Torque and Static Equilibrium

Types of Motion - Large Objects

The motion of large objects can be divided into two types, ***translational*** and ***rotational***.

translational motion - the motion of an object from one point to another

rotational motion - the motion of an object about one point (pivot point or fulcrum)

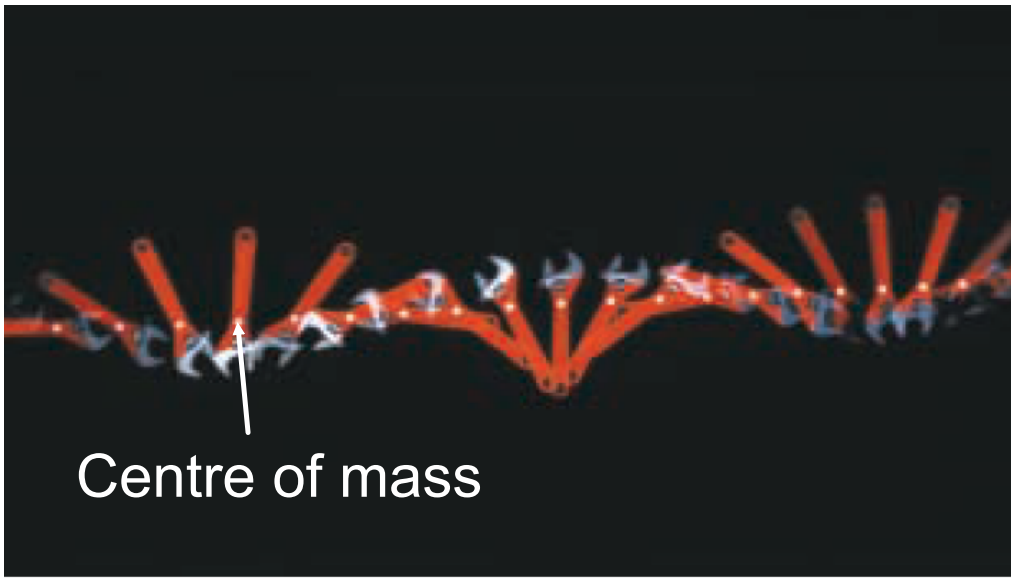


Figure 10.15 The wrench is rotating around the mark on the wrench while the mark is moving in a straight line.

Torque occurs when a force is applied to an object and that force causes the object to rotate.

$\tau = r_\perp F = r F_\perp$

TORQUE

Torque is the product of the lever arm and the magnitude of the force. Lever arm is the perpendicular distance between the line along which the force is acting and the pivot point. Torque is positive if it will rotate the object counterclockwise and negative if it will rotate the object clockwise.

$\tau = r_\perp F$ or $\tau = rF_\perp$ ← we use this

Quantity	Symbol	SI unit
torque	τ	N·m (newton·metre)
magnitude of the force	F	N (newton)
lever arm	$r_\perp$	m (metre)

Unit Analysis

(force)(lever arm) = N·m

Note: The unit of torque, the newton·metre, is *not* a joule. A newton·metre is a joule only when the force and the displacement of an object are in the same direction and the force is therefore doing work on the object. In the case of torque, the force and the lever arm are perpendicular. No object is moving a distance equal to the lever arm.

Torque is a ***vector***. The direction of torque is based on the direction in which the force would cause the object to rotate if it were acting alone.

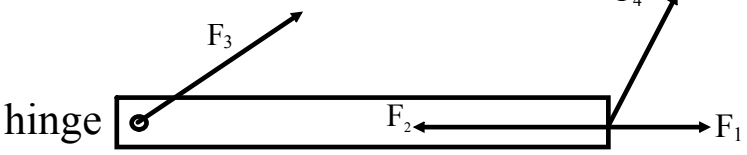
$\tau = r F_\perp$

CW: clockwise (-)

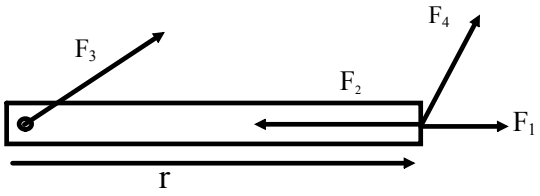
CCW: counter-clockwise (+)

The diagram below shows four forces acting on a door. Which forces will cause the door to rotate?

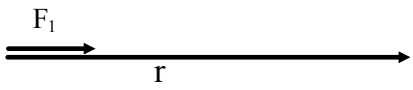
$\tau = r F_\perp$



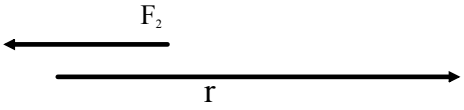
Only the component of F_4 perpendicular to r produces torque.



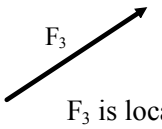
We can verify our previous answers by examining the equation.



F_1: $\theta = 0^o$
$\sin 0^o = 0$
$\tau = 0$ Nm

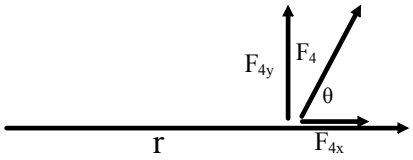


F_2: $\theta = 180^o$
$\sin 180^o = 0$
$\tau = 0$ Nm



F_3 is located at the pivot point.

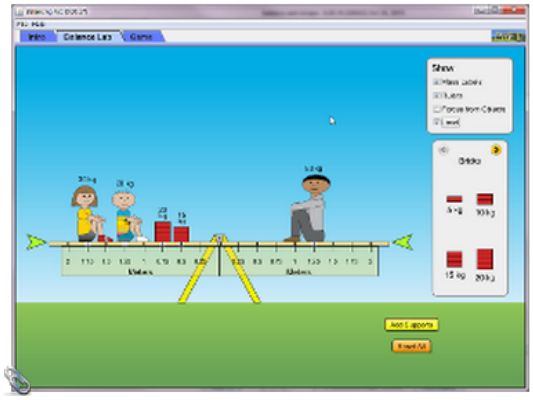
F_3: $r = 0$ m
$\tau = 0$ Nm



F_4: $r \neq 0$ m and $\sin \theta \neq 0$
F_{4x} will cause the door to rotate!

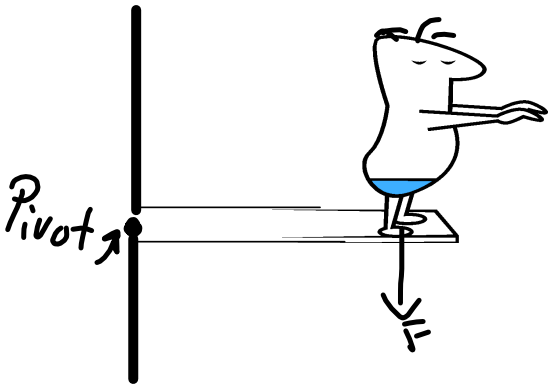
Visualizing Torque and Static Equilibrium

Balancing Act



Label the Pivot Point

Example: A 1490 N Mr. Martin stands at the end of a diving board at distance of 1.5 m from the point at which it is attached to thetower. What is the torque the man exerts on the board? (~~735 Nm, CW or -735 Nm~~)



$\tau = r F_\perp$

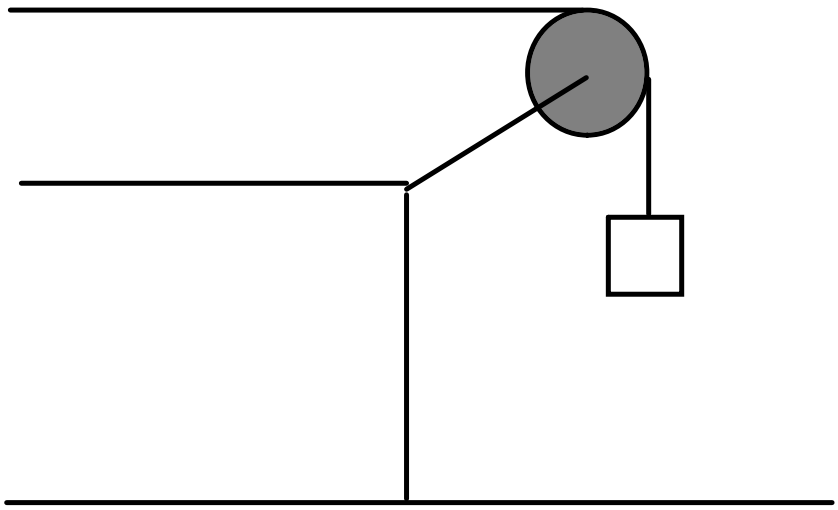
$r = 1.5\,m$

$F_\perp = F_g = 1490\,N$

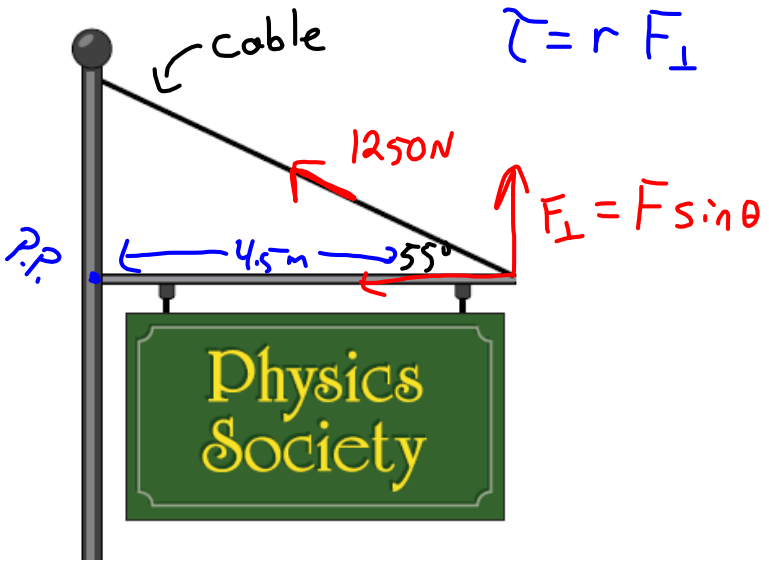
$\tau = (1.5)(1490)$

$= -2235\,Nm$ or CW

Example: A 5.0 kg mass is attached as shown to a pulley ofradius 0.05 m. What torque is produced by the mass? (2.5 Nm, CW or -2.5 Nm)



Calculate the torque on the beam provided by the cable if the cable applies a force of 1250 N and is attached 4.5 m from the left end. The cable makes an angle of 55° with the beam.



$\tau = r F_\perp$

$= (4.5)(1250)\sin 55$

$\tau = 4607\ Nm$

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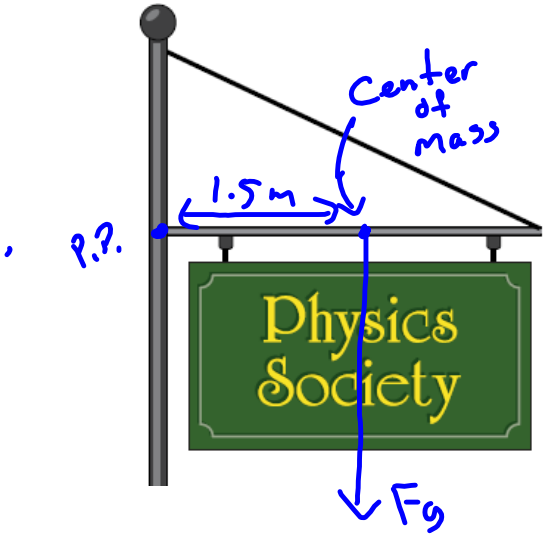
Calculate the torque that the beam applies. The beam is 3.0 m long and has a mass of 6.8 kg.



$m_{beam} = 6.8\,kg$

beam is 3.0m long.

$\tau = r F_\perp$ $\quad r = 1.5m$

F_g

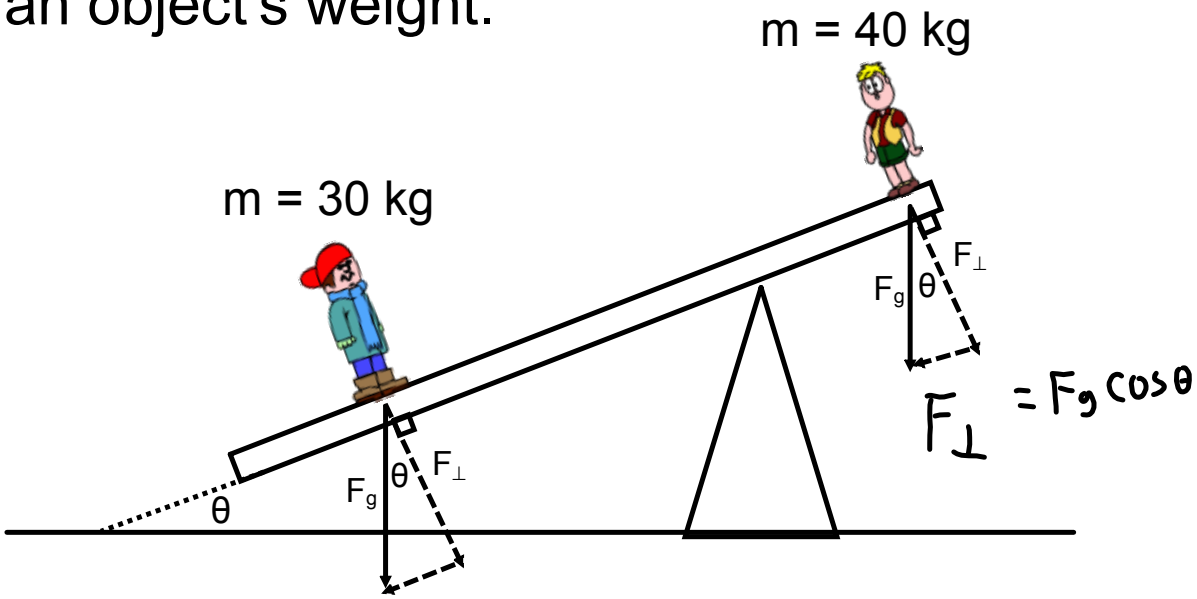
$\tau = -rmg$

$= -(1.5)(6.8)(9.81)$

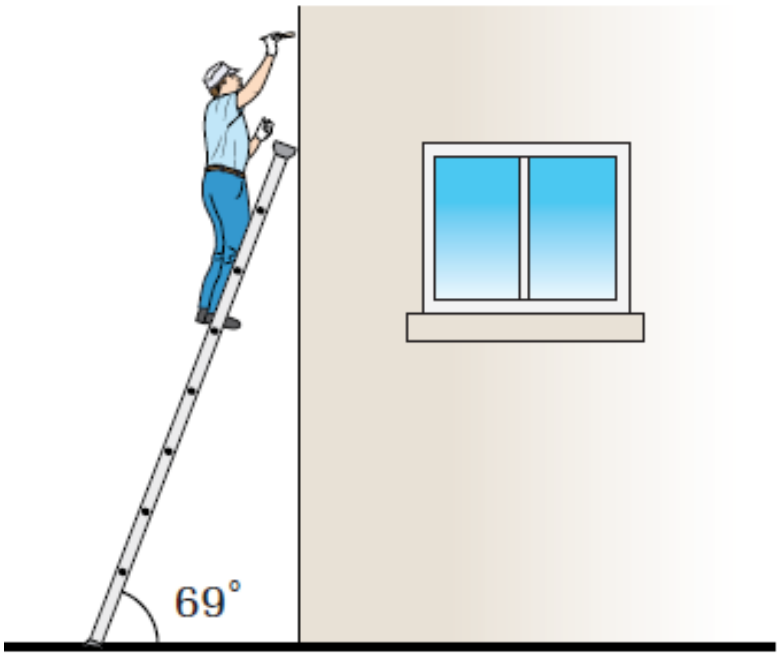
$= -100\,Nm$

Angled Beam & Torque

Like the incline plane questions earlier, if the beam is inclined the trig functions for component calculations switch. This mainly occurs for problems in which the force acting on the beam is an object's weight.



Example: A 64 kg painter is standing 2.25 m of the distance up a ladder that is 3.0 m long. If the ladder makes an angle of 69° with the ground, what torque does the painter's weight exert on the ladder? (5.1×10^2 Nm, CW)



Torque Review

Grade: 12

Subject: Physics 122

Date: 2014

1 An object can rotate even if the net force adds to zero.

True

False

2 Translational motion is the angular motion around one point.

True

False

3 Objects rotate about a(n) _____.

A Equilibrium point

B Force applied point

C lever arm point

D pivot point

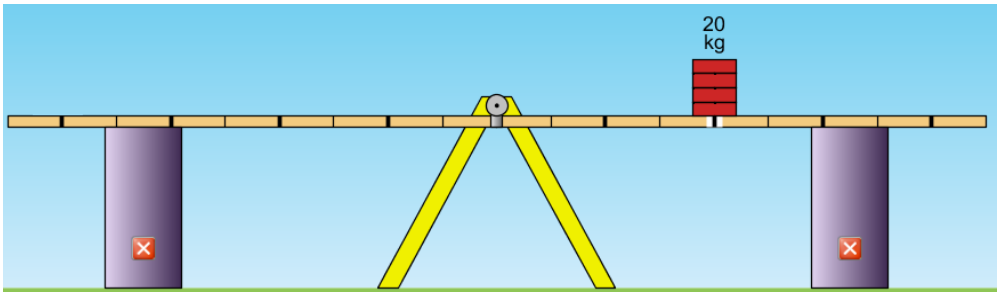
4 What statement best describes what will happen when the supports are removed?

A The beam will rotate.

B The beam will experience negative torque.

C The beam will experience positive torque.

D The beam will not rotate.



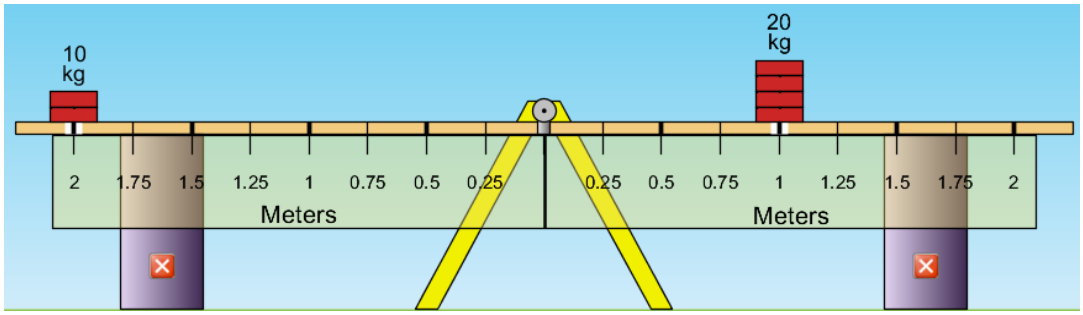
5 What statement best describes what will happen when the supports are removed?

A The beam will rotate

B The beam will experience negative torque.

C The beam will experience positive torque.

D The beam will not rotate.

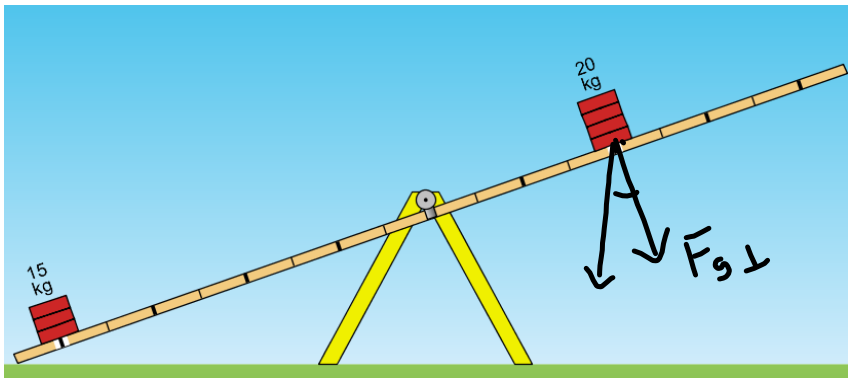


6 In the image below, what trig function must be used to determine the force of gravity perpendicular to the beam?

A sin

B cos

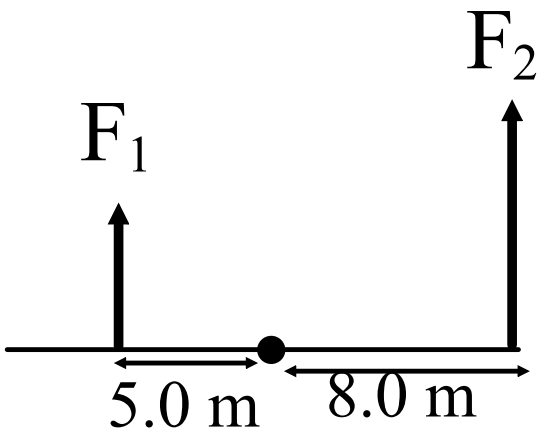
C tan



Net Torque

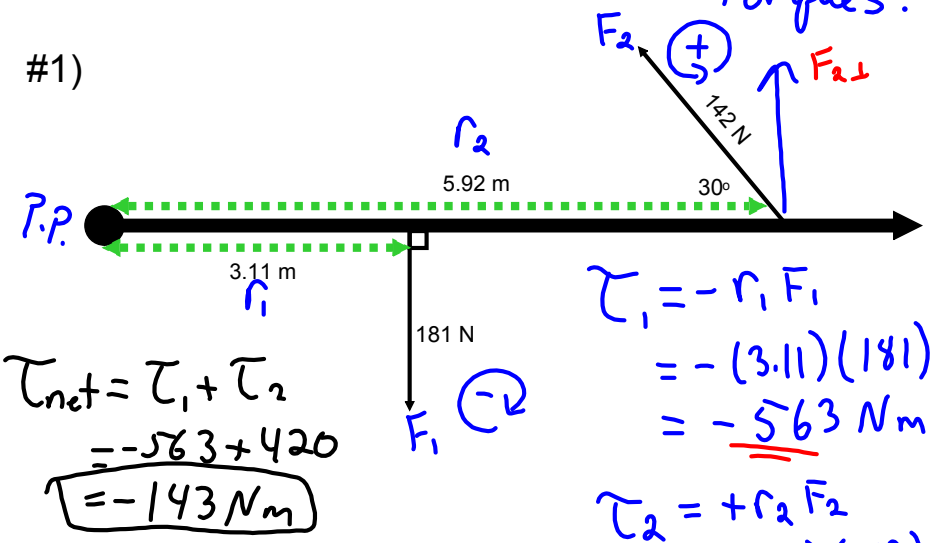
Just as net force sometimes plays a part in a problem, so does net torque. Net torque is the vector sum of all torques.

Example: Two forces act on the beam as shown in the diagram below. If F_1 = 10 N and F_2 = 15 N, what is the net torque on the beam?



Net Torque Practice ← Sum of all Torques.

#1)



$\tau_{net} = \tau_1 + \tau_2$

$= -563 + 420$

$= -143\ Nm$

$\tau_1 = -r_1 F_1$

$= -(3.11)(181)$

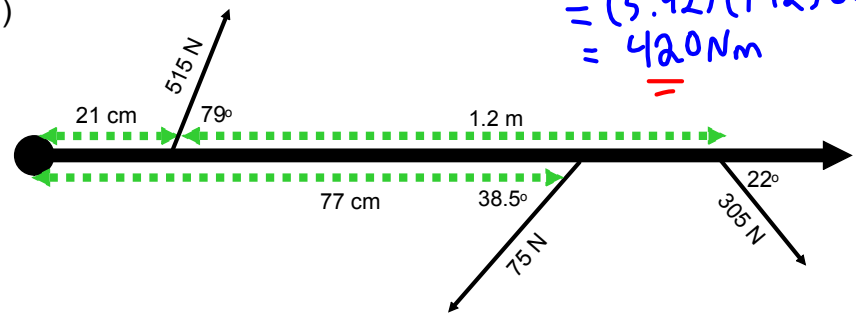
$= -563\ Nm$

$\tau_2 = +r_2 F_2$

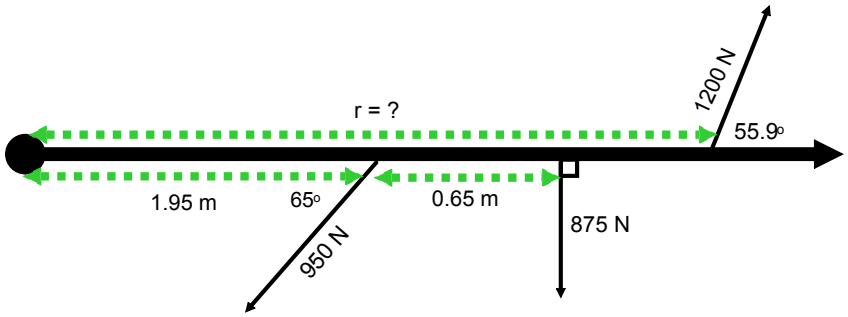
$= (5.92)(142)\sin 30°$

$= 420\ Nm$

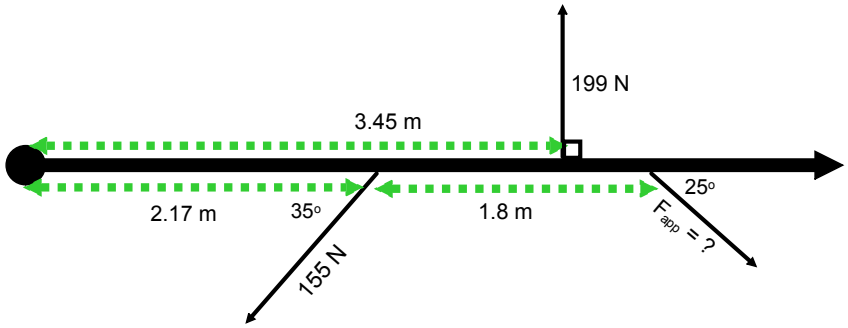
#2)



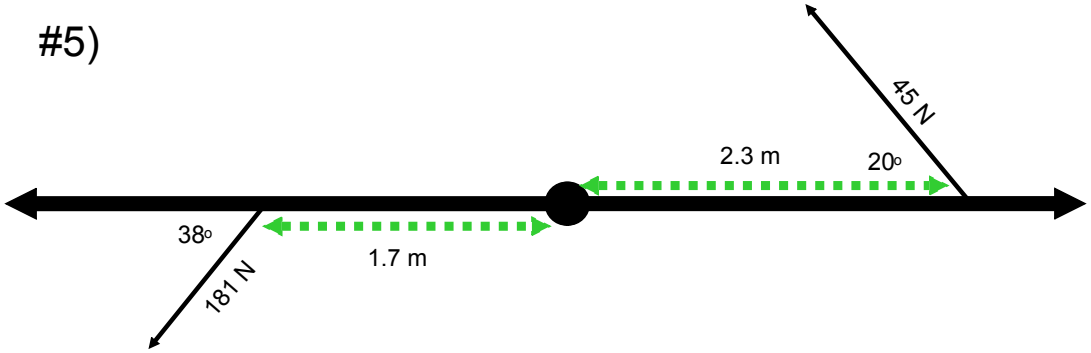
#3) $\tau_{net} = 0$ Nm



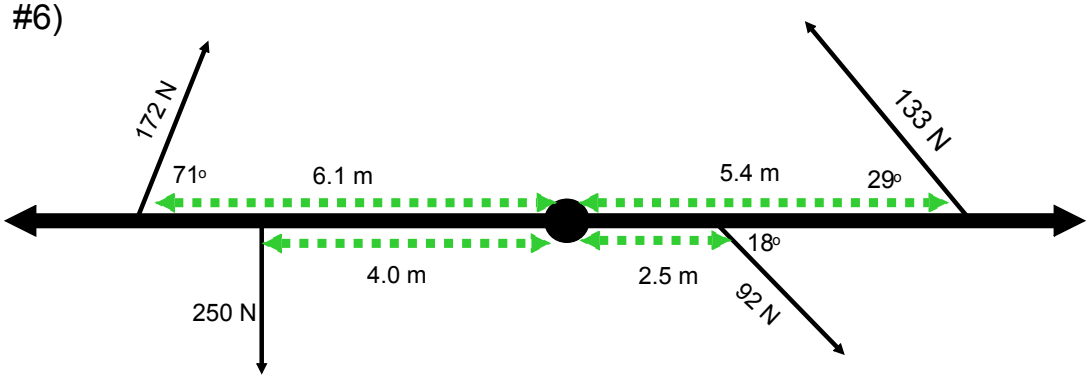
#4) $\tau_{net} = 0$ Nm



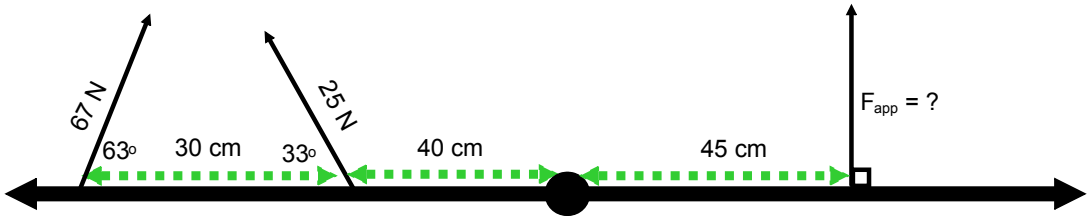
#5)



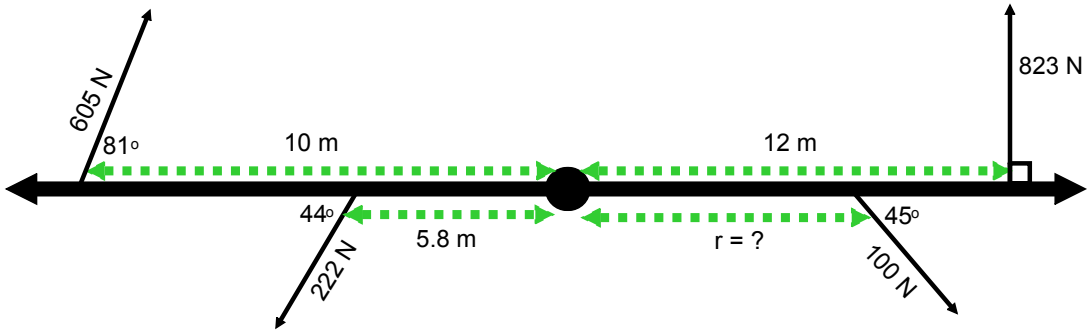
#6)



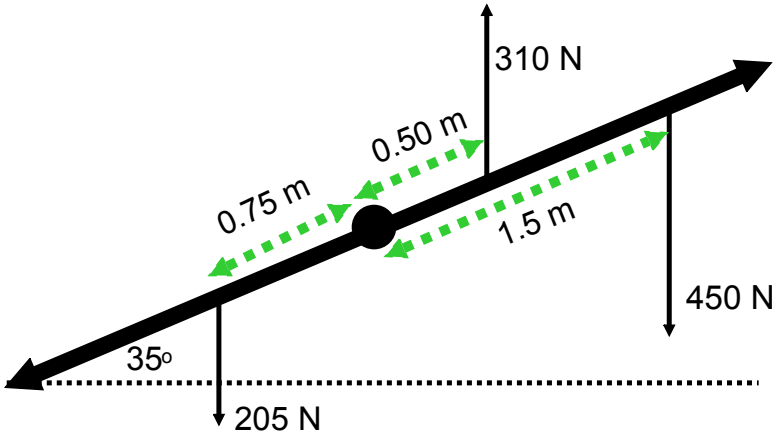
#7) τ_{net} = 0 Nm



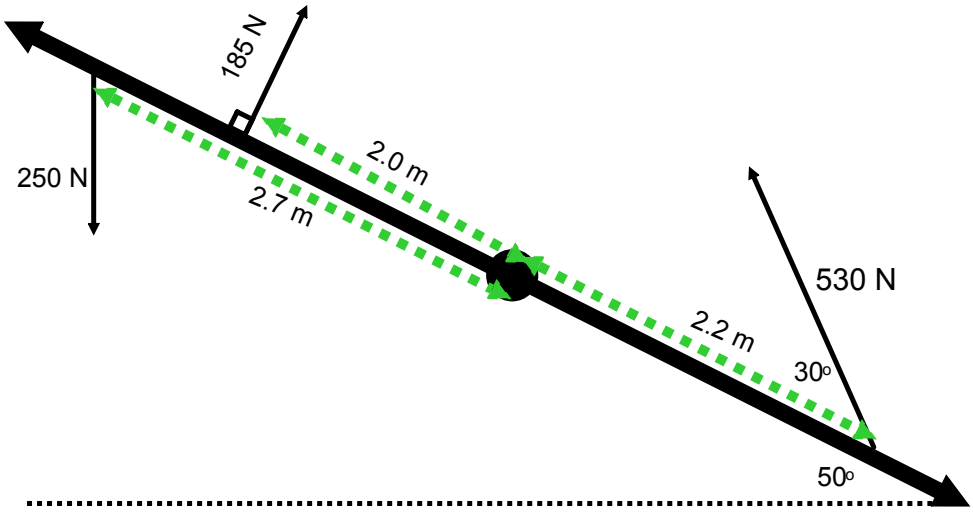
#8) τ_{net} = 0 Nm



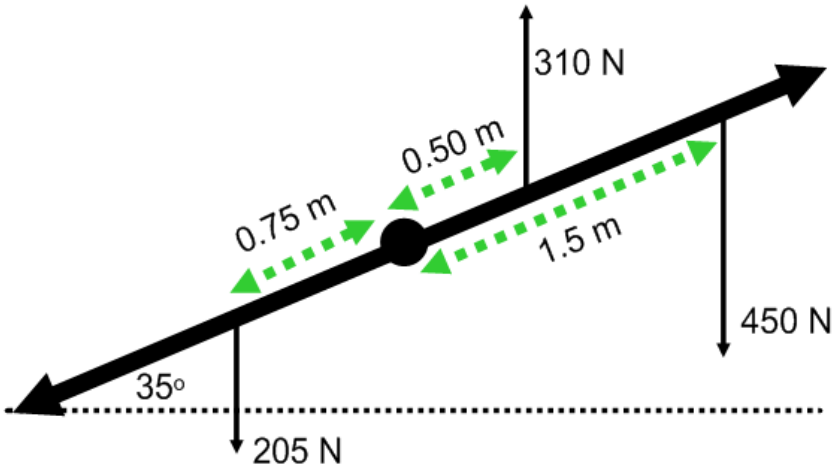
#9) All forces are perpendicular to the horizontal dashed line.



#10) Unless indicated, all forces are perpendicular to the horizontal dashed line.

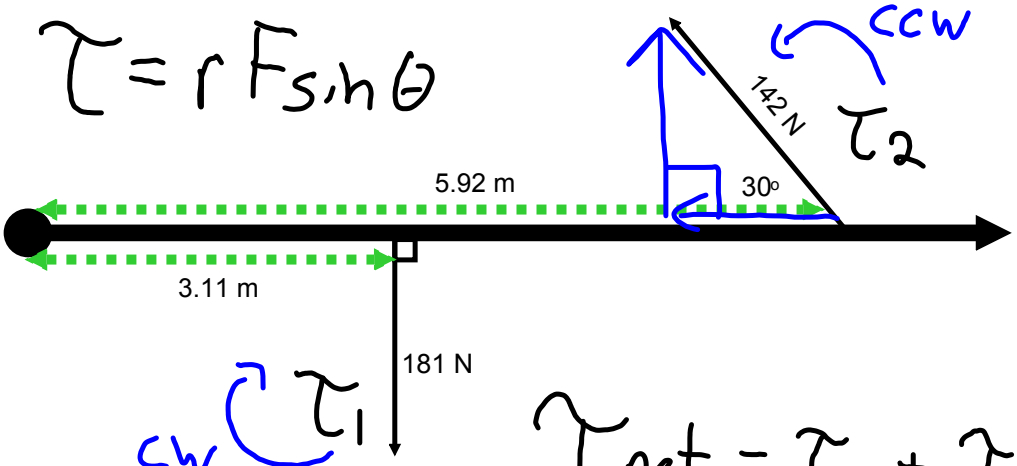


#9) All forces are perpendicular to the horizontal dashed line.



Net Torque Practice - Solutions

#1) $\tau = rF\sin\theta$



$\tau_{net} = \tau_1 + \tau_2$

$\tau_1 = -(3.11\text{m})(181)\sin 90°$

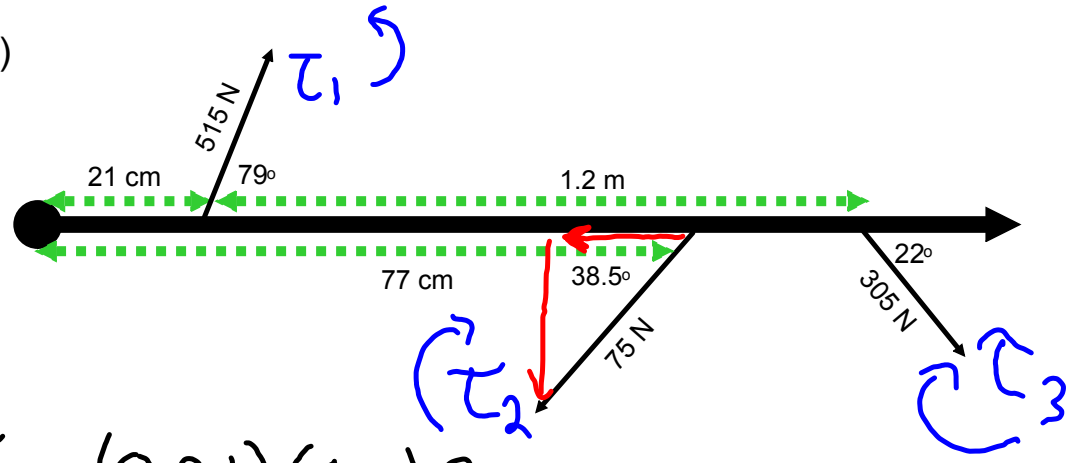
$= -563\ \text{Nm}$

$\tau_2 = 420\ \text{Nm} \Leftarrow (5.92\text{m})(142)\sin 30°$

$\tau_{net} = -563\ \text{Nm} + 420\ \text{Nm}$

$= -143\ \text{Nm}$ or $143\ \text{Nm}$ [cw]

#2)



$\tau_1 = (0.21)(515)\sin 79$

$= 106 \text{ Nm}$

$\tau_2 = -(0.77)(75)\sin 38.5°$

$= -35.9 \text{ Nm}$

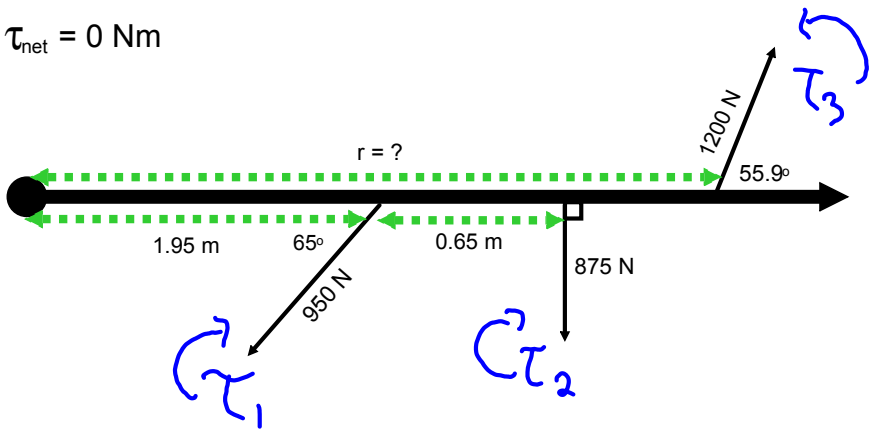
$\tau_3 = -(1.2+0.21)(305)(\sin 22°)$

$= -161 \text{ Nm}$

$\tau_{net} = \tau_1 + \tau_2 + \tau_3 = 106 \text{ Nm} - 35.9 \text{ Nm} - 161 \text{ Nm}$

$\boxed{\tau_{net} = -90.9 \text{ Nm or } 90.9 \text{ Nm [cw]}}$

#3) $\tau_{net} = 0$ Nm



$\tau_1 = -(1.95)(950)\sin 65°$

$= -1679$ Nm

$\tau_2 = -(1.95 + 0.65)(875)\sin 90°$

$= -2275$ Nm

$\tau_3 = +r(1200)\sin 55.9°$

$= 994r$

$\tau_{net} = \tau_1 + \tau_2 + \tau_3$

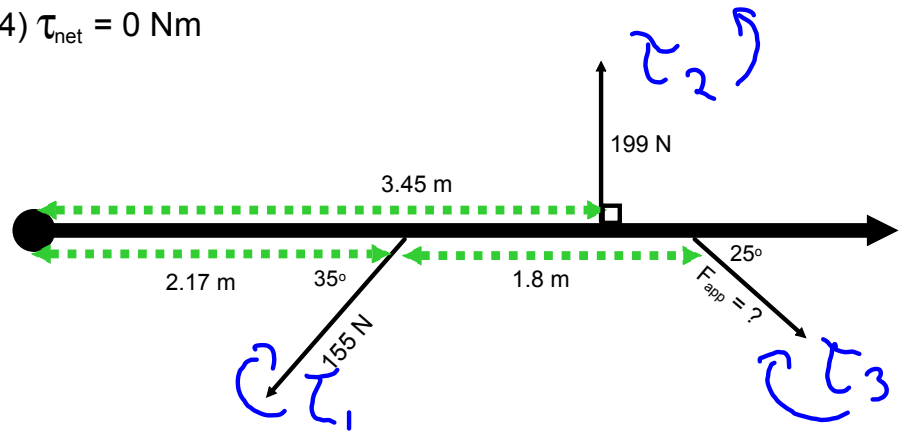
$0 = -1679\text{ Nm} - 2275\text{ Nm} + (994\text{ N})r$

$3954\text{ Nm} = (994\text{ N})r$

$\frac{3954\text{ Nm}}{994\text{ N}} = r$

$\boxed{3.98\text{ m} = r}$

#4) $\tau_{net} = 0$ Nm



$\tau_1 = (2.17)(155)\sin 35°$

$= -193$ Nm

$\tau_2 = (3.45)(199)\sin 90°$

$= 687$ Nm

$\tau_3 = -(2.17 + 1.8)F \sin 25°$

$= -1.68F$

$\tau_{net} = \tau_1 + \tau_2 + \tau_3$

$0 = -193\text{ Nm} + 687\text{ Nm} - 1.68F$

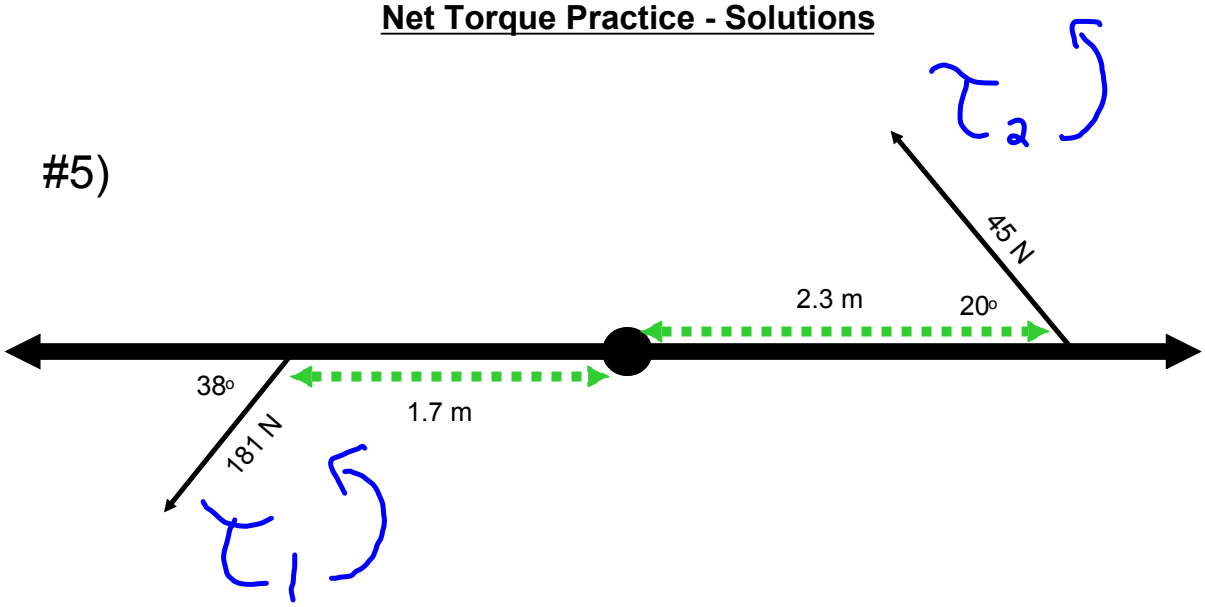
$-494 = -1.68F$

$\frac{-494\text{ Nm}}{-1.68\text{ m}} = F$

$294\text{ N} = F$

Net Torque Practice - Solutions

#5)



$\tau_1 = (1.7)(181)\sin 38°$

$= 189\ Nm$

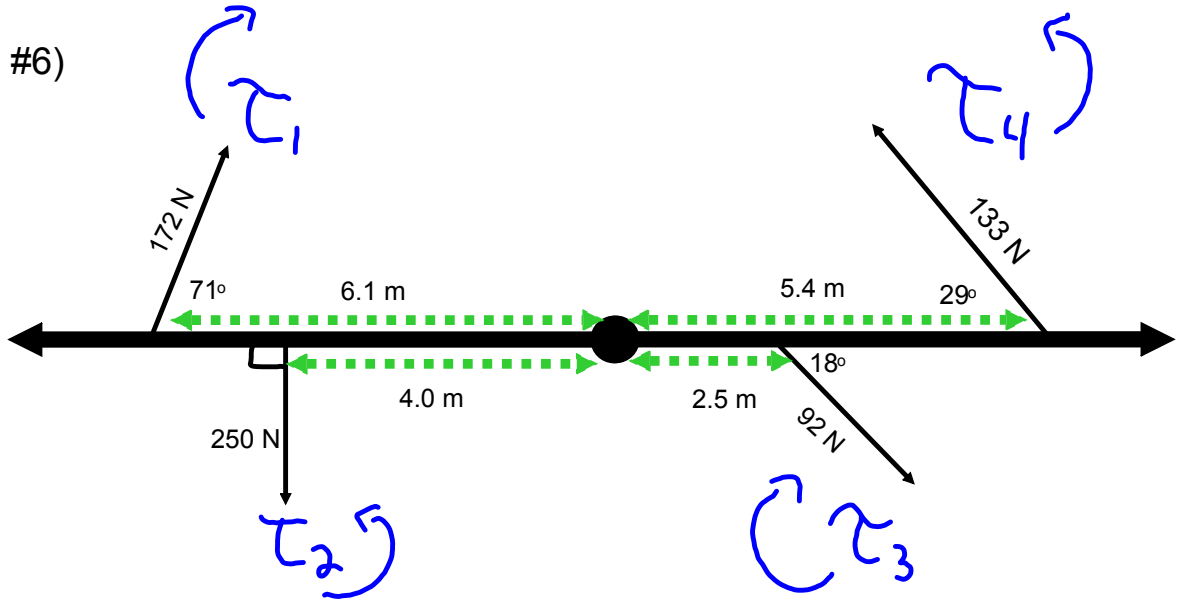
$\tau_2 = (2.3)(45)\sin 20°$

$= 35.4\ Nm$

$\tau_{net} = 189\ Nm + 35.4\ Nm$

$= 224\ Nm\ [ccw]$

#6)



$\tau_1 = -(6.1)(172)\sin 71°$

$= -992\ Nm$

$\tau_2 = (4.0)(250)\sin 90°$

$= 1000\ Nm$

$\tau_3 = -(2.5)(92)\sin 18°$

$= -71.1\ Nm$

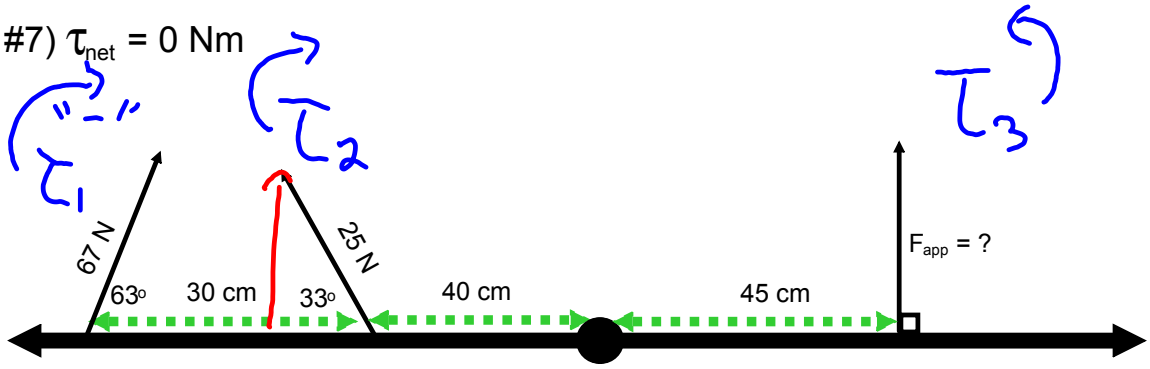
$\tau_4 = (5.4)(133)\sin 29°$

$= 348\ Nm$

$\tau_{net} = -992\ Nm + 1000\ Nm - 71\ Nm + 348\ Nm$

$= 285\ Nm$ or $285\ Nm\ [ccw]$

#7) $\tau_{net} = 0$ Nm



$$\tau_1 = -(0.30 + 0.40)(67)\sin 63^\circ$$

$$= -41.8 \text{ Nm}$$

$$\tau_2 = -(0.40)(25)\sin 33^\circ$$

$$= -5.45 \text{ Nm}$$

$$\tau_3 = (0.45\text{m})(F)\sin 90^\circ$$

$$= 0.45F$$

$$\tau_{net} = \tau_1 + \tau_2 + \tau_3$$

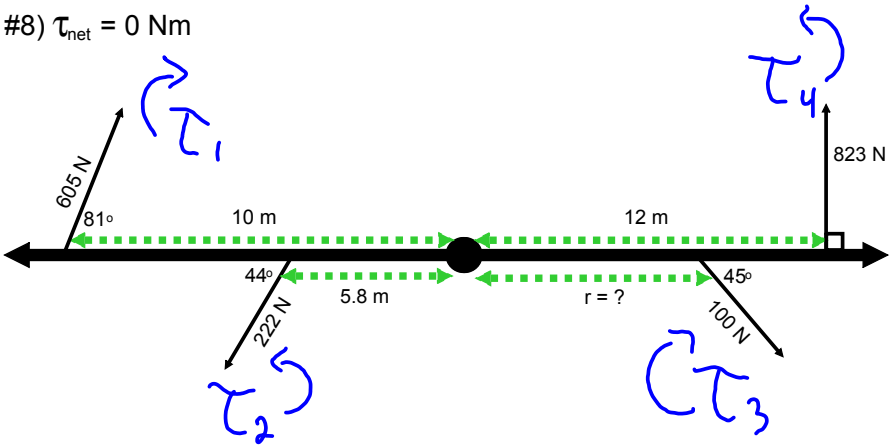
$$0 = -41.8 \text{ Nm} - 5.45 \text{ Nm} + 0.45F$$

$$47.25 \text{ Nm} = 0.45F$$

$$\frac{47.25 \text{ Nm}}{0.45 \text{ m}} = F$$

$$\boxed{105 \text{ N} = F}$$

#8) $\tau_{net} = 0$ Nm



$\tau_1 = -(10)(605)\sin 81°$

$= -5976$ Nm

$\tau_2 = (5.8)(222)\sin 44°$

$= 894$ Nm

$\tau_3 = -r(100)\sin 45°$

$= -70.7r$

$\tau_4 = (12)(823)\sin 90°$

$= 9876$ Nm

$\tau_{net} = \tau_1 + \tau_2 + \tau_3 + \tau_4$

$0 = -5976\text{ Nm} + 894\text{ Nm} - 70.7r + 9876\text{ Nm}$

$0 = 4794\text{ Nm} - 70.7r$

$-4794\text{ Nm} = -70.7r$

$\frac{-4794\text{ Nm}}{-70.7\text{ N}} = r$

$\boxed{67.8\text{ m} = r}$

Attachments

balancing-act_en.jar