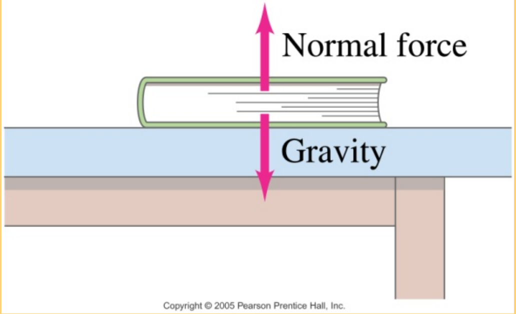
Chapter 9 – Static Equilibrium

Static – study of forces acting on structures in **equilibrium**
net force and net torque are zero
objects are at rest

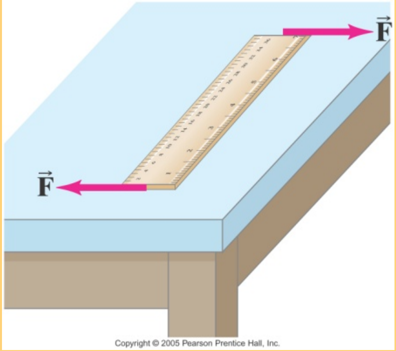
Important to avoid *deformations and fractures*
bridges, machines, human body (forces in muscles and joints), etc



Two forces – net force zero – object at rest

First Condition for Equilibrium:

$$\boxed{\Sigma F_x = 0 \;\; \Sigma F_y = 0 \;\; \Sigma F_z = 0}$$



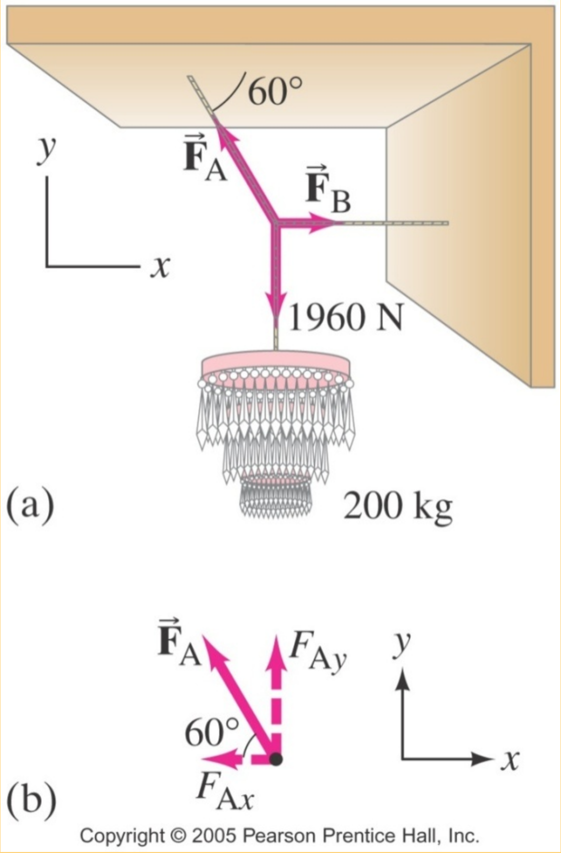
Second Condition for Equilibrium:

$$\boxed{\Sigma \tau = 0}$$

We will consider forces on a plane (xy). Choose an axis perpendicular to it to calculate torque.

Example

Ex. 9-2 Calculate the tensions F_A and F_B in the cord that are connected to the vertical cord supporting the 200-kg chandelier.

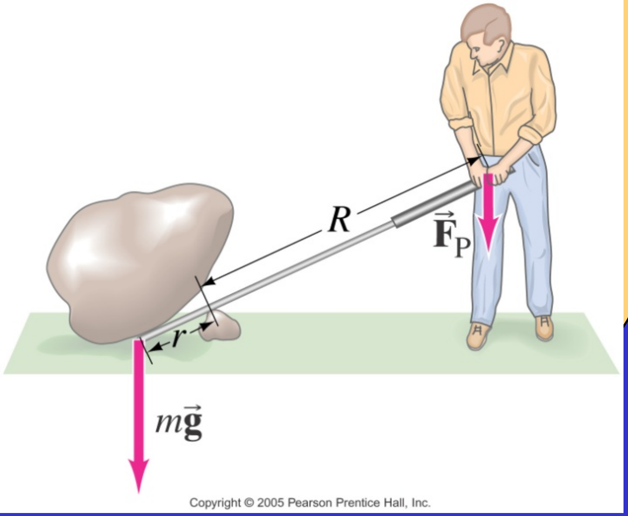


F_A = (231 kg) g = 2260 N
F_B = (115 kg) g = 1130 N

Note: the wire must be able to hold more than 230 kg. F_A has to be greater than the chandelier's weight, because it has to balance also the sideways force F_B

A lever can multiply your force. (pulley)
Ex. 9-3 How to increase the leverage?

increase R
or/and
decrease r



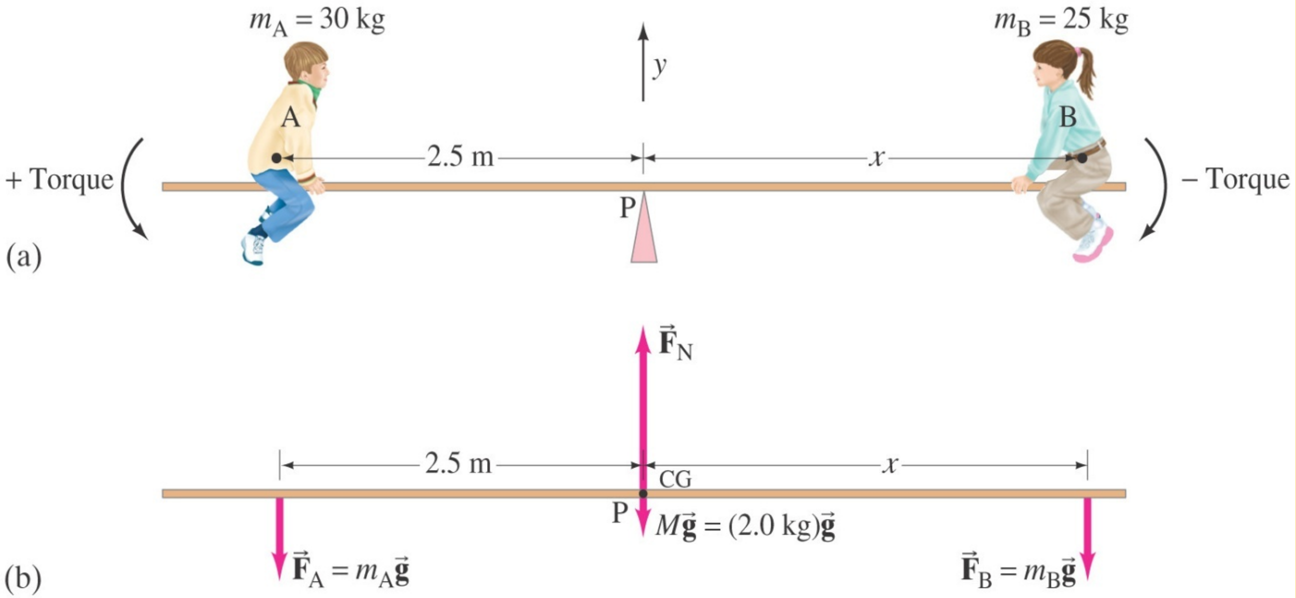
Solving Statics Problems

1. Choose one object at a time, and make a free-body diagram showing all the forces on it and where they act.
2. Choose a coordinate system and resolve forces into components.
3. Write equilibrium equations for the forces.
4. Choose any axis perpendicular to the plane of the forces and write the torque equilibrium equation. A clever choice here can simplify the problem enormously.
5. Solve.

We will have two force equations (x and y components) and one torque equation.
Torque that tends to rotate the object **counterclockwise** is **positive.**
We can consider the force of gravity on the object acting on its **CG=CM**
For uniform symmetrically shaped objects, the CG is at the geometric center.

Example

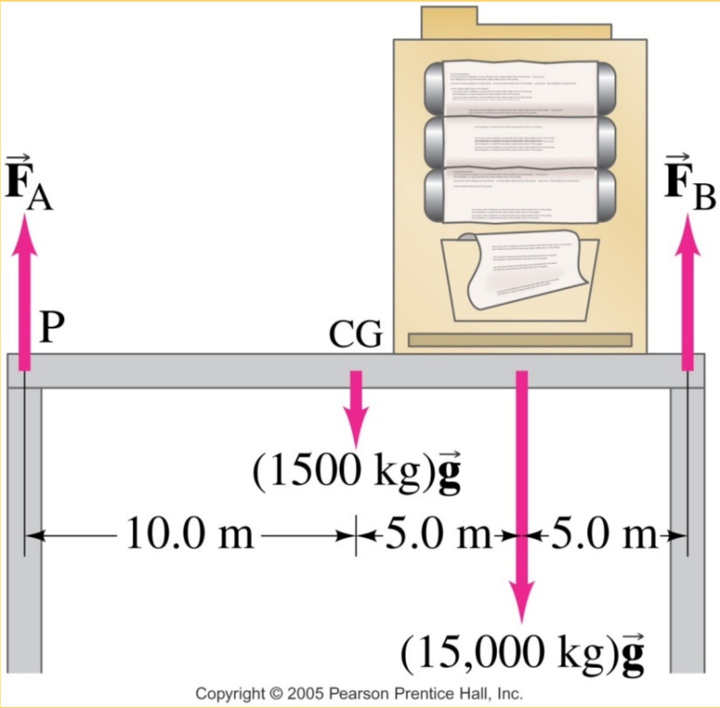
Ex. 9-4 A board of mass M=2.0 kg serves as a seesaw for two children. Child A has a mass of 30 kg and sits 2.5 m from the pivot point P. At what distance x from the pivot must child B, of mass 25 kg, place herself to balance the seesaw? The board is uniform and centered over the pivot.
Choose the board as the object.



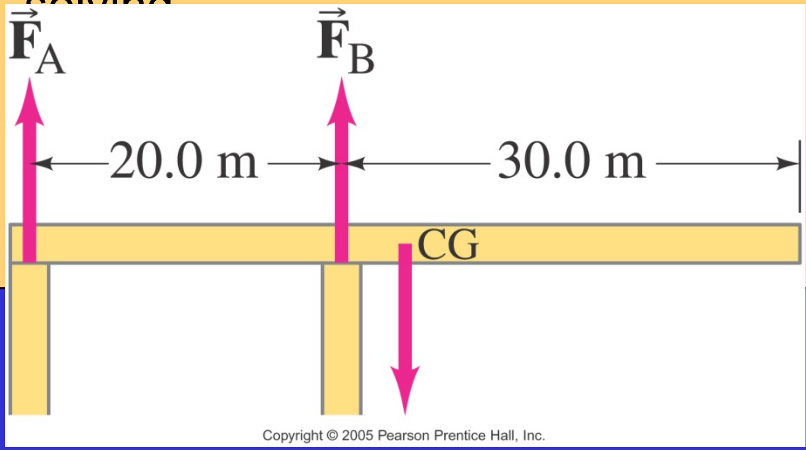
x=3.0 m

Examples

Ex. 9-5 A uniform 1500-kg beam, 20.0 m long, supports a 15,000-kg printing press 5.0 m from the right support column. Calculate the force on each of the vertical support columns.
(our object is the beam)



If a force in your solution comes out negative (as F_A will below), it just means that it's in the opposite direction from the one you chose. This is trivial to fix, so don't worry about getting all the signs of the forces right before you start solving.



F_B=(12,000 kg)g=118,000 N
F_A=(4500 kg)g=44,100 N

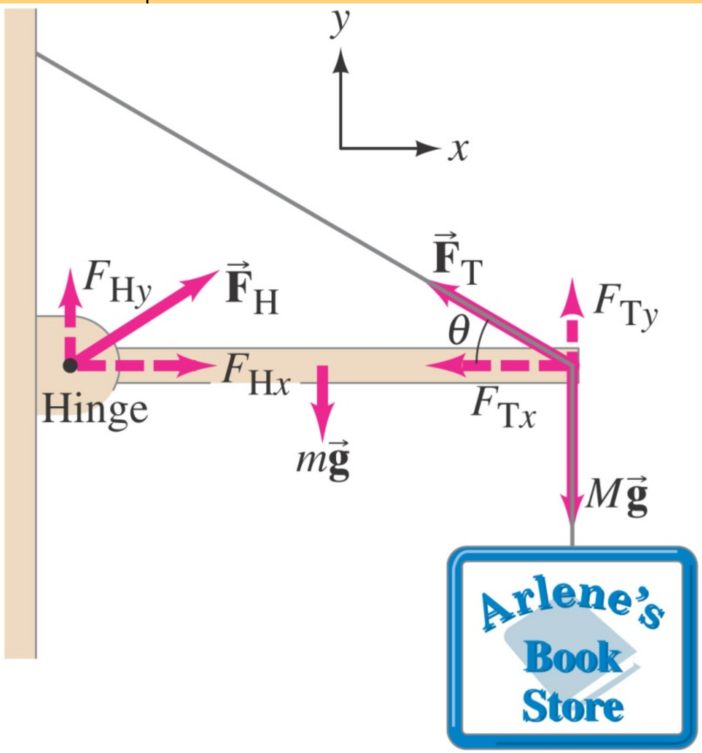
For m=1250kg
F_B=1.5x10^4 N
F_A= - 3.1x10^3 N

Example

If there is a cable or cord in the problem, it can support forces only along its length. Forces perpendicular to that would cause it to bend.

But for a rigid device, such as a hinge, the force can be in any direction

Ex. 9-6 A uniform beam, 2.20 m long with mass m=25.0 kg is mounted by a hinge on a wall. The beam is held in a horizontal position by a cable that makes 30 degree angle. The beam supports a sign of mass M=28.0 kg suspended from its end. Determine the components of the force F_H that the hinge exerts on the beam and the tension F_T in the supporting cable.
(our object is the beam – choose axis at hinge Compare it if the choice at point Mg acts)



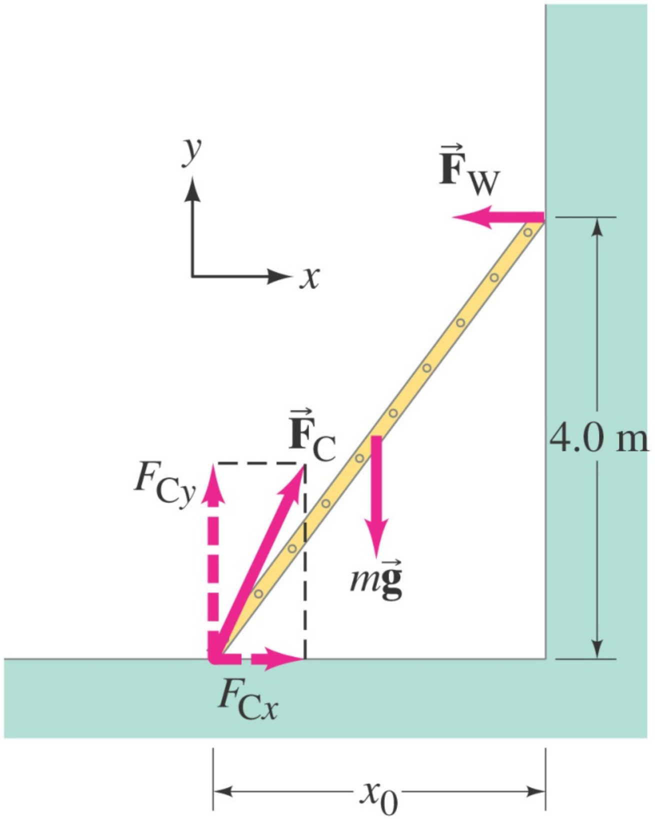
F_{Hy}=122N
Fty=397N, Ft=794N
F_{Hx}=688N

Example

Ex. 9-7 A 5.0-m-long ladder of mass m=12.0 kg leans against a wall at a point 4.0 m above a cement floor. Assume the wall is frictionless (but not the floor) and determine the forces exerted on the ladder by the floor and by the wall.

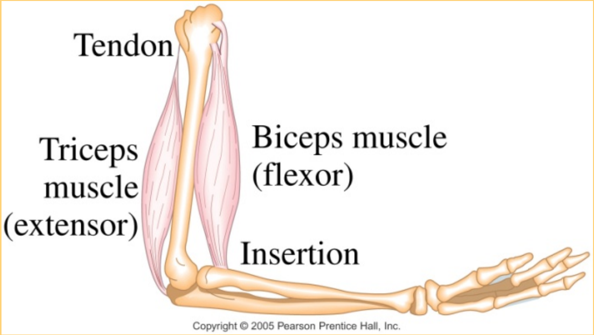
F_W=44N=F_{Cx}
F_{Cy}=118N

F_C=130N
Angle = 70 degrees



Notice that F_C does NOT have to act along the ladder's direction, because it is rigid.

Applications to Muscles and Joints

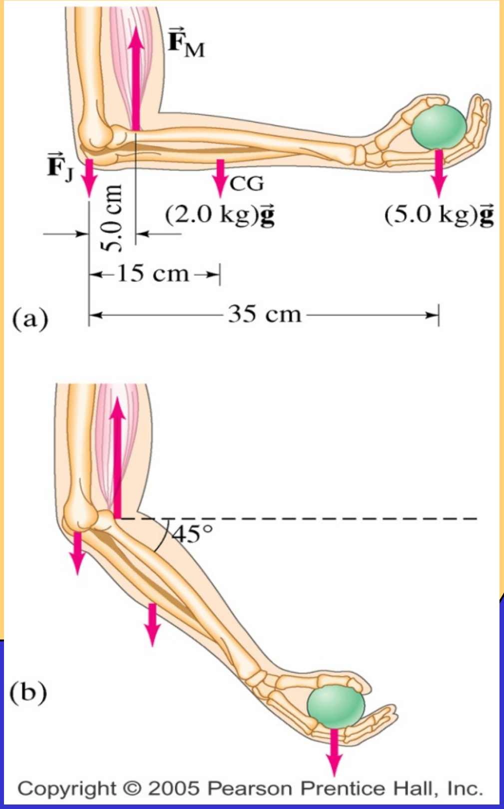


A muscle is attached via tendons to 2 bones
Attachments – insertions
Two bones – connected at a joint
Muscle can exert a pull when its fibers contract
Flexors bring limbs closer (biceps)
Extensors extend a limb outward (triceps)
Flexors to lift an object and extensors to throw.

Ex. 9-8 How much force must the biceps muscle exert when a 5.0-kg mass is held in the hand (a) with the arm horizontal, and (b) when the arm is at a 45 degree angle? Assume that the mass of forearm and hand together is 2.0 kg.

F_M=400N for (a) and (b)

Champion athletes are often found to have muscles insertions farther from the joint than the average person



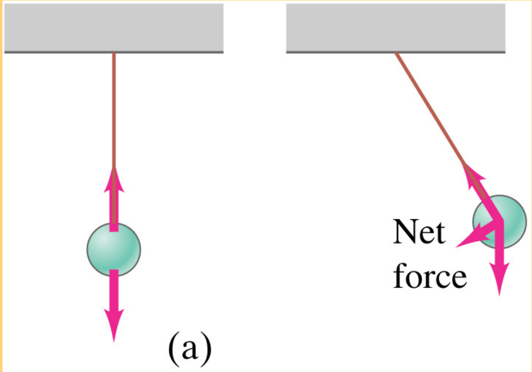
Stability and Balance

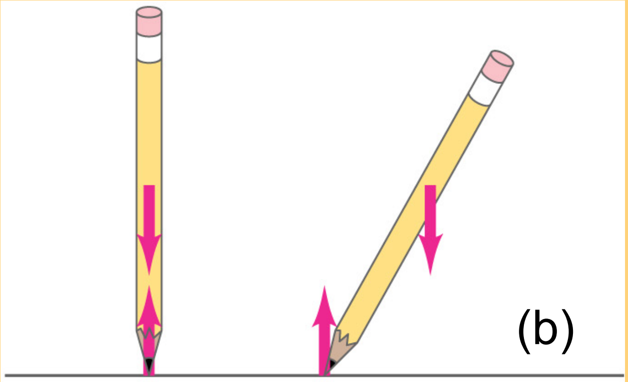
If an object in static equilibrium is displaced slightly, then:

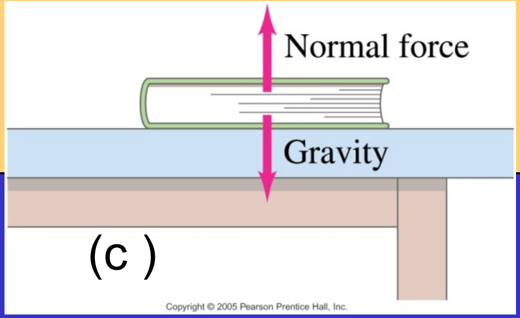
(a) If the forces are such that it tend to **return** to its equilibrium position, it is said to be in **stable equilibrium**.

(b) If, however, the forces tend to move it **away** from its equilibrium point, it is said to be in **unstable equilibrium**.

(c) If the object **remains** in its new position, it is said to be in **neutral equilibrium**.

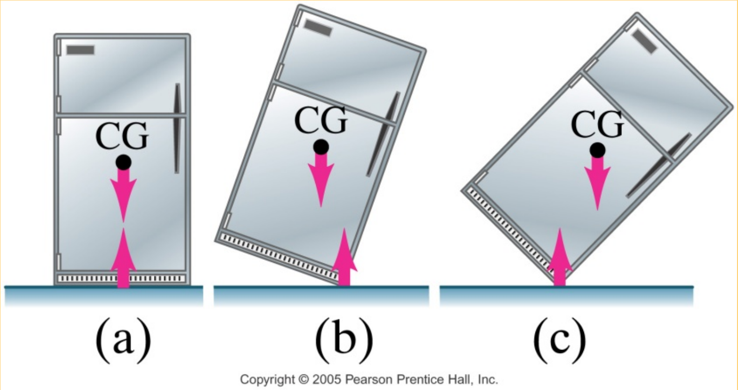






Stability and Balance

An object in stable equilibrium may **become unstable** if it is tipped so that its center of gravity is outside the pivot point. Of course, it will be stable again once it lands!



People carrying heavy loads automatically adjust their posture so their center of mass is over their feet. This can lead to injury if the contortion is too great.