BTU 1113 Physics

Chapter 4:Static Equilibrium

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Chapter Description

- Aims
  - Illustrate the forces in equilibrium concept.
  - Identify the condition for equilibrium and calculate rigid objects in static equilibrium.

- Expected Outcomes
  - Students should be able to illustrate the forces in equilibrium concept.
  - Students should be able to identify the condition for equilibrium and calculate rigid objects in static equilibrium.

- References
  - Giancoli, D.C., 2008. Physics for Scientists & Engineers. 4th edition. Prentice Hall, USA.
  - Jones, E., 2002. Contemporary College Physics. 3rd Ed, McGraw-Hill, Singapore.
  - Young, H. D. and Freedman, R. A., 2012. University Physics with Modern Physics. 13th edition, Pearson, San Francisco

1st aim:
Illustrate the forces in equilibrium concept.

Equilibrium Concept

An object is in “Equilibrium” when:

1. **There is no net force acting on the object**
2. There is no net Torque *(we’ll get to this later)*

In other words, the object is **NOT experiencing linear acceleration** or rotational acceleration.

→

$$a = \frac{\Delta v}{\Delta t} = 0$$

$$\alpha = \frac{\Delta \omega}{\Delta t} = 0$$

Static Equilibrium

An object is in “Static Equilibrium” when it is

<u>NOT MOVING.</u>

$$v = \frac{\Delta x}{\Delta t} = 0$$

$$a = \frac{\Delta v}{\Delta t} = 0$$

Dynamic Equilibrium

An object is in “Dynamic Equilibrium” when it is **MOVING with constant linear velocity** and/or rotating with constant angular velocity.

$$a = \frac{\Delta v}{\Delta t} = 0$$

$$\alpha = \frac{\Delta \omega}{\Delta t} = 0$$

2^{nd} aim:
Identify the condition for equilibrium and calculate rigid objects in static equilibrium.

Equilibrium Conditions

Let’s focus on condition 1: net force = 0

$$\sum \vec{F} = 0$$

The x components of force cancel

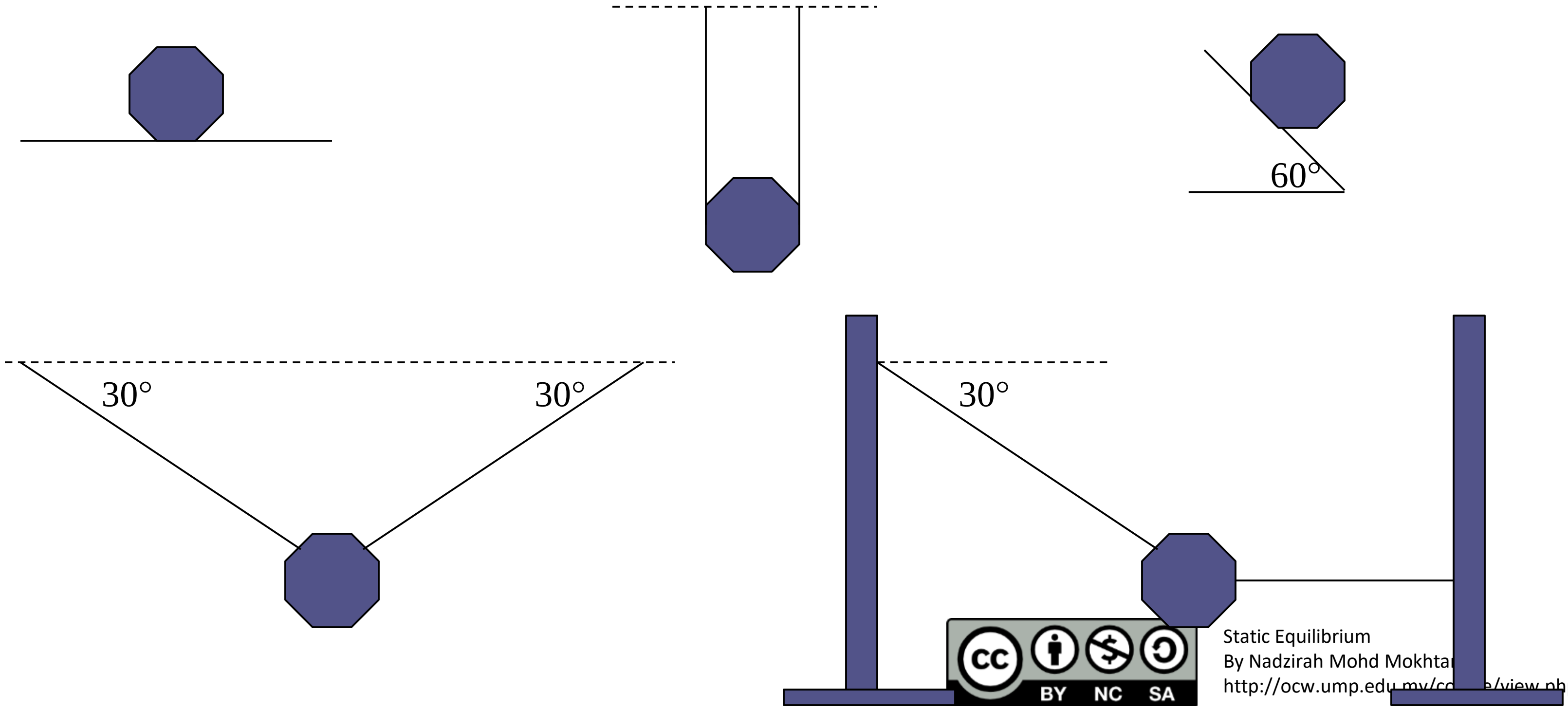
$$\sum \vec{F}_x = 0$$

The y components of force cancel

$$\sum \vec{F}_y = 0$$

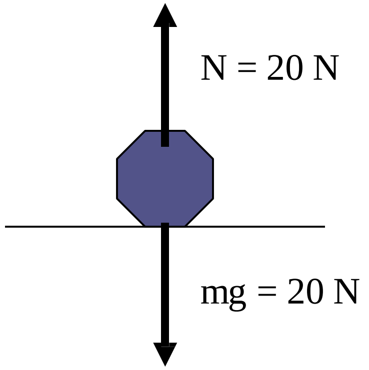
Condition 1: No net Force

We have already looked at situations where the **net force = zero**. Determine the magnitude of the forces acting on each of the **2 kg** masses **<u>at rest</u>** below.



Condition 1: No net Force

$\sum F_x = 0$ and $\boldsymbol{\sum F_y = 0}$



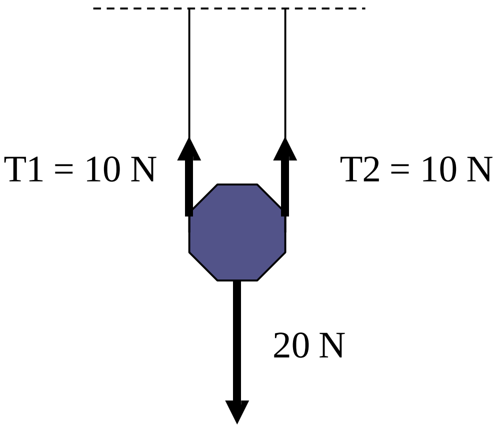
$\boldsymbol{\sum F_y = 0}$

$N - mg = 0$

$\mathbf{N = mg = 20\ N}$

Condition 1: No net Force

$\sum F_x = 0$ and $\boldsymbol{\sum F_y = 0}$



$\boldsymbol{\sum F_y = 0}$

$T1 + T2 - mg = 0$

$T1 = T2 = T$

$T + T = mg$

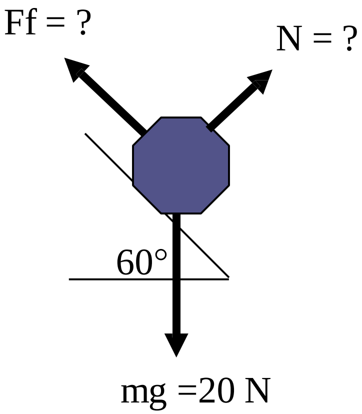
$2T = 20\ N$

$T = 10\ N$

Condition 1: No net Force

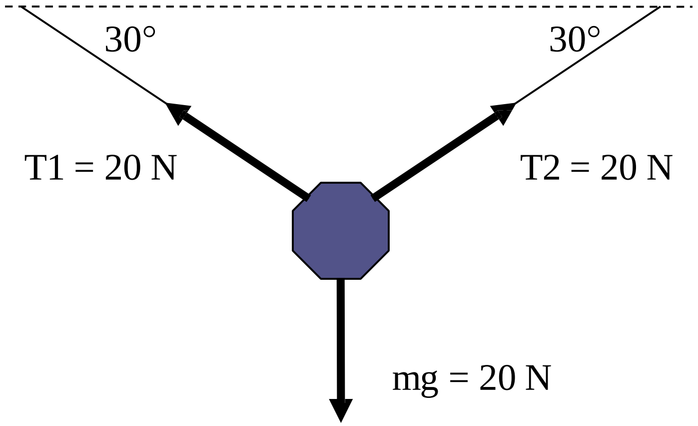
$$\sum F_x = 0$$

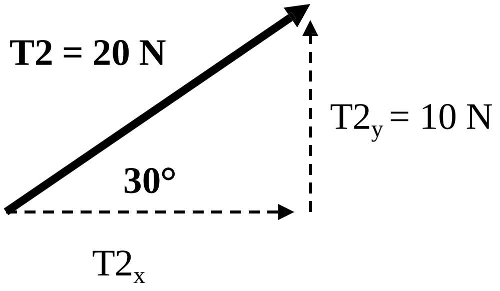
$$\sum F_y = 0$$



Condition 1: No net Force

$\sum F_x = 0$ and $\mathbf{\sum F_y = 0}$





$\mathbf{\sum F_x = 0}$

$T2x - T1x = 0$

$\mathbf{T1_x = T2_x}$

Equal angles ==> T1 = T2

$\mathbf{\sum F_y = 0}$

$T1_y + T2_y - mg = 0$

$2T_y = mg = 20\ N$

$\mathbf{T_y = mg/2 = 10\ N}$

$\mathbf{T_y/T = \sin 30}$

$T = T_y/\sin 30$

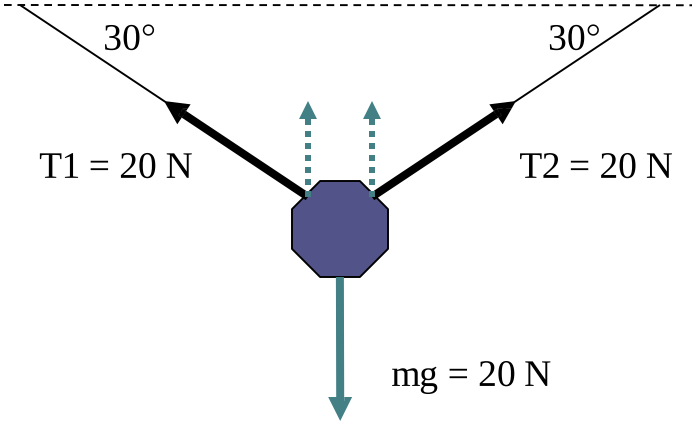
$T = (10\ N)/\sin 30$

$\mathbf{T = 20\ N}$

Note: unequal angles ==> T1 ≠ T2

Condition 1: No net Force

$\sum F_x = 0$ and $\sum \mathbf{F}_y = \mathbf{0}$



Note:
The y-components cancel, so $T1_y$ and $T2_y$ both equal 10 N

Equilibrium

An object is in “Equilibrium” when:

1. There is no net force acting on the object
2. **There is no net Torque**

In other words, the object is **NOT experiencing** linear acceleration or **rotational acceleration.**

$$a = \frac{\Delta v}{\Delta t} = 0$$

$$\alpha = \frac{\Delta \omega}{\Delta t} = 0$$

What is Torque?

Torque is like "twisting force"

The more torque you apply to a wheel the more quickly its rate of spin changes

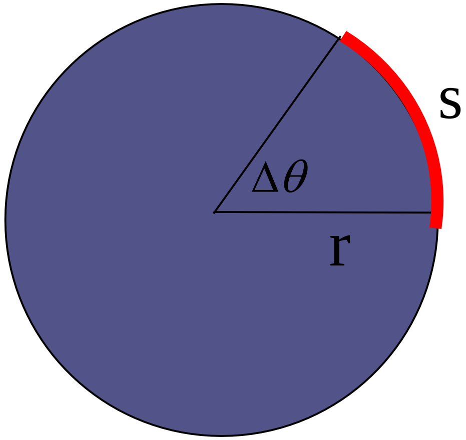
$$\boxed{\textbf{Torque} = \mathbf{Fr}}$$

Math Review:

1. Definition of angle in "radians"

$$\Delta\theta = s/r$$

$$\Delta\theta = \frac{\text{arc length}}{\text{radius}}$$



2. One revolution = 360° = 2π radians
   ex: π radians = 180°
   ex: π/2 radians = 90°

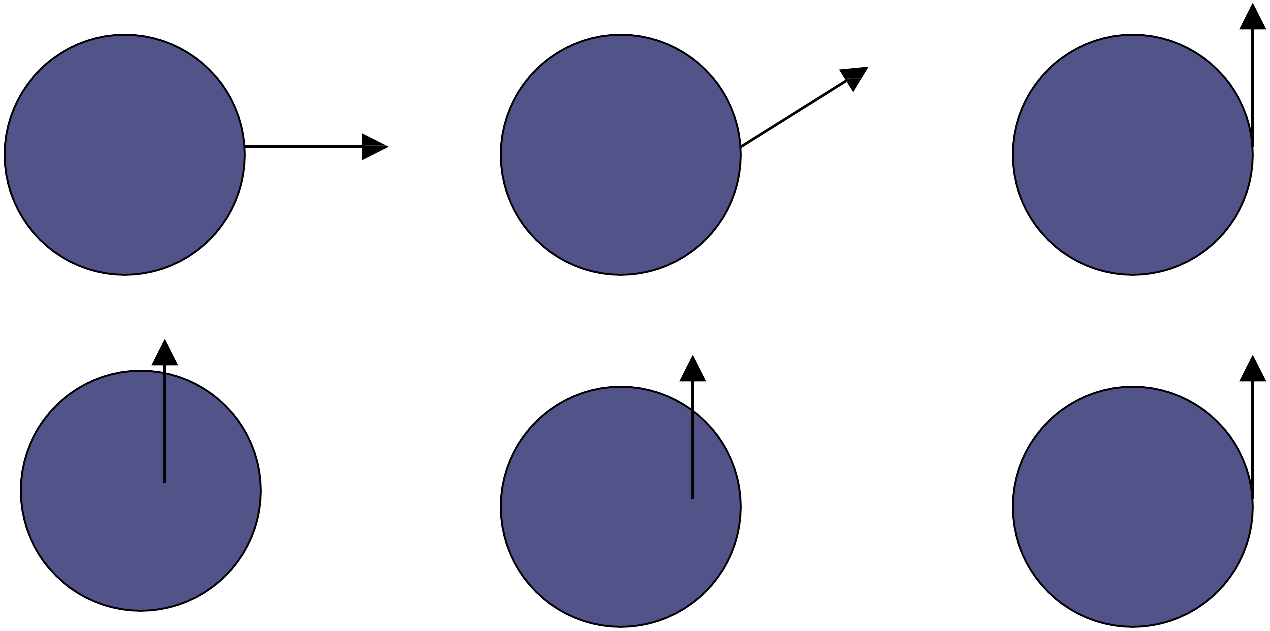
Torque

Torque is like “twisting force”

The more torque you apply to a wheel, the more quickly its rate of spin changes

Torque is like "twisting force"

Imagine a bicycle wheel that can only spin about its axle. If the force is the same in each case, which case produces a more effective "twisting force"?



This one!

Torque is like “twisting force”

Imagine a bicycle wheel that can only spin about its axle.

What affects the torque?

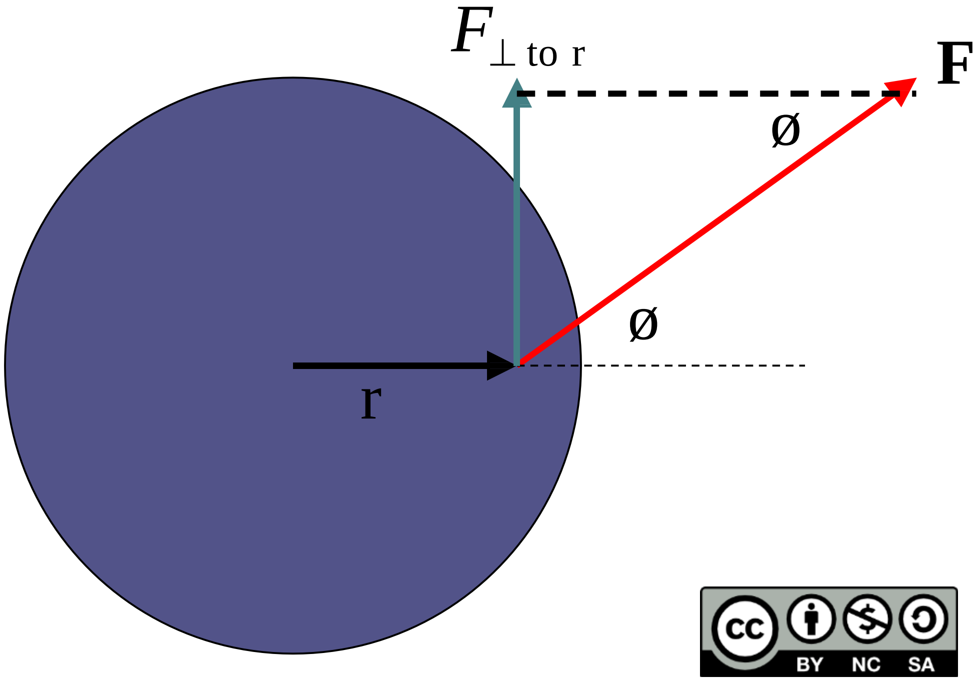
1. *The place where the force is applied: the distance “r”*
2. *The strength of the force*
3. *The angle of the force*

Torque = r . Fsinø

Imagine a bicycle wheel that can only spin about its axle.

What affects the torque?

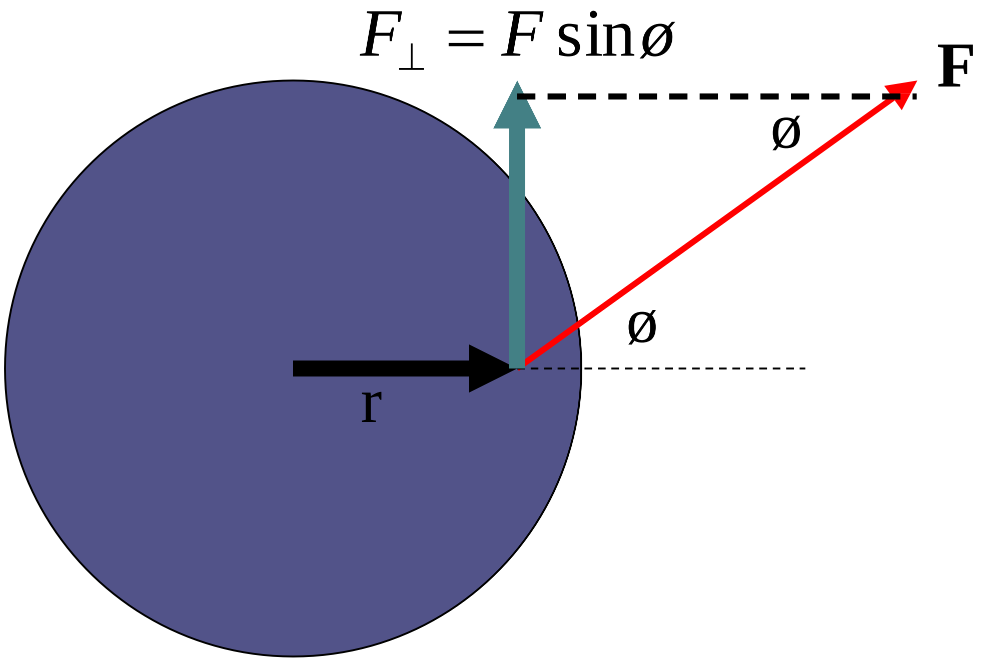
1. ***The distance from the axis rotation "r"*** *that the force is applied*
2. ***The component of force perpendicular to the r-vector***



$$\tau = (F_{\perp})(r)$$

$$\tau = (F \sin ø)(r)$$

$$\tau = F r \sin ø$$



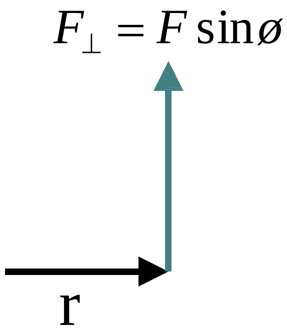
Two different ways of looking at torque

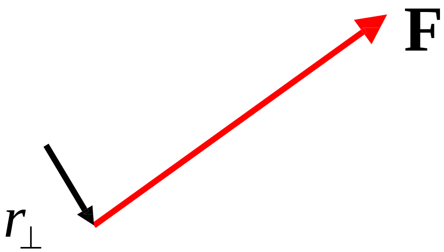
Torque = (Fsinø)(r)

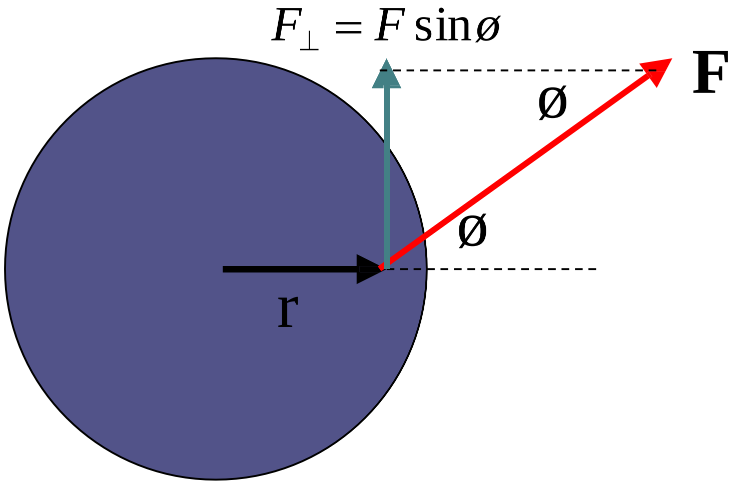
$$Torque = (F_\perp)(r)$$

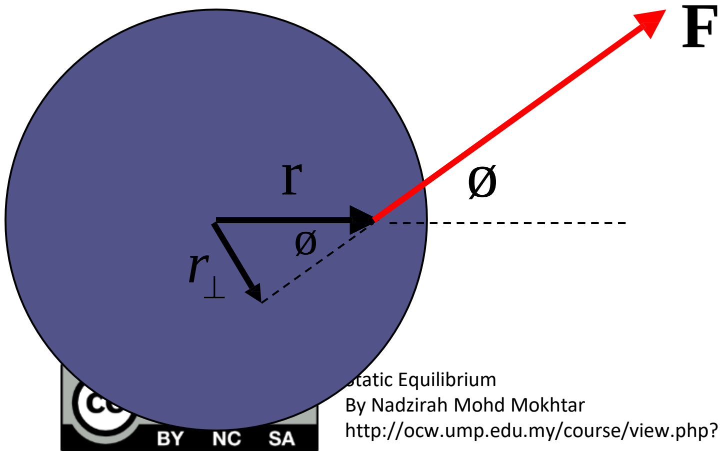
Torque = (F)(rsinø)

$$Torque = (F)(r_\perp)$$









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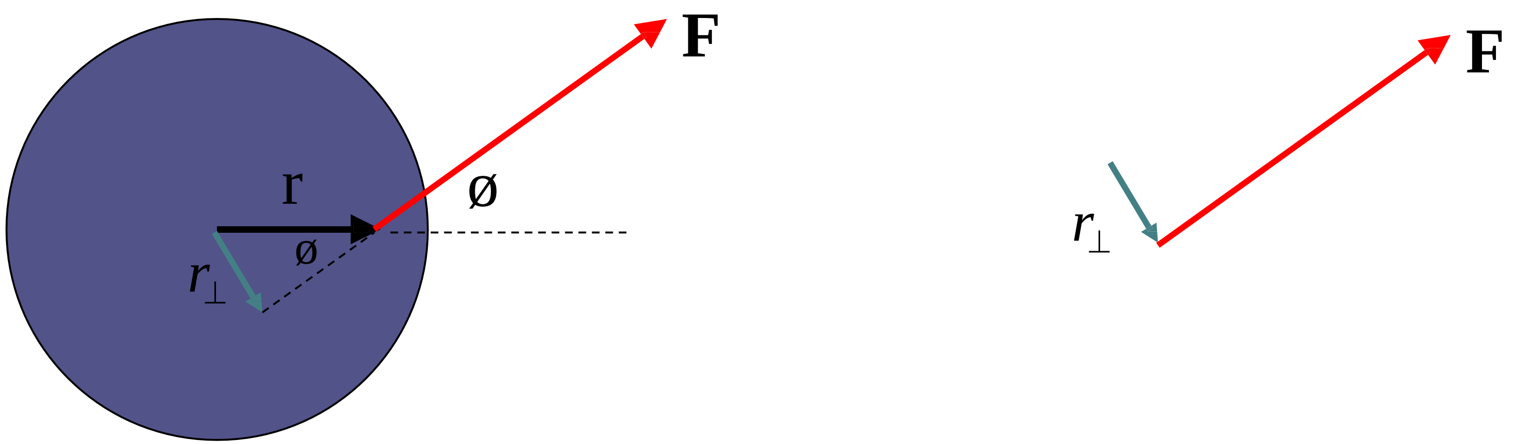
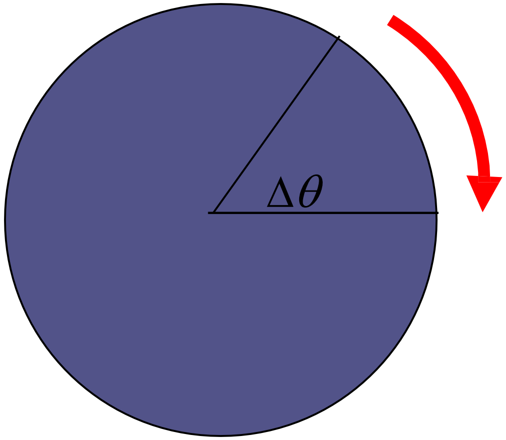
Torque = (F)(rsinø)

$r_\perp$ is called the "moment arm" or "moment"

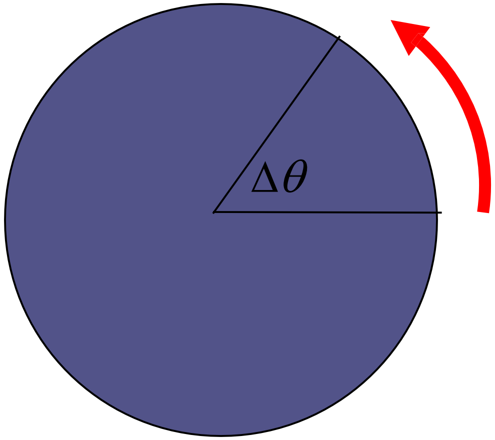


Condition 2: net torque = 0

Torque that makes a wheel want to rotate clockwise is +
Torque that makes a wheel want to rotate counterclockwise is -



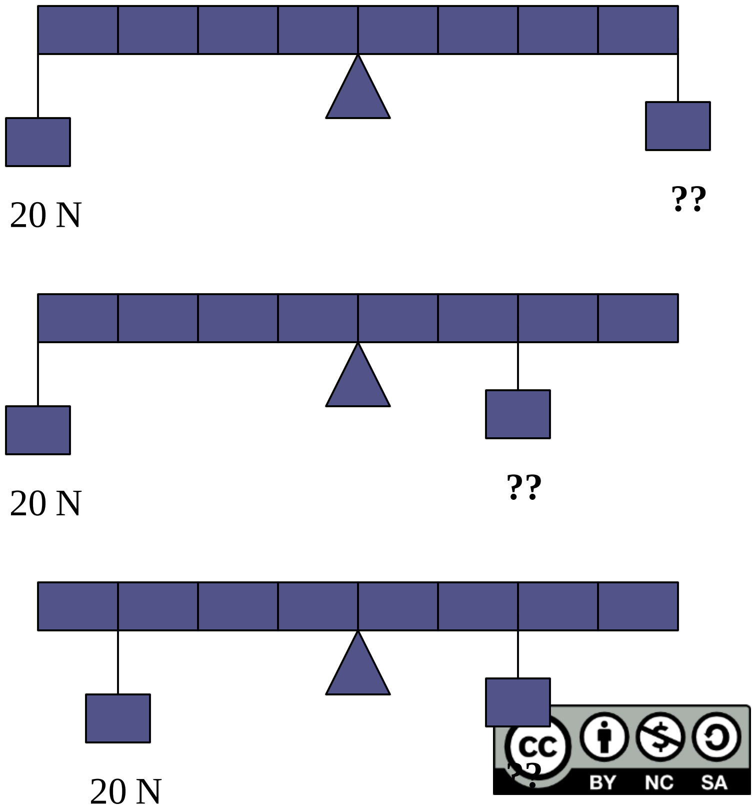
Positive Torque



Negative Torque

Condition 2: No net Torque

Weights are attached to **8 meter** long levers **at rest**. Determine the unknown **weights** below



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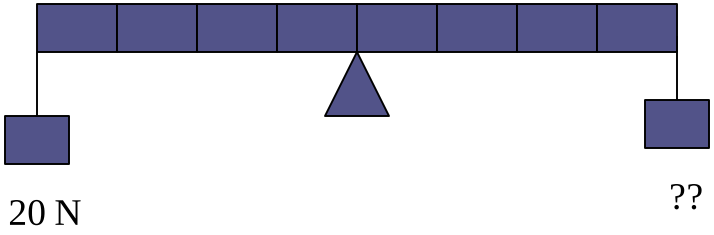
Condition 2: No net Torque

Weights are attached to an 8 meter long lever **at rest**. Determine the unknown **weight** below



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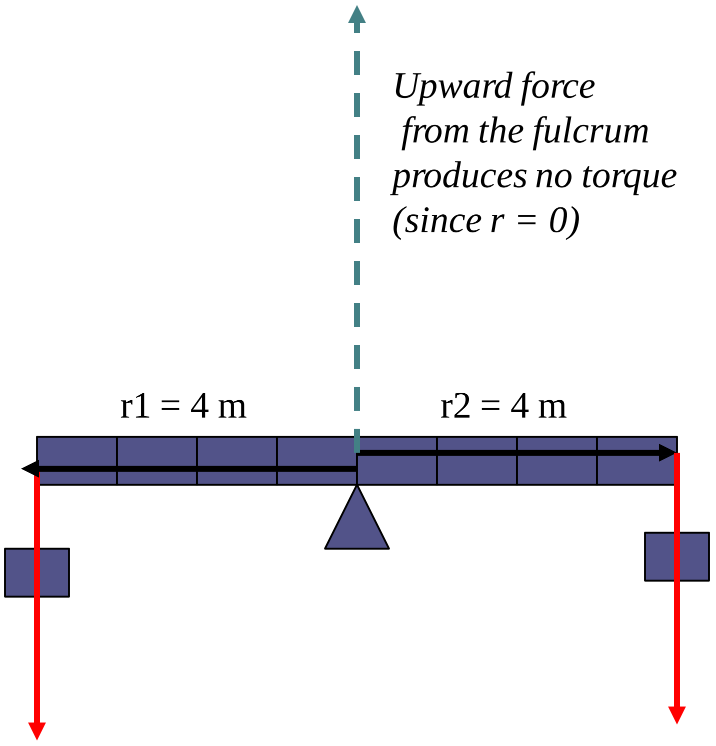
Condition 2: No net Torque



Upward force from the fulcrum produces no torque (since r = 0)

$r1 = 4$ m

$r2 = 4$ m

$F_1 = 20$ N

F_2 =??

$$\sum T\text{'s} = 0$$

$$T2 - T1 = 0$$

$$T2 = T1$$

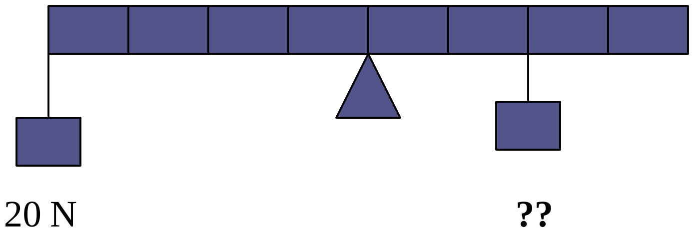
$$F_2 r_2 = F_1 r_1$$

$$(F_2)(4) = (20)(4)$$

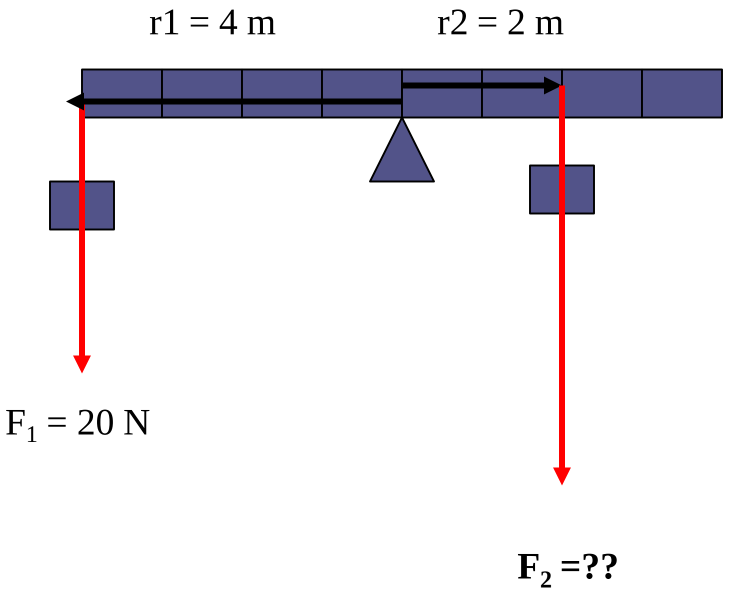
$F_2 = 20$ N … same as F_1

Condition 2: No net Torque

Weights are attached to an 8 meter long lever **at rest**. Determine the unknown **weight** below



Condition 2: No net Torque



$\sum T\text{'s} = 0$

$T2 - T1 = 0$

$T2 = T1$

$F_2 r_2 \sin ø_2 = F_1 r_1 \sin ø_1$

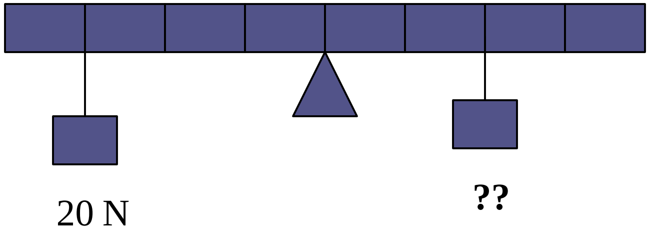
$(F_2)(2)(\sin 90) = (20)(4)(\sin 90)$

$F_2 = 40$ N

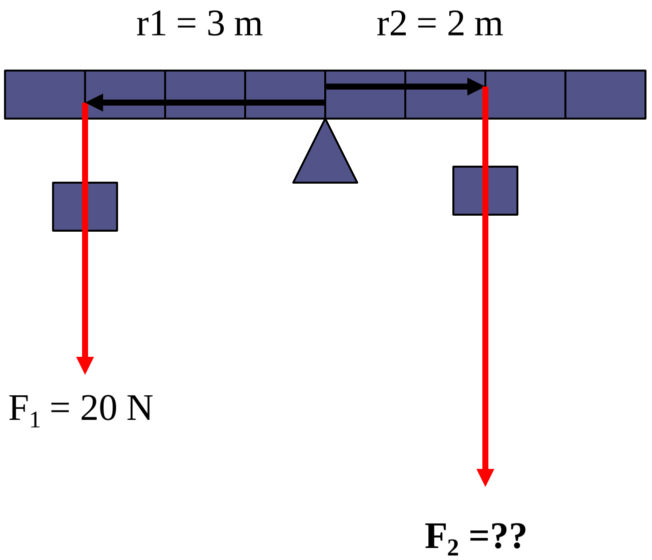
(force at the fulcrum is not shown)

Condition 2: No net Torque

Weights are attached to an 8 meter long lever **at rest**.
Determine the unknown **weight** below



Condition 2: No net Torque



$$\sum T\text{'s} = 0$$

$$T2 - T1 = 0$$

$$T2 = T1$$

$$F_2 r_2 \sin ø_2 = F_1 r_1 \sin ø_1$$

$$(F_2)(2)(\sin 90) = (20)(3)(\sin 90)$$

$$\mathbf{F_2 = 30\ N}$$

(force at the fulcrum is not shown)

Conclusion of The Chapter

Statics is concerned about the calculation of the forces acting on and within structures that are in equilibrium. There are two conditions applied for the object in equilibrium; no net force acting on the object and no net torque.

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Reference

Giancoli, D.C., 2008. Physics for Scientists & Engineers. 4th edition. Prentice Hall, USA.