

EXAMPLE 8-8 Biceps torque. The biceps muscle exerts a vertical force on the lower arm, bent as shown in Figs. 8-14a and b. For each case, calculate the torque about the axis of rotation through the elbow joint, assuming the muscle is attached 5.0 cm from the elbow as shown.

APPROACH The force is given, and the lever arm in (a) is given. In (b) we have to take into account the angle to get the lever arm.

SOLUTION (a) $F = 700 \text{ N}$ and $r_{\perp} = 0.050 \text{ m}$, so

$$\tau = r_{\perp} F = (0.050 \text{ m})(700 \text{ N}) = 35 \text{ m} \cdot \text{N}.$$

(b) Because the arm is at an angle below the horizontal, the lever arm is shorter (Fig. 8-14c) than in part (a): $r_{\perp} = (0.050 \text{ m})(\sin 60^\circ)$, where $\theta = 60^\circ$ is the angle between \vec{F} and r . F is still 700 N, so

$$\tau = (0.050 \text{ m})(0.866)(700 \text{ N}) = 30 \text{ m} \cdot \text{N}.$$

The arm can exert less torque at this angle than when it is at 90° . Weight machines at gyms are often designed to take this variation with angle into account.

NOTE In (b), we could instead have used $\tau = rF_{\perp}$. As shown in Fig. 8-14d, $F_{\perp} = F \sin 60^\circ$. Then $\tau = rF_{\perp} = rF \sin \theta = (0.050 \text{ m})(700 \text{ N})(0.866)$ gives the same result.

EXERCISE B Two forces ($F_B = 20 \text{ N}$ and $F_A = 30 \text{ N}$) are applied to a meter stick which can rotate about its left end, Fig. 8-15. Force \vec{F}_B is applied perpendicularly at the midpoint. Which force exerts the greater torque?

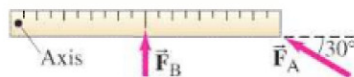


FIGURE 8-15 Exercise B.

When more than one torque acts on an object, the angular acceleration α is found to be proportional to the *net* torque. If all the torques acting on an object tend to rotate it in the same direction about a fixed axis of rotation, the net torque is the sum of the torques. But if, say, one torque acts to rotate an object in one direction, and a second torque acts to rotate the object in the opposite direction (as in Fig. 8-16), the net torque is the difference of the two torques. We normally assign a positive sign to torques that act to rotate the object counterclockwise, and a negative sign to torques that act to rotate the object clockwise.

EXAMPLE 8-9 Torque on a compound wheel. Two thin disk-shaped wheels, of radii $r_A = 30 \text{ cm}$ and $r_B = 50 \text{ cm}$, are attached to each other on an axle that passes through the center of each, as shown in Fig. 8-16. Calculate the net torque on this compound wheel due to the two forces shown, each of magnitude 50 N.

APPROACH The force \vec{F}_A acts to rotate the system counterclockwise, whereas \vec{F}_B acts to rotate it clockwise. So the two forces act in opposition to each other. We must choose one direction of rotation to be positive—say, counterclockwise. Then \vec{F}_A exerts a positive torque, $\tau_A = r_A F_A$, since the lever arm is r_A . \vec{F}_B , on the other hand, produces a negative (clockwise) torque and does not act perpendicular to r_B , so we must use its perpendicular component to calculate the torque it produces: $\tau_B = -r_B F_{B\perp} = -r_B F_B \sin \theta$, where $\theta = 60^\circ$. (Note that θ must be the angle between \vec{F}_B and a radial line from the axis.)

SOLUTION The net torque is

$$\begin{aligned} \tau &= r_A F_A - r_B F_B \sin 60^\circ \\ &= (0.30 \text{ m})(50 \text{ N}) - (0.50 \text{ m})(50 \text{ N})(0.866) = -6.7 \text{ m} \cdot \text{N}. \end{aligned}$$

This net torque acts to accelerate the rotation of the wheel in the clockwise direction.

NOTE The two forces have the same magnitude, yet they produce a net torque because their lever arms are different.

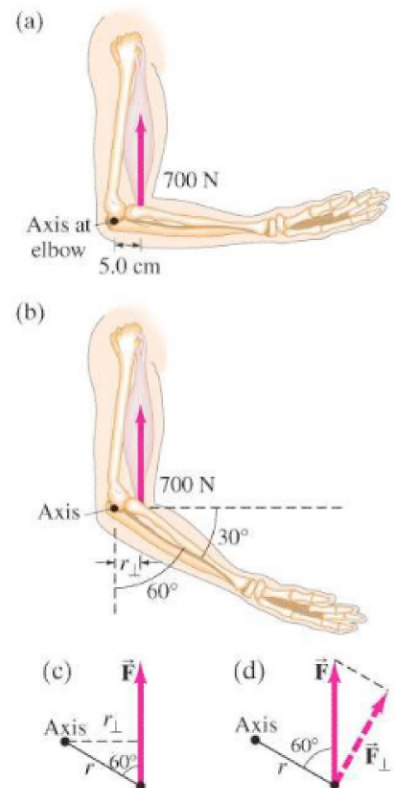


FIGURE 8-14 Example 8-8.

FIGURE 8-16 Example 8-9. The torque due to \vec{F}_A tends to accelerate the wheel counterclockwise, whereas the torque due to \vec{F}_B tends to accelerate the wheel clockwise.

