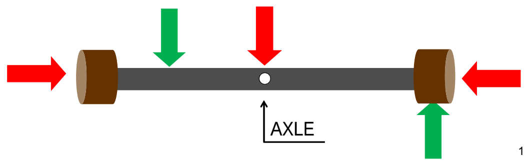
L-10(M-9) torque and rotational inertia

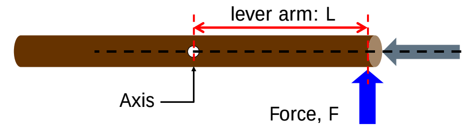
- We consider the rotation of *rigid bodies*. A rigid body is an extended object in which the mass is distributed spatially.
- Where should a force be applied to make it rotate (spin)? The same force applied at *different* locations produces *different* results.



1

TORQUE – Greek letter tau τ

- To make an object rotate, a force must be applied in the right place.
- the combination of force and point of application is called TORQUE
- The lever arm L is the distance from the axis of rotation to the point where the force is applied
- If the line of action of F passes through the axis of rotation, it produces no torque.



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Torque: τ (Greek tau)

Torque = force (F) x lever arm (L)

$$\tau = F\ L$$

- force F in Newtons, N
- lever arm L in meters, m
- Torque τ in units of N m

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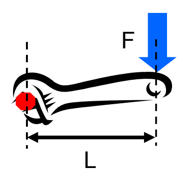
Torque example



What is the torque on a bolt applied with a wrench that has a lever arm: L= 20 cm with a force: F = 30 N?

Solution:

$\tau = F\ L$

$= 30\ N \times (1/5)\ m$

$= 6\ N\ m$

For the same force, you get more torque with a bigger wrench → the job is easier!

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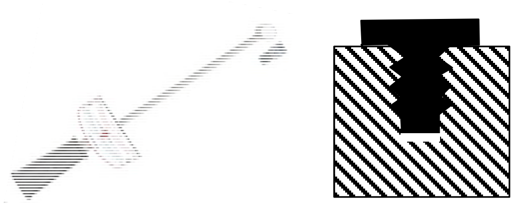
Torque wrench



- A torque wrench is a wrench that applies a calibrated torque to a bolt.
- It prevents a bolt from being over-tightened and possibly breaking.

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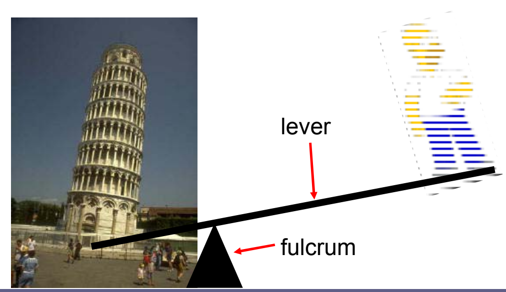
Homer attempts to straighten out the leaning tower of Pisa



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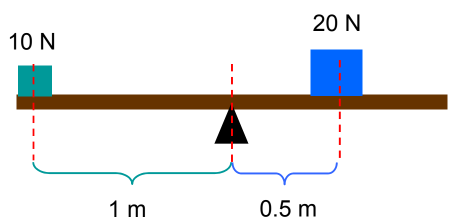
Net Force = 0 , Net Torque ≠ 0

- > The net force = 0, since the forces are applied in opposite directions so it will not accelerate.
- > However, together these forces will make the rod rotate in the clockwise direction.

Net torque = 0, net force ≠ 0

The rod will accelerate upward under these two forces, but will not rotate.

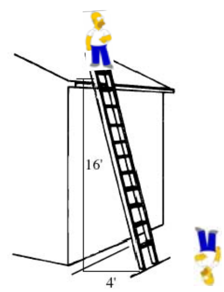
Balancing torques



Left torque = 10 N x 1 m = 10 n m
Right torque = 20 N x 0.5 m = 10 N m

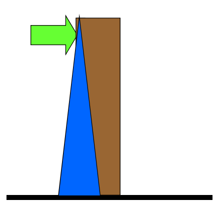
Equilibrium

- To ensure that an object does not accelerate or rotate two conditions must be met:
  – net force = 0
  – net torque = 0
- this results in the practical 4-1 “ladder rule”



When is an object stable?

- If you can tip it over a bit and it doesn’t fall
- The object may wobble a bit but it eventually stops and settles down to its upright position.



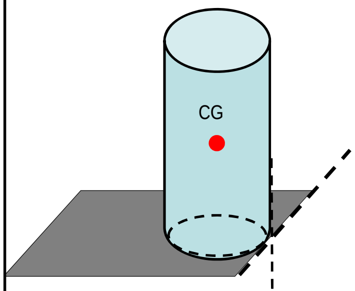
A thinner object is easier to topple

An object that is thicker at its base is more stable

Why do tall objects tend to fall over

- Every object has a special point called the center of gravity (CG). The CG is usually in the center of the object.
- if the center of gravity is supported, the object will not fall over.
- The lower the CG the more **stable** an object is. stable → not easy to knock over!

Condition for stability



If the CG is above the edge of the table, the object will not fall off.

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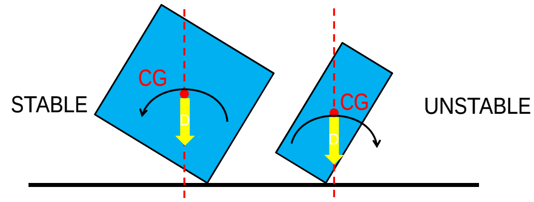
Why makes an object tip over?



- For the wide object, the dashed line extending from the CG down is to the left of the point of contact; the torque due to the weight tends to rotate the object counterclockwise
- For the narrow object, the dashed line extending from the CG down is to the right of the point of contact, the torque due to the weight tends to rotate the object clockwise.

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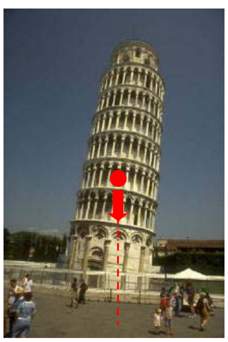
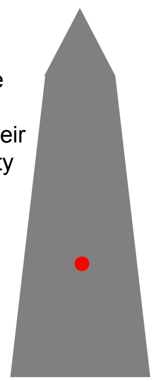
Stable structures



Structures are wider at their base to lower their center of gravity



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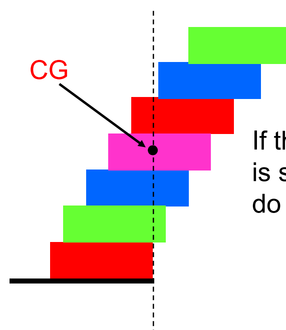
Playing with blocks



If the center of gravity is supported, the blocks do not fall over

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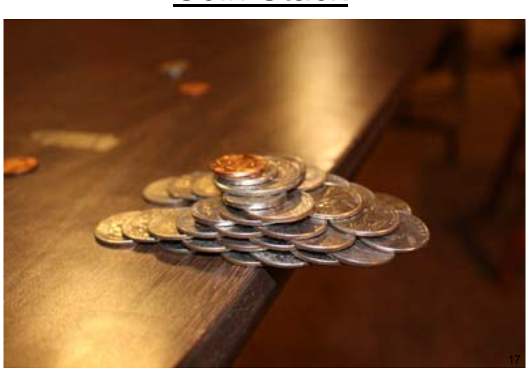
Coin Stack



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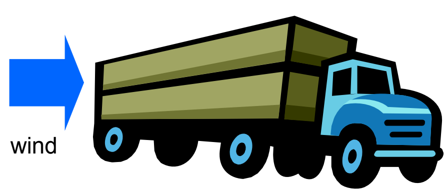
High Profile Vehicles



As more stuff is loaded into a semi, its center of gravity moves upward, making it susceptible to tipping over in high winds.

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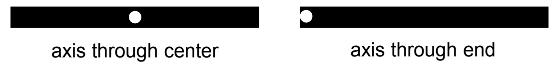
Rotational Inertia
(moment of inertia) symbol I

- A rigid body is characterized by a parameter called its rotational inertia
- The rotational inertia of a RB depends on how its mass is distributed relative to the axis of rotation
- The rotational inertia of a RB is the parameter that is analogous to inertia (mass) for a non-extended object
- For a RB, the rotational inertia determines how much torque is needed to produce a certain amount of rotational acceleration (spin).

rotational inertia examples

Rods of equal mass m and length L



$$I_{end} = 4\, I_{center}$$

The rod with the axis through the end requires more torque to get it rotating.

How fast does it spin?

- For spinning or rotational motion, the rotational inertia of an object plays the same role as ordinary mass for simple motion
- For a given amount of torque applied to an object, its rotational inertia determines its rotational acceleration → the smaller the rotational inertia, the bigger the rotational acceleration

Same torque, different rotational inertia

$$\tau = F\,L = mgR$$