Name:

Skill Sheet 9.1 Torque

In this skill sheet, you will practice solving problems that involve torque. Torque is an action that is created by an applied force and causes an object to rotate. Any object that rotates has a torque associated with it.

1. What is torque?

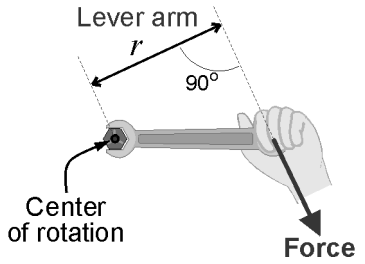
Torque, τ, can be calculated by multiplying the applied force, F, by r. The value, r, is the perpendicular distance between the point of rotation and the line of action of the force (the line along which the force is applied.

$$\tau = F \times r$$

The unit of torque is newton-meter (N-m).

For many situations the distance r is also called the lever arm.

The lever arm of a force



2. Example torque problem

When you use a wrench to release a rusted bolt, you apply a torque around the axis of the bolt. You might have noticed that the longer the wrench, the easier it is to perform the task. The length of the wrench is related to the lever arm. However if you just pull at the end of the wrench you know that there is no way to release the rusted bolt. The reason is that by pulling you have made the lever arm equal to zero. Zero lever arm, zero torque and the bolt will keep on rusting.

Since the force has magnitude and direction so does the torque. We talk about torque in the counterclockwise (CCW) direction, which we call positive and torque in the clockwise (CW) direction which we call negative.

Let's do some numbers. If you have a wrench of length r = 30 centimeters and you apply a force of 1,000 N at the end and perpendicular (90°) to the wrench. Because the force is applied downward so the wrench rotates clockwise around the bolt, the force is negative (-1,000 N). The resulting torque is:

$\tau = F \times r$ = -1,000 N × 0.3 m = -300 N-m

If you now apply the same force at an angle of 45 degrees from vertical the resulting torque is:

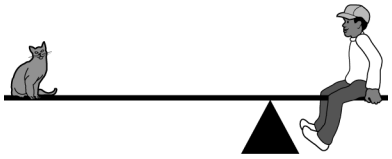
$\tau = F \cos 45° \times r$ = -1,000 N cos 45° × 0.3 m = -212 N-m

Although you applied the same force, you get less torque at 45°. If you wanted to create a torque of -300 N-m while applying the force at a 45 degree angle, you would need to apply -1,414 N of force!

$$F = \frac{-300 \text{ N-m}}{\cos 45° \times 0.3 \text{ m}} = -1{,}414 \text{ N}$$

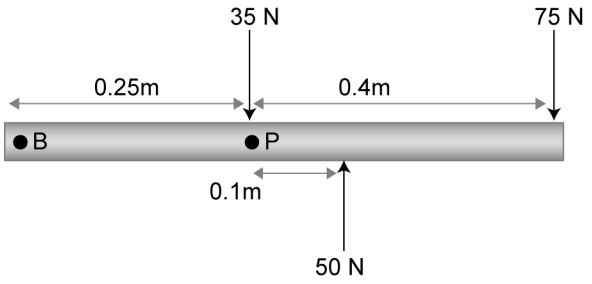
A see-saw works based on the ideas of torque. As you know, the lighter person (or a cat!) has to sit further out for the saw to be level. You know now that this is so because the only way to make the torque of the heavy person equal to the torque of the light person is to increase the lever arm of the light person.

Can you see why the see-saw is balanced?



3. Solving problems

Solve the following problems. Show your work. The first problem is done for you as an example.



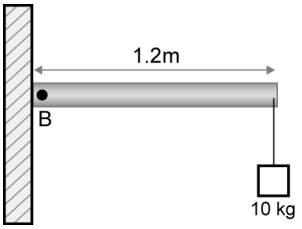
1. For an object to be in rotational equilibrium about a certain point, the total torque about this point must be zero. For the example shown in the figure calculate the magnitude and direction of a force that must be applied at point B for rotational equilibrium about point P.
Solution: First note that the 35 N force does not create any torque about point P because this force passes through that point (lever arm = 0).
Let, the force at point B equal F_B.
For rotational equilibrium, the following must be true: Torque on to the left of P = Torque to the right of P

$$F_B \times 0.25 \text{ m} = (50 \text{ N} \times 0.1 \text{ m}) - (75 \text{ N} \times 0.4 \text{ m})$$

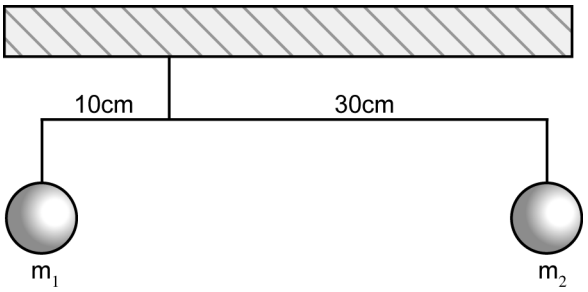
$$F_B = \frac{-25 \text{ N-m}}{0.25 \text{ m}} = -100 \text{ N}$$

For rotational equilibrium, 100 N must be applied downward at point B.

2. A 10-kilogram mass is suspended from the end of a beam that is 1.2 meters long. The beam is attached to a wall. Find the magnitude and direction (clockwise or counterclockwise) of the resulting torque at point B.



3. Two masses m_1 and m_2 are suspended on an ornament. The ornament is hung from the ceiling at a point which is 10 centimeters from mass m_1 and 30 centimeters from mass m_2.
   a. If m_1 = 6 kg, what does m_2 have to be for the ornament to be in rotational equilibrium?

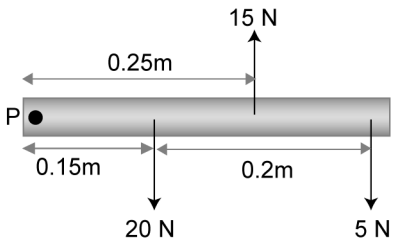


   b. Calculate the ratio of $\frac{m_1}{m_2}$ so that the ornament will be horizontal.

   c. Suppose m_1 = 10 kg and m_2 = 2 kg. You wish to place a third mass, m_3 = 5 kg, on the ornament to make it balance. Should m_3 be placed to the right or to the left of the ornament's suspension point? Explain your answer.

   d. Calculate the exact location where m_3 should be placed.

4. Forces are applied on the beam as shown on the figure at right.



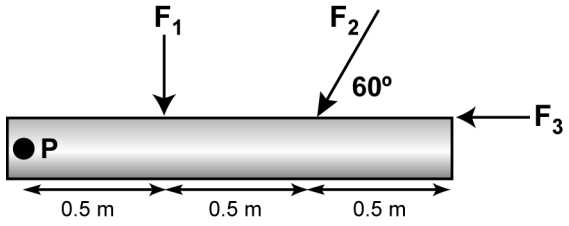
   a. Find the torque about point P produced by each of the three forces.

   b. Find the net torque about point P.

   c. A fourth force is applied to the beam at a distance of 0.30 m to the right of point P. What must the magnitude and direction of this force be to make the beam in rotational equilibrium?

5. A flag pole 2.5 meters long is attached to a wall at a 40° angle from vertical. A 50-kilogram mass is suspended at the end. Calculate the resulting torque at the point of attachment to the wall.

6. Three 10-newton forces act on a beam as shown to the right.



   a. Calculate the torque produced by force 1 about point P.

   b. Calculate the torque produced by force 2 about point P.

   c. Calculate the torque produced by force 3 about point P.

   d. Calculate the net torque about point P.