Selected Topics in Physics for Medical Sciences Students

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Unit 2

Static and Equilibrium

Lecture 4

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Contents

Statics & Equilibrium

- Introduction
- Torques
- Couples
- Equilibrium of Rigid Bodies
- Selected Topics
- Problems

Introduction

- **What is a "Force?"**
- A **force** causes something with **mass** to move (accelerate).
- **From Newton's Second Law of Motion**

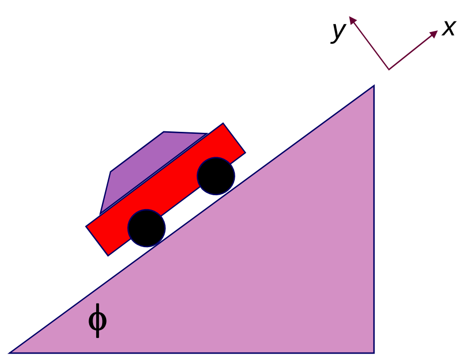
F = m x a

- The unit of force is Newton "N"

Example

- What are all of the forces acting on a car (mass m) parked on a hill?

Solution



Car on Hill:

Use Newton's 2nd Law: $F_{NET} = ma = 0$

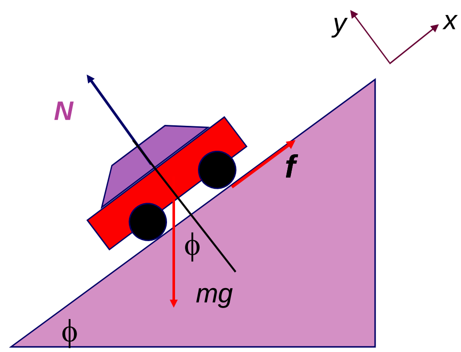
Resolve this into x and y components:

x: $f - mg \sin\phi = 0$

➡ $f = mg \sin\phi$

y: $N - mg \cos\phi = 0$

➡ $N = mg \cos\phi$



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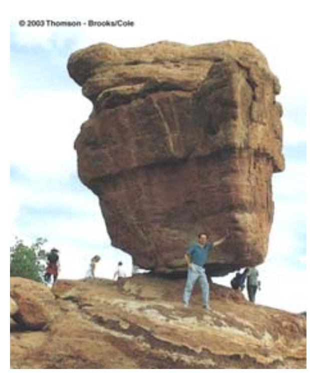
Statics

- **What is a "Statics?"**
- Statics is the study of forces acting on an object that is in **equilibrium** and at **rest**.



- *e.g. Ladders, sign-posts, balanced beams,*
- *buildings, bridges, some parts of*
- *Human body, etc…*

- *Statics can help to understand levers in our body.*
- *Statics study the balance and stability of*
- *many structures.*

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The Conditions of Equilibrium

- Any **rigid Body** is in equilibrium when two conditions are satisfied:

Condition (1)

- The net force acting on the body is zero.

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

Condition (2)

- The net torque about any axis must be zero

$$\sum \tau = 0$$

An object extend in space that does not change its size or shape when subjected to a force.

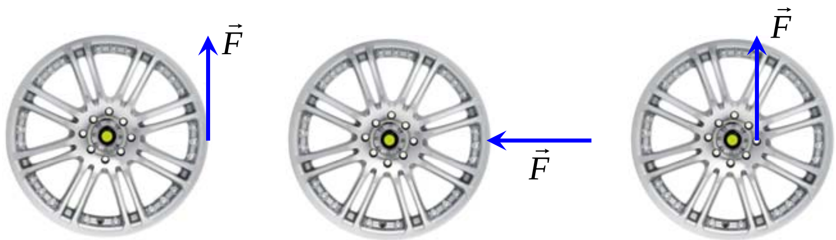
Static Equilibrium

- Translational Equilibrium: $\sum \mathbf{F} = 0$
- Rotational Equilibrium: $\sum \tau = 0$

هذا ما سنركز عليه في هذه الوحدة

Torques

Torque makes things spin!



which applied force will cause the wheel to spin the fastest?

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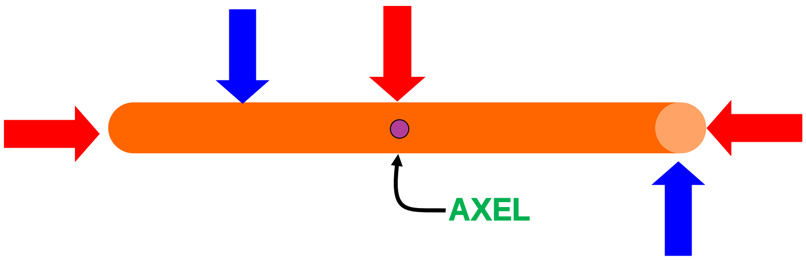
- **What makes something rotate in the first place?**

TORQUE

How do I apply a force to make the rod rotate about the axel? Not just anywhere!



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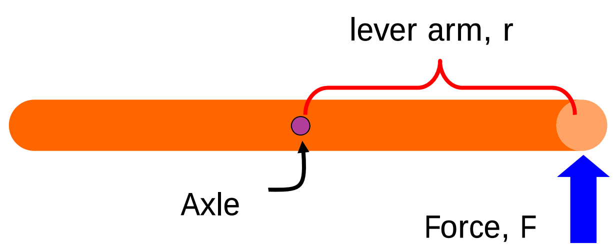
To make an object rotate, a force must be applied in the right place.

the combination of force and point of application is called **TORQUE**



Net torque = 0, net force ≠ 0

The rod will accelerate upward under these two forces, but will not rotate.

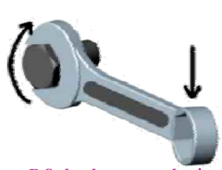
Net Force = 0 , Net Torque ≠ 0

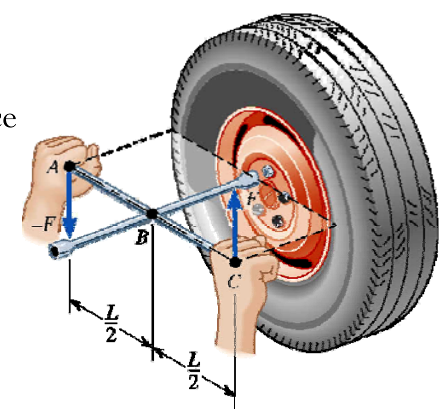
- The net force = 0, since the forces are applied in opposite directions so it will not accelerate.
- However, together these forces will make the rod rotate in the clockwise direction.

Torque

- When object is subjected to equal opposite forces. The net force is zero (the object is in translational equilibrium) But it may not in rotational equilibrium.

For example when the line of action of the two opposite force are not on the same line, then the object will rotate.





Force and Torque

How are force and torque related?

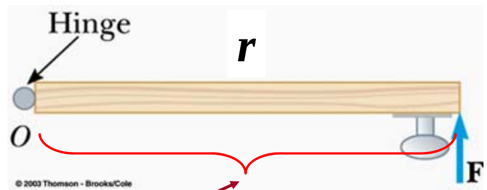
A force can create a torque by acting through a **moment arm**.

Torque

Torque, τ, is the force to rotate an object about some axis

Door example:

$$\tau = Fr$$



SI unit: [N m]

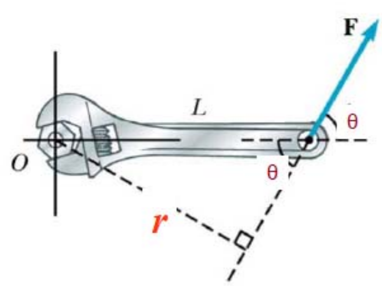
- τ is the torque
- *r* is the *lever arm* (or moment arm)
- *F* is the force

•The lever arm is the distance between the axis of rotation and the "line of action".

The lever arm, r, is the shortest *(perpendicular)* distance from the axis of rotation to a line drawn along the direction of the force

$$r = L \sin \theta$$

It is not necessarily the distance between the axis of rotation and point where the force is applied



Example

- **A mechanic holds a wrench 0.3m from the center of a nut. How large is the torque applied to the nut if he pulls at right angles to the wrench with a force of 200N?**

- Since he exerts the force at right angles to the wrench, the angle θ = 90°, and torque is

$$\tau = Fr\sin\theta = 0.3\times 200 = 60\,Nm$$

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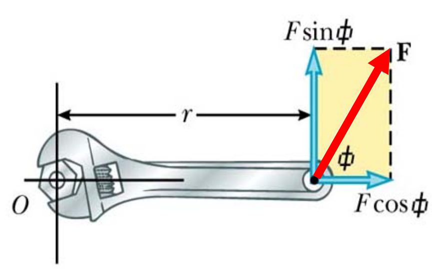
An Alternative Look at Torque

The force could also be resolved into its x- and y-components

- The x-component, F cosθ, produces 0 torque
- The y-component, F sinθ, produces a non-zero torque



$$\tau = rF\sin\theta$$

r is the distance along the object

F is the force

θ is the angle between force and object

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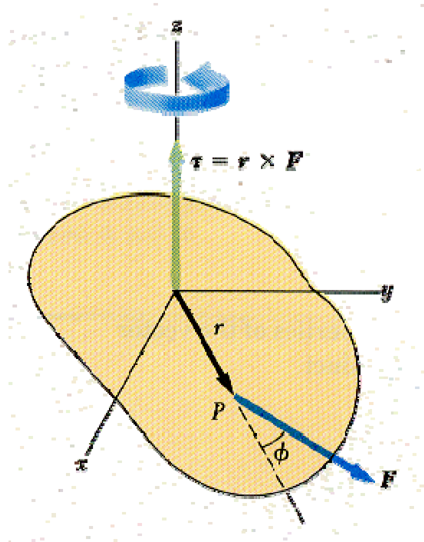
$$\tau = rF\sin\theta$$

- we can write the equation as

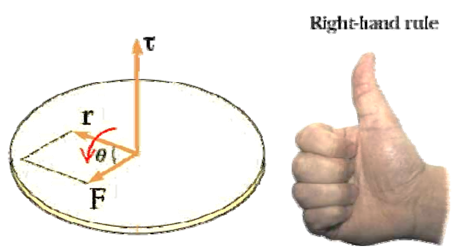
$$\vec{\tau} = \vec{r} \times \vec{F}$$



- The torque is a vector quantity and its direction is determine by the right hand rule,

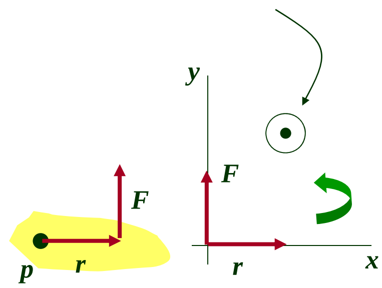
If the turning tendency of the force is counterclockwise, the torque will be positive

If the turning tendency is clockwise, the torque will be negative



Torque is out of Page

Torque is into Page



Torque is +ve

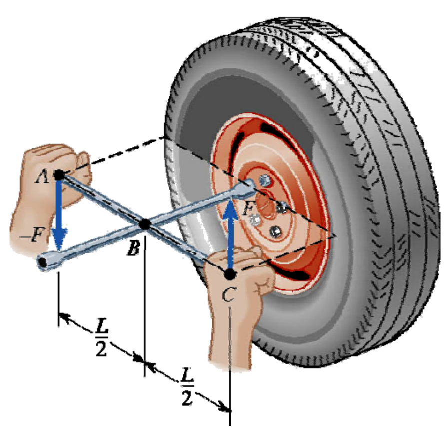
Torque is -ve

Couples

- Is a pair of forces with equal magnitudes but opposite directions acting along different lines of action.

Couples do not exert net force on an object

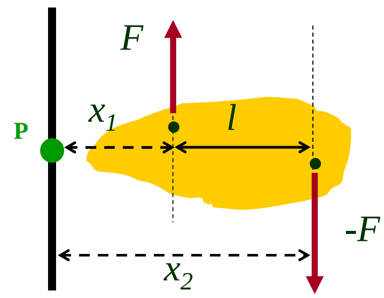
Couples produce torque, that is independent of the point of the point P



Example

- Two forces with equal magnitudes but opposite directions act on an object with different lines of action as shown in the figure.

Find the net torque on the object resulting from these forces.



Solution

نقوم بحساب الازدواج الناتج عن كل قوة عند النقطة P

- The torque resulting from the force at x_2 is

$$\tau_2 = -x_2 F$$

- The torque resulting from the force at x_1 is

$$\tau_1 = x_1 F$$

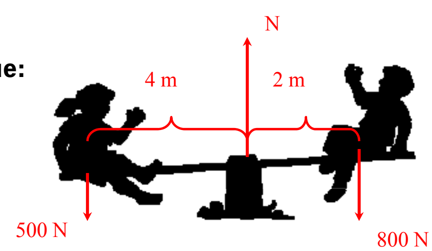
- The net torque is

$$\tau = \tau_1 + \tau_2 = x_1 F - x_2 F$$
$$\tau = (x_1 - x_2) F = -lF$$

- The minus sign means that the net torque tends to cause clockwise rotation.
- The torque is directed into the page.
- The torque is independent on the location of the point **P**, since the distance between the lines of forces is important.

Example 1

Determine the net torque:



Given:

weights: $w_1 = 500\ N$
$w_2 = 800$ N
lever arms: $d_1 = 4\ m$
$d_2 = 2\ m$

Find:

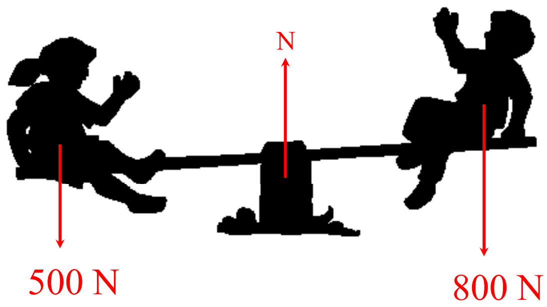
$\Sigma\tau = ?$

1. Draw all applicable forces

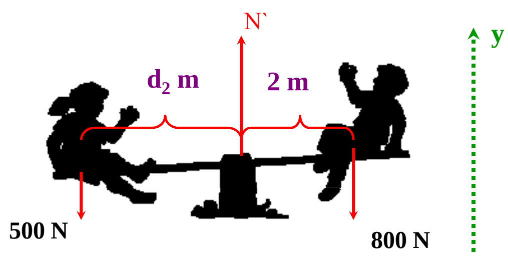
$$\sum \tau = (500\,N)(4\,m) + (-)(800\,N)(2\,m)$$
$$= +2000\,N \cdot m - 1600\,N \cdot m$$
$$= +400\,N \cdot m \quad \checkmark$$

Rotation would be CCW

Where would the 500 N person have to be relative to pivot for zero torque?



Example 2



Given:

weights: $w_1 = 500\ N$
$w_2 = 800$ N
lever arms: $d_1 = 4\ m$
$\Sigma\tau = 0$

Find:

$d_2 = ?$

1. Draw all applicable forces and moment arms

$$\sum \tau_{RHS} = -(800\,N)(2\,m)$$

$$\sum \tau_{LHS} = (500\,N)(d_2\,m)$$

$$-800 \cdot 2\,[N \cdot m] + 500 \cdot d_2\,[N \cdot m] = 0 \quad \Rightarrow \quad d_2 = 3.2\,m$$ ✓

According to our understanding of torque there would be <u>no rotation</u> and <u>no motion</u>!

What does it say about acceleration and force?

Thus, according to 2nd Newton's law ΣF=0 and a=0!

$$\sum F_i = (-500\,N) + N' + (-800\,N) = 0$$

$$N' = 1300\,N$$