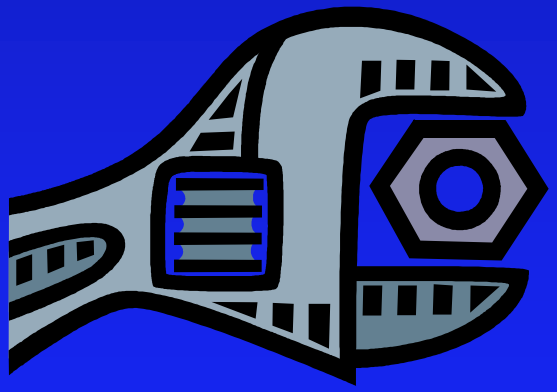
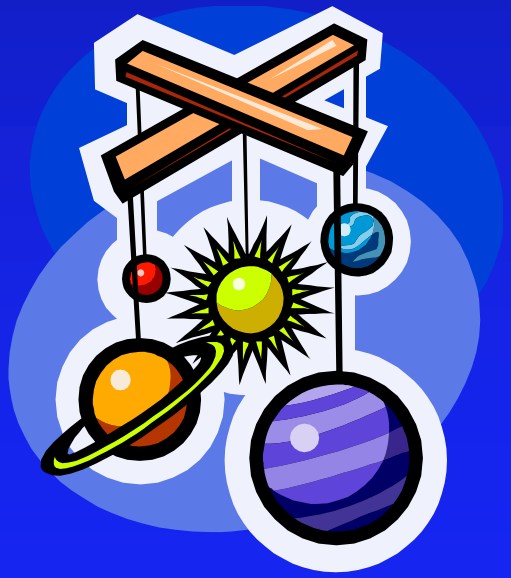
Physics 101: Lecture 14
Torque and Equilibrium

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

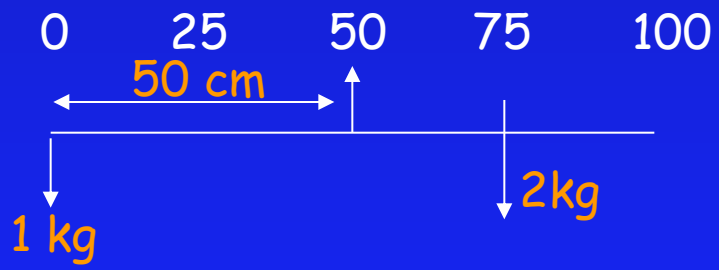
- Torque!

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

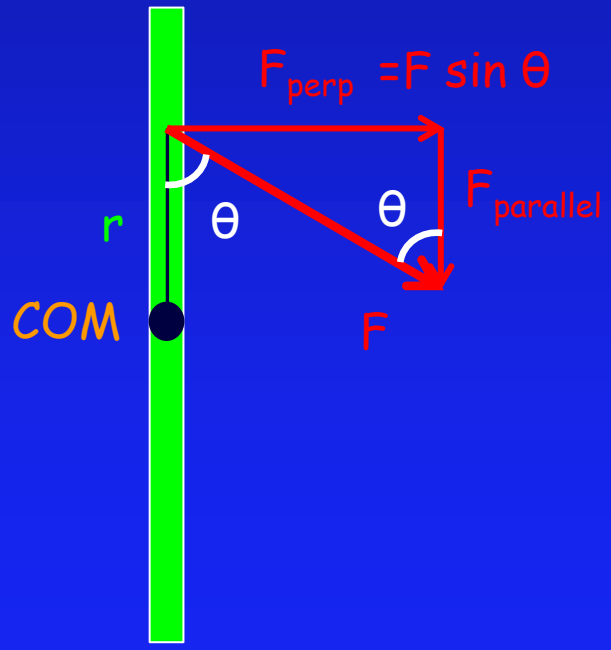


Balance Demo

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

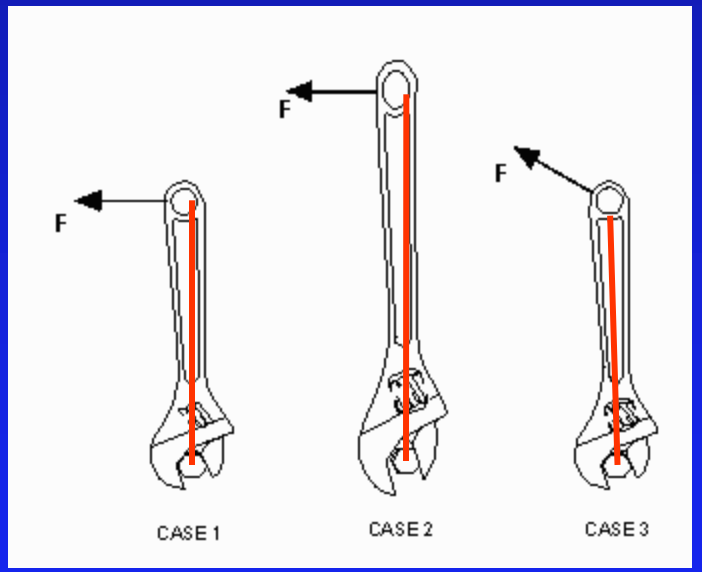


ACT

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

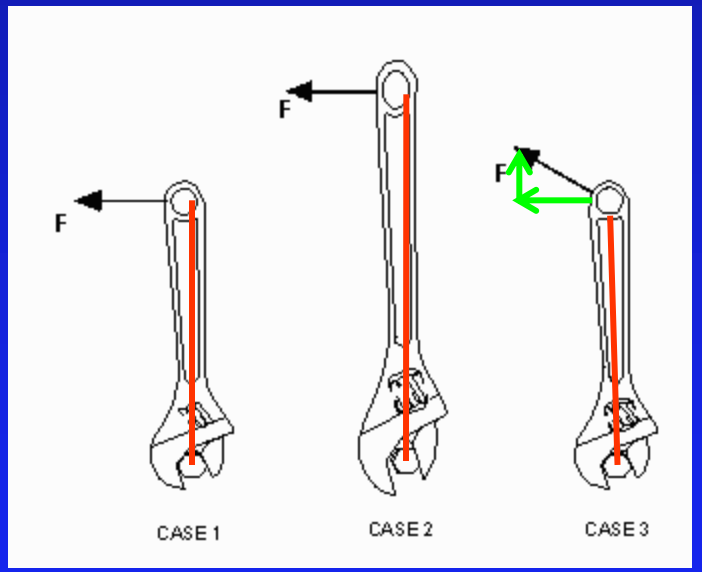


ACT 2

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



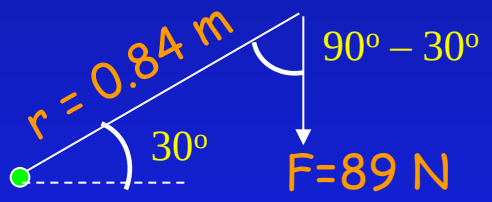
Torque Example and ACT

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

$= F\ r \sin(90 - 30)$ $= 65$ N m

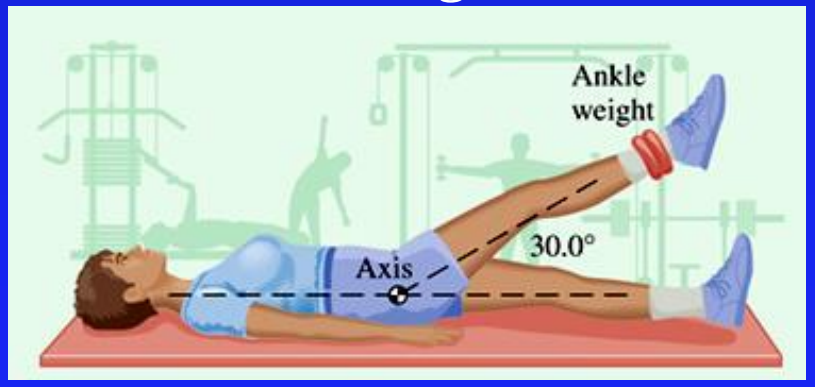


If she raises her leg higher, the torque due to the weight will

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?

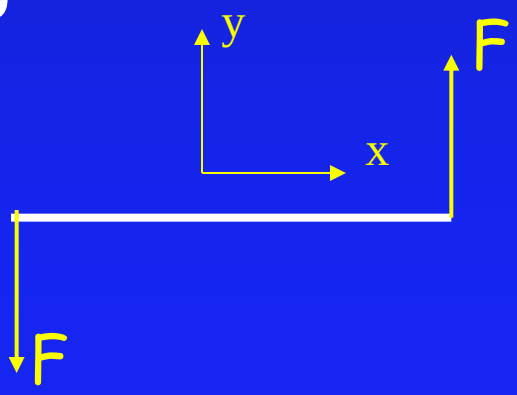
A) Up B) Down C) Zero

Y direction: $\Sigma F_y = ma_y$

$+F - F = 0$

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

Yes, it rotates!



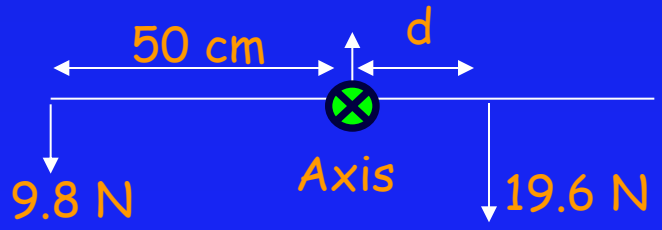
Equilibrium

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



$\tau_{Net} = 0$

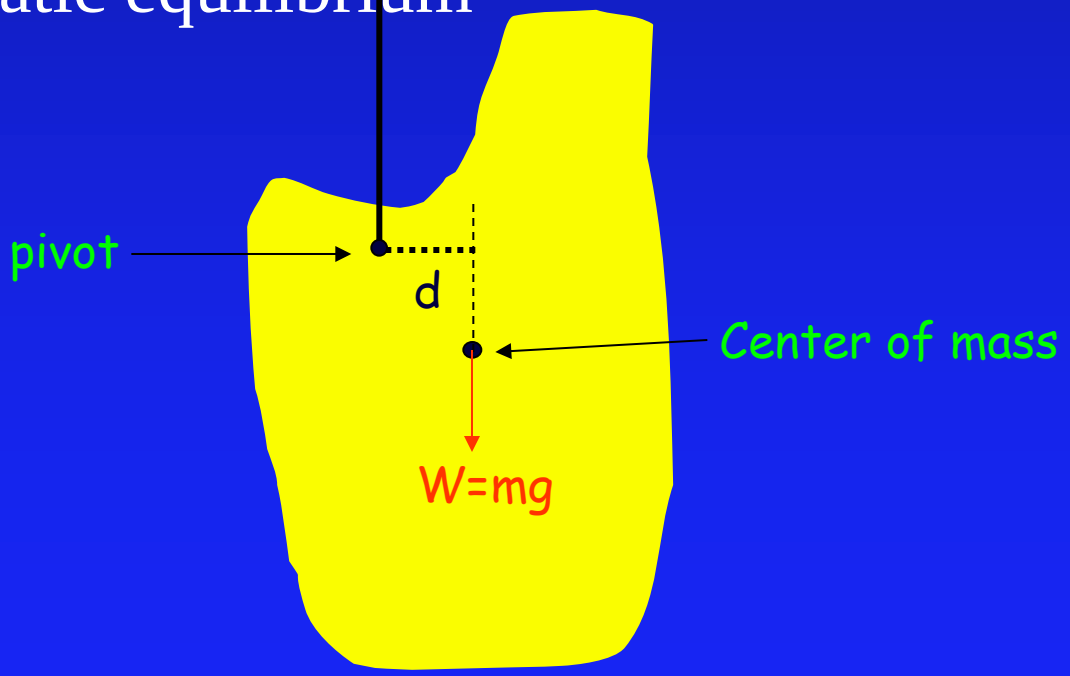
$9.8\ (0.5) - (19.6)d = 0$

$d = 25$

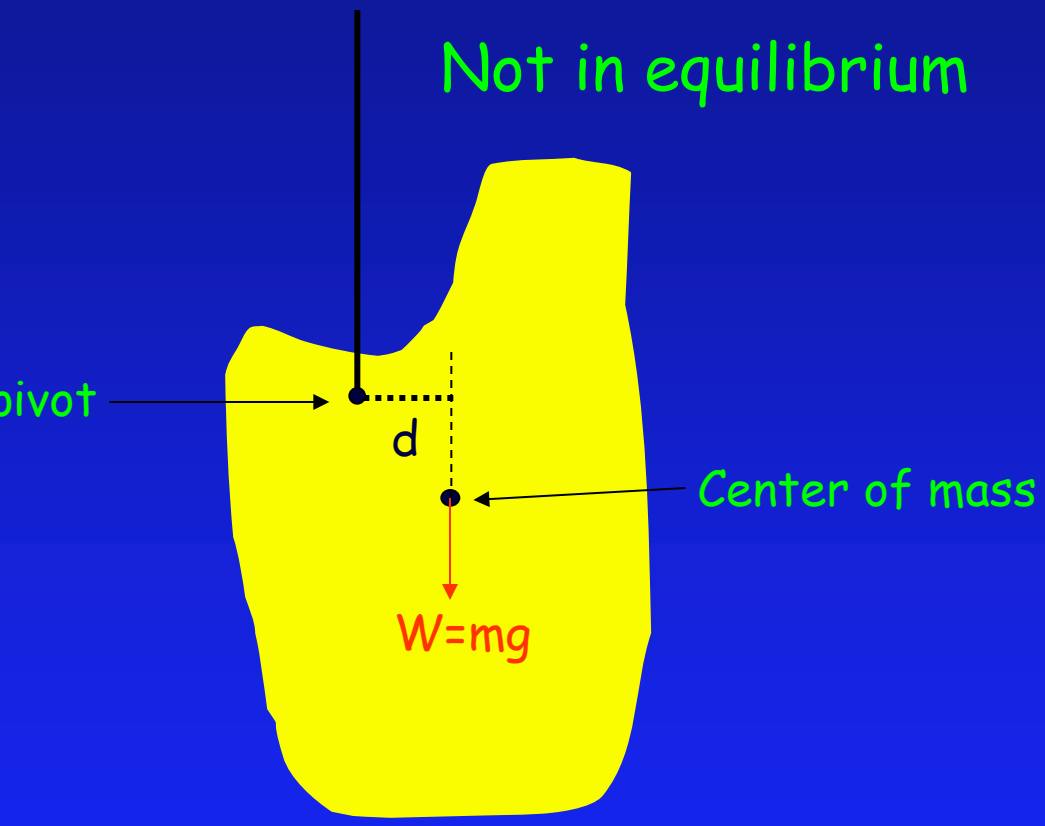
Balance Demo

Static Equilibrium and Center of Mass

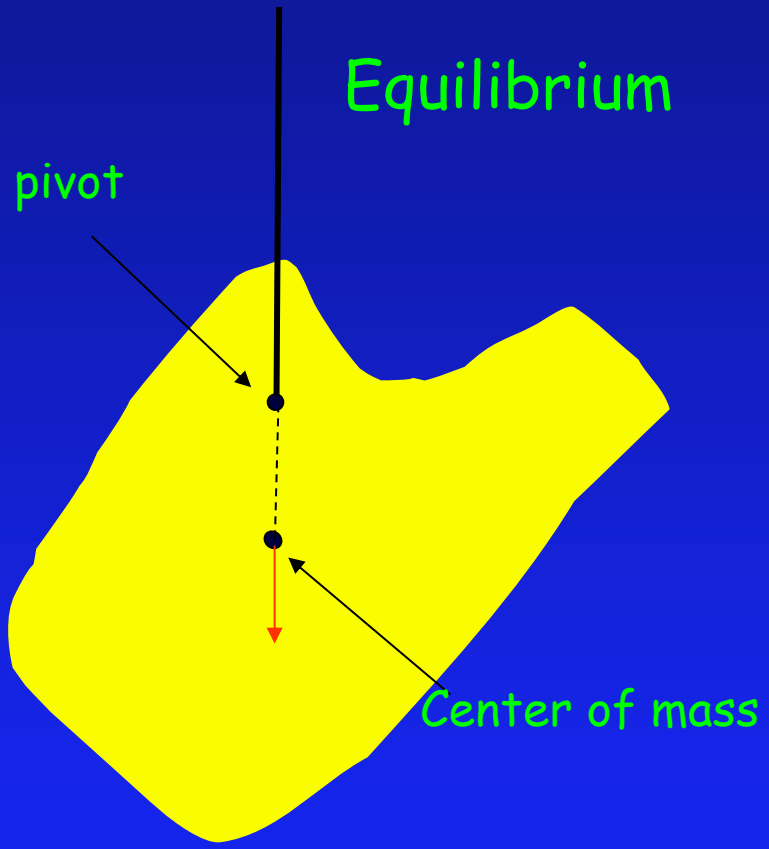
- Gravitational Force Weight = mg
  - ➔Acts as force at center of mass $r_{cm} = \frac{\sum r_i m_i}{\sum m_i}$
  - ➔Torque about pivot due to gravity $\tau = mgd$
  - ➔Object not in static equilibrium



Static Equilibrium



Torque about pivot ≠ 0



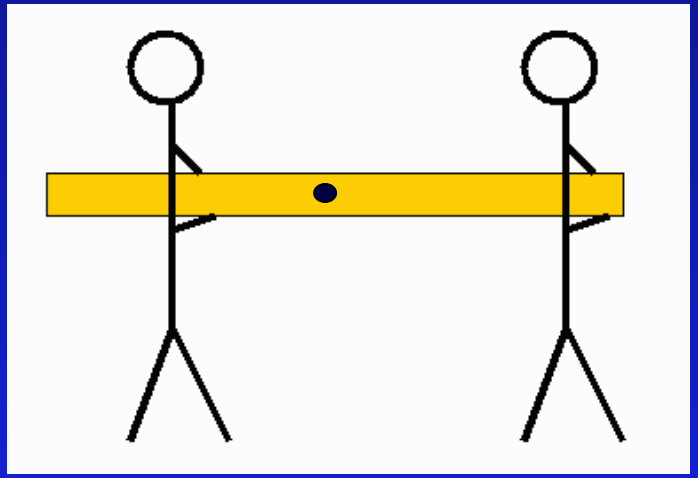
Torque about pivot = 0

A method to find center of mass of an irregular object

Checkpoint

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

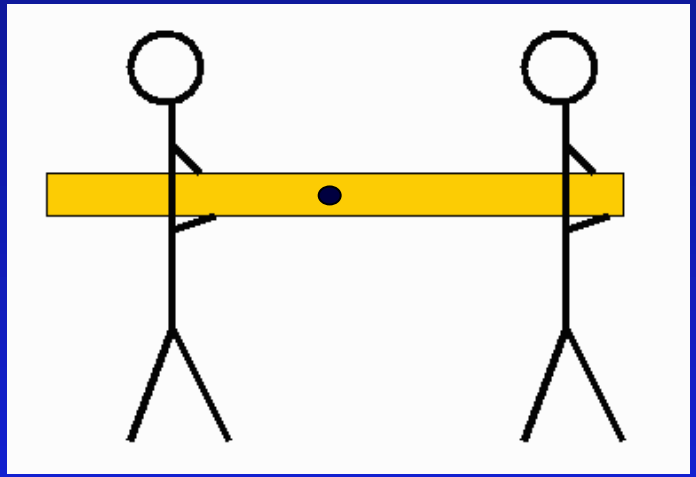
1. The person on the left is supporting the greatest weight ← CORRECT
2. The person on the right is supporting the greatest weight
3. They are supporting the same weight



Checkpoint

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

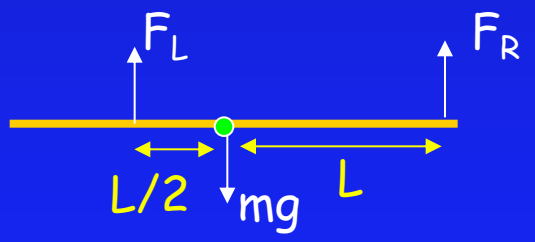
1. The person on the left is supporting the greatest weight ← CORRECT
2. The person on the right is supporting the greatest weight
3. They are supporting the same weight



Look at torque about center:

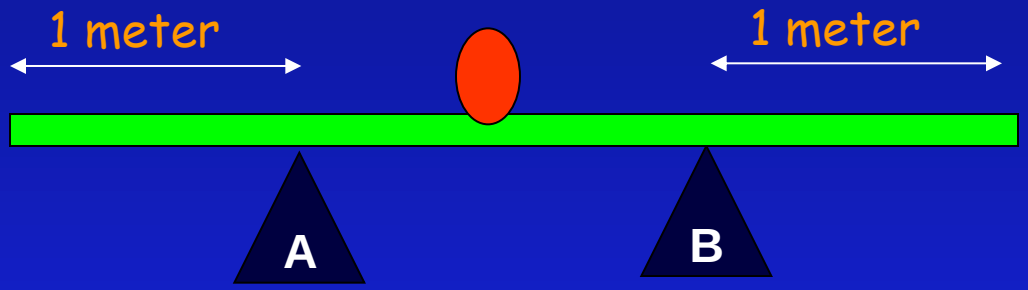
$F_R L - F_L L/2 = 0$

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



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.

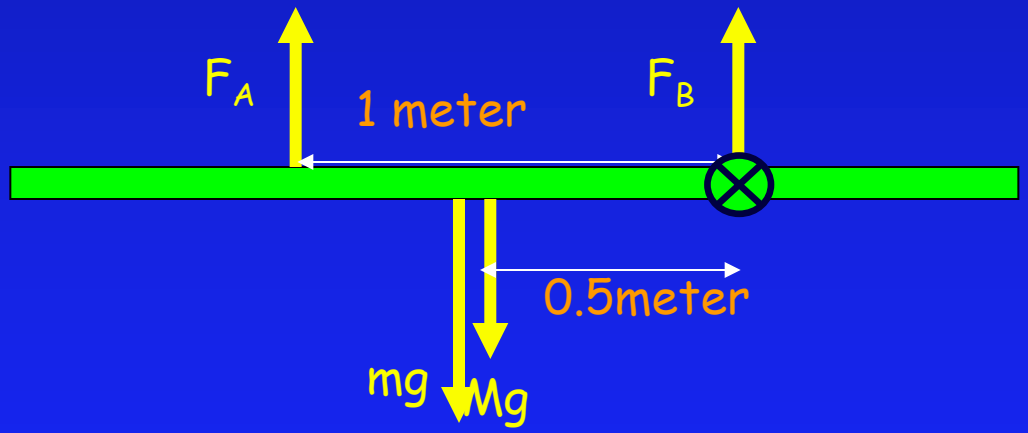


1) Draw FBD

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

3) Choose pivot

4) $\tau_{Net} = 0$



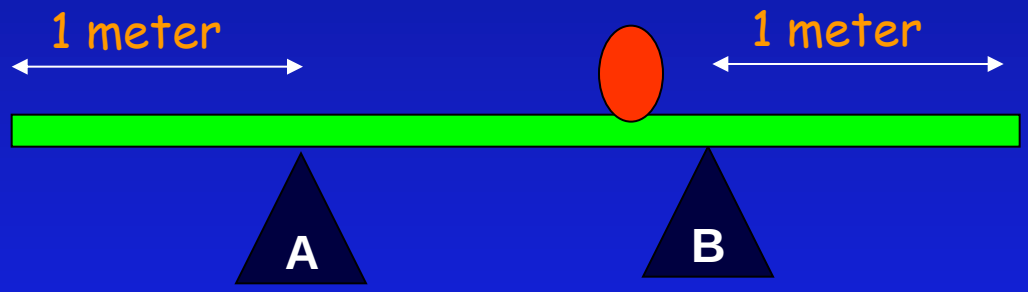
$-F_A\,(1)\sin(90) + F_B\,(0)\sin(90) + mg\,(0.5)\sin(90) + Mg(0.5)\sin(90) = 0$

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

Homework 8 Hints

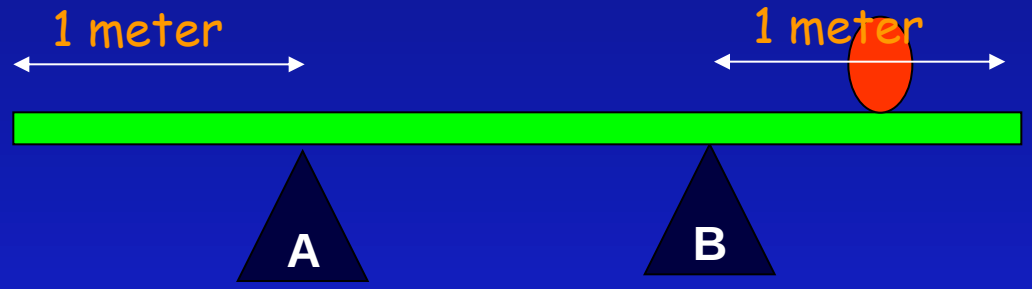
If the painter moves to the right, the force exerted by support A

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?



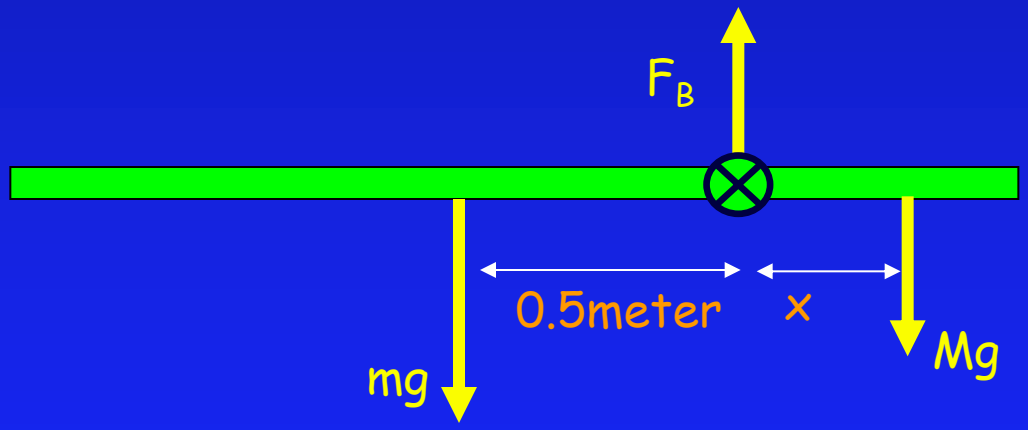
Just before the board tips, force from A becomes zero!

1) Draw FBD

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

3) Choose pivot

4) $\tau_{Net} = 0$

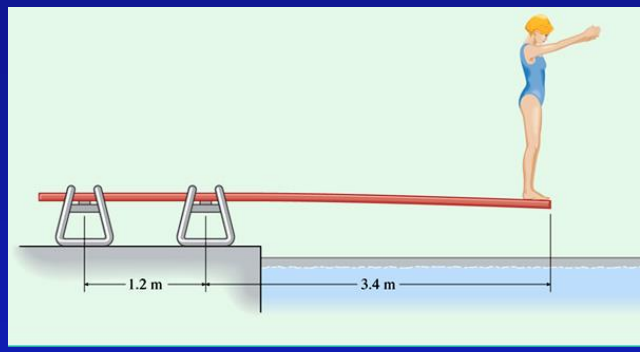


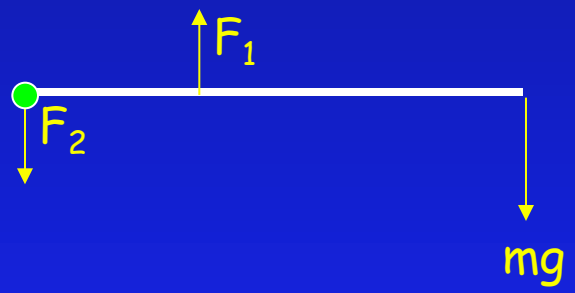
$F_B (0) \sin(90) + mg (0.5) \sin(90) - Mg(x) \sin(90) = 0$

$0.5\ m = x\ M$

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

$F_1 (1.2) - mg (4.6) = 0$

$F_1 = 4.6 (50 * 9.8) / 1.2$

$F_1 = 1880$ N

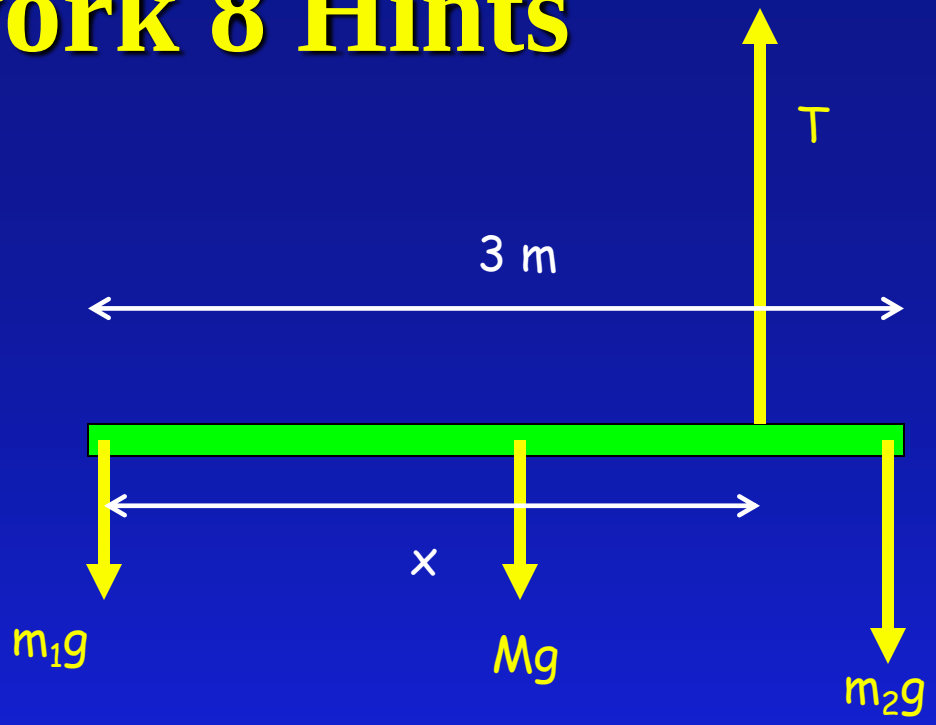
4) $F_{Net} = 0$ Translational EQ

$F_1 - F_2 - mg = 0$

$F_2 = F_1 - mg = 1390$ N

Homework 8 Hints

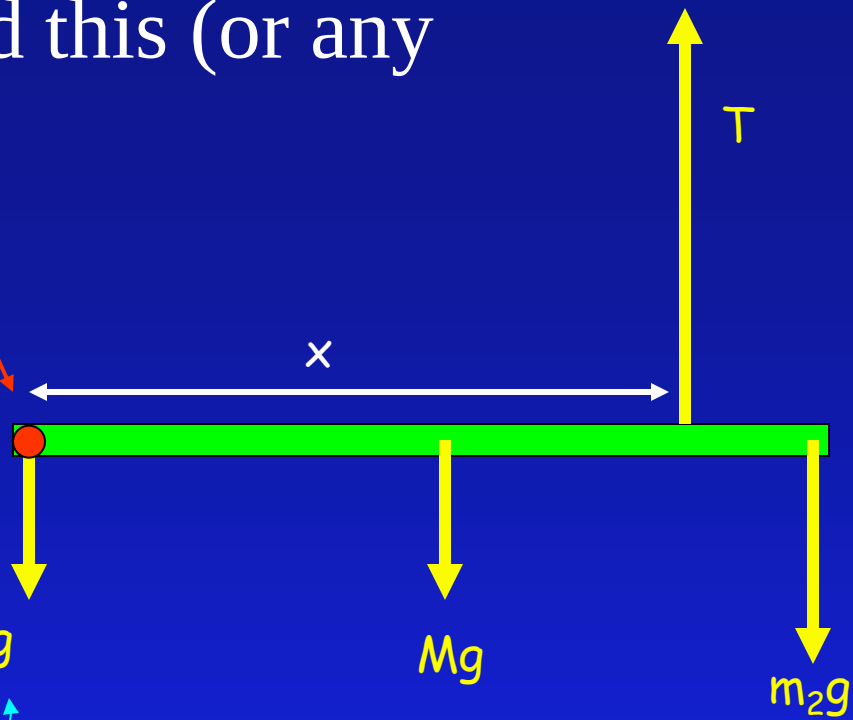
- Bar & Weights
- Given:
  - ➔ m_2
  - ➔ M
  - ➔ T
- Find m_1 and x



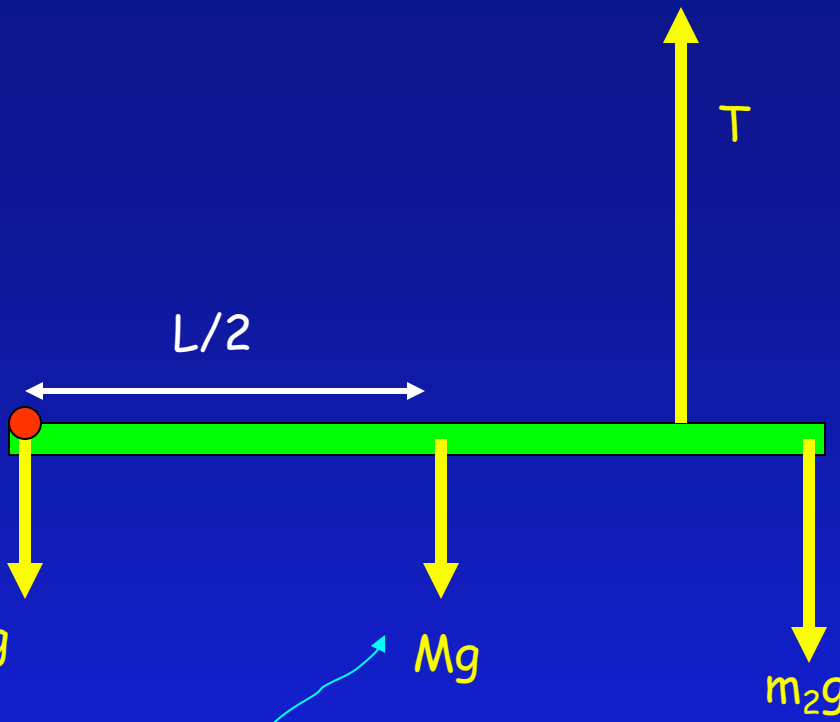
Using $F_{Net} = 0$: $T = m_1g + m_2g + Mg$

allows you to solve for m_1

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

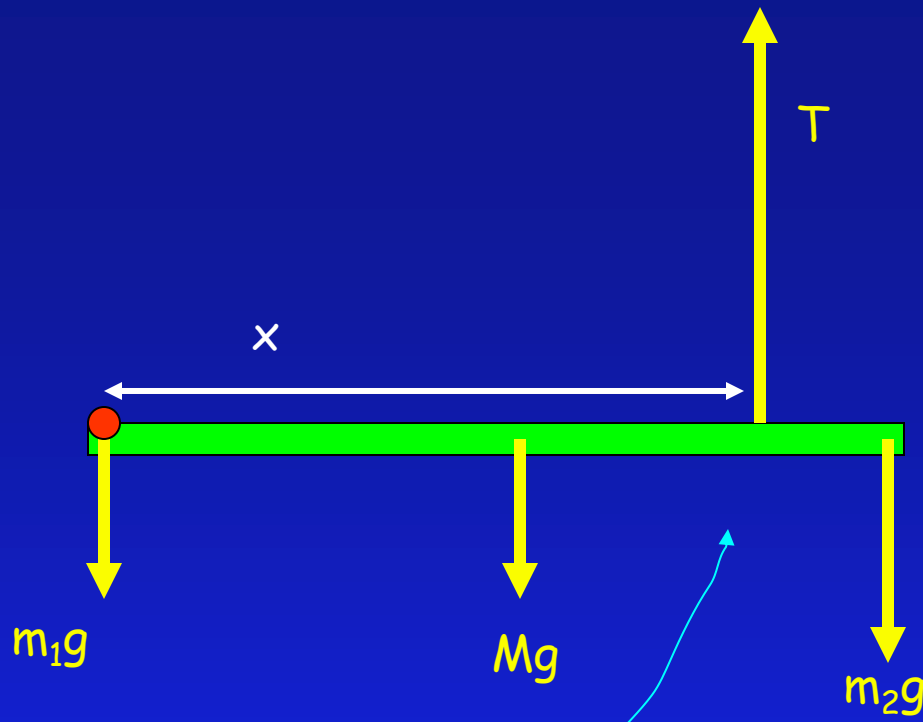


$\tau\ (m_1g) = 0$ since lever arm is 0



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

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

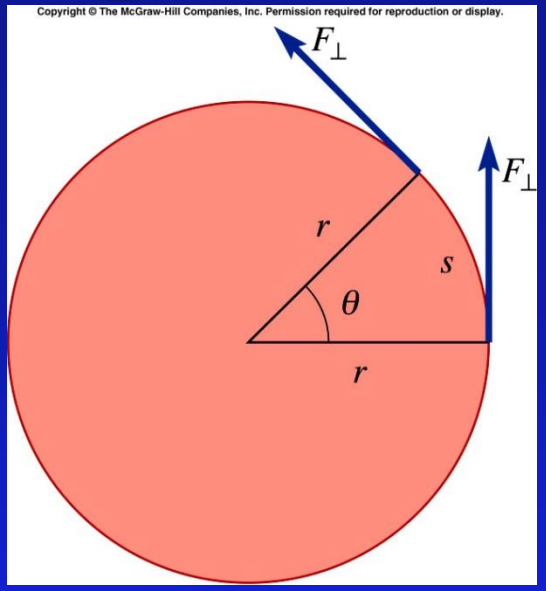


$\tau\ (m_1 g) = 0$ since lever arm is 0

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

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

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)

  $= \tau\ \theta$

Summary

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