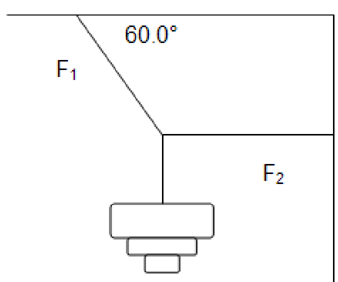
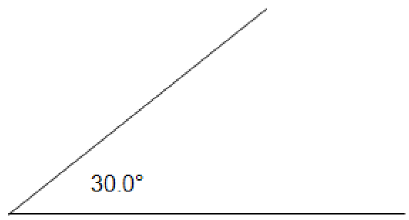
Static Equilibrium and Torque

Static Equilibrium:
All forces applied to an object lead to no acceleration and zero velocity. The object is still, or in static equilibrium. Being in static equilibrium does not mean that the object has no forces acting on it, but that all forces are balanced.

Example:
Calculate the tensions F_1 and F_2 in the two cords shown below.

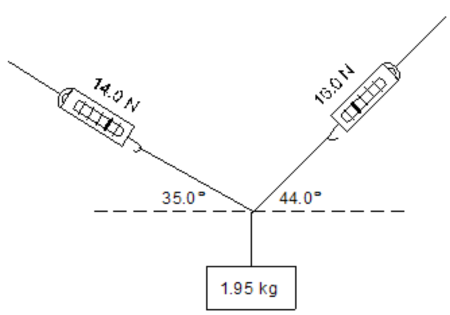


Example:
A truck is pulling a boat of mass 400.0 kg up a hill as shown, at a constant velocity. Ignoring friction, what is the tension in the cable?

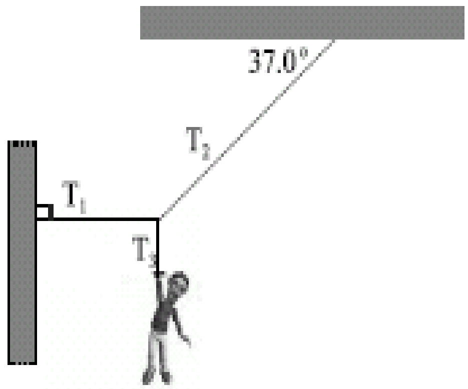


If there is a coefficient of static friction of 0.25 between the boat and the trailer rollers, what is the tension in the cable to keep the boat in static equilibrium?

Example:
In the diagram below, spring scales are used to measure the tension in each string supporting the 1.95 kg mass.
Calculate whether the system is in static equilibrium.



A 56.0 kg person suspended by cables hangs motionless as shown. Calculate the magnitude of the tension T_1, T_2 and T_3 in each cable.

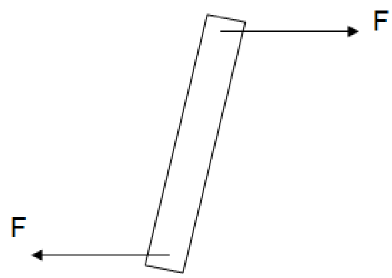


Torque

Center of Mass:
A single point at which the entire mass of a body is considered to be concentrated. For uniform shapes like a sphere, the center of mass would be its geometric center.

For oddly shaped objects, the center of mass is located at its balance point in any gravitational field. It is also referred to as the center of gravity. There would only be a difference between center of mass and center of gravity if a body were large enough so that the acceleration due to gravity was different at different parts of the body. We will assume they are the same.

Note that having a net force of zero is condition for translational equilibrium.



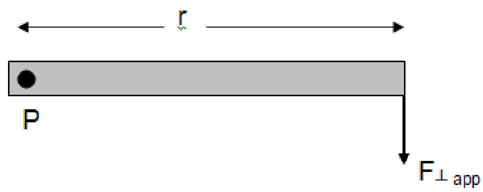
In the diagram shown the net force is zero. However, the object can still rotate because the object has a net torque. If a body is to remain at rest, the net torque must be zero as well.

What is torque?

Torque = the rotational effect caused by a force. Also called the moment of force.

Consider the case of opening a door. Why is the doorknob located farthest from the hinge? Other examples include opening a bottle or turning a steering wheel.

Consider:



r = the perpendicular distance (m) between the place where the force is applied and the pivot point

P = the pivot or point of rotation

$F_{\perp app}$ = the applied force (N) at 90° to the surface

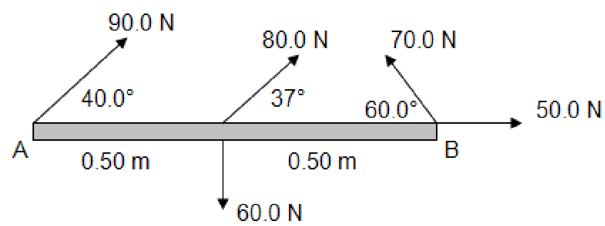
Θ = the angle between the surface and the applied force

τ = torque in Newton metres (N·m)

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

If the applied force is not at 90° to the surface, then we must use the perpendicular component of the force.

Example:
Fill in the missing information in the chart for the diagram shown.



Pivot A

Force (N)	Moment Arm (r)	torque	direction of rotation
50.0			
60.0			
70.0			
80.0			
90.0			

Pivot B

Force (N)	Moment Arm (r)	torque	direction of rotation
50.0			
60.0			
70.0			
80.0			
90.0			

Balancing Torques:

Two conditions for static equilibrium:

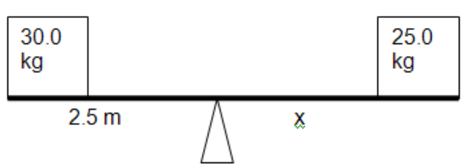
i) $F_{net} = 0$ means there is no translational motion

ii) $\tau_{net} = 0$ means there is no rotational motion

Or,

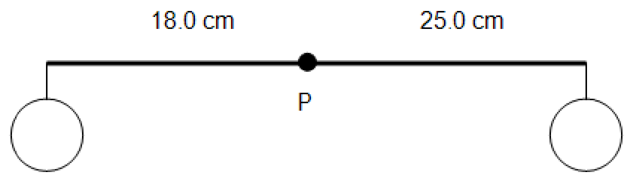
$$\tau_{clockwise} = \tau_{counterclockwise}$$

Example:
A 2.0 kg board serves as a seesaw for two children as shown. One child has a mass of 30.0 kg and sits 2.5 m from the pivot point. At what distance, x, from the pivot must a 25.0 kg child sit to balance the seesaw? Assume the board is uniform and is centered over the pivot.

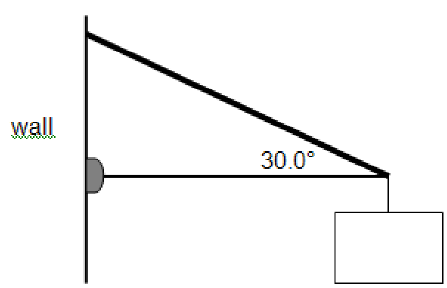


Example:
A mobile hangs as shown in the diagram. The 10.0 g figure on the left balances the other figure to maintain static equilibrium.

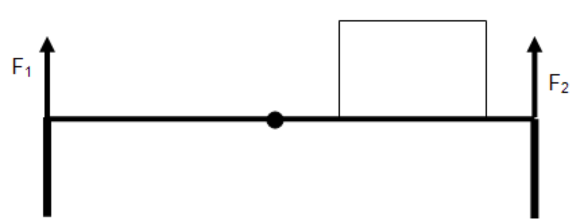
a) What is the mass of the figure on the right?
b) What is the tension in the single string supporting the entire mobile?



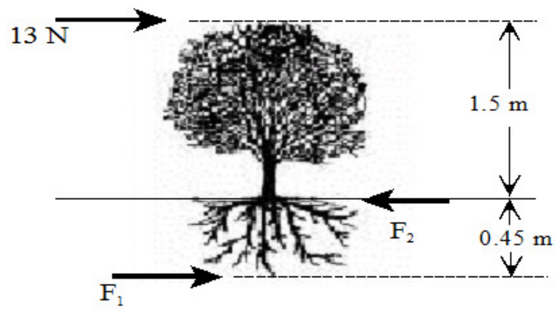
Example:
A uniform rod of length L and mass of 4.0 kg is hinged at the left end. A 25.0 kg sign is suspended from the right end as shown. Determine the tension in the wire connecting the end of the rod to the wall.



Example:
A uniform 1500 kg beam, 20.0 m long supports a 15 000 kg printing press that is 5.0 m from the right support column as shown. Determine the forces exerted on the beam by the support columns.

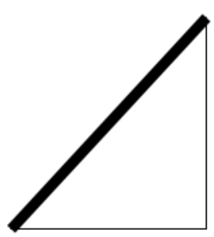


Example:
The wind exerts a force of 13 N on the top of the tree shown below. Calculate the forces, F_1 and F_2, required for the tree to remain in static equilibrium.



Example:
A weightless ladder 7.0 m long rests against a frictionless wall at an angle of 65° above the horizontal. A 72 kg person is 1.2 m from the top of the ladder.

a) What force is exerted on the ladder by the wall?
b) What horizontal force at the bottom of the ladder is required to keep it from slipping?
c) What force does the ground exert on the ladder?



Example:
The diagram below shows a uniform 7.0 kg ladder resting against a frictionless wall. The person on the ladder has a mass of 65 kg. If the ladder is 5.0 m long, what force does the wall exert on the ladder?