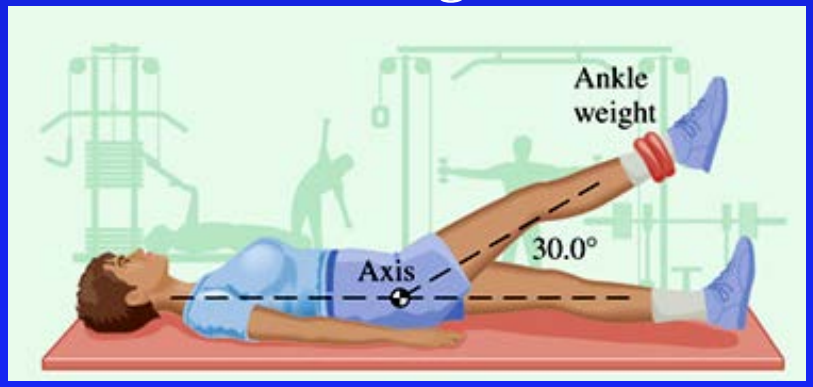


If she raises her leg higher, the torque due to the weight will

A) Increase

B) Same

C) Decrease



Equilibrium Acts

- A rod is lying on a table and has two equal but opposite forces acting on it. What is the net force on the rod?

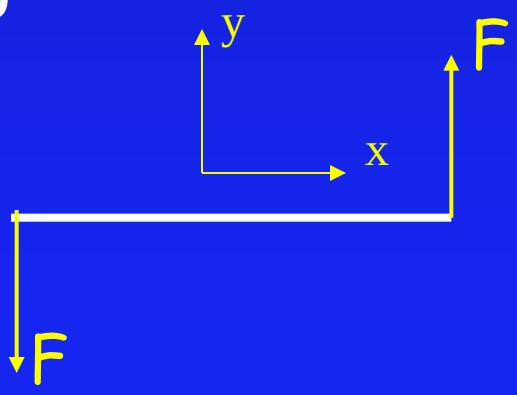
A) Up B) Down C) Zero

Y direction: $F_{Net,y} = ma_y$

$+F - F = 0$

- Will the rod move? A) Yes B) No

Yes, it rotates!



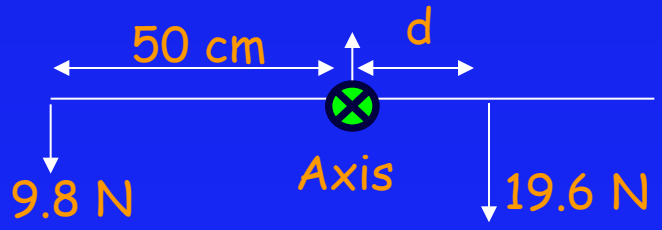
Equilibrium

- Conditions for Equilibrium
  - ➔ $F_{Net} = 0$ Translational EQ (Center of Mass)
  - ➔ $\tau_{Net} = 0$ Rotational EQ (True for any axis!)
    - » Choose axis of rotation wisely to make problems easier!
    - » But as long as you're consistent everything will be OK!

- A meter stick is suspended at the center. If a 1 kg weight is placed at x=0. Where do you need to place a 2 kg weight to balance it?

A) x = 25 B) x=50 C) x=75 D) x=100

E) 1 kg can't balance a 2 kg weight.



$\tau_{Net} = 0$

$9.8\ (0.5) - (19.6)d = 0$

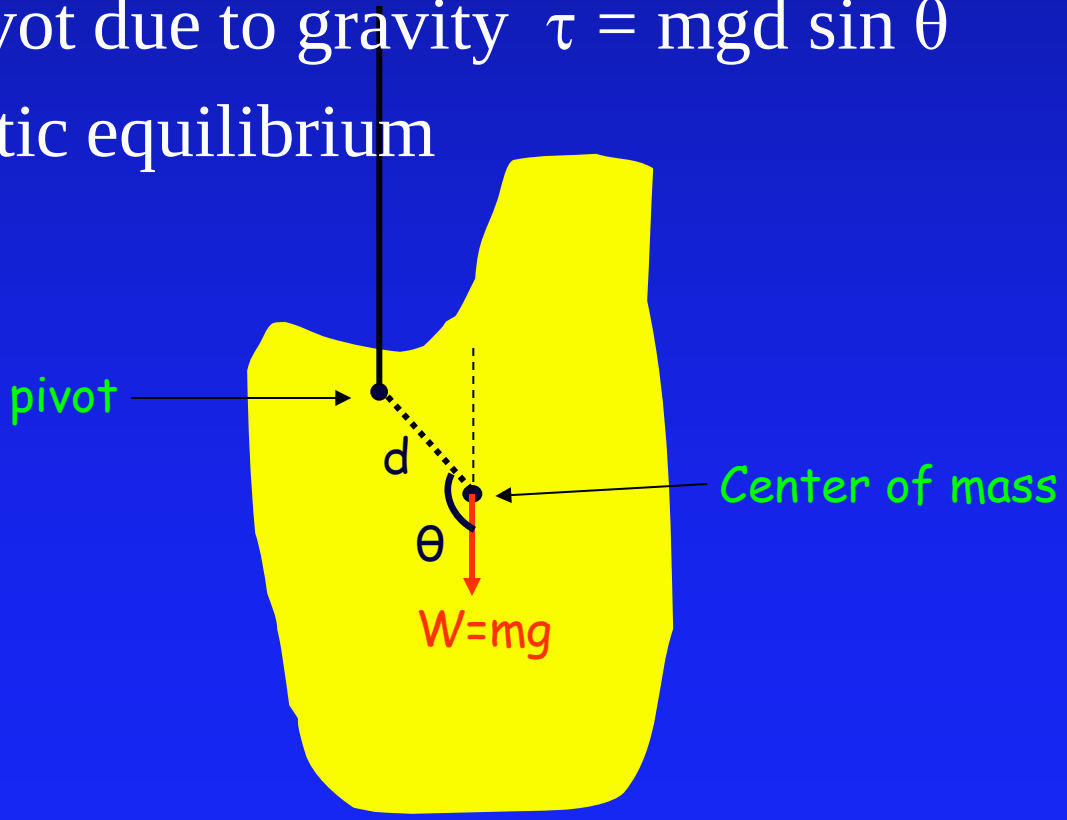
$d = 25$

Balance Demo

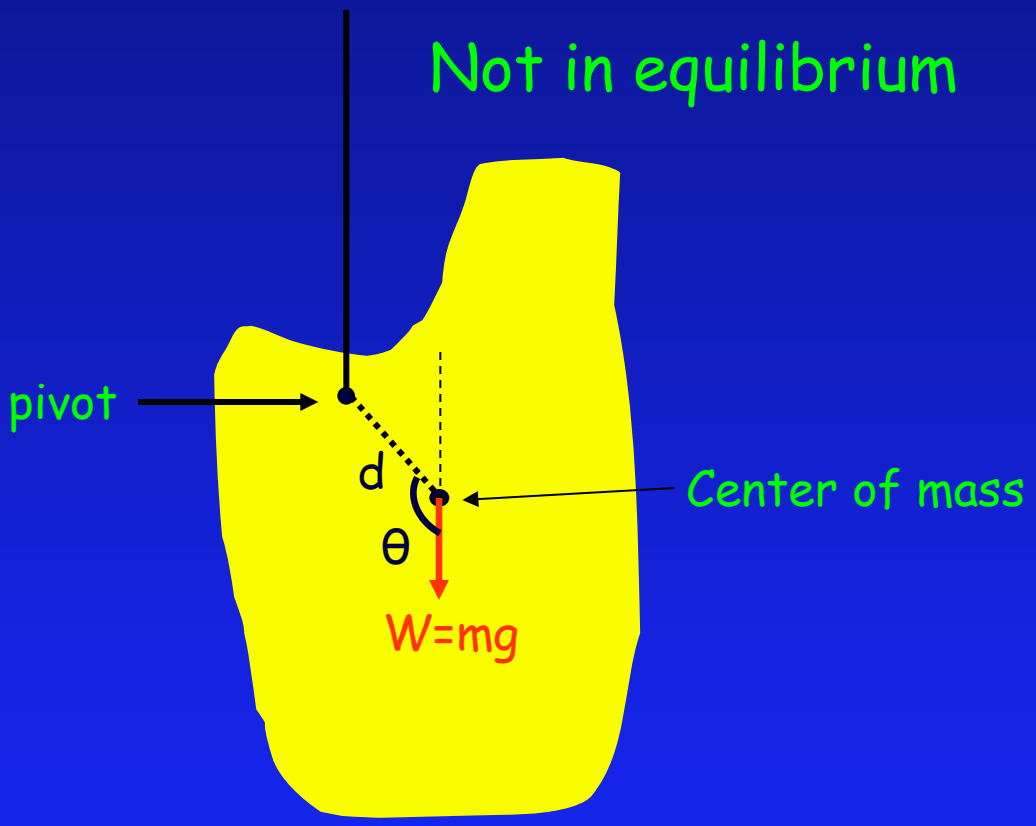
Static Equilibrium and Center of Mass

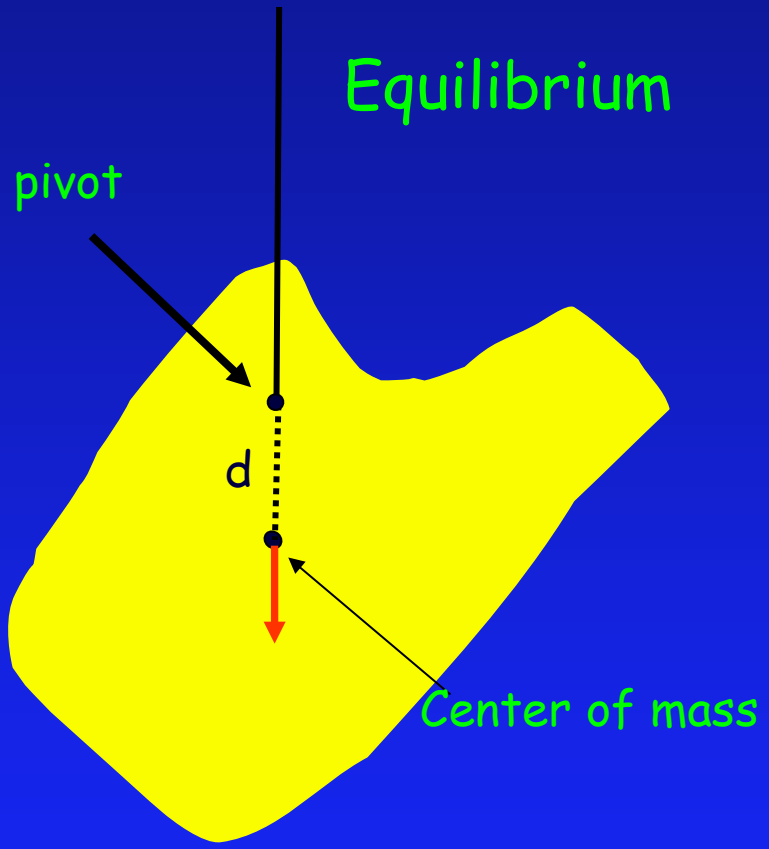
- Gravitational Force Weight = mg
  - ➔Acts as force at center of mass
  - ➔Torque about pivot due to gravity $\tau = mgd \sin\theta$
  - ➔Object not in static equilibrium

$$r_{cm} = \frac{\sum r_i m_i}{\sum m_i}$$



Static Equilibrium





Torque about pivot ≠ 0

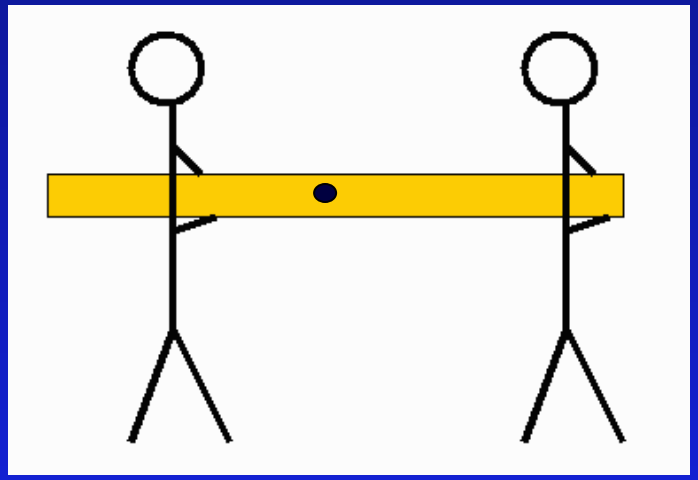
Torque about pivot = 0

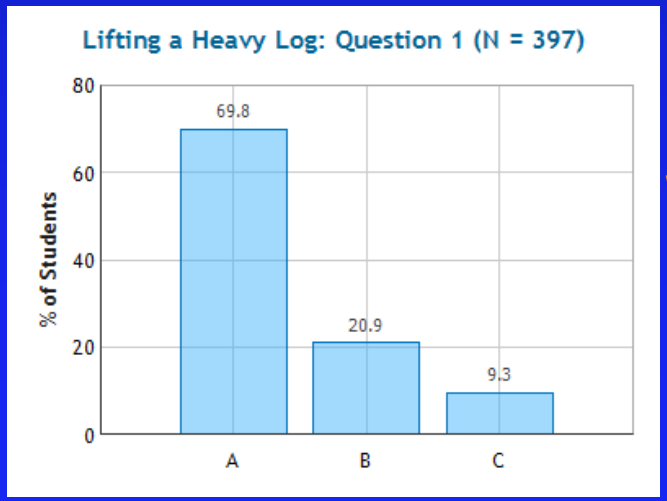
A method to find center of mass of an irregular object

Prelecture

The picture below shows two people lifting a heavy log.
Which of the two people is supporting the greatest weight?

1. The person on the left is supporting the greatest weight ← CORRECT
2. The person on the right is supporting the greatest weight
3. They are supporting the same weight





"The guy on the left has to support more weight because he is further in and has to support more of the board."

Prelecture

The picture below shows two people lifting a heavy log.
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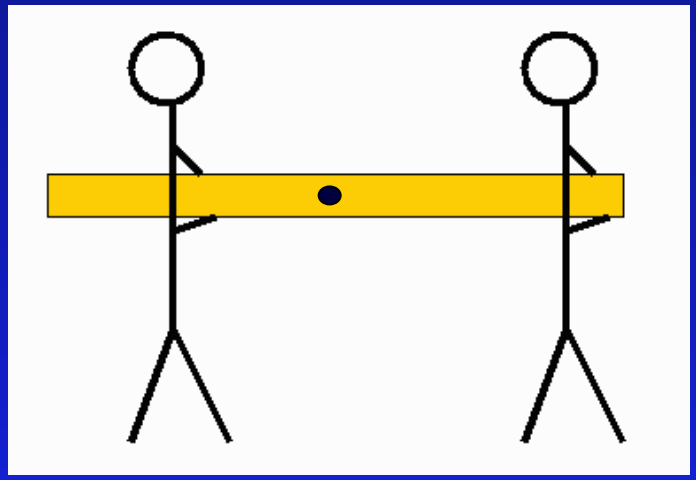
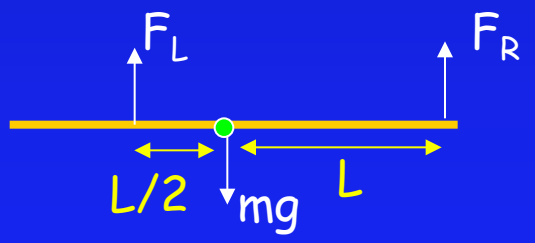


Look at torque about center:

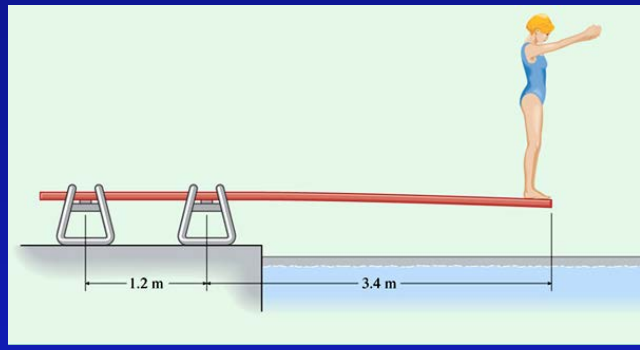
$F_R L - F_L L/2 = 0$

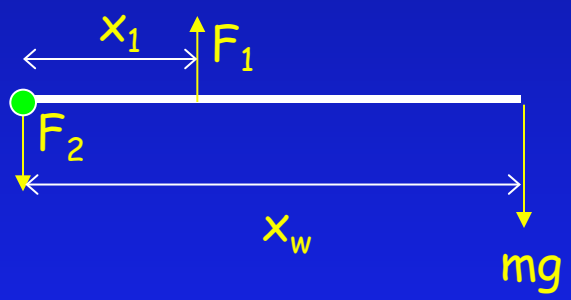
$F_R = \frac{1}{2} F_L$



Equilibrium Example

A 50 kg diver stands at the end of a 4.6 m diving board. Neglecting the weight of the board, what is the force on the pivot 1.2 meters from the end?





1) Draw FBD

2) Choose Axis of rotation

3) $\tau_{Net} = 0$ Rotational EQ

$F2(0) + F_1 (x_1) - mg (x_w) = 0$

$F_1 = mg(x_w)/x_1 = 4.6 (50 * 9.8) / 1.2$

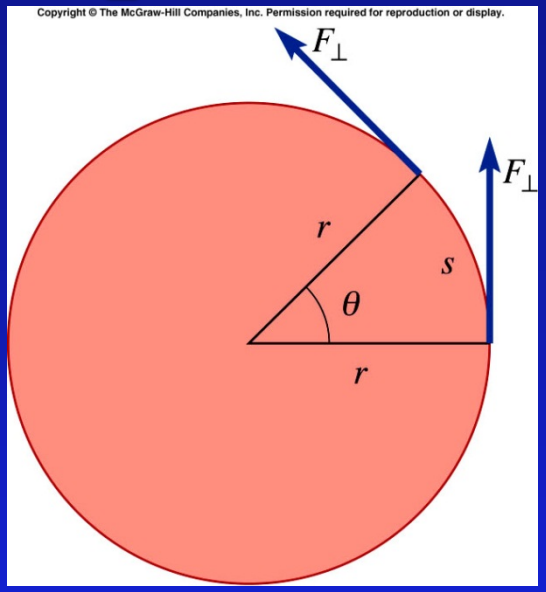
$F_1 = 1880$ N

4) $F_{Net} = 0$ Translational EQ

$F_1 - F_2 - mg = 0$

$F_2 = F_1 - mg = 1390$ N

Work Done by Torque



- Recall $W = F\ d \cos\theta$

- For a wheel

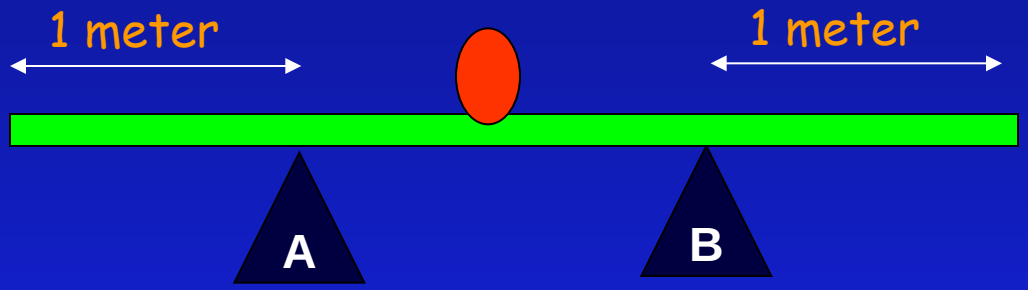
  ➔ Work: $W = F_{tangential}\ s$

  $= F_{tangential}\ r\ \theta$ (s = r θ, θ in radians)

  $= \tau\ \theta$

Homework 8 Hints

A 75 kg painter stands at the center of a 50 kg, 3 meter plank. The supports are 1 meter in from each edge. Calculate the force on support A.

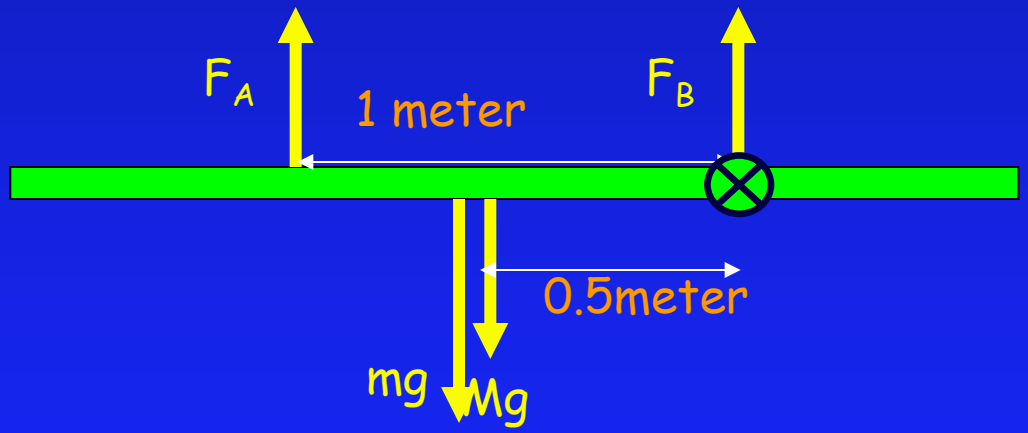


1) Draw FBD

2) $F_{Net} = 0$ $F_A + F_B - mg - Mg = 0$

3) Choose pivot

4) $\tau_{Net} = 0$



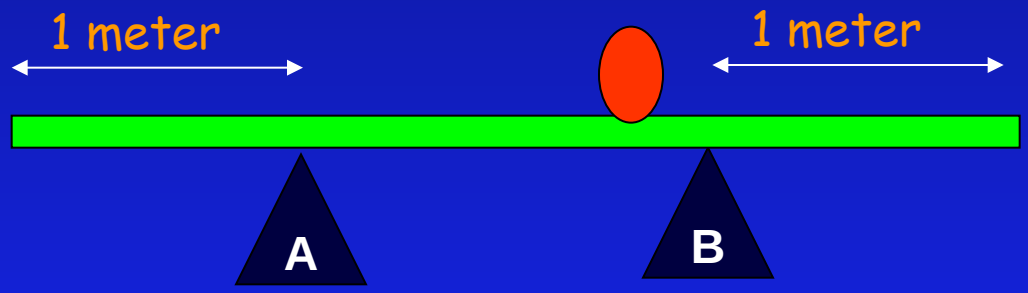
$-F_A\,(1)\sin(90) + F_B\,(0)\sin(90) + mg\,(0.5)\sin(90) + Mg(0.5)\sin(90) = 0$

$F_A = 0.5\,mg + 0.5\,Mg = 612.5$ Newtons

Homework 8 Hints

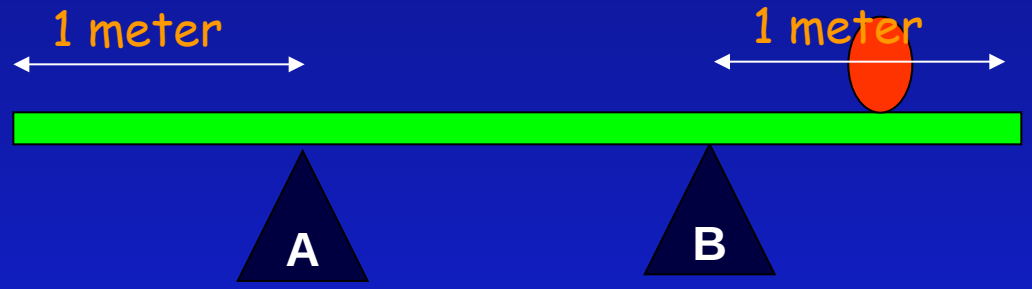
If the painter moves to the right, the force exerted by support A

A) Increases B) Unchanged C) Decreases



Homework 8 Hints

How far to the right of support B can the painter stand before the plank tips?



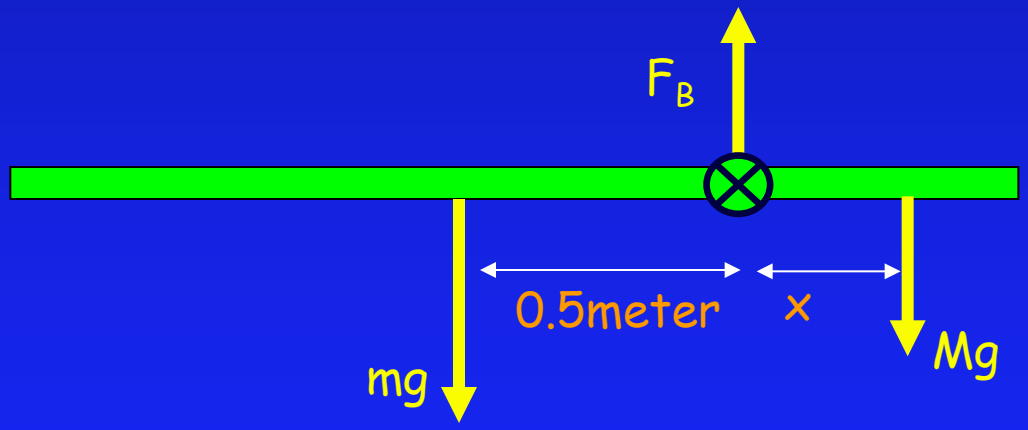
Just before the board tips, force from A becomes zero!

1) Draw FBD

2) $F_{Net} = 0$ $F_B - mg - Mg = 0$

3) Choose pivot

4) $\tau_{Net} = 0$

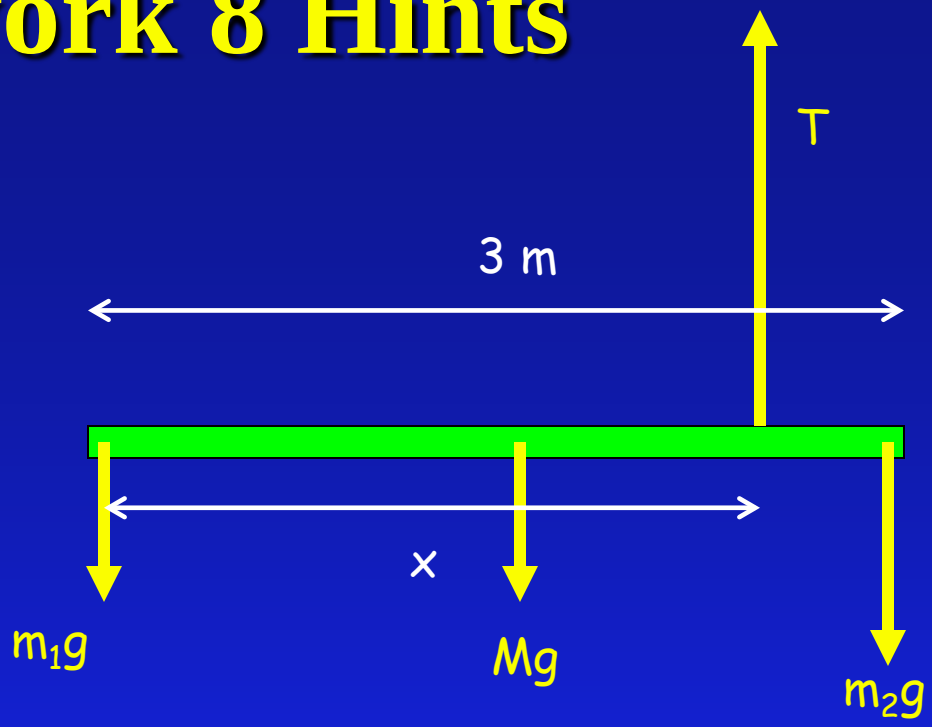


$F_B (0) \sin(90) + mg (0.5) \sin(90) - Mg(x) \sin(90) = 0$

$0.5\ m = x\ M$

Homework 8 Hints

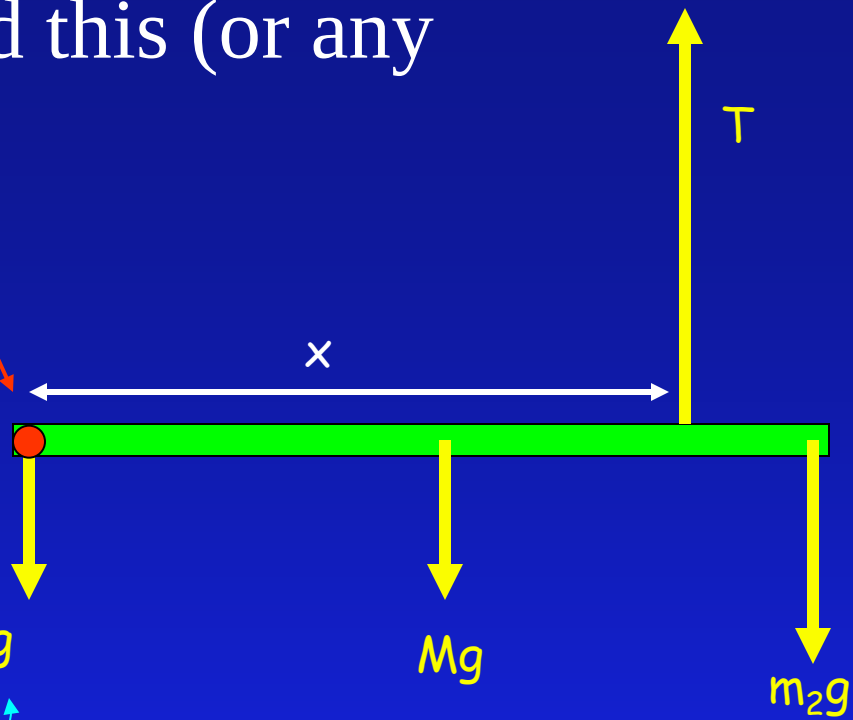
- Bar & Weights
- Given:
  - ➔ m_2
  - ➔ M
  - ➔ T
- Find m_1 and x



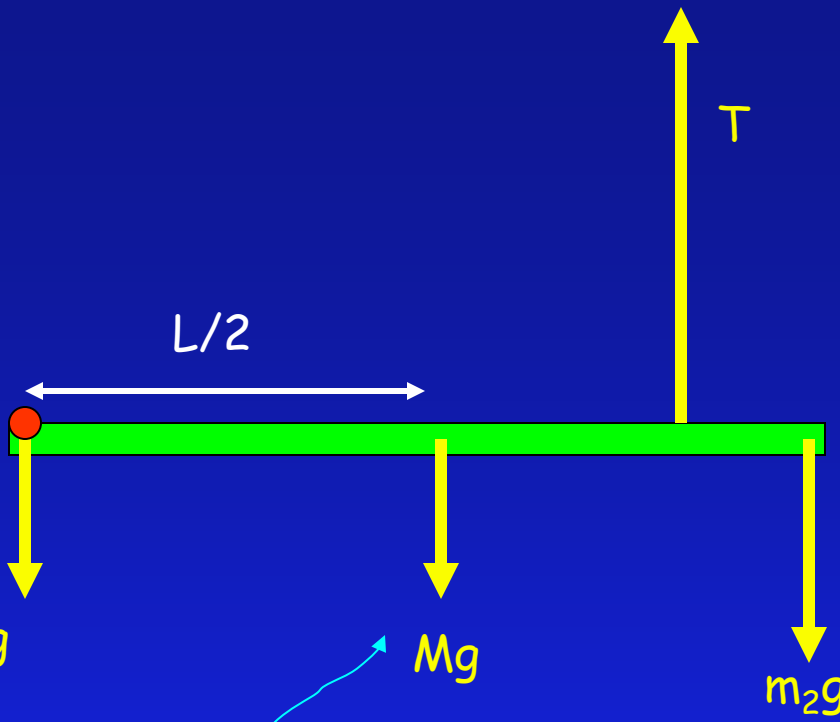
Using $F_{Net} = 0$: $T = m_1g + m_2g + Mg$

allows you to solve for m_1

- Find net torque around this (or any other) place

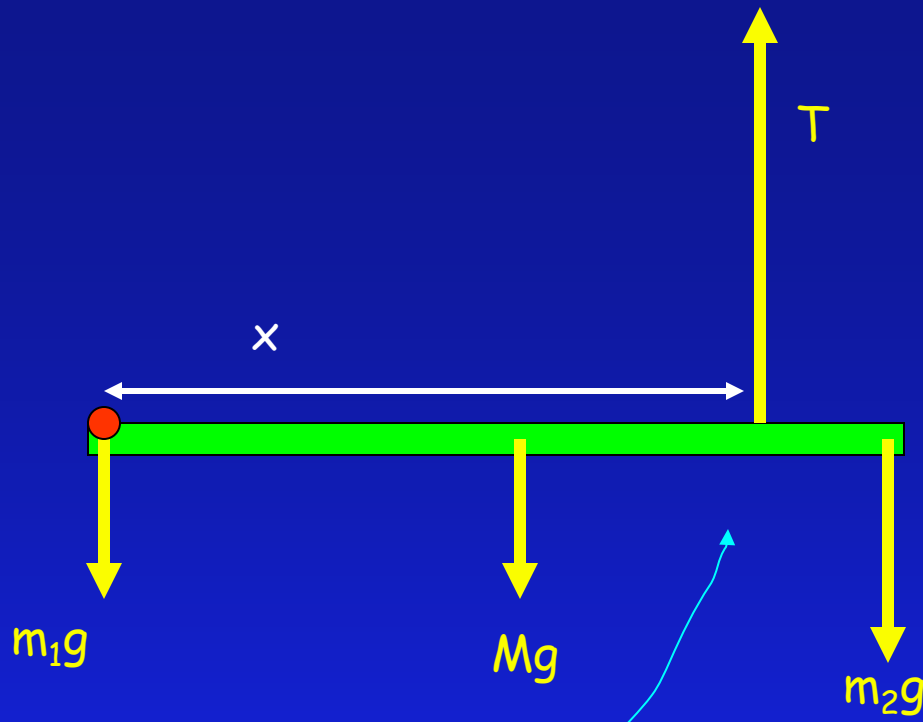


$\tau\ (m_1g) = 0$ since lever arm is 0



$\tau\ (m_1g) = 0$ since lever arm is 0

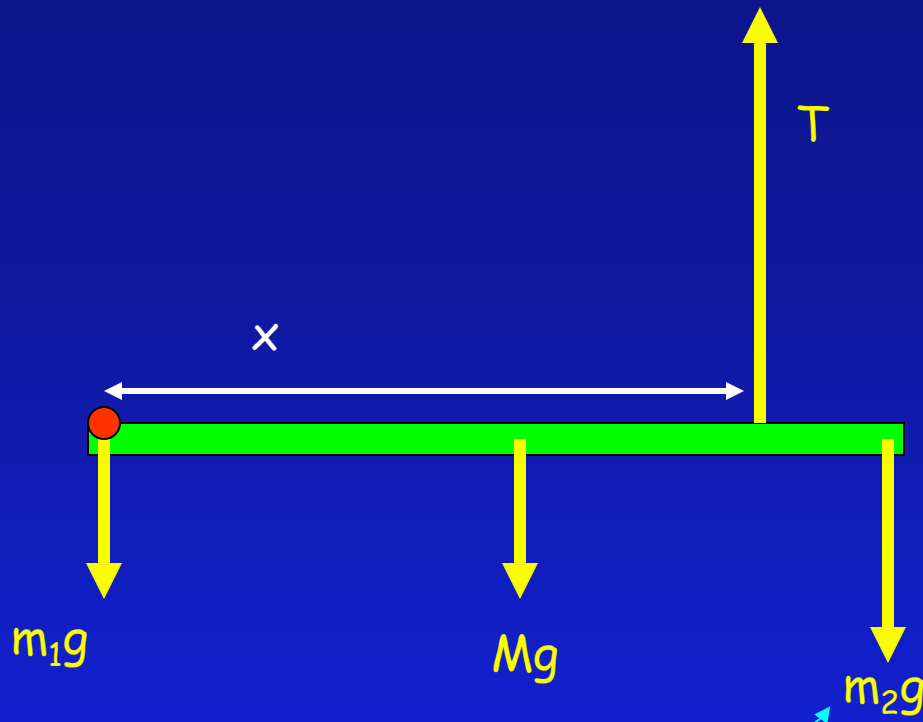
$\tau\ (Mg\ ) = -Mg\ L/2$



$\tau\ (m_1 g) = 0$ since lever arm is 0

$\tau\ (Mg\ ) = -Mg\ L/2$

$\tau\ (T\ ) = T\ x$



$\tau\ (m_1g) = 0$ since lever arm is 0

$\tau\ (Mg\ ) = -Mg\ L/2$

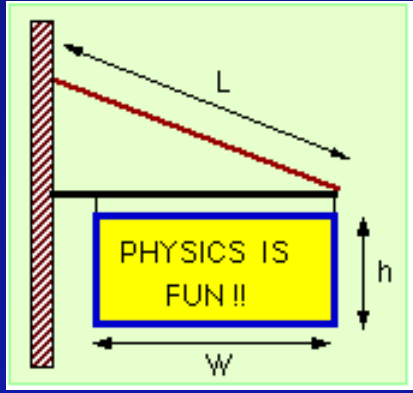
$\tau\ (T\ ) = T\ x$

$\tau\ (m_2g\ ) = m_2g\ L$

Summary

- Torque = Force that causes rotation
  - ➔ $\tau = F\ r \sin\theta$
  - ➔ Work done by torque $W = \tau\ \theta$
- Equilibrium
  - ➔ $F_{Net} = 0$
  - ➔ $\tau_{Net} = 0$
    - » Can choose any axis.

Sign Problem



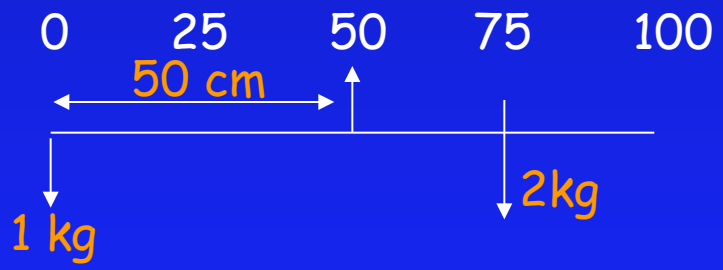
There is no hinge attaching the black rod to the wall, what is the minimum coefficient of friction necessary to keep the sign from falling?

You Know Torque!

- A meter stick is suspended at the center. If a 1 kg weight is placed at x=0. Where do you need to place a 2 kg weight to balance it?

A) x = 25 B) x=50 C) x=75 D) x=100

E) 1 kg can't balance a 2 kg weight.



Balance Demo