Chapter 4:Dynamics: Newton's Laws of Motion

Lecture 1
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Force: - vector quantity
- causes motion of objects.

Kinematics: Studying motion of objects without taking the cause of motion (Forces) into account.

Remember: Equations of motion were all expressed in terms of v, a, x, t BUT NO Force.

Dynamics: Studying motion of objects taking the cause of motion (Forces) into account.

When we pull or push an object we act on it by a force.

Netwon's first law

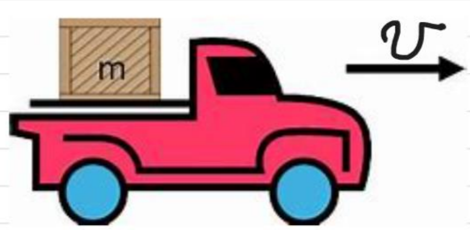
Every object remains in its state of rest or of constant velocity (constant in magnitude and direction) as long as no net (resultant) force acts on it.

This means an object cannot change its state of motion (at rest OR constant v) on its own. It needs a net force to change from: rest to motion
motion to rest
accelerate or decelerate

The first law is sometimes called the law of inertia. (قانون القصور الذاتي)

Example

The truck is moving to the right. Suddenly, the driver applies the breaks and the truck stops.



Question: what happens to the box?

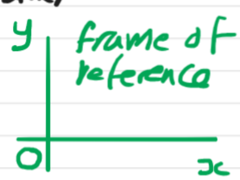
Answer: the box slides forward. Why?

The truck stopped because a net force acted on it and changed its state of motion.

This force did not act on the box. The box needs a net force to act on it to stop it or reduce its velocity.

The box cannot change its state of motion (rest or constant velocity) unless a net force acts on it. This is what is called inertia.

Inertial frame of reference: A frame that does NOT accelerate (→ either at rest → or moving at constant velocity). Newton's laws hold in such a frame (can be applied in such a frame).



If you are
- standing at rest, or
- moving at constant velocity

then you are in an inertial frame of reference.

If you are in a car that is accelerating or decelerating, then you are in a non-inertial frame of reference. If you apply Newton's laws they give wrong answers (don't hold).

Mass: a measure of an objects resistance to motion (measure of the inertia of an object).

large mass → large inertia

small mass → small inertia

Note A large force is needed to move a large mass or stop it.

Comparison between mass and weight.

Mass (measure of resistance to motion)	Weight (Gravitational force acting on an object)
- Scalar	- Vector [Force]
- Does NOT change with location	- Depends on location. A 1kg on earth has a different weight on the moon.

On earth's surface $g_E = 9.81\, m/s^2$ ‖ On moon's surface $g_M = \frac{9.81}{6}\, m/s^2$

Newton's Second Law

$$\underbrace{\sum \vec{F}}_{\text{net force}} = m\vec{a}$$

sigma (sum) → $\sum$

[For a constant mass].

Gives the relation between the net force acting on an object, its mass and its acceleration.

$$\therefore \quad \vec{a} = \frac{1}{m}\Sigma\vec{F}$$

vector equation

Gravitational acc. g is ALWAYS vertically downwards parallel the net force (weight) (for free fall)

NOTE: - A net force is needed to cause acceleration.

- $\vec{a}$ is ALWAYS parallel to the net force
- $\vec{a}$ is propotional to $\Sigma\vec{F}$
- $\vec{a}$ is inversely proportional to m.

We can write

net force along x-axis

$\Sigma F_x = ma_x$ (along x-axis)

$\Sigma F_y = ma_y$ (along y-axis)

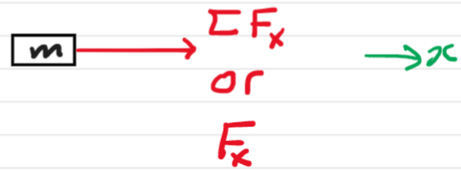
$\Sigma F_z = ma_z$ (along z-axis)

Unit of force: Newton (N). (in mks international system) — m: meter, k: kg, s: second

Is N a basic unit? No. N is a derived unit. i.e expressed in terms of meter, kg and second

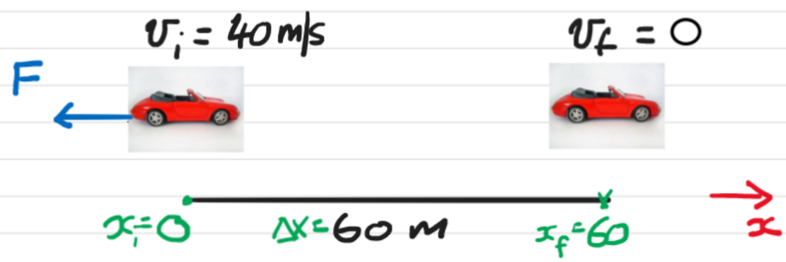
$1\ N \equiv 1\ kg \cdot 1\frac{m}{s^2} = 1 kg\frac{m}{s^2}$ $\quad F = ma$

Example: Find the net force required to give a 3 kg mass an acceleration of $a = 2\ m/s^2$ in the positive x-axis.



$$\Sigma F_x = (3)(2) = 6\ kg\frac{m}{s^2} \equiv 6\ N.$$

Example: Find the net force required to stop a 1000 kg car moving at 40 m/s in 60 m.



$F = ma$ ← ?

Use equations of motion to find the acceleration.

$$v_f^2 - v_i^2 = 2a\,\Delta x \quad \text{displacement}$$

$$0 - (40)^2 = 2a(60)$$

$a = -\frac{1600}{120} \sim -13.3\ m/s^2$.

$a < 0$, $v > 0$ } ⇒ deceleration since the signs of a and v are different.

net force ↓ ΣF_x

$F = 1000(-13.3)$

$= -13300$ N

↑ the force is in the negative x-direction.

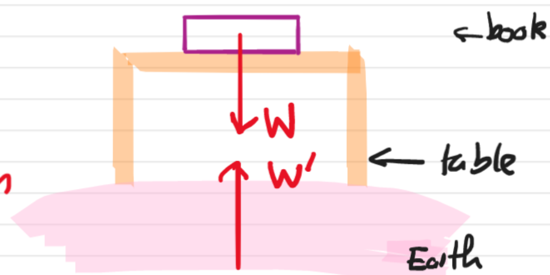
Newton's Third Law

Each action has a reaction equals to it in magnitude and opposite to it in direction.

(action reaction forces are equal and opposite)

It is very important to identify the correct pair of action-reaction forces.

Exmple: A book on a tube which rests on the ground. Find the pairs of action reaction forces.



W: force of earth on book. Call it action (weight).

W′: force of book on earth. Call it reaction.

$W' = -W$ (equal in magnitude and opposite in direction.

NOTE: action (W) acts on the book, while the reaction (W') acts on the earth.

W and W' are action-reaction pair and act on different objects.