

# Chapter 4

## The Laws of Motion قوانين الحركة

### The concept of force

The force is what cause any change in velocity of an object.

القوة هي المسبب لاي تغير في سرعة الجسم

**Or**

The force is what cause an acceleration.

القوة هي المسبب للتسارع

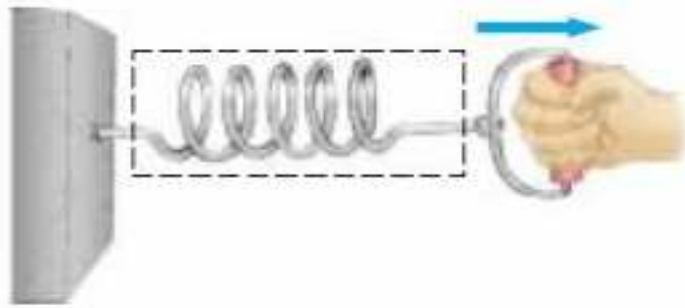
**The force is a vector quantity.**

**Its units are  $N = kg \ m/s^2$  and its dimensions are  $MLT^{-2}$**

# Fundamental Forces

- 1- Gravitational forces قوي الجذب بين الأجسام  
(between two objects) بين الاجسام
- 2- Electromagnetic forces القوي الكهرومغناطيسية  
(between two charges) بين الشحنات
- 3- Nuclear forces القوي النووية  
(between two subatomic particles) بين انوية الجسيمات
- 4- Weak forces القوي الضعيفة  
(Those arise in certain radioactive decay processes)  
الناجة عن الاضمحلال الاشعاعي

Contact forces



(a)

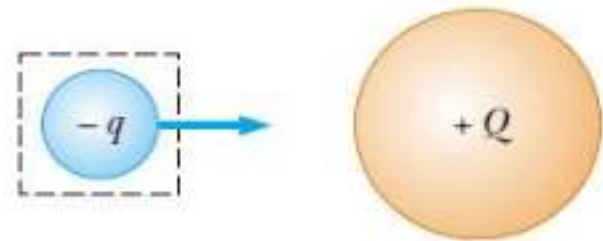
Field forces



(d)



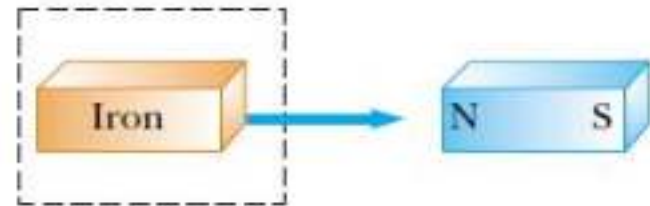
(b)



(e)



(c)



(f)

# القانون الاول لنيوتن 1- Newton's First Law

It states that:

If an object does not interact with other objects, it is possible to identify a reference frame in which the object has zero acceleration.

OR: In the absence of external forces, an object at rest remains at rest and an object in motion continues in motion with constant velocity

في عدم وجود قوة خارجية الجسم الساكن يبقى ساكن والجسم المتحرك يبقى متحرك بسرعة ثابتة

When no force acts on an object, the acceleration of the object is zero.

في عدم وجود قوة خارجية مؤثرة علي الجسم تسارع الجسم يساوي صفر.

**The mathematical form :**

$$\text{The net force} = 0 \quad \text{or} \quad \Sigma F = 0$$

**Mass of inertia**

It is the resistance of an object to change its velocity

هي مقاومة الجسم لتغيير سرعته

Newton's first law sometimes called **The law of inertia**

## القانون الثاني لنيوتن 2- Newton's Second Law

It states that:

The acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

تسارع الجسم يتناسب طردياً مع القوة المؤثرة عليه وعكسياً مع كتلته.

$$\frac{m_1}{m_2} = \frac{a_2}{a_1}$$

The mathematical form:

$$\Sigma F = m a$$

or

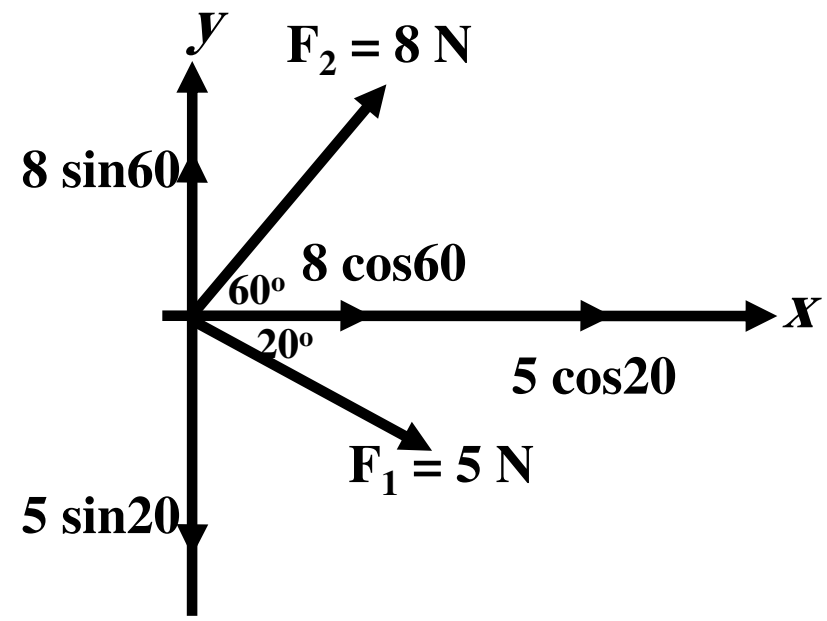
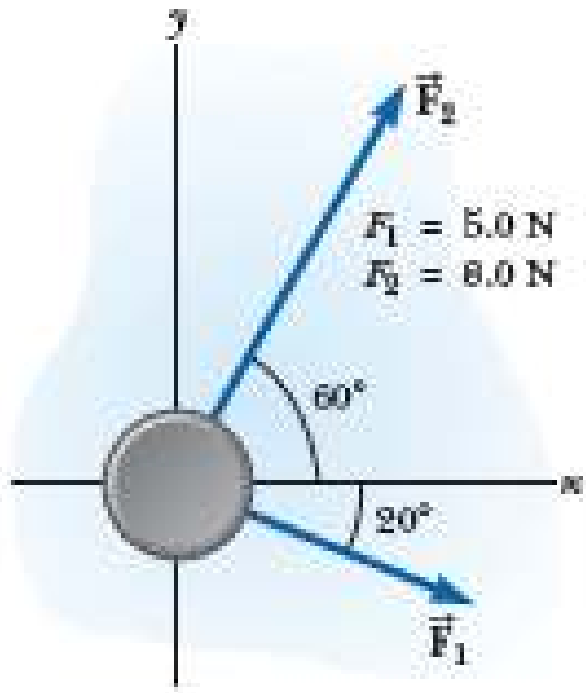
$$\Sigma F_x = m a_x \quad , \quad \Sigma F_y = m a_y \quad ,$$
$$\Sigma F_z = m a_z$$

**Example** Ex. 5.1 page 116 in the book

A hockey puck having a mass of a 0.3 kg slides on the horizontal, frictionless surface of an ice rink. Two hockey sticks strike the puck simultaneously, exerting the forces on the puck shown in the figure. The force  $F_1$  has a magnitude of 5 N and the force  $F_2$  has a magnitude of 8 N.

جسم كتلته 0.3 كجم تؤثر عليه قوتان 5 نيوتن و 8 نيوتن علي الترتيب كما هو موضح بالشكل.

Determine both the magnitude and direction of the puck's acceleration.  
اوجد مقدار واتجاه التسارع للجسم الموضح الناتج من القوتين المؤثرتين عليه



# Answer

$$F_x = 5 \cos(-20) + 8 \cos(60) = 8.7 \text{ N}$$

محصلة القوي في اتجاه محور X

$$a_x = \frac{F_x}{m} = \frac{8.7}{0.3} = 29 \text{ m / s}^2$$

التسارع في اتجاه محور X

$$F_y = 5 \sin(-20) + 8 \sin 60 = 5.2 \text{ N}$$

محصلة القوي في اتجاه محور y

$$a_y = \frac{F_y}{m} = \frac{5.2}{0.3} = 17 \text{ m / s}^2$$

التسارع في اتجاه محور y

$$|a| = \sqrt{a_x^2 + a_y^2} = \sqrt{(29)^2 + (17)^2} = 33.6 \text{ m / s}^2$$

مقدار محصلة القوي

$$\theta = \tan^{-1} \frac{a_y}{a_x} = \tan^{-1} \frac{17}{29} = 30.4^\circ$$

اتجاه محصلة القوي

# قوي الجذب والوزن Gravitational Force and Weight

## Gravitational Force:

It is the attraction force that the Earth exerts on an object.

هي قوة الجذب التي تؤثر بها الأرض على جسم ما.

## Weight $F_g$ :

It is the gravitational force acting on an object.

هي قوة الجاذبية التي تؤثر على جسم ما.

$$F_g = mg$$

Weight is a vector quantity

Units of weight:

$$N = \text{kg m/s}^2$$

Dimensions:

$$MLT^{-2}$$

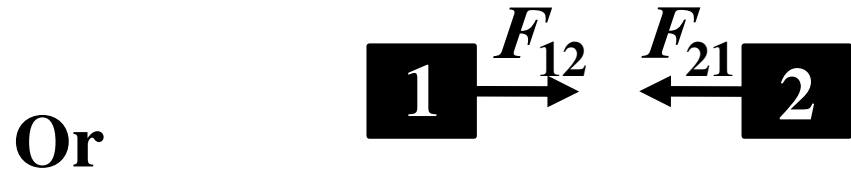
# Differences between Mass and Weight

Mass	Weight
It is the amount of substance included in an object هي كمية المادة التي يحتويها الجسم	It is the gravitational force acting on an object هي قوة جذب الارض للجسام
Scalar quantity	Vector quantity
Unit is kg	Unit is N
Dimension is M	Dimensions are $MLT^{-2}$
Constant every where ثابتة في اي مكان	Depends on the location تعتمد علي المكان

### القانون الثالث لنيوتن 3- Newton's Third Law

**It states that:**

If two objects interact, the force  $F_{12}$  exerted by object 1 on object 2 is equal in magnitude and opposite in direction to the force  $F_{21}$  exerted by object 2 on object 1



The action force is equal in magnitude to the reaction force but opposite in direction

قوة الفعل تساوي قوة رد الفعل في المقدار وتضادها في الاتجاه

**The mathematical form:**

$$F_{12} = - F_{21}$$

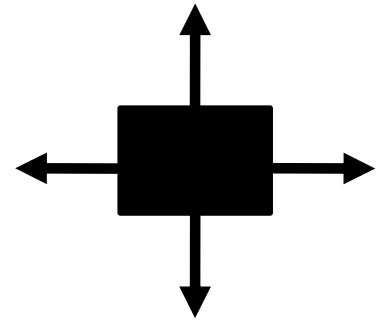
## 4- Analysis Models Using Newton's Second Law

It is the vector sum of all forces acting on an object.

### Equilibrium forces

The forces are said to be in equilibrium if:

$$\text{The net force} = 0 \quad \text{or} \quad \Sigma F = 0$$



At equilibrium forces: في حالة اتزان القوي

1- Acceleration = 0 التسارع يساوي صفر

2- Velocity remains constant (uniform) السرعة تبقى ثابتة

## Example 5.6: The Runaway Car Page:(124&125)

A car of mass  $m$  is on an icy driveway inclined at an angle  $\theta$  as in Figure 5.11a.

(A) Find the acceleration of the car, assuming the driveway is frictionless.

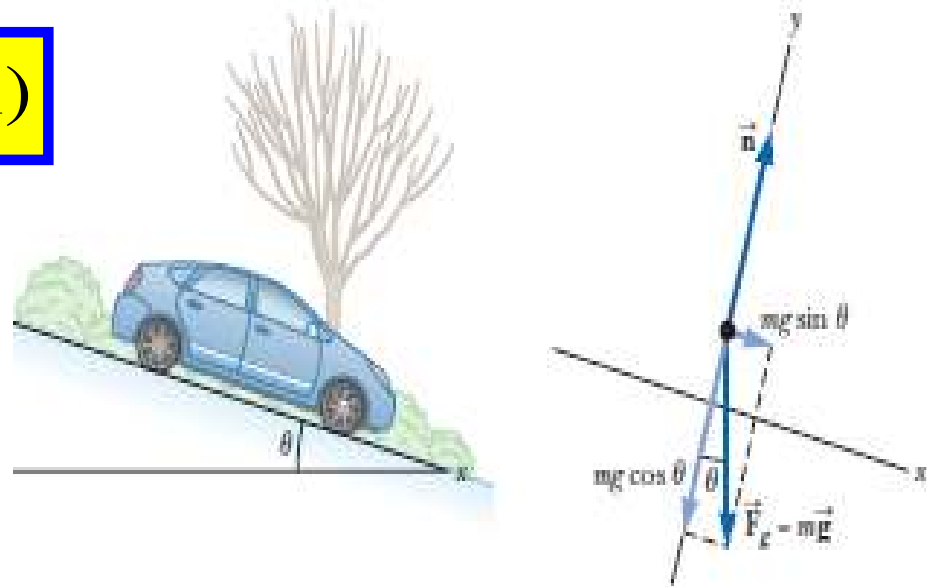
اوجد تسارع الجسم الذي كتلته  $m$  يسير علي منحدر جليدي بزاوية  $\theta$  كما هو مبين بالشكل

Apply these models to the car:

$$\sum F_x = mg \sin \theta = ma_x \quad (1)$$

Solve Equation (1) for  $a_x$ :

$$a_x = g \sin \theta \quad (2)$$



(B) Suppose the car is released from rest at the top of the incline and the distance from the car's front bumper to the bottom of the incline is  $d$ . How long does it take the front bumper to reach the bottom of the hill, and what is the car's speed as it arrives there?

افترض ان الجسم تحرك من السكون علي قمة المنحني وكانت المسافة بين مقدمة السيارة واسفل المنحني  $d$ . احسب

الزمن اللازم لكي تصل مقدمة السيارة لقاع المنحدر

$$x_f = x_i + v_{xi}t + \frac{1}{2} a_x t^2 \quad \therefore d = \frac{1}{2} a_x t^2$$

Solve for  $t$ ,

$$\therefore t = \sqrt{\frac{2d}{a_x}} = \sqrt{\frac{2d}{g \sin \theta}}$$

**C- Find the final velocity of the car with  $v_0 = 0$ :**

احسب سرعته النهائية

$$\therefore v_{xf}^2 = v_0^2 + 2a_x d$$

$$\therefore v_{xf}^2 = 2a_x d$$

بالتعويض من المعادلة (2) عن قيمة  $a_x$

$$\therefore v_{xf} = \sqrt{2a_x d} = \sqrt{2gd \sin \theta}$$

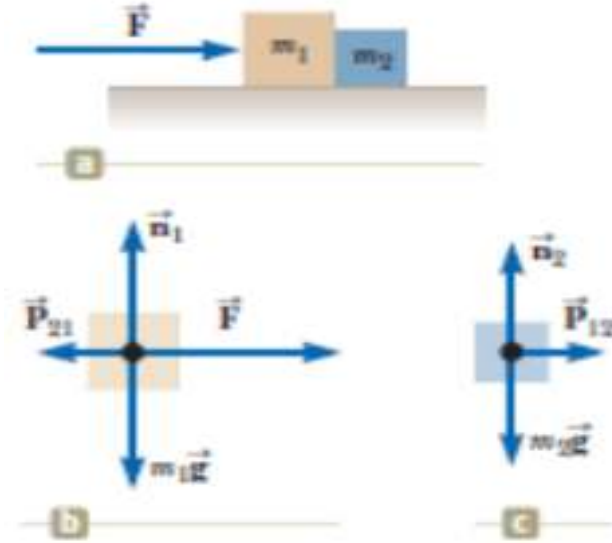
## Example 5.7: One Block Pushes Another Page:(125&126)

Two blocks of masses  $m_1$  and  $m_2$ , are placed in contact with each other on a frictionless, horizontal surface as in the figure. A constant horizontal force  $\mathbf{F}$  is applied to  $m_1$  as shown.

**(A)** Find the magnitude of the acceleration of the system.

First model the combination of two blocks as a single particle under a net force. Apply Newton's second law to the combination in the  $x$  direction to find the acceleration:

$$\sum \mathbf{F}_x = \mathbf{F} = (\mathbf{m}_1 + \mathbf{m}_2)\mathbf{a}_x$$
$$\mathbf{a}_x = \left[ \frac{\mathbf{F}}{\mathbf{m}_1 + \mathbf{m}_2} \right] \quad (1)$$



**(B)** Determine the magnitude of the contact force between the two blocks.

Apply Newton's second law to  $m_2$ :

$$\sum \mathbf{F}_x = \mathbf{P}_{12} = \mathbf{m}_2\mathbf{a}_x \quad (2)$$

Substitute the value of the acceleration  $a_x$  given by Equation (1) into Equation (2):

$$\mathbf{P}_{12} = \mathbf{m}_2\mathbf{a}_x = \left[ \frac{\mathbf{m}_2}{\mathbf{m}_1 + \mathbf{m}_2} \right] \mathbf{F} \quad (3)$$

Apply Newton's second law to  $m_1$ :

$$\sum \mathbf{F}_x = \mathbf{F} - \mathbf{P}_{12} = \mathbf{F} - \mathbf{P}_{21} = \mathbf{m}_1 \mathbf{a}_x \quad (4)$$

Solve for  $P_{12}$  and substitute the value of  $a_x$  from Equation (1):

$$\mathbf{P}_{12} = \mathbf{F} - \mathbf{m}_1 \mathbf{a}_x = \mathbf{F} - \mathbf{m}_1 \left[ \frac{\mathbf{F}}{\mathbf{m}_1 + \mathbf{m}_2} \right] = \left[ \frac{\cancel{\mathbf{m}_1} + \mathbf{m}_2 - \cancel{\mathbf{m}_1}}{\mathbf{m}_1 + \mathbf{m}_2} \right] \mathbf{F} = \left[ \frac{\mathbf{m}_2}{\mathbf{m}_1 + \mathbf{m}_2} \right] \mathbf{F}$$

This result agrees with Equation (3), as it must.

# Example 5.9: The Atwood Machine Page:(129)

When two objects of unequal mass are hung vertically over a frictionless pulley of negligible mass as in the figure, the arrangement is called an *Atwood machine*. The device is sometimes used in the laboratory to determine the value of  $g$ . Determine the magnitude of the acceleration of the two objects and the tension in the lightweight string.

According to this sign convention, the  $y$  component of the net force exerted on object 1 is  $T - m_1g$ , and the  $y$  component of the net force exerted on object 2 is  $m_2g - T$ .

From the particle under a net force model, apply Newton's second law to object 1:

$$\sum F_y = T - m_1g = m_1a_y \quad (1)$$

Apply Newton's second law to object 2:

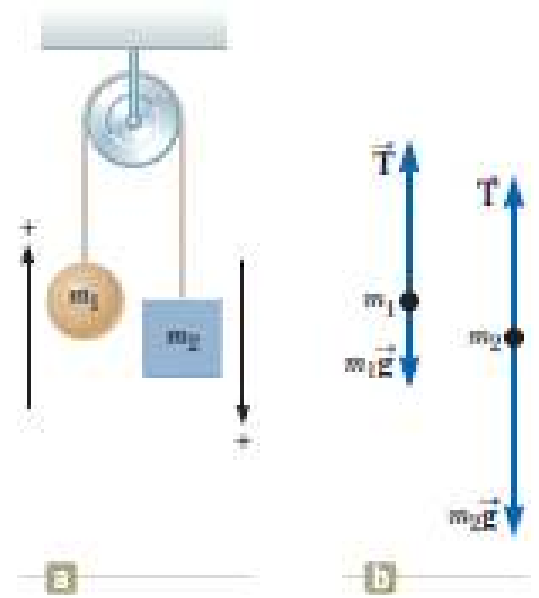
$$\sum F_y = m_2g - T = m_2a_y \quad (2)$$

Add Equation (2) to Equation (1), noticing that  $T$  cancels:

$$-m_1g + m_2g = m_1a_y + m_2a_y$$

Solve for the acceleration:

$$a_y = \left[ \frac{m_2 - m_1}{m_1 + m_2} \right] g \quad (3)$$



Substitute Equation (3) into Equation (1) to find  $T$ :

$$\mathbf{T} = \mathbf{m}_1(\mathbf{g} + \mathbf{a}_y) = \left[ \frac{2\mathbf{m}_1\mathbf{m}_2}{\mathbf{m}_1 + \mathbf{m}_2} \right] \mathbf{g} \quad (4)$$

**Homework:  
19, 40**