COLLEGE PHYSICS

Chapter 9 STATICS AND TORQUE

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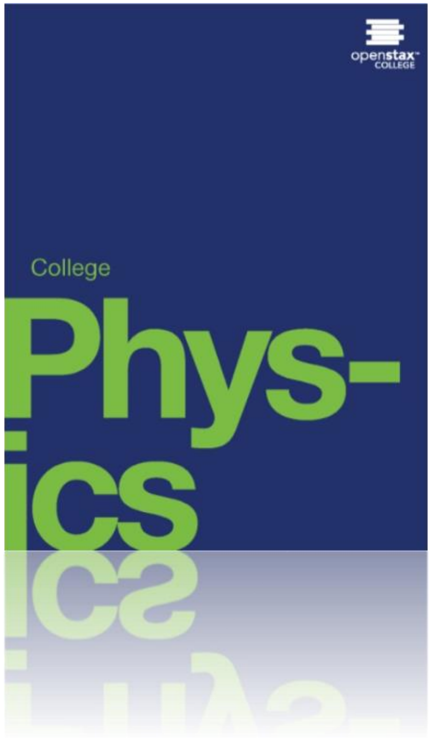

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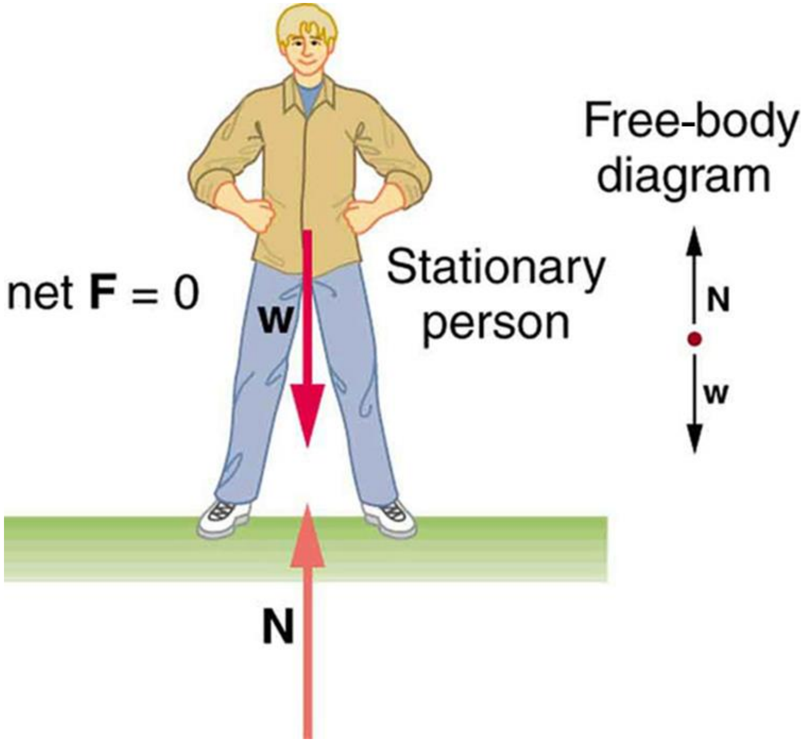
Chapter 9
Static Equilibrium and Torque

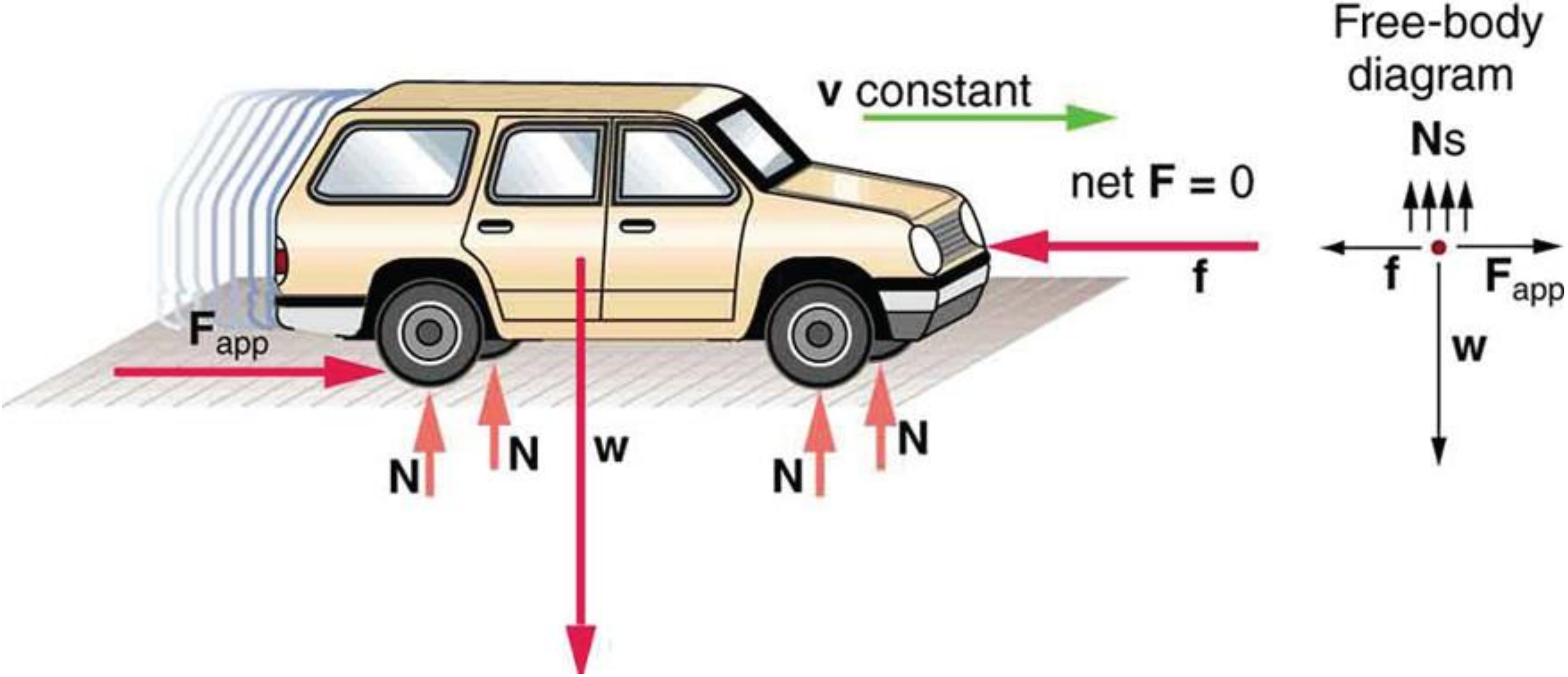
- The Conditions for Equilibrium
- Solving Statics Problems
- Applications to Muscles and Joints
- Stability and Balance

Static equilibrium



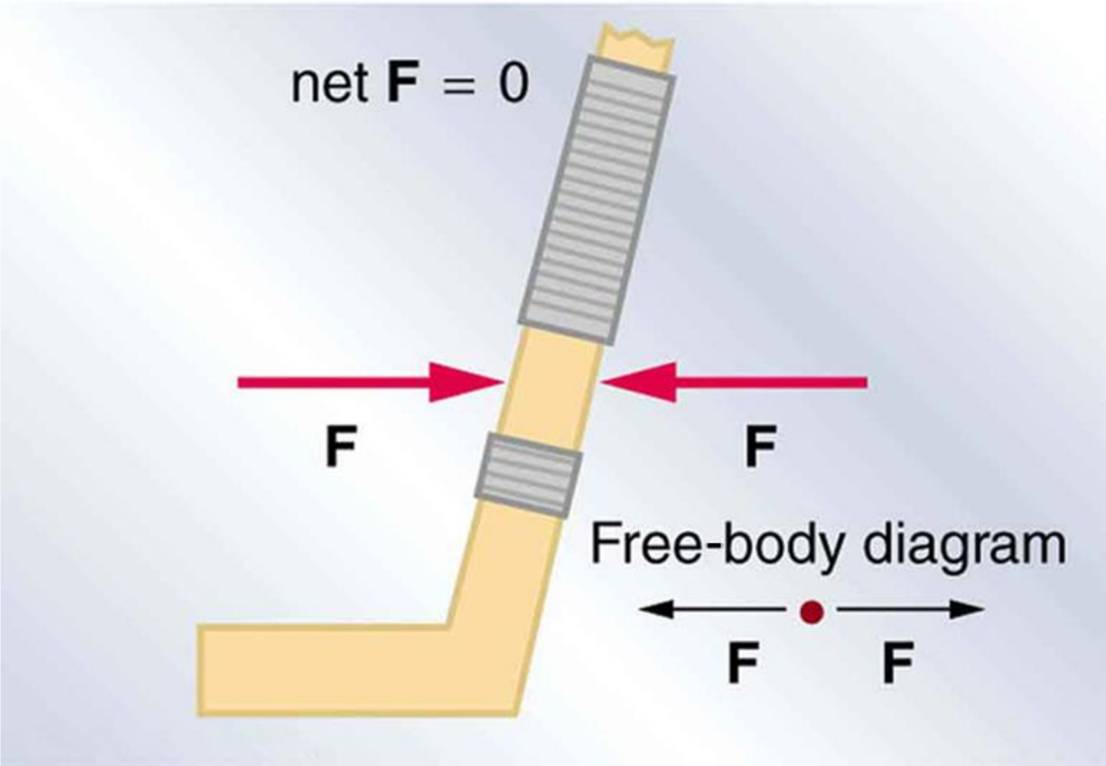
This motionless person is in static equilibrium. The forces acting on him add up to zero. Both forces are vertical in this case.

Dynamic equilibrium

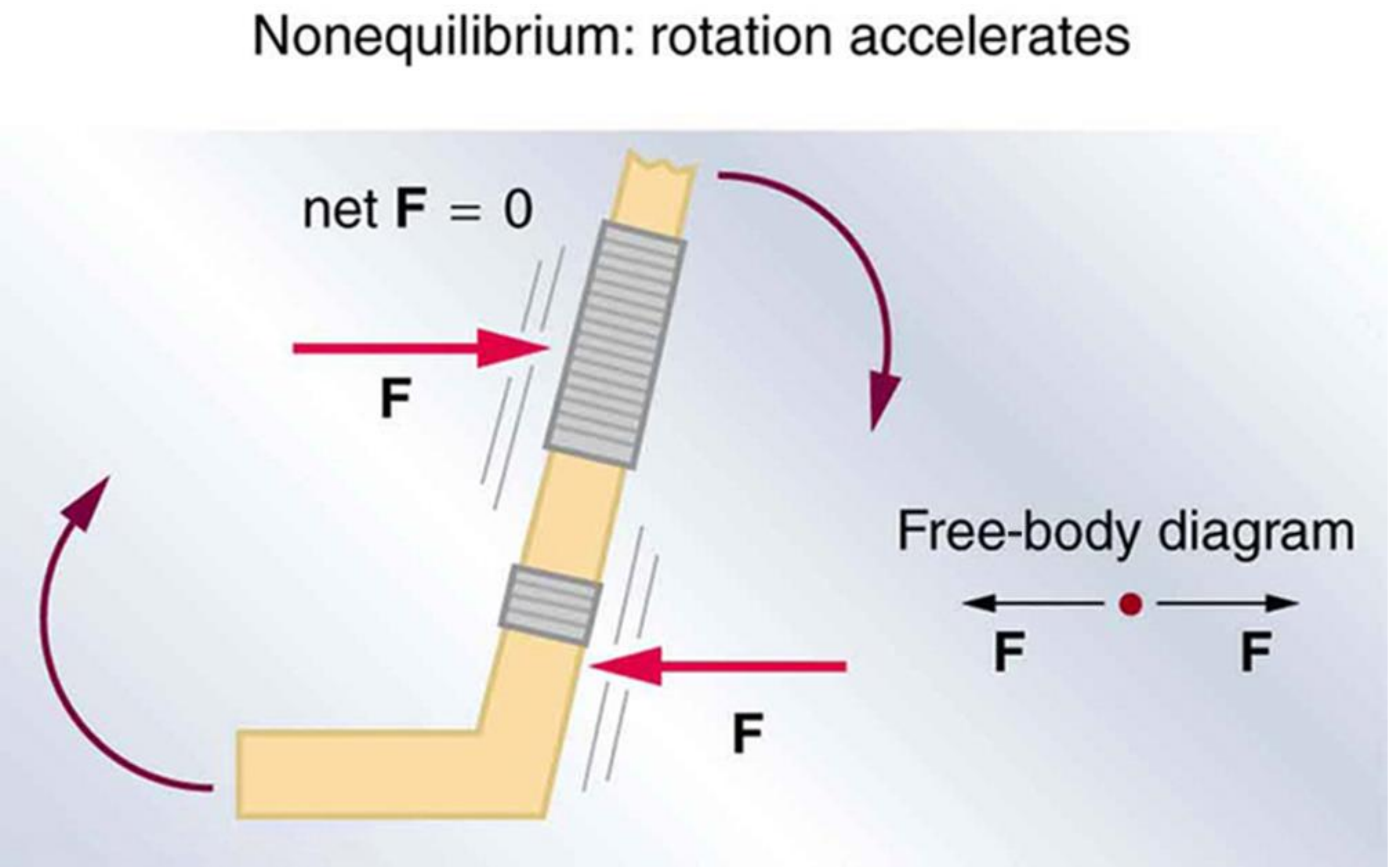


This car is in dynamic equilibrium because it is moving at constant velocity. There are horizontal and vertical forces, but the net external force in any direction is zero. The applied force F_{app} between the tires and the road is balanced by air friction, and the weight of the car is supported by the normal forces, here shown to be equal for all four tires.

Equilibrium: remains stationary



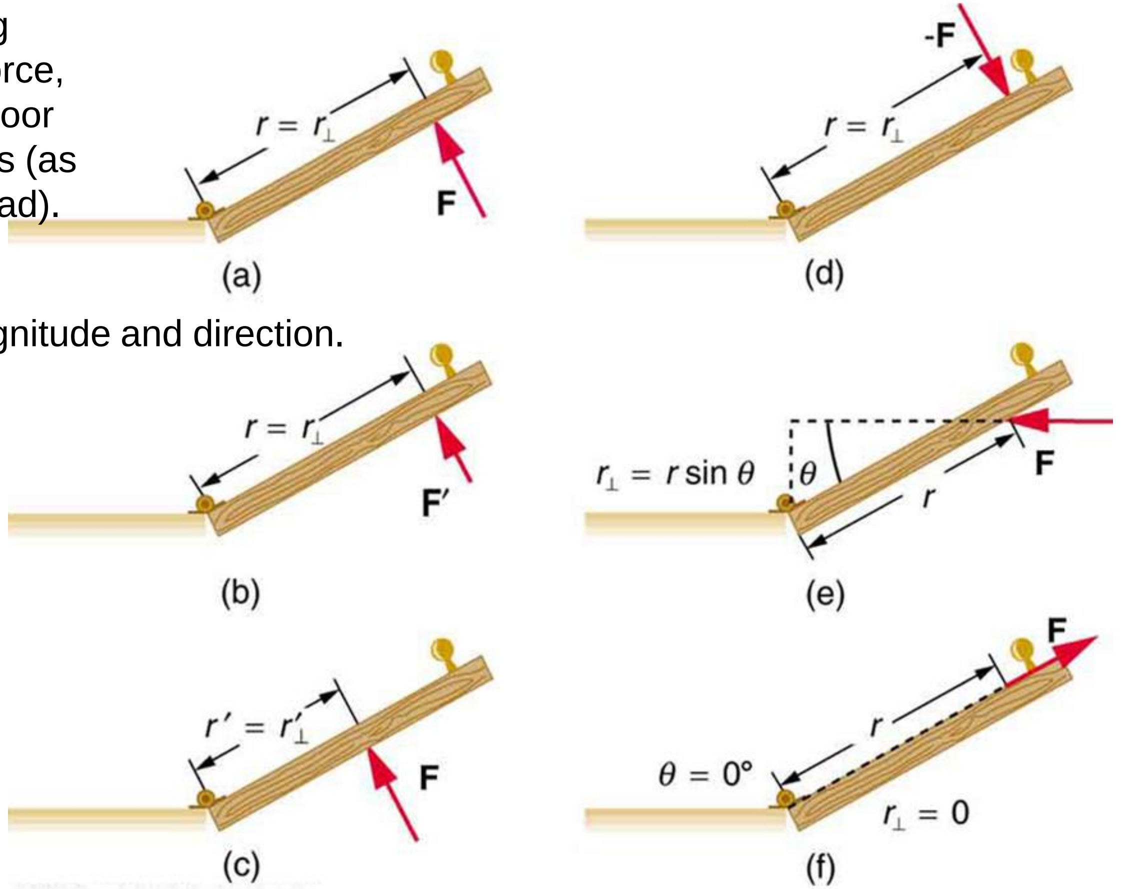
An ice hockey stick lying flat on ice with two equal and opposite horizontal forces applied to it. Friction is negligible, and the gravitational force is balanced by the support of the ice (a normal force). Thus, net $F = 0$. Equilibrium is achieved, which is static equilibrium in this case.



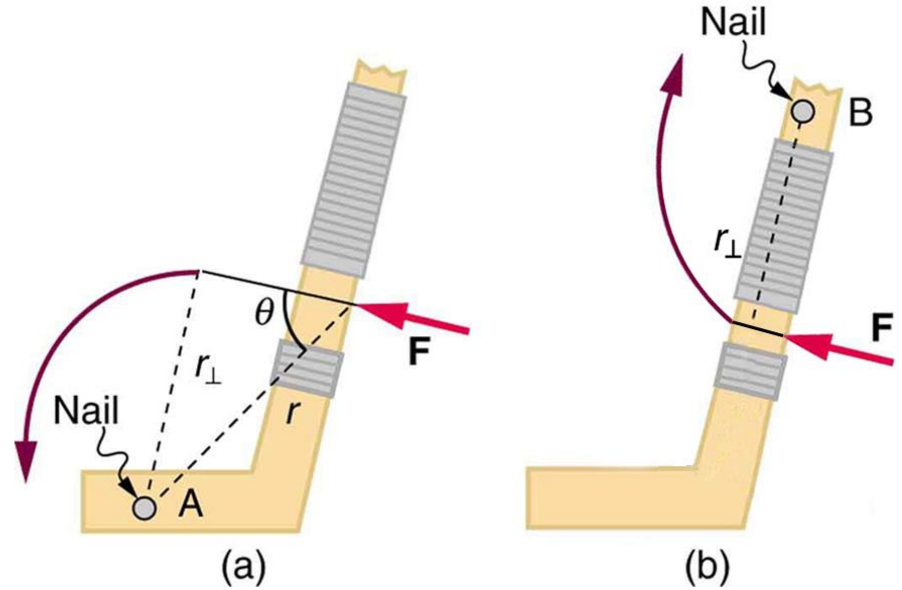
The same forces are applied at other points and the stick rotates—in fact, it experiences an accelerated rotation. Here net F = 0 but the system is not at equilibrium. Hence, the net F = 0 is a necessary—but not sufficient—condition for achieving equilibrium.

Torque is the turning effectiveness of a force, illustrated here for door rotation on its hinges (as viewed from overhead).

Torque has both magnitude and direction.



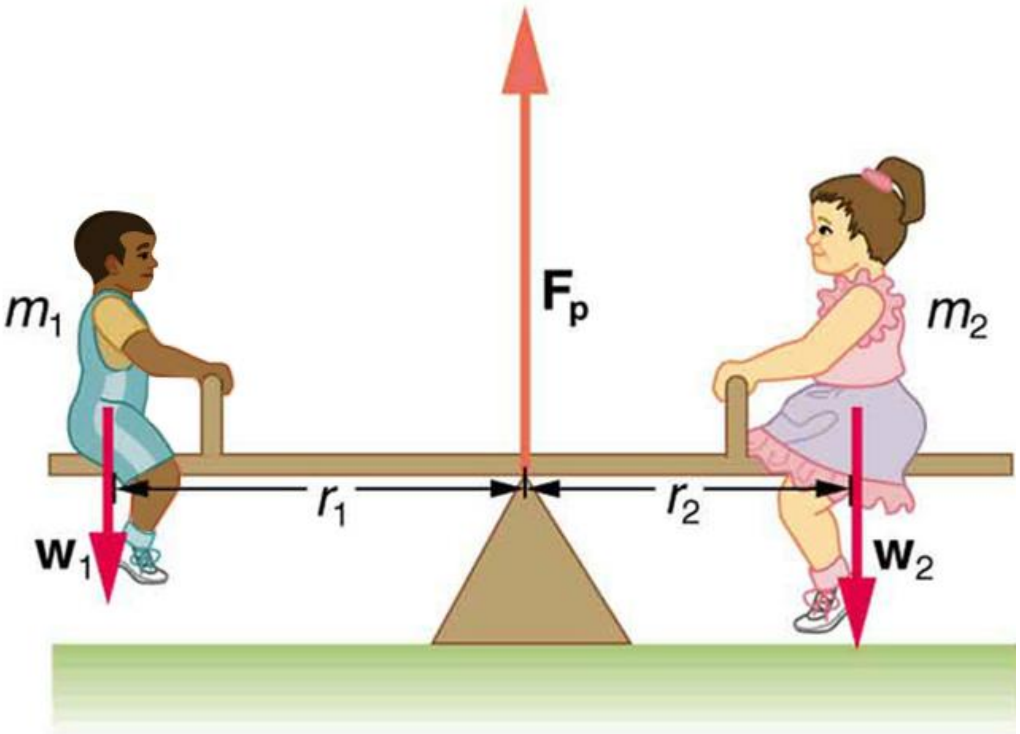
(a) Counterclockwise torque is produced by this force, which means that the door will rotate in a counterclockwise due to **F** . Note that $r_\perp$ is the perpendicular distance of the pivot from the line of action of the force. (b) A smaller counterclockwise torque is produced by a smaller force **F′** acting at the same distance from the hinges (the pivot point). (c) The same force as in (a) produces a smaller counterclockwise torque when applied at a smaller distance from the hinges. (d) The same force as in (a), but acting in the opposite direction, produces a clockwise torque. (e) A smaller counterclockwise torque is produced by the same magnitude force acting at the same point but in a different direction. Here, θ is less than 90º . (f) Torque is zero here since the force just pulls on the hinges, producing no rotation. In this case, $\theta = 0º$.



A force applied to an object can produce a torque, which depends on the location of the pivot point.

(a)The three factors r, F, and θ for pivot point A on a body are shown here— r is the distance from the chosen pivot point to the point where the force F is applied, and θ is the angle between **F** and the vector directed from the point of application to the pivot point. If the object can rotate around point A, it will rotate counterclockwise. This means that torque is counterclockwise relative to pivot A.

(b)In this case, point B is the pivot point. The torque from the applied force will cause a clockwise rotation around point B, and so it is a clockwise torque relative to B.

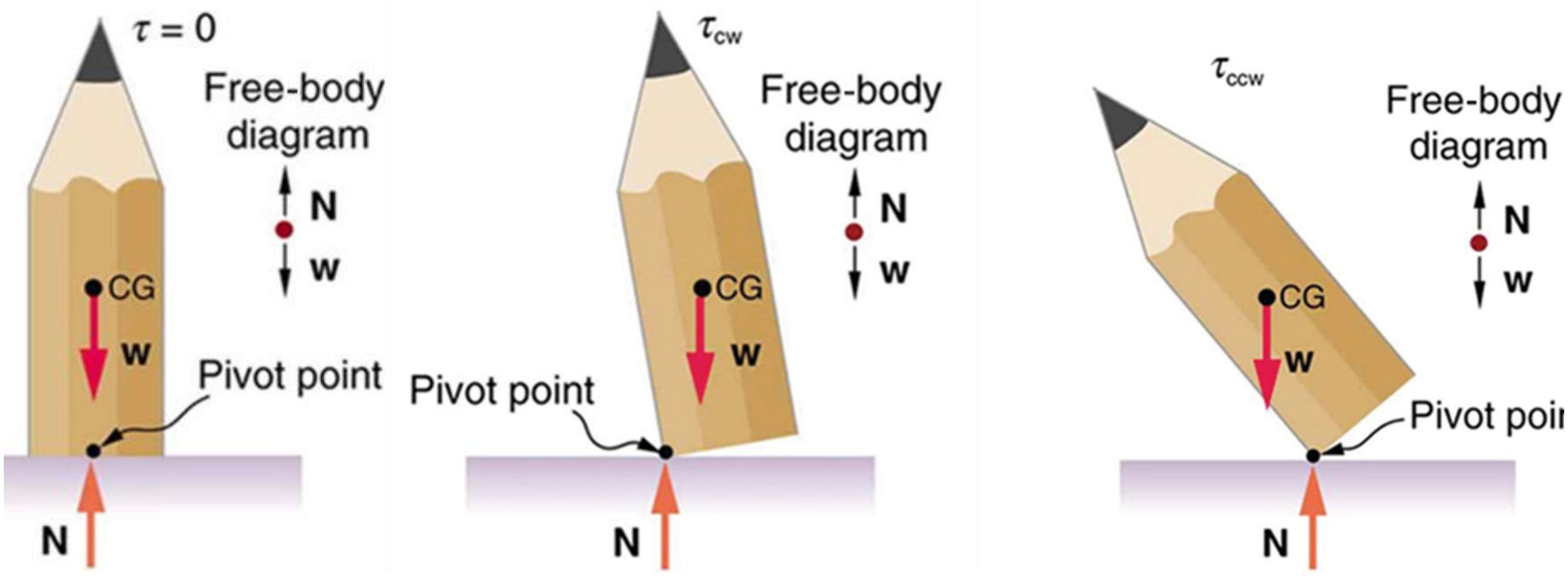


Two children balancing a seesaw satisfy both conditions for equilibrium. The lighter child sits farther from the pivot to create a torque equal in magnitude to that of the heavier child.

This pencil is in the condition of equilibrium. The net force on the pencil is zero and the total torque about any pivot is zero.

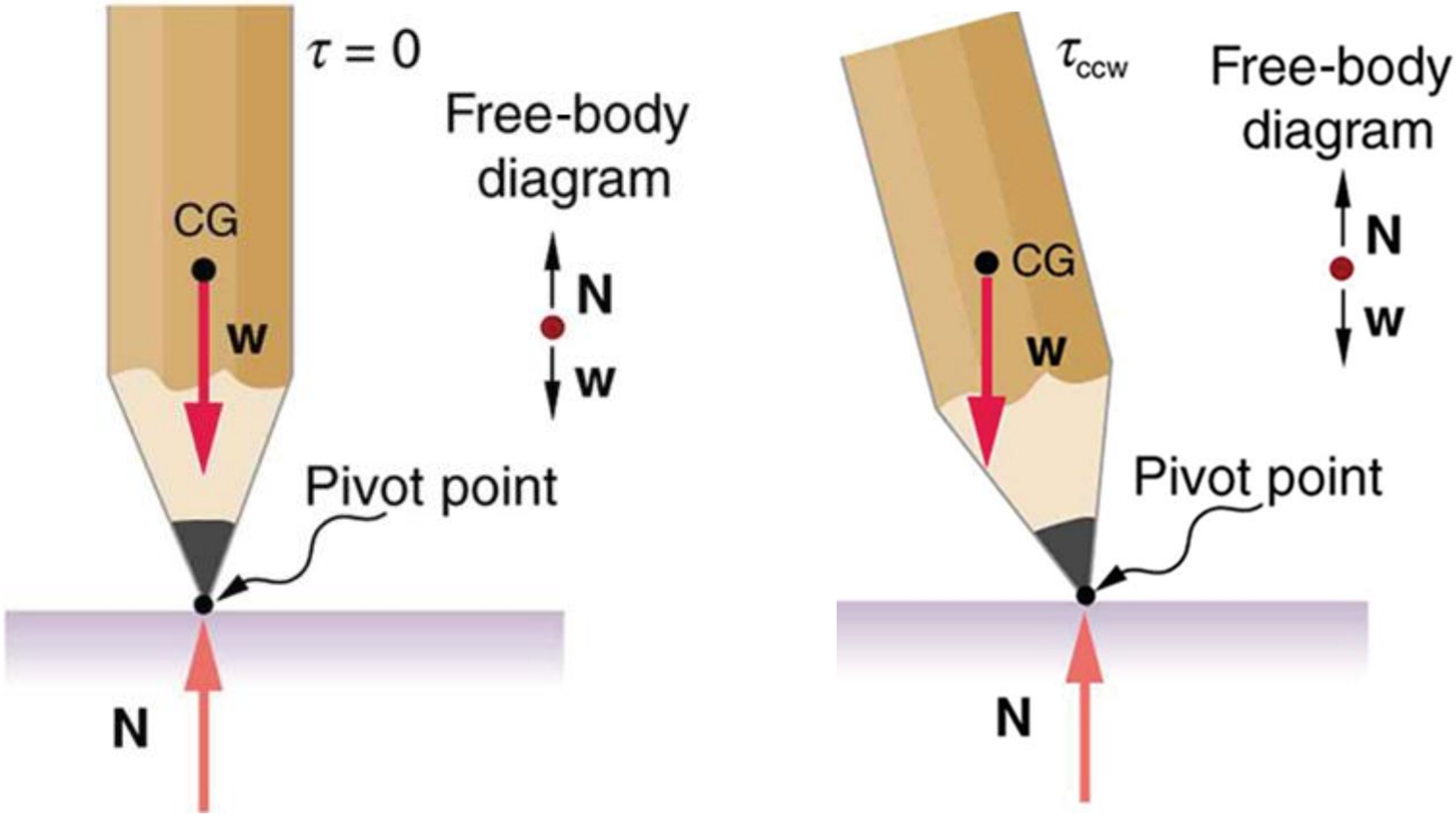
If the pencil is displaced slightly to the side (counterclockwise), it is no longer in equilibrium. Its weight produces a clockwise torque that returns the pencil to its equilibrium position.

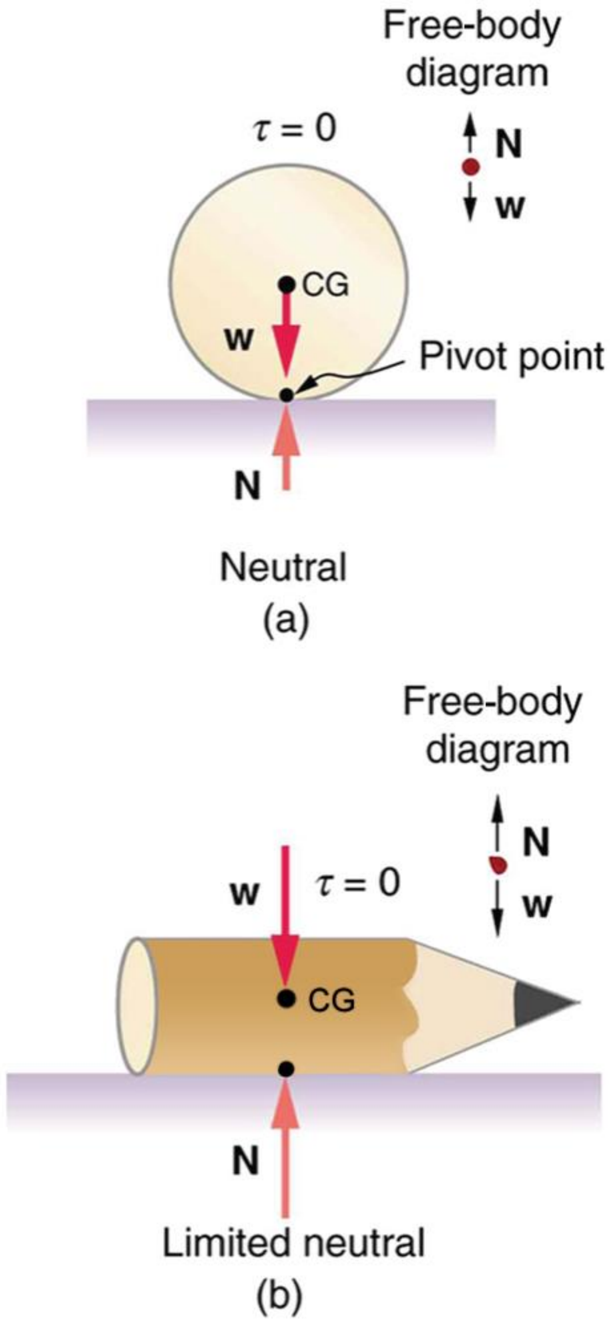
If the pencil is displaced too far, the torque caused by its weight changes direction to counterclockwise and causes the displacement to increase.



This figure shows unstable equilibrium, although both conditions for equilibrium are satisfied.

If the pencil is displaced even slightly, a torque is created by its weight that is in the same direction as the displacement, causing the displacement to increase.



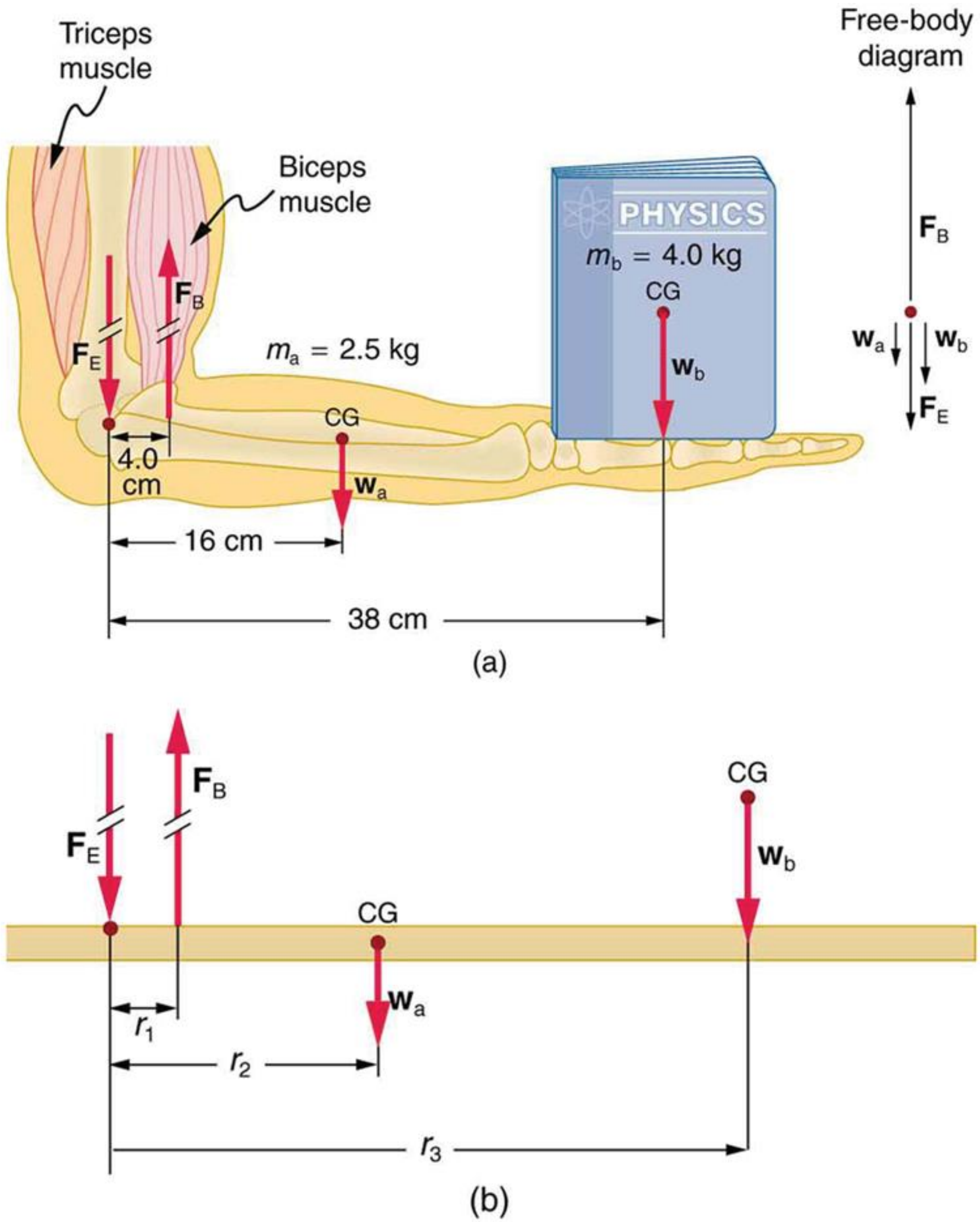


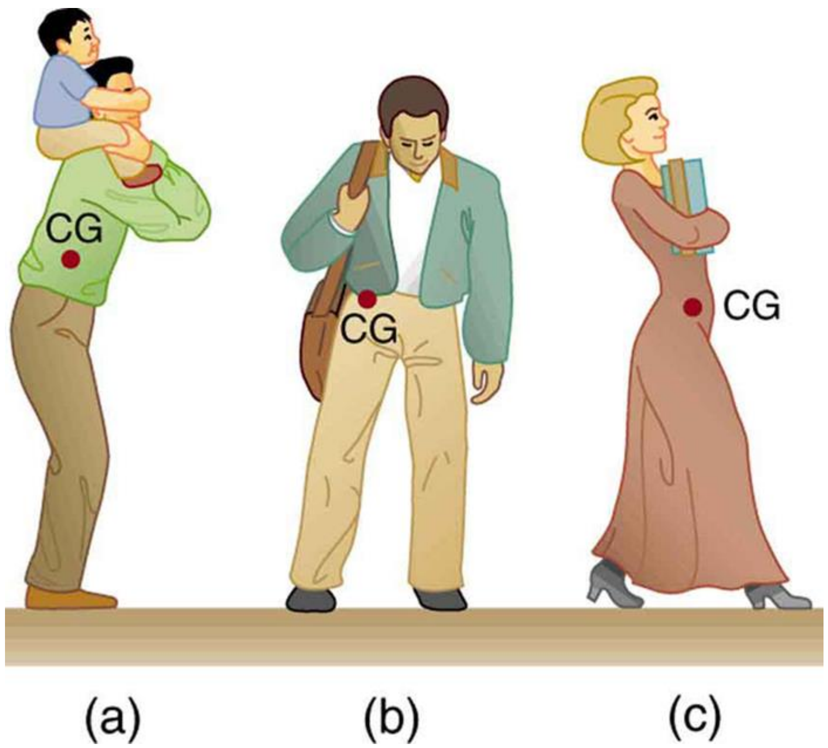
(a) Here we see neutral equilibrium. The CG of a sphere on a flat surface lies directly above the point of support, independent of the position on the surface. The sphere is therefore in equilibrium in any location, and if displaced, it will remain put.

(b) Because it has a circular cross section, the pencil is in neutral equilibrium for displacements perpendicular to its length.

(a) The figure shows the forearm of a person holding a book. The biceps exert a force $\mathbf{F}_B$ to support the weight of the forearm and the book. The triceps are assumed to be relaxed.

(b) Here, you can view an approximately equivalent mechanical system with the pivot at the elbow joint.





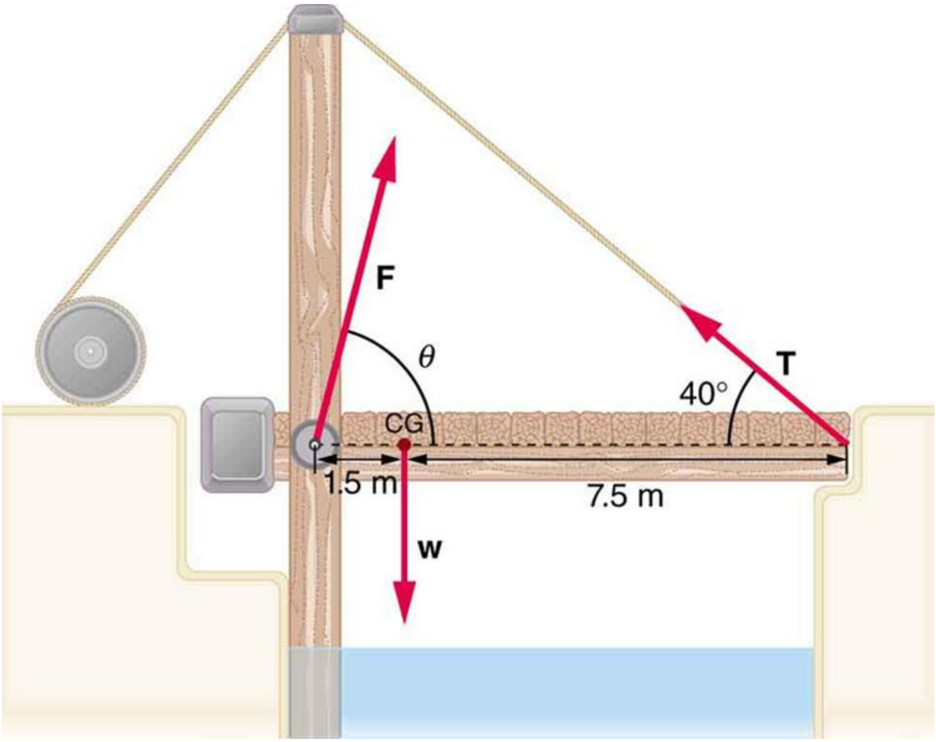
People adjust their stance to maintain balance.

(a) A father carrying his son piggyback leans forward to position their overall CG above the base of support at his feet.

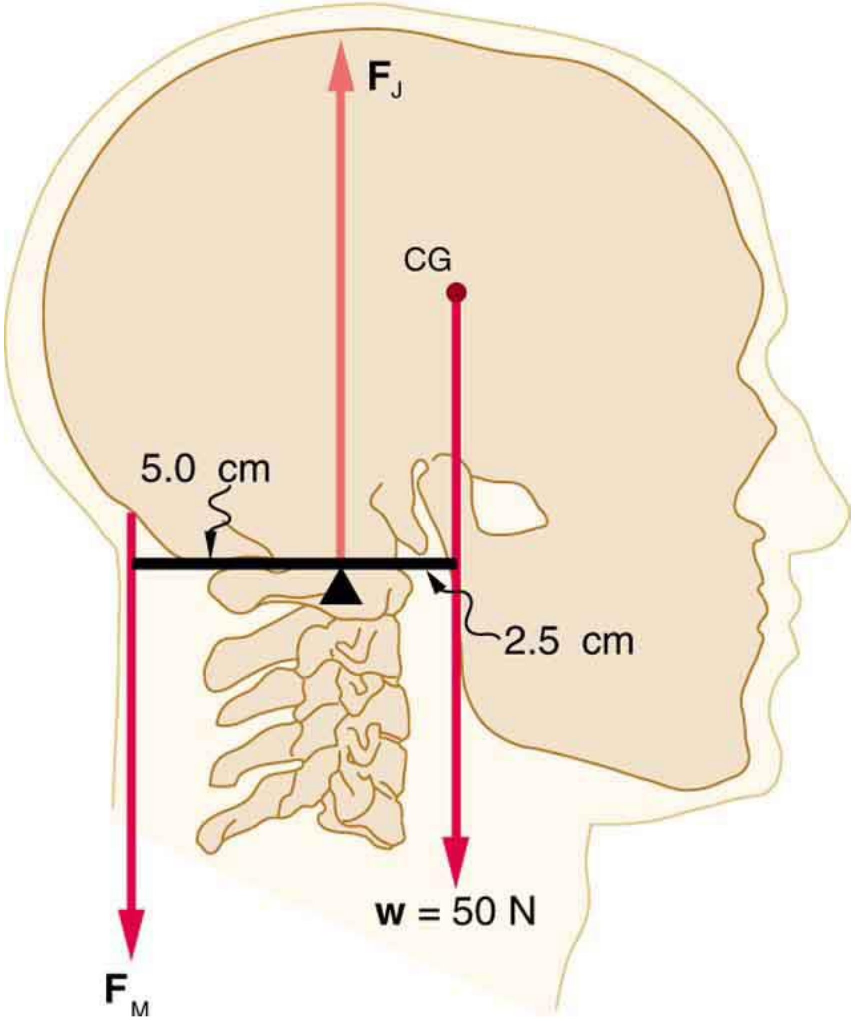
(b) A student carrying a shoulder bag leans to the side to keep the overall CG over his feet.

(c) Another student carrying a load of books in her arms leans backward for the same reason.

FIGURE 9.33



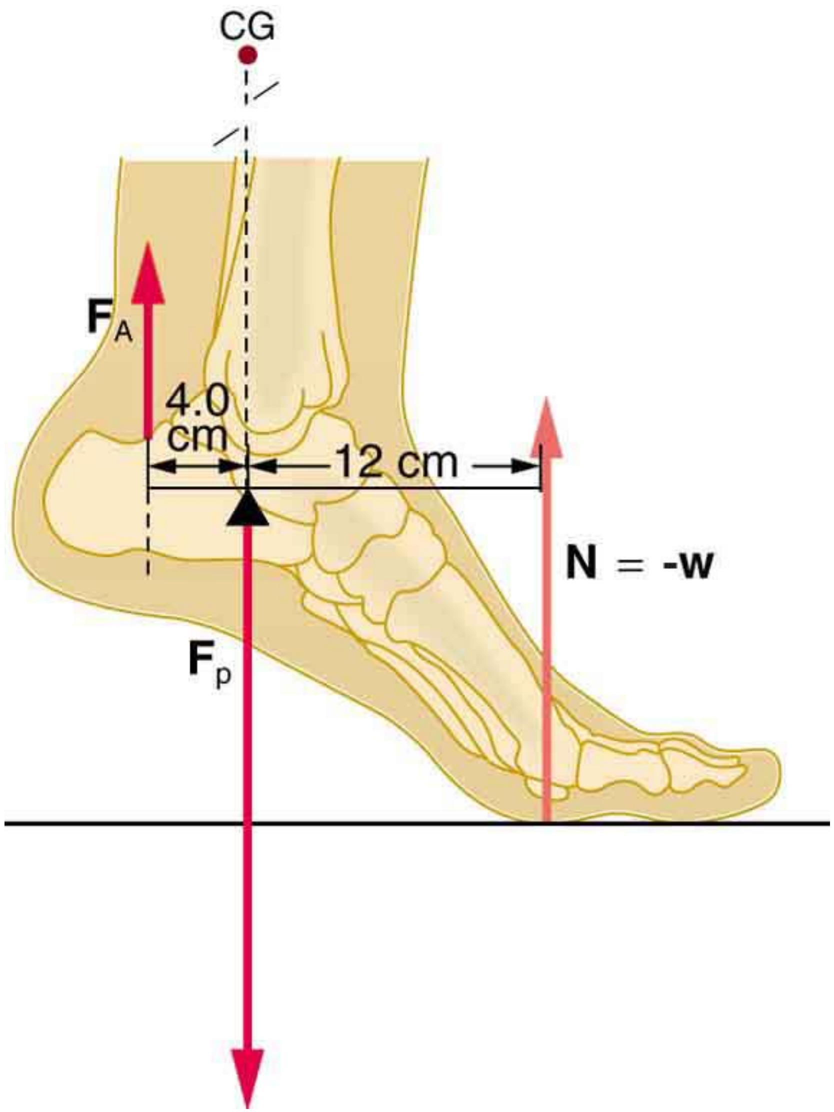
A small drawbridge, showing the forces on the hinges (F), its weight (w), and the tension in its wires (T).



The center of mass of the head lies in front of its major point of support, requiring muscle action to hold the head erect. A simplified lever system is shown.

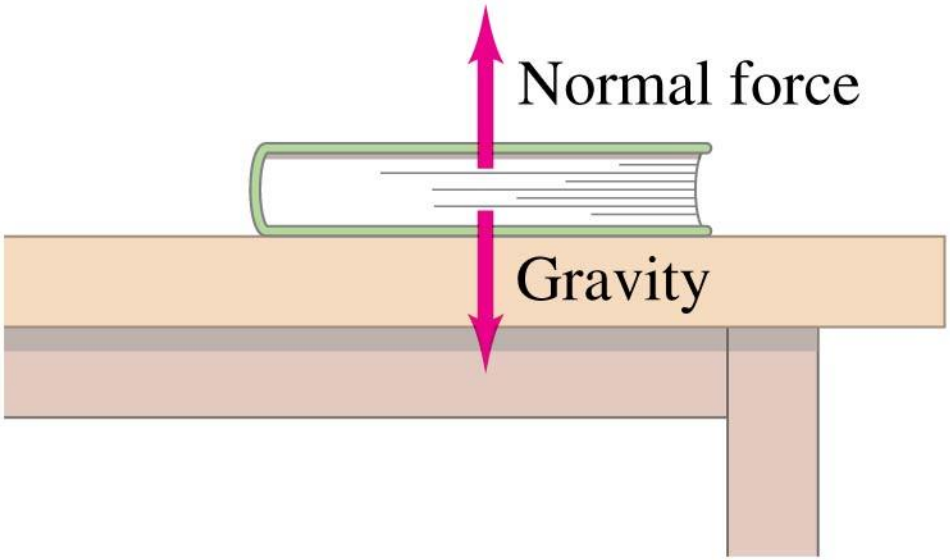
FIGURE 9.41

The muscles in the back of the leg pull the Achilles tendon when one stands on one’s toes. A simplified lever system is shown.



THE CONDITIONS FOR EQUILIBRIUM

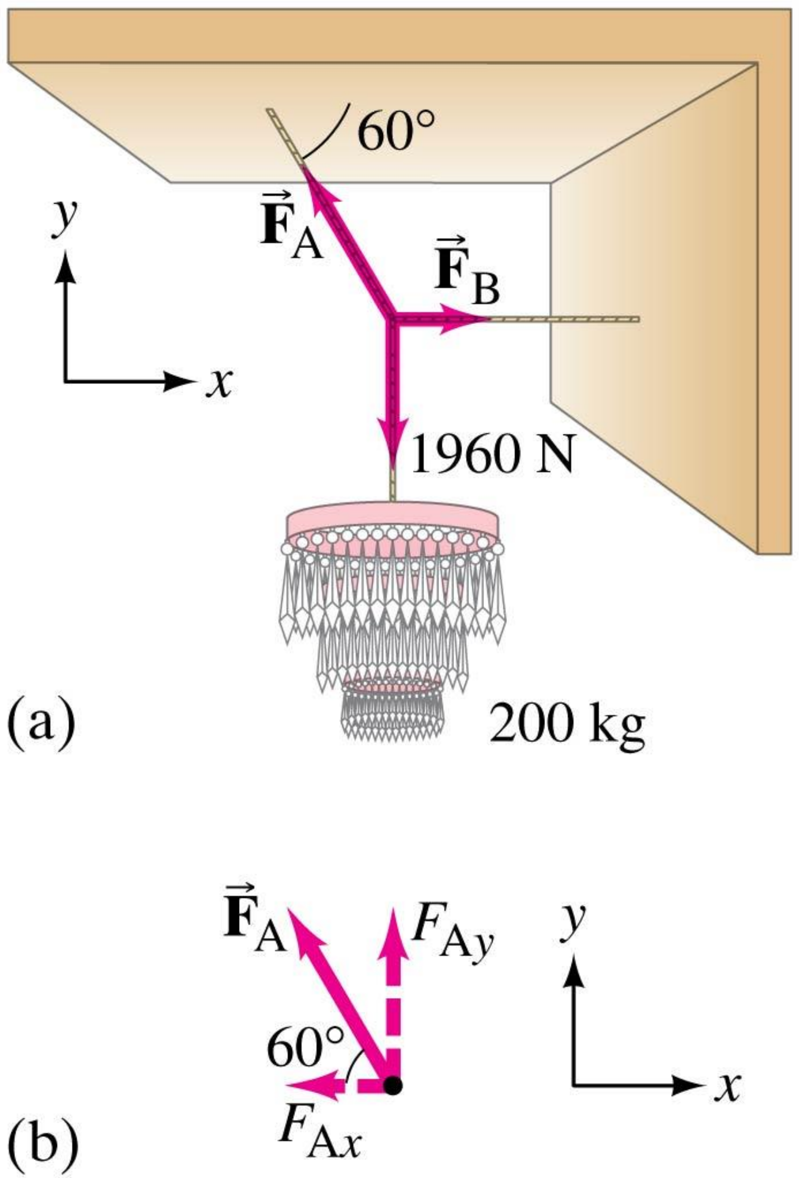
An object with forces acting on it, but that is not moving, is said to be in equilibrium.



THE CONDITIONS FOR EQUILIBRIUM

The first condition for equilibrium is that the forces along each coordinate axis add to zero.

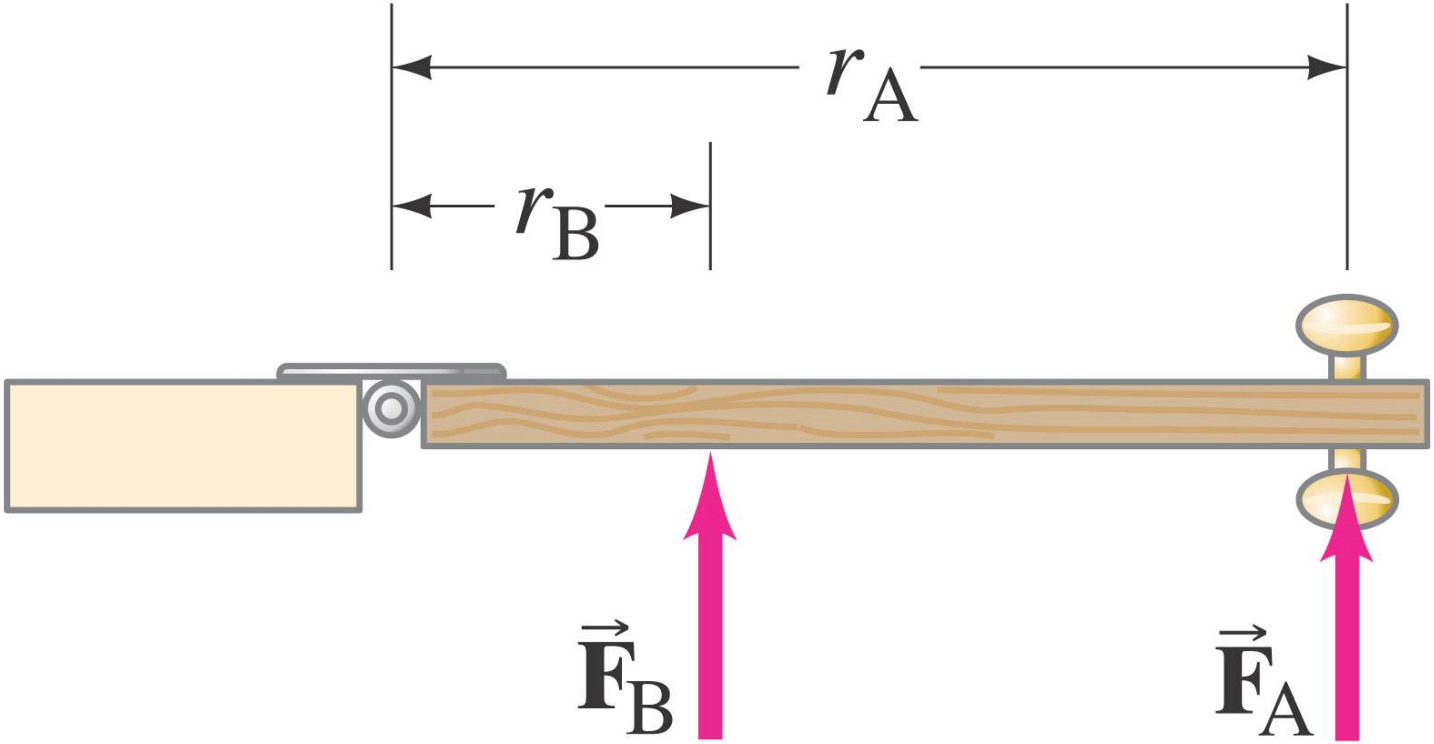
$$F_{NET} = 0$$



Torque

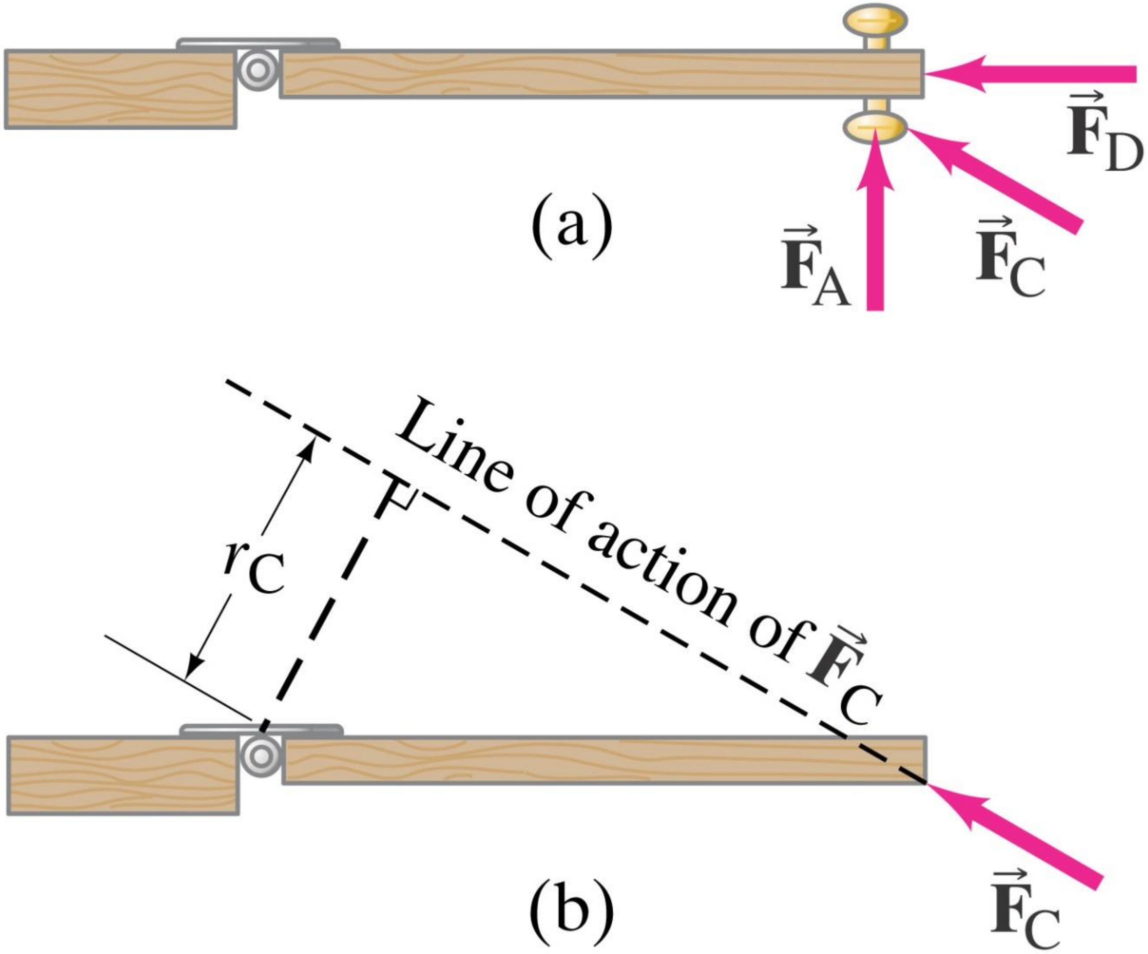
To make an object **start** rotating, a **force** is needed; the **position** and **direction** of the force matter as well.

The **perpendicular** distance from the axis of rotation to the line along which the force acts is called the **lever arm**.

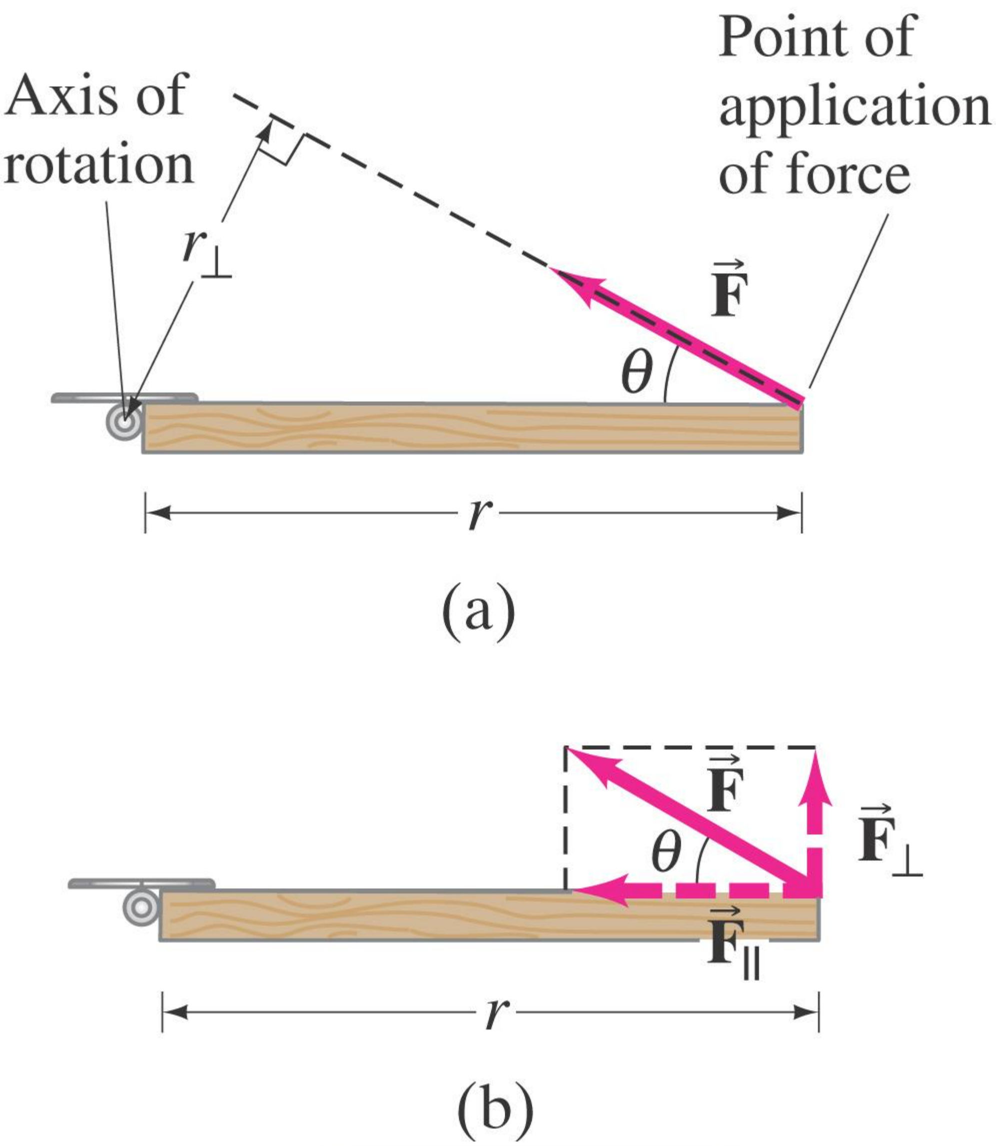


Torque

Here, the lever arm for F_A is the distance from the **knob** to the **hinge**; the lever arm for F_D is **zero**; and the lever arm for F_C is as shown.



Torque



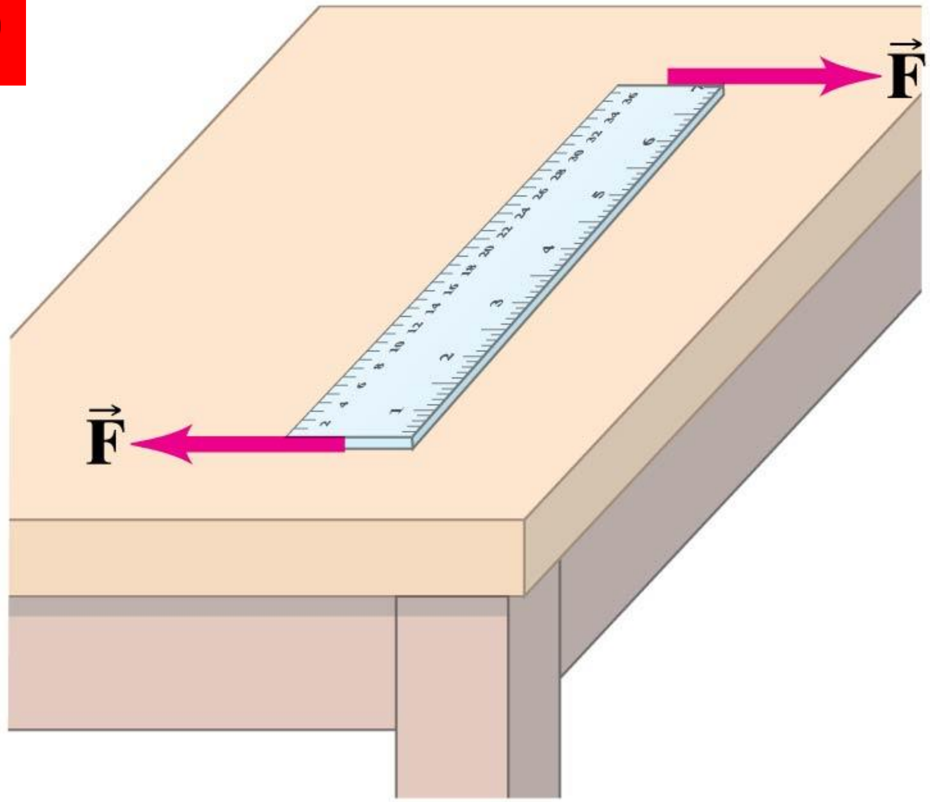
The **torque** is defined as:

$$\tau = r_\perp F$$

THE CONDITIONS FOR EQUILIBRIUM

The second condition of equilibrium is that there be no torque around any axis; the choice of axis is arbitrary.

$\tau_{NET} = 0$



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.

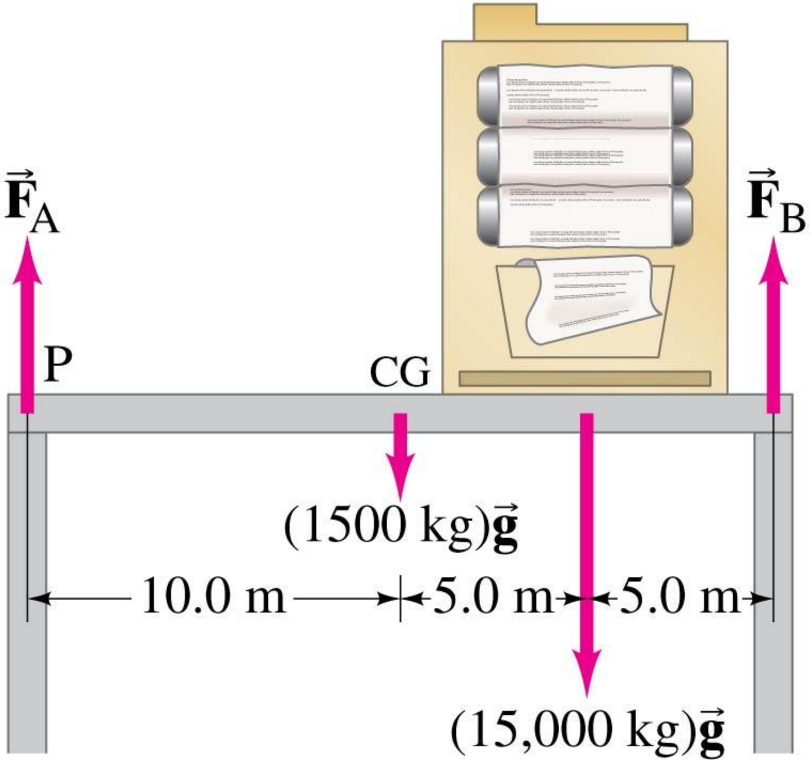
2. Choose a coordinate system and resolve forces into components.

3. Write equilibrium equations for the forces.

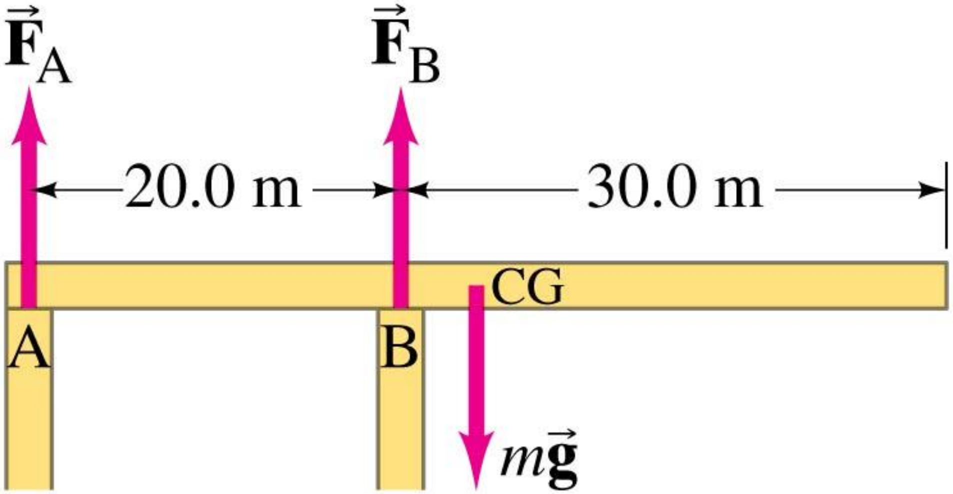
4. Choose any axis perpendicular to the plane of the forces and write the torque equilibrium equation. A clever choice here can simplify the problem enormously.

5. Solve.

The previous technique may not fully solve all statics problems, but it is a good starting point.

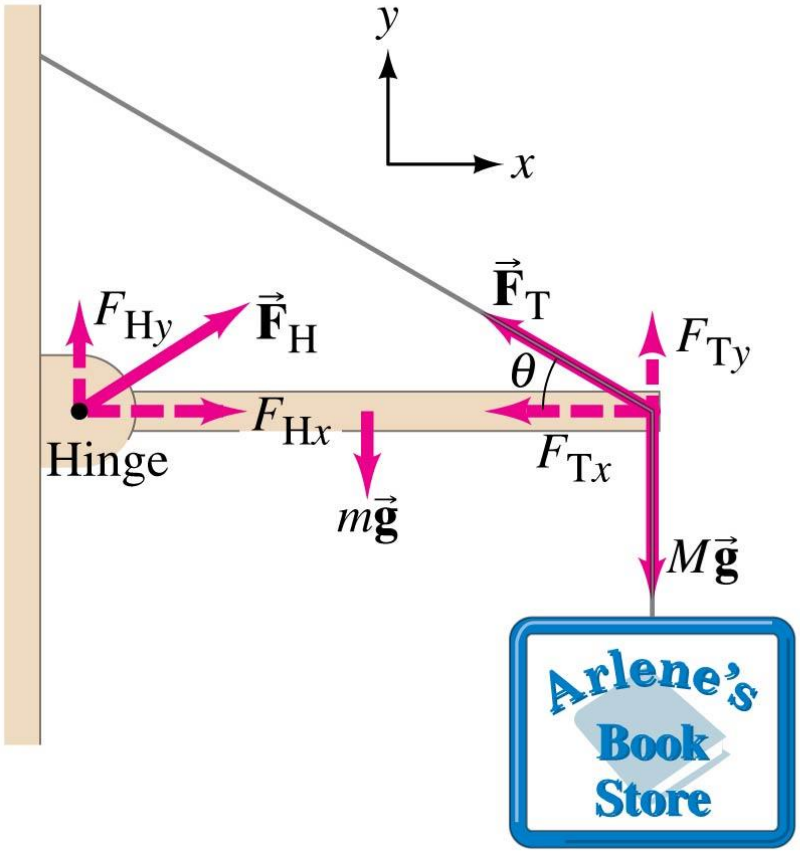


If a force in your solution comes out negative (as F_A will here), it just means that it's in the opposite direction from the one you chose. This is trivial to fix, so don't worry about getting all the signs of the forces right before you start solving.



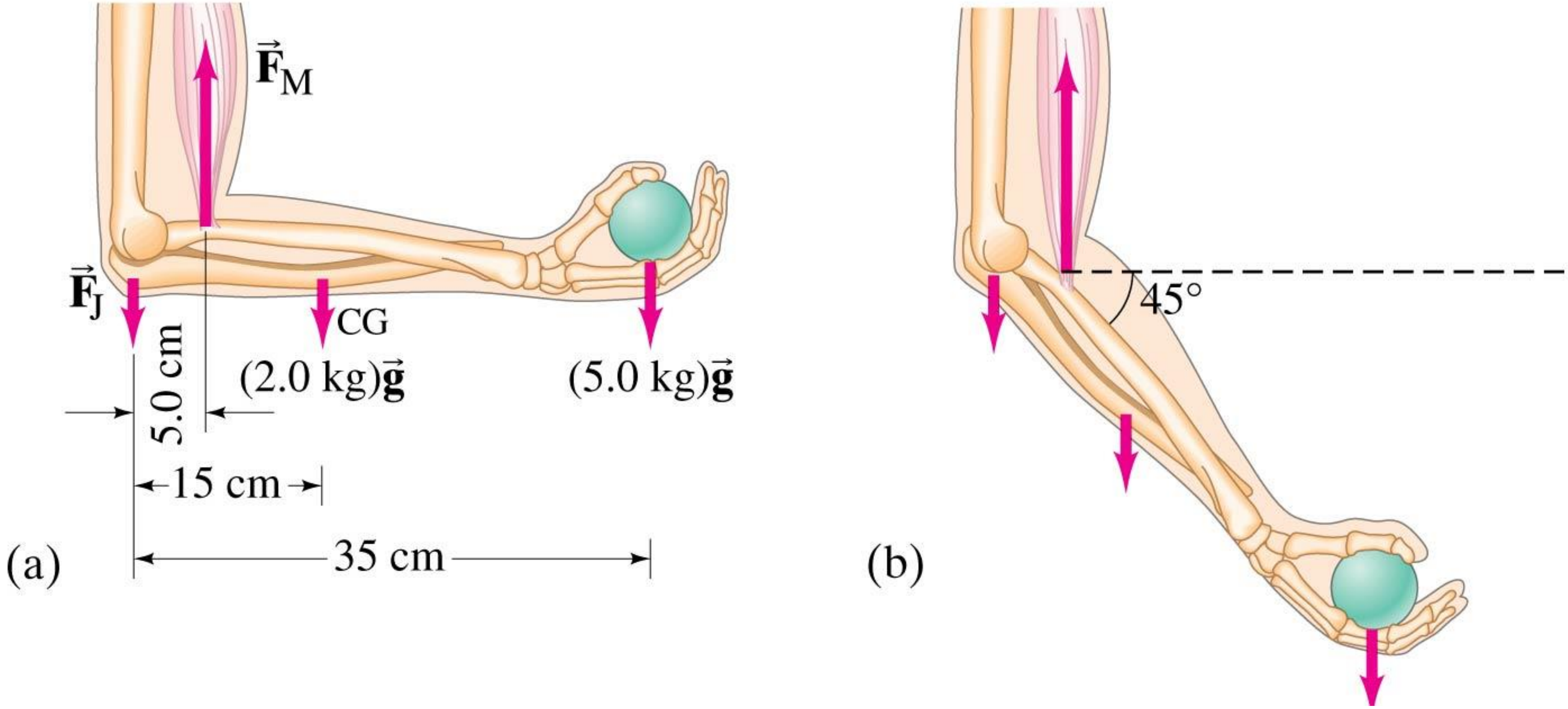
SOLVING STATICS PROBLEMS

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.



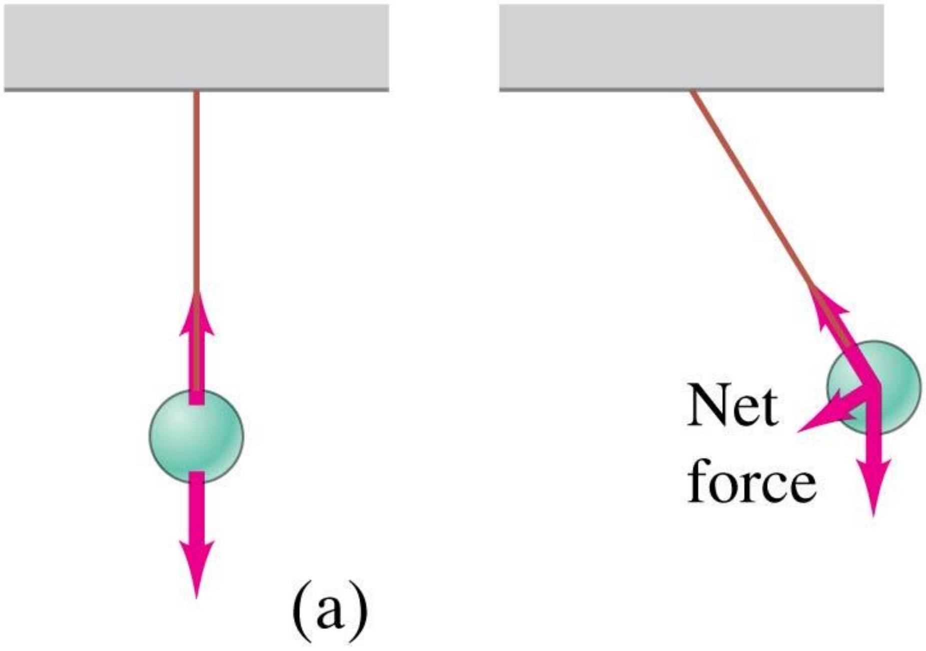
APPLICATIONS TO MUSCLES AND JOINTS

These same principles can be used to understand forces within the body.



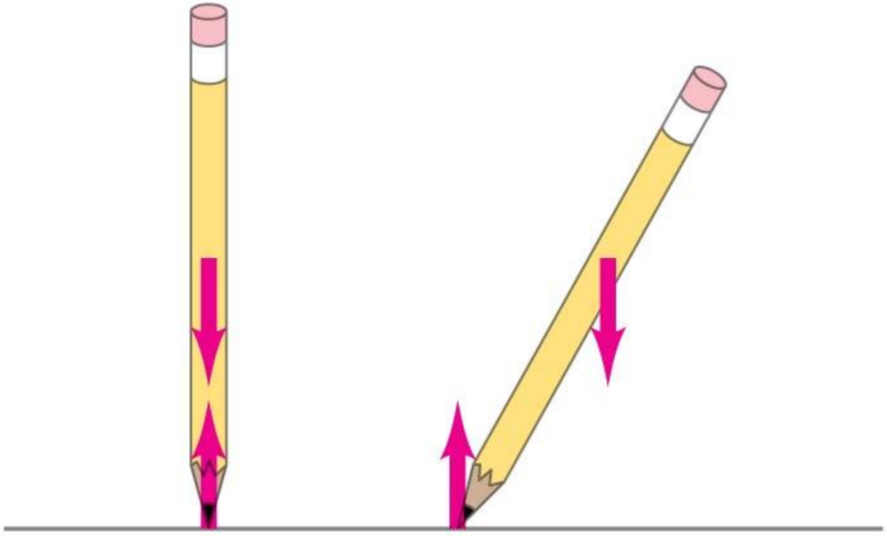
STABILITY AND BALANCE

If the forces on an object are such that they tend to return it to its equilibrium position, it is said to be in stable equilibrium.



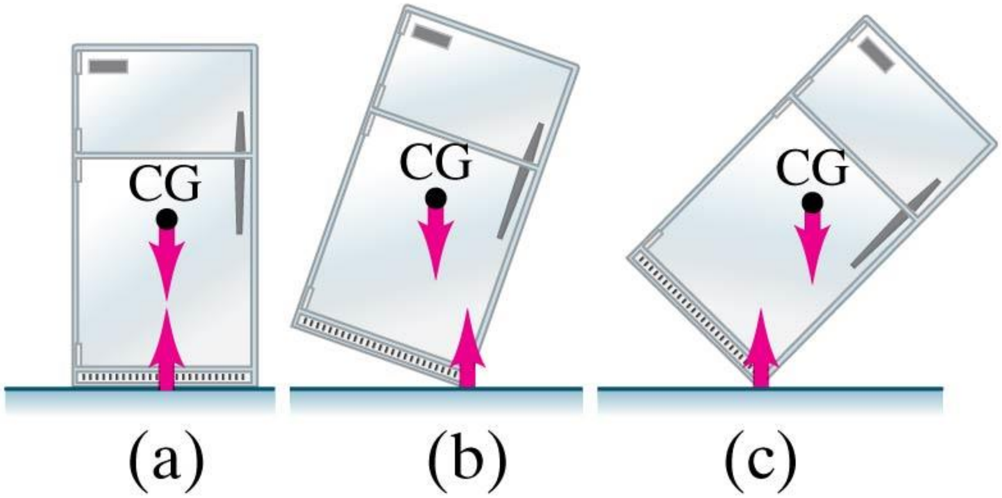
STABILITY AND BALANCE

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



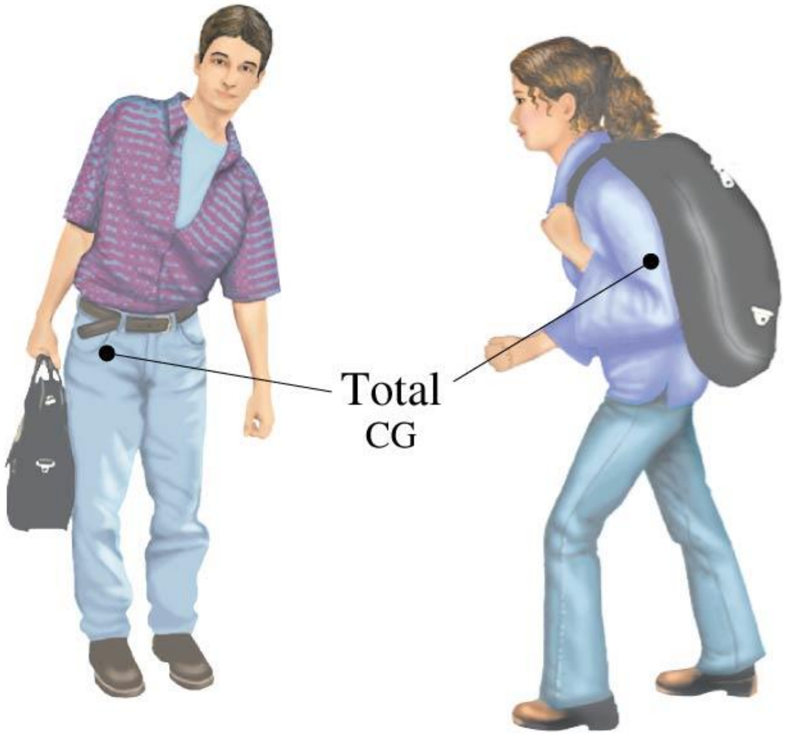
STABILITY AND BALANCE

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!



STABILITY AND BALANCE

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.



SUMMARY OF CHAPTER 9

- An object at rest is in equilibrium; the study of such objects is called statics.
- In order for an object to be in equilibrium, there must be no net force on it along any coordinate, and there must be no net torque around any axis.
- An object in static equilibrium can be either in stable, unstable, or neutral equilibrium.