Torque

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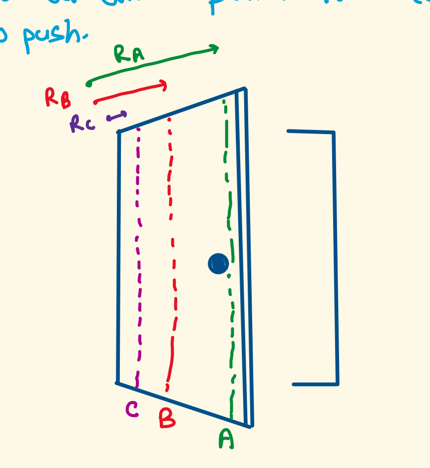
1. Introduction:

Imagine, there is a door and we pushed the door at 3 points, let's say, A, B and C.

Now, at which point, it is most difficult to push and at which point it is comparatively easier to push.



Let's say, we apply the same force F at A, B and C. We will find out pushing at A is much easier compared to B and C. Pushing the door at C will be comparatively more difficult.

Reason: Torque is high at point A.

Torque, $\tau = F \cdot R$

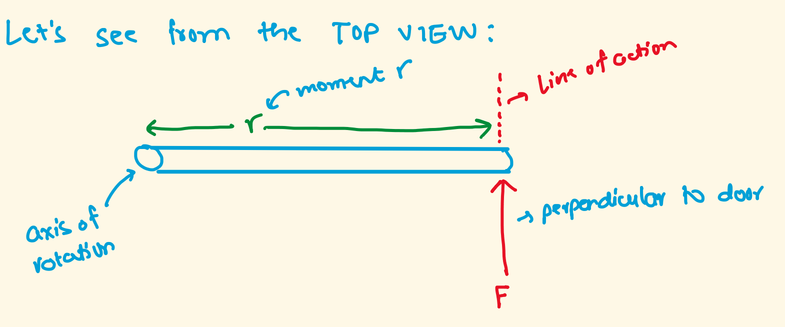
$\tau_A = FR_A$ $\quad\quad$ $\tau_B = FR_B$ $\quad\quad$ $\tau_C = FR_C$

Since, $R_A > R_B > R_C$

So,

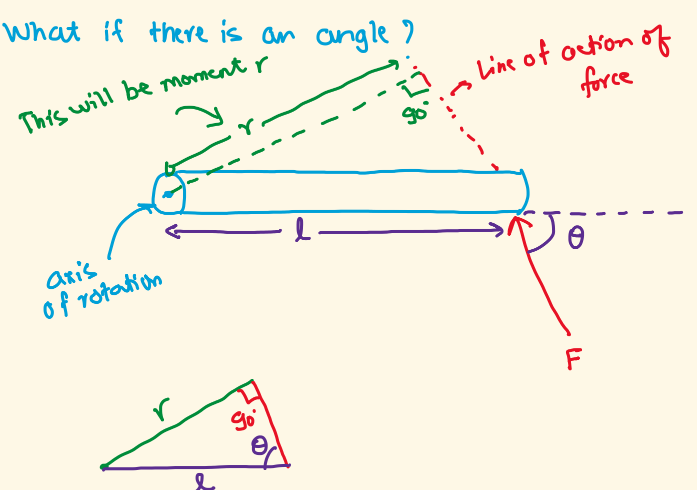
$$\tau_A > \tau_B > \tau_C$$

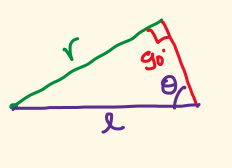
Let's see from the TOP VIEW:



$$\boxed{\tau = F \cdot r}$$

What if there is an angle?



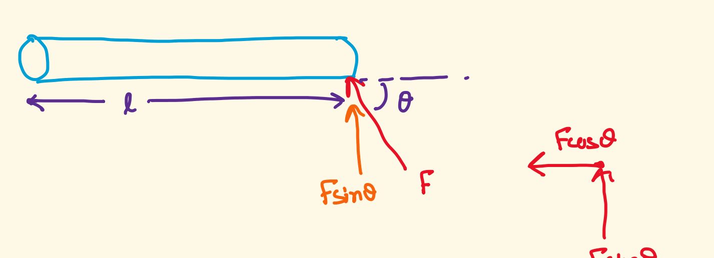


$$\sin\theta = \frac{r}{l} \Rightarrow \boxed{r = l\sin\theta}$$

So, Torque: $\tau = F \cdot r$

$\quad\quad\quad\quad = F \cdot l\sin\theta$

Another method, to calculate the same Torque. This time let's see components of F.

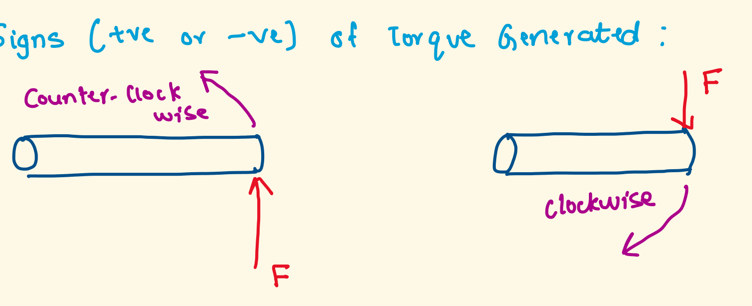


Torque, $\tau = \underbrace{F_\perp}_{\text{perpendicular component of force}} \cdot \underbrace{l}_{\text{distance from axis of rotation}}$

$= (F\sin\theta) \cdot l$

$= Fl\sin\theta$

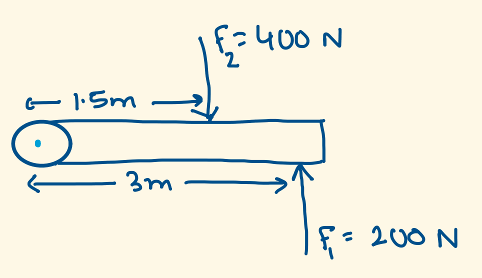
- Signs (+ve or −ve) of Torque Generated:



Torque generated, $\tau = +ve$ $\quad\quad$ Torque Generated, $\tau = -ve$

2. Problems:

Example:



Solution:

$\tau_{net} = \underbrace{+}_{\text{clockwise}} \tau_1 \ \underbrace{-}_{\text{counter-clockwise}} \tau_2$

$= +F_1(3) - F_2(1.5)$

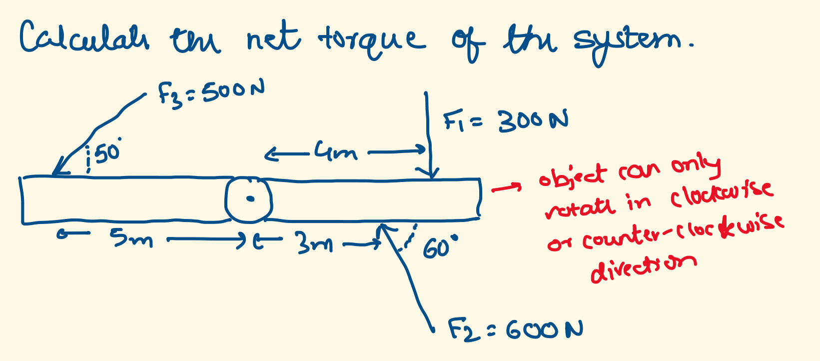
$= 3(200) - 1.5(400)$

$= 600 - 600$

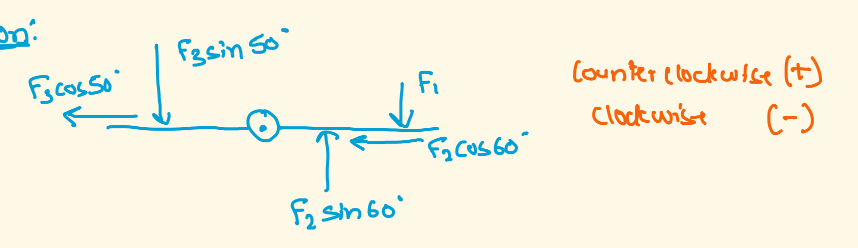
$= 0$ Nm

∴ This means object will not rotate. Clockwise torque is equal to the counter-clockwise torque. Therefore, the object will be in equilibrium.

Example: Calculate the net torque of the system.



Solution:



We should understand that $(F_3\cos 50°)$ & $(F_2\cos 60°)$ component of forces do not produce any torque.

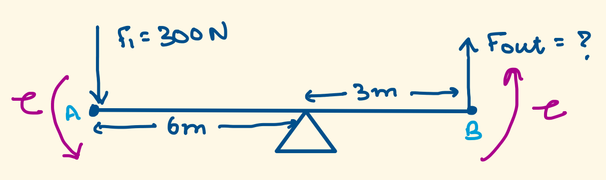
$\therefore \tau_{net} = +(F_2\sin 60°)(3) - F_1(4) + (F_3\sin 50°)(5)$

$= 600\left(\frac{\sqrt{3}}{2}\right) \cdot 3 - (300)(4) + (500)(0.766)(5)$

$= 1558.845 - 1200 + 1915$

$= \underbrace{+}_{\text{counter-clockwise}} 2273.845$ Nm

Example:



Solution: At point A:

$\tau = +F_1 \cdot 6$

$= (300) \cdot 6$

$= 1800$ Nm

At Point B: $\tau = +F_{out} \cdot (3)$

$1800 = F_{out} \cdot (3)$

$\therefore F_{out} = \frac{1800}{3}$

$= 600$ N

Important learning: In this system, we just applied a force of 300 N and we got an output force of 600N. We get 2 times the applied force. Therefore,

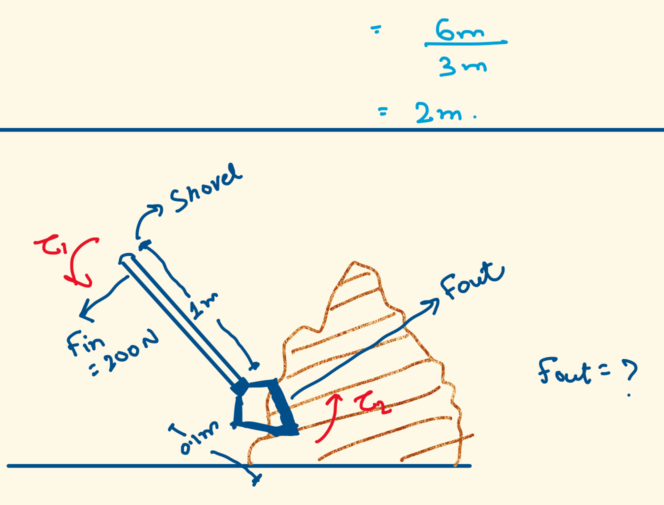
$$\left(\text{Mechanical Advantage of this system}\right) = 2$$

In general:-

$$\boxed{\text{Actual Mechanical Advantage, } MA = \frac{F_{out}}{F_{in}}}$$

$$\boxed{\begin{aligned}\text{Ideal Mechanical Advantage, } IMA &= \frac{\text{Input Lever Arm}}{\text{Output Lever Arm}} \\ &= \frac{l_{in}}{l_{out}} \\ &= \frac{6m}{3m} \\ &= 2m.\end{aligned}}$$

Example:



Solution:

$\tau_1 = \tau_2$

$(F_{in})(1) = (F_{out})(0.1)$

$(200)(1) = F_{out}(0.1)$

$$\boxed{F_{out} = 2000 \text{ N}}$$

Notice:
- Smaller force is associated with the longer side. (1m in our case).
- Larger force is associated with the smaller side (0.1m in our case).

Mechanical Advantage of system $= \frac{F_{out}}{F_{in}}$

$= \frac{2000}{200}$

$= 10$

which means, it increases the output force by a factor of 10.

3. References:

1. The Organic Chemistry Tutor

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