General Physics II course

Chapter 1 – Electric force and electric field

@ m_multicourses

050-683-9050

Outlines :

- Coulomb's Law
- Electric field due to a point charge
- Electric field of a continuous charge distribution
- Electric field lines
- Motion of a charged particle in a uniform electric field

Coulomb’s Law

Coulomb's law

Coulomb's law

- There are two kinds of the electric charges in the nature , which are positive and negative charges .
- The charges of opposite sign attract one another and the charges of the same sign repel one another .
- The charge is quantized .
- The charge of an isolated system is conversed , which means that charge cannot be created nor destroyed , it can be only transferred from one system to another .

Coulomb's law

Units of the electric charge :

- 1 milli coulomb ($1\ mC$) $= \ 10^{-3}\ C$
- 1 micro coulomb ($1\ \mu C$) $= \ 10^{-6}\ C$
- 1 nano coulomb ($1\ nC$) $= \ 10^{-9}\ C$
- 1 pico coulomb ($1\ pC$) $= \ 10^{-12}\ C$

Coulomb's law

- Charles coulomb (1736 – 1806) measured the magnitude – and direction – of the electric force between charged objects .

And he found that :

- The electric force is inversely proportional to the square of the separation r between the particles

$$F \propto \frac{1}{r^2}$$

- The electric force is – directly – proportional to the product of the of the charges q1 and q2 .

$$F \propto q_1 \, q_2$$

- The electric force is attractive if the charges are of opposite sign and repulsive if the charges have the same sign .

Coulomb's law

- The electric force is conservative force .

$$F_e = \frac{K_e \times q_1 \times q_2}{r^2}$$

- K : Coulomb's constant
- q : Charge (C)
- r : Separation – distance (m)

$$K = \frac{1}{4\,\pi\,\epsilon_0} = 9 \times 10^9 \quad \frac{N\,.m^2}{C^2}$$

$$\epsilon_0 = 8.8510^{-12} \qquad \frac{C^2}{m^2\,.N}$$

Coulomb's law

- The electric force is conservative force .

$$F_G = \frac{G \times m \times M}{r^2}$$

- G : Gravity constant
- m : mass of proton (Kg)
- M : mass of electron (Kg)

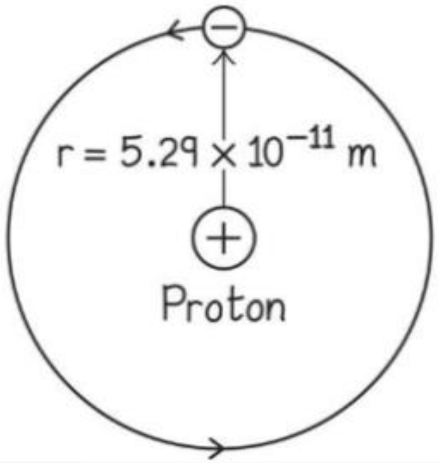
Coulomb's law

Charge and Mass of the Electron, Proton, and Neutron		
Particle	**Charge (C)**	**Mass (kg)**
Electron (e)	$-1.6021917 \times 10^{-19}$	9.1095×10^{-31}
Proton (p)	$+1.6021917 \times 10^{-19}$	1.67261×10^{-27}
Neutron (n)	0	1.67492×10^{-27}

Coulomb’s law

- **Example 1 : Forces in HYDROGEN atom ,**

The electron and proton of a hydrogen atom are separated (on the average) by a distance of approximately $5.29 \times 10^{-11}\ m$. Find the magnitudes of the electric force and the gravitational force between two particles .

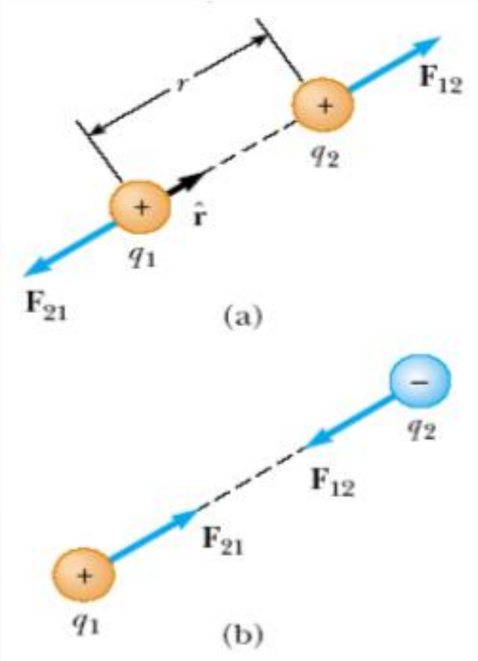


Coulomb's law

- When dealing with Coulomb's law , you must remember that the force is a vector quantity .

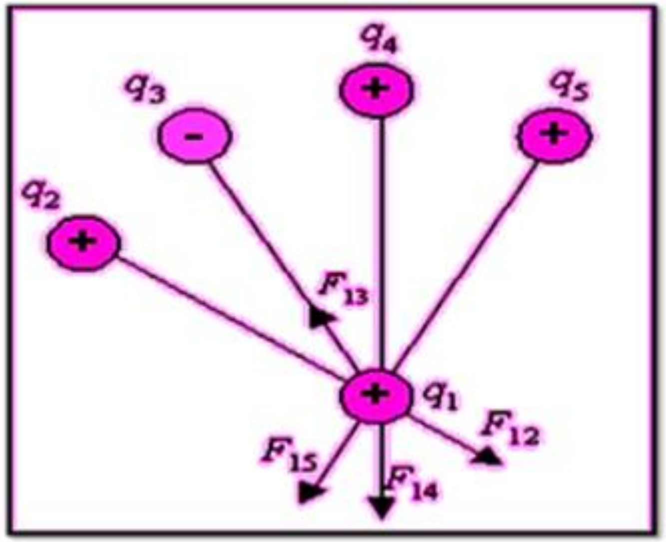
- Electric force obeys Newton's third law .

$$\boldsymbol{F}_{21} = -\boldsymbol{F}_{12}$$



Coulomb's law

If five charges are present , as shown in this figure , then the resultant force exerted by particles 2 , 3 , 4 and 5 on particle 1 is $\overline{\boldsymbol{F}_1} = \overline{\boldsymbol{F}_{21}} + \overline{\boldsymbol{F}_{31}} + \overline{\boldsymbol{F}_{41}} + \overline{\boldsymbol{F}_{51}}$`



Coulomb's law

صيغة وشكل السؤال بالكتاب

Quiz Object A has a charge of $+2\ \mu C$, and object B has a charge of $+6\ \mu C$. Which statement is true about the electric forces on the objects? (a) $\mathbf{F}_{AB} = -3\mathbf{F}_{BA}$ (b) $\mathbf{F}_{AB} = -\mathbf{F}_{BA}$ (c) $3\mathbf{F}_{AB} = -\mathbf{F}_{BA}$ (d) $\mathbf{F}_{AB} = 3\mathbf{F}_{BA}$ (e) $\mathbf{F}_{AB} = \mathbf{F}_{BA}$ (f) $3\mathbf{F}_{AB} = \mathbf{F}_{BA}$

- Quiz : Object A has a charge of $+2\mu C$ and object B has a charge of $+6\mu C$. Which statement is true about the electric forces on the objects ?

A) $F_{AB} = -3F_{BA}$

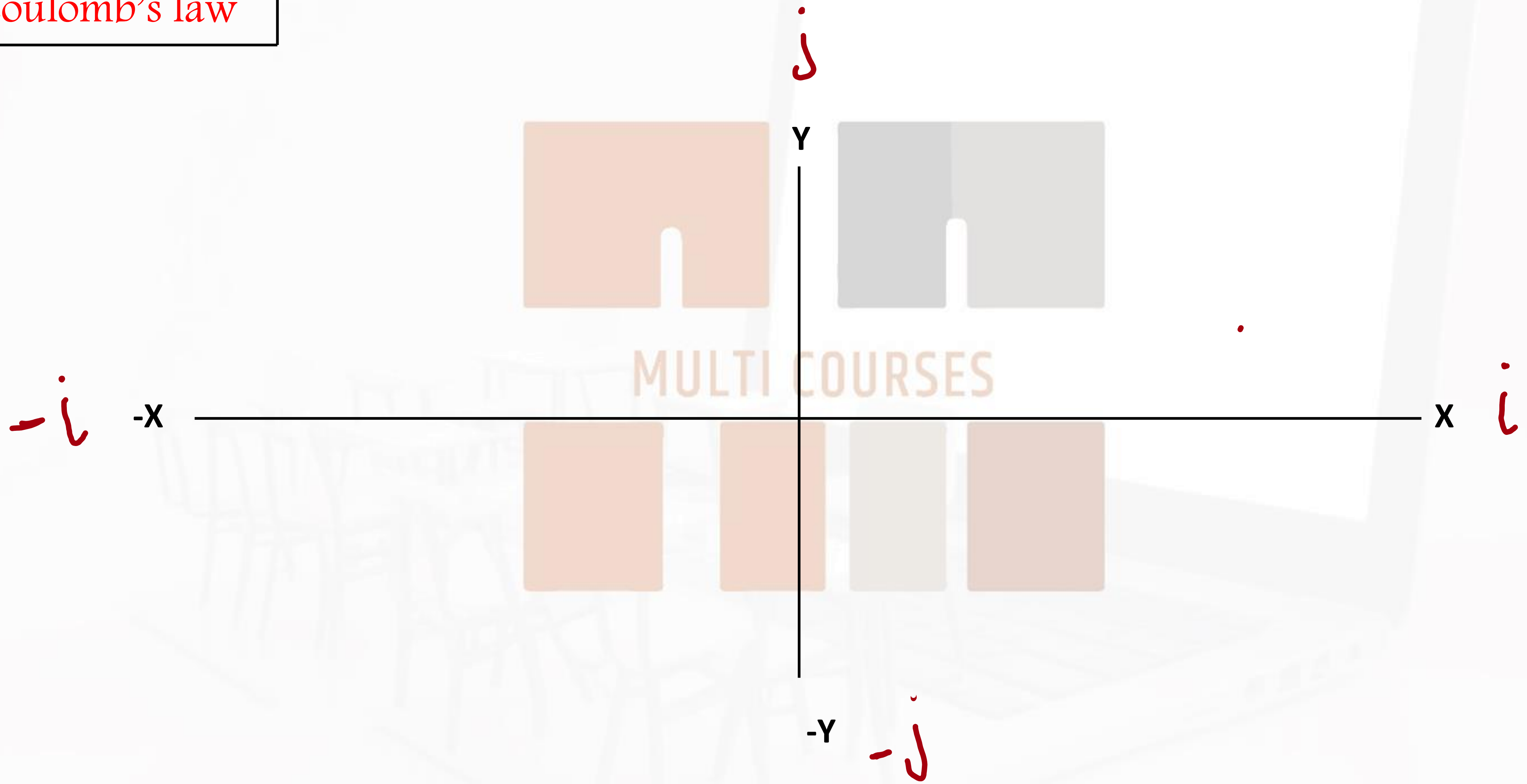
B) $F_{AB} = -F_{BA}$

C) $3F_{AB} = -F_{BA}$

D) $F_{AB} = 3F_{BA}$

E) $3F_{AB} = F_{BA}$

Coulomb's law



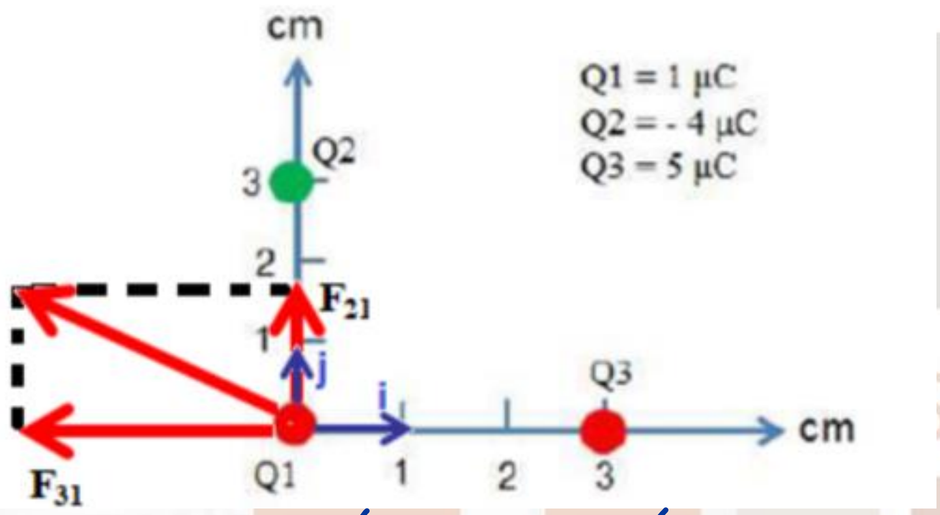
Coulomb's law

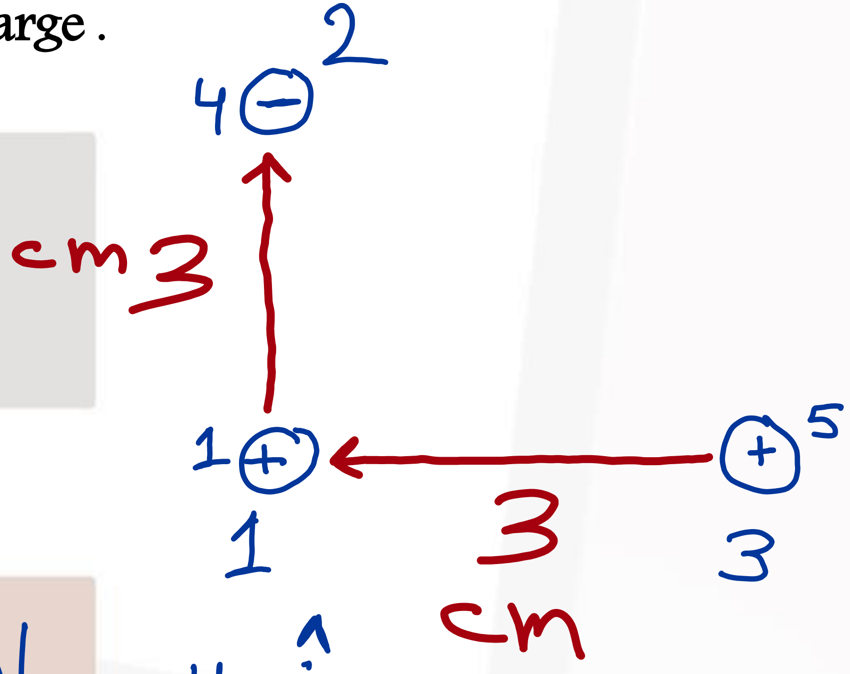
$cm \rightarrow m \times 10^{-2}$

- **Example 2 : Resultant force**

Find the resultant force exerted on $Q_1 = 1\ \mu C$ Charge .

$$\vec{F} = \vec{F}_{21} + \vec{F}_{31}$$





$$\bullet\ F_{21} = \frac{K q_1 q_2}{r^2} = \frac{9\times10^9 \times 1\times10^{-6} \times 4 \times 10^{-6}}{(3\times10^{-2})^2} = 40 N = 40\hat{j}$$

$$\bullet\ F_{31} = \frac{K q_1 q_3}{r^2} = \frac{9\times10^9 \times 1\times10^{-6} \times 5\times10^{-6}}{(3\times10^{-2})^2} = 50 N = -50\hat{i}$$

$$F = -50\hat{i} + 40\hat{j}$$

Electric field due to a point charge

Electric field due to a point charge

- The electric field vector E at a point in space is defined as the electric force F_e , acting on a positive test charge Q_0 ,placed at the point divided by the test charge .

قوة كهربية

$$\frac{N}{C} \quad E = \frac{F_e}{q_0}$$

شحنة الاختبار

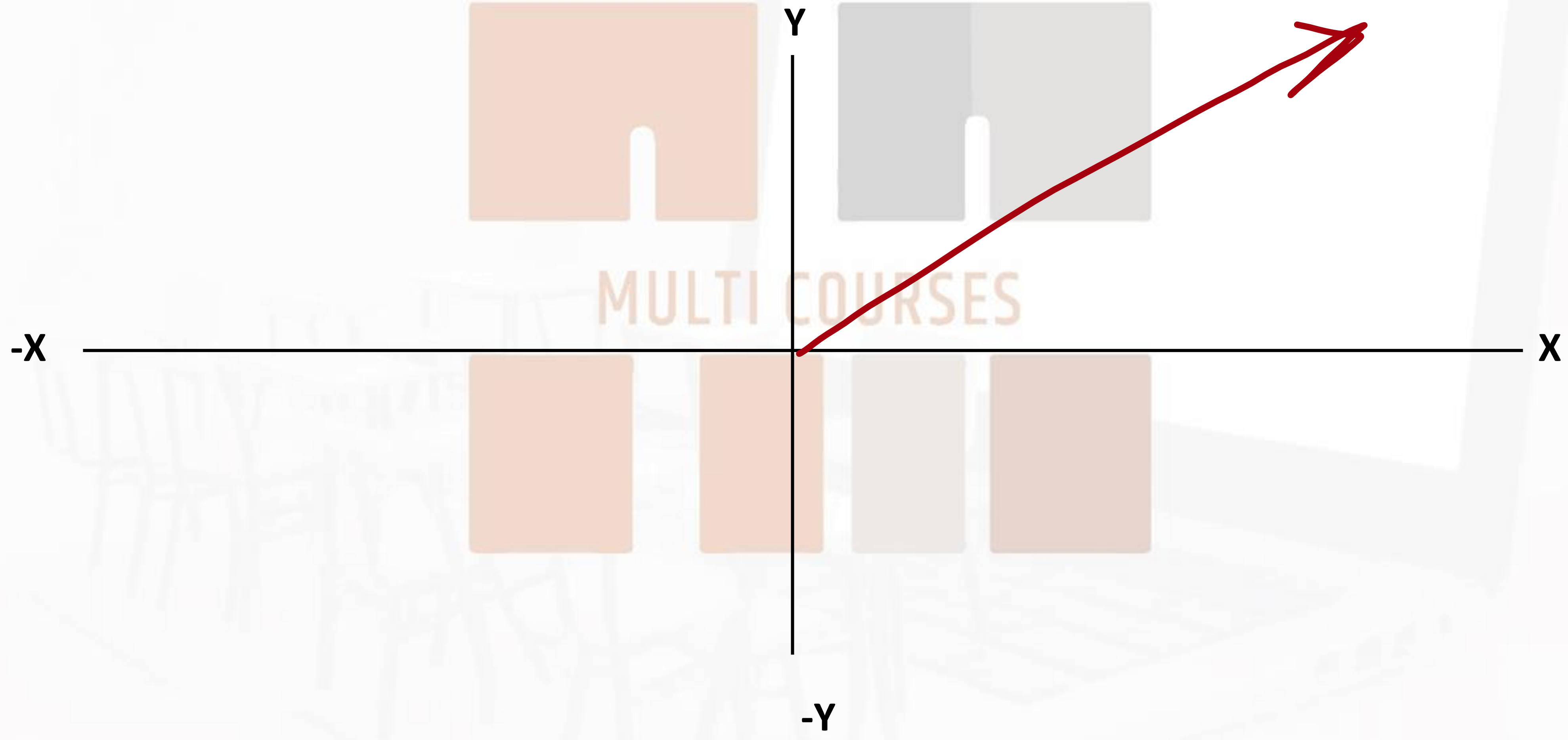
- The vector E has the SI units of newtons per coulomb (N/C) وحدة المجال الكهربائي

- Note that : E is the field produced by some charge or charge distribution separate from the test charge .

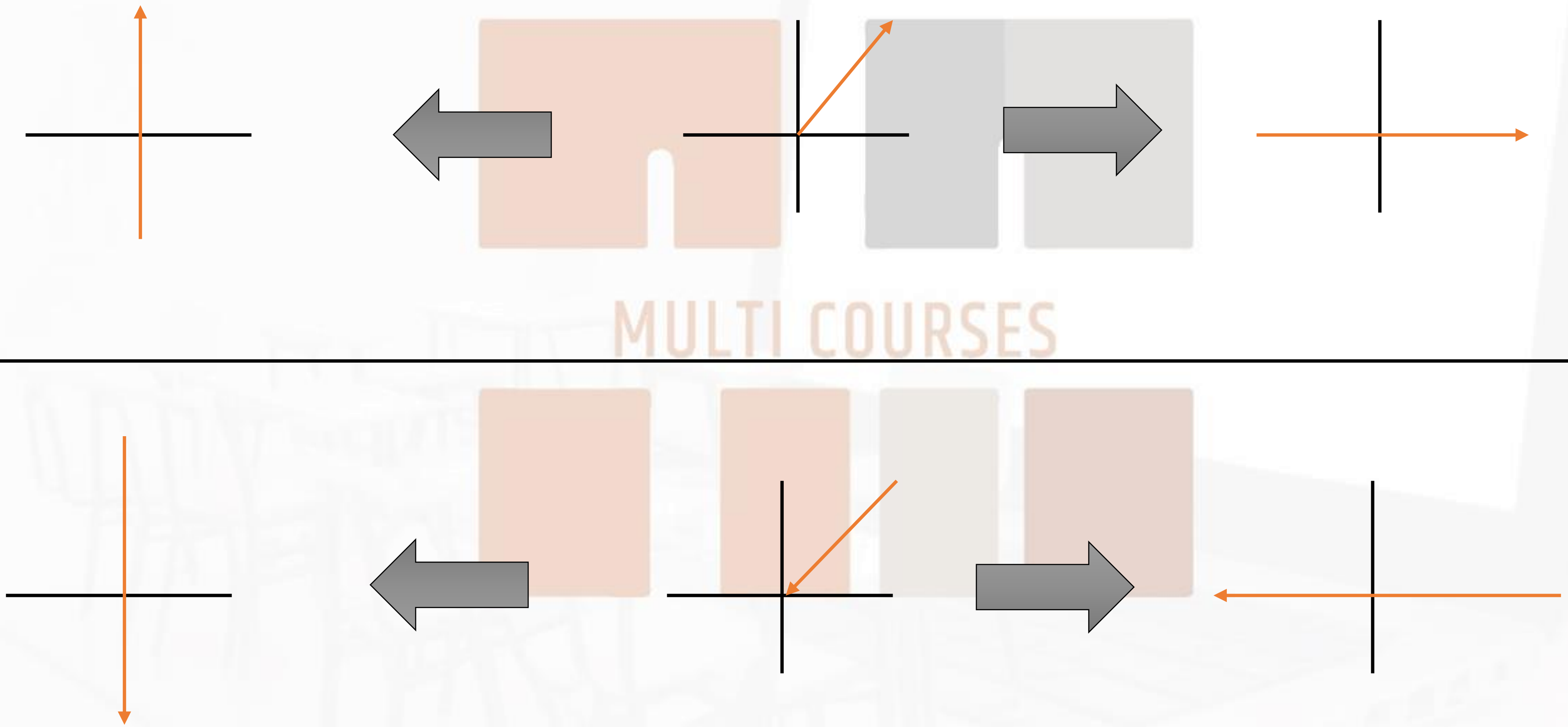
- The test charge serves as a detector of the electric field .

$$F_e = E\, q_0$$

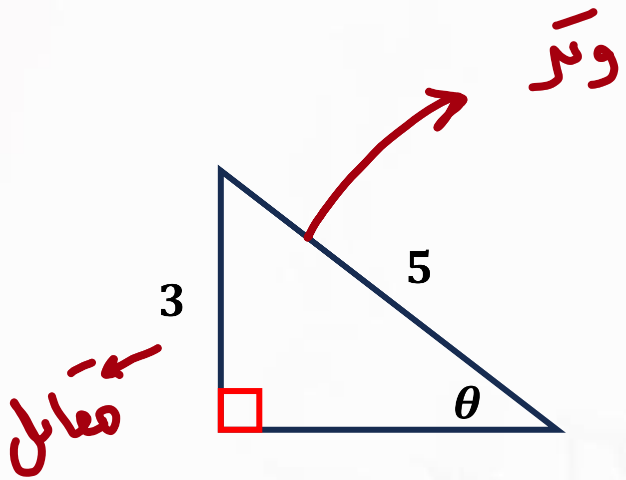
Electric field due to a point charge

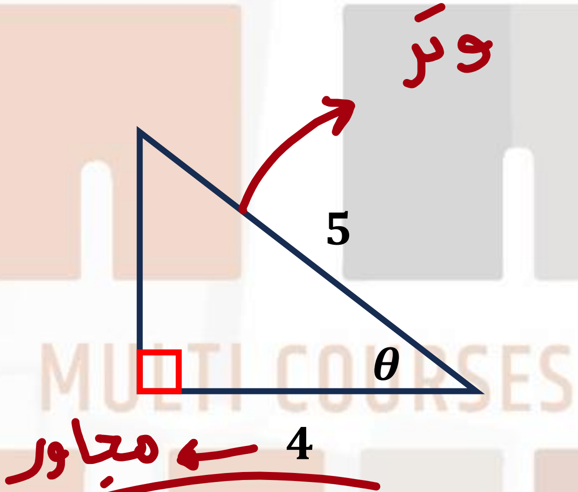


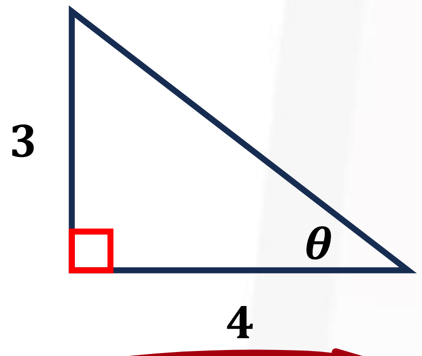
Electric field due to a point charge



Electric field due to a point charge







$$\sin\theta = \frac{\text{المقابل}}{\text{الوتر}}$$

$$\cos\theta = \frac{\text{المجاور}}{\text{الوتر}}$$

$$\tan\theta = \frac{\text{المقابل}}{\text{المجاور}}$$

$$\theta = sin^{-1}\frac{\text{المقابل}}{\text{الوتر}}$$

shift + sin

$$\theta = cos^{-1}\frac{\text{المجاور}}{\text{الوتر}}$$

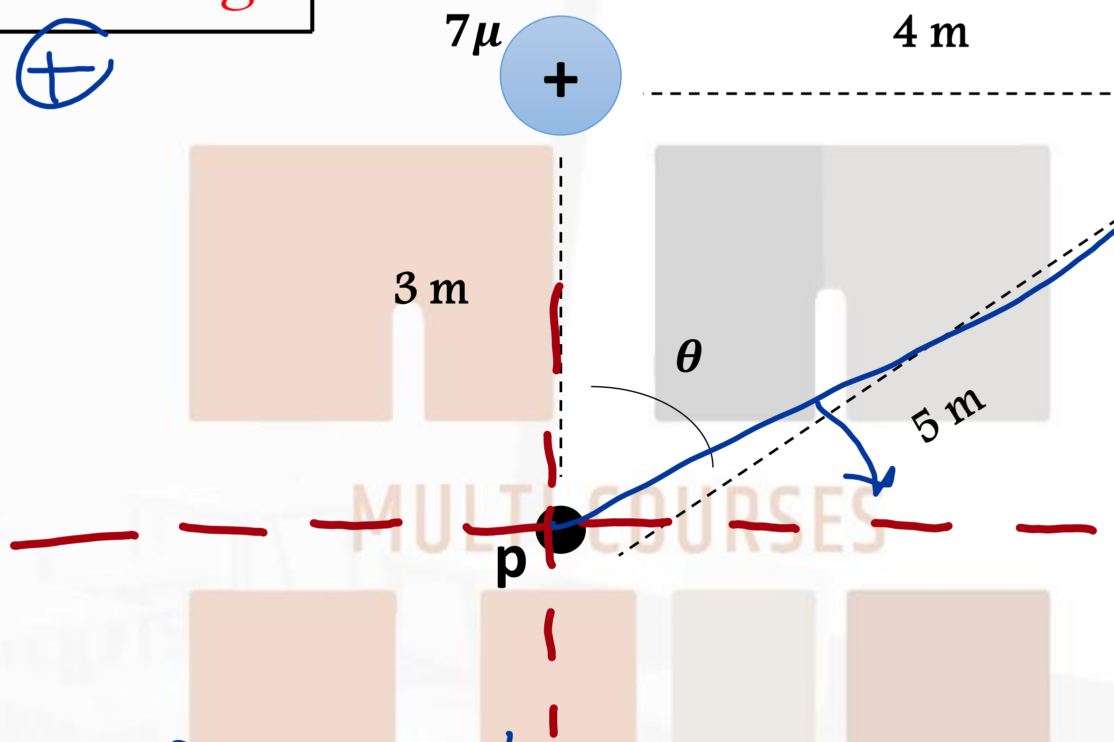
shift + cos

$$\theta = tan^{-1}\frac{\text{المقابل}}{\text{المجاور}}$$

shift + tan

Electric field due to a point charge

Test charge always (+)

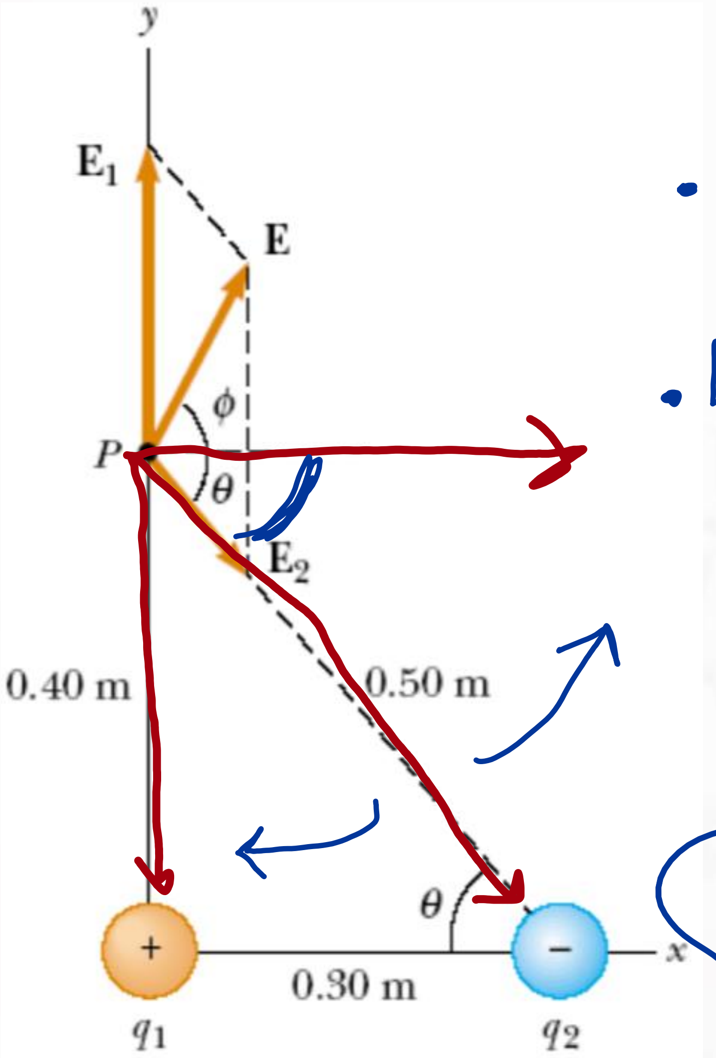


$200 \times \cos\theta = \hat{j}$

$200 \times \sin\theta = \hat{i}$

- $E_1 = \frac{kq_1}{r^2} = \frac{9\times10^9 \times 7\times10^{-6}}{(3)^2} = \boxed{} \rightarrow 100\ N/C = 100\,\hat{j}$
- $E_2 = \frac{kq_2}{r^2} = \frac{9\times10^9\times10\times10^{-6}}{(5)^2} = \boxed{} \rightarrow 200\ N/C$

Electric field due to a point charge



- **Example 3 : Electric field due to two charges**

A charge $Q_1 = 7\ \mu C$ is located at the origin . And a second charge $Q_2 = -5\ \mu C$ is located on the x-axis , 0.30 m from the origin . Find the electric field at the point p which has coordinates (0.40 m)

- $E_1 = \frac{K q_1}{r^2} = \frac{9\times10^9 \times 7\times10^{-6}}{(0.40)^2} = 3.9\times10^5\ N/C$
$= 3.9\times10^5\ \hat{j}$

- $E_2 = \frac{K q_2}{r^2} = \frac{9\times10^9 \times 5\times10^{-6}}{(0.50)^2} = 1.8\times10^5\ N/C$

$1.8\times10^5 \times \frac{0.30}{0.50} = 1.1\times10^5\ \hat{i}$

$1.8\times10^5 \times \frac{0.40}{0.50} = -1.4\times10^5\ \hat{j}$

$3.9 - 1.4$

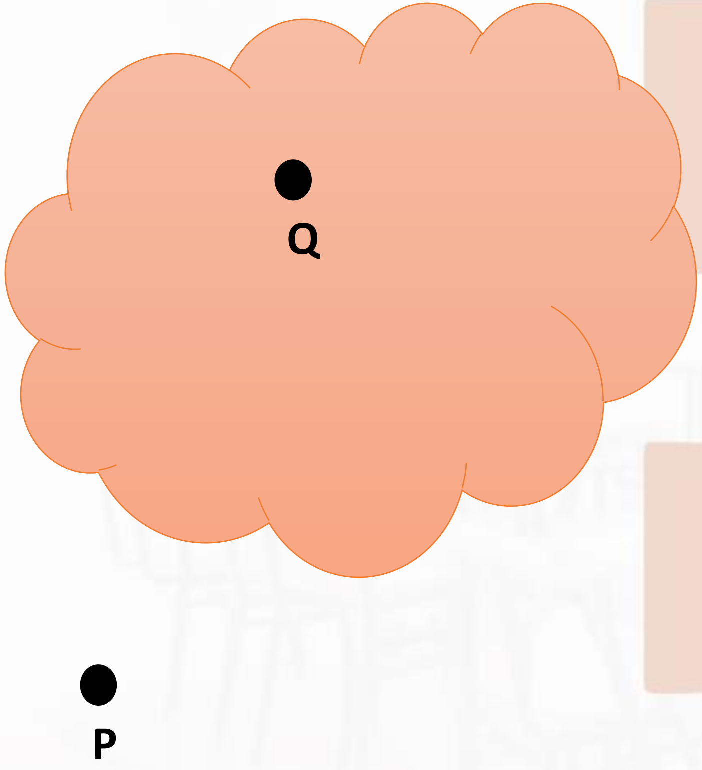
$\sin\theta = \frac{0.40}{0.50}$

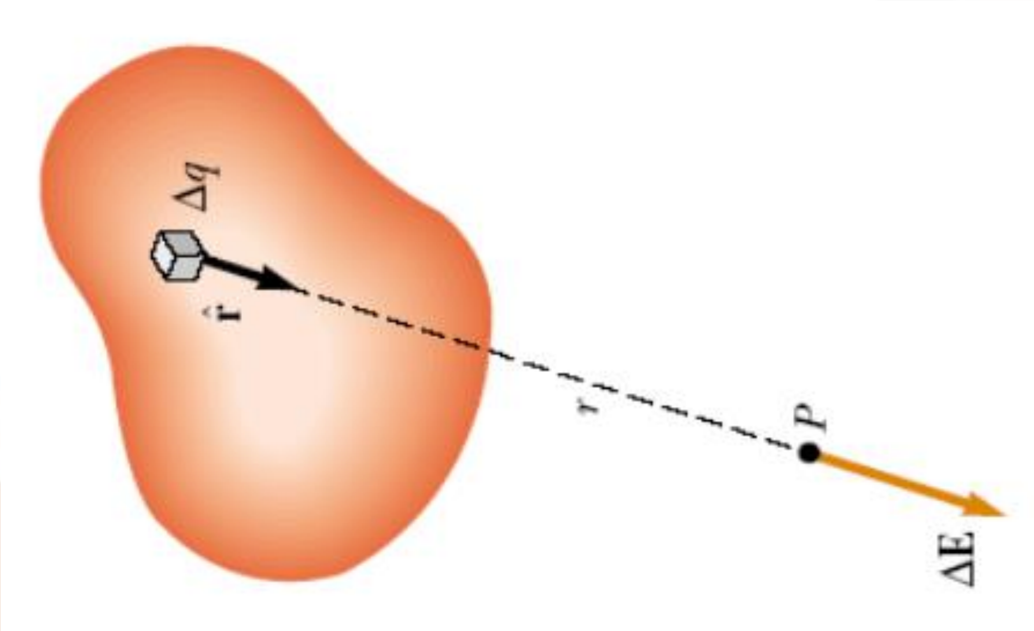
$E = 1.1\times10^5\ \hat{i} + 2.5\times10^5\ \hat{j}$

$\cos\theta = \frac{0.30}{0.50}$

Electric field of a continuous charge distribution

Electric field of a continuous charge distribution

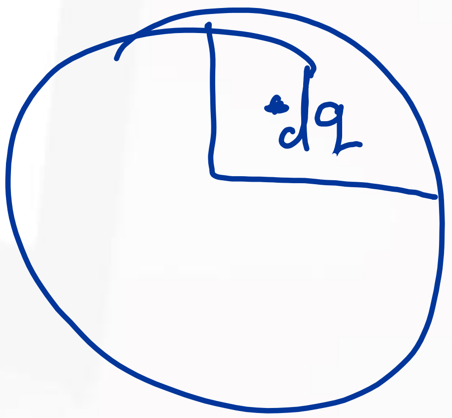




Electric field of a continuous charge distribution

- To evaluate the electric field created by a continuous charge distribution , we use the following procedure
- First , we divide the charge distribution into small elements , each element has a small charge
- Finally, we evaluate the total electric field at P due to the charge distribution by summing the contributions of all the charge elements.

$$E = k\int \frac{dq}{r^2} \Rightarrow \Delta E = k\frac{\Delta q}{r^2}$$



$$E = \int \frac{k \cdot dq}{r^2} = E = k\int \frac{dq}{r^2}$$

Electric field of a continuous charge distribution

Uniformly distributed

- Volume charge density :

If a charge Q is uniformly distributed throughout a volume V, the volume charge density is ρ defined by :

حجم

$$\rho = \frac{Q}{v}$$ The SI unit of ρ is $\frac{C}{m^3}$

row رو

- Surface charge density :

If a charge Q is uniformly distributed on a surface of area A, the surface charge density σ is defined by :

سطح

$$\sigma = \frac{Q}{A}$$ The SI unit of σ is $\frac{C}{m^2}$

sigma

- Linear charge density :

If a charge Q is uniformly distributed along a line of length L , the linear charge density λ is defined by:

طولي

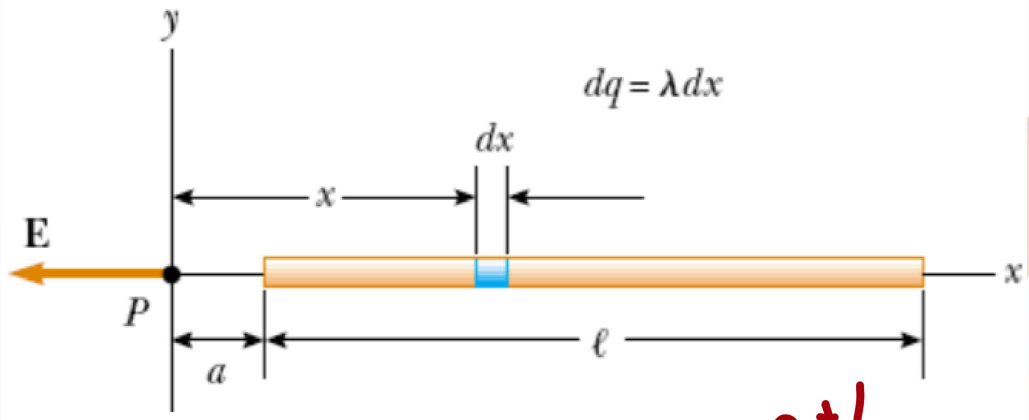
$$\lambda = \frac{Q}{l}$$ The SI unit of λ is $\frac{C}{m}$

Lemda لمدا

- If the charge is nonuniformly distributed over a volume, surface, or line, the amounts of charge dq in a small volume, surface, or length element are

$dq = \rho\, dV$ $dq = \sigma\, dA$ $dq = \lambda\, dl$

Electric field of a continuous charge distribution



- **Example 4 : The electric field due to a charged rod**

$$dE = \frac{k \cdot dq}{x^2} \Longrightarrow dE = \frac{k \cdot \lambda \cdot dx}{x^2}$$

$$E = \int_{a}^{a+L} \frac{k \cdot \lambda \cdot dx}{x^2} \Longrightarrow E = k\lambda \int_{a}^{a+L} \frac{dx}{x^2}$$

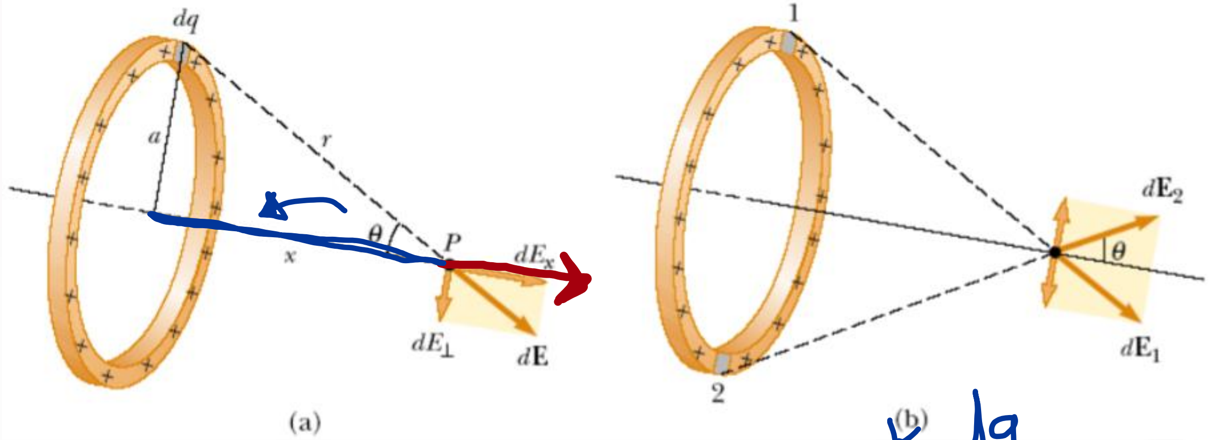
$$E = k \cdot \lambda \cdot \left[\frac{-1}{x}\right]_{a}^{a+L} \Longrightarrow E = k \cdot \lambda \left[\frac{-1}{a+L} - \frac{-1}{a}\right]$$

$$E = k\lambda \left[\frac{1}{a} - \frac{1}{a+L}\right] \xrightarrow{\text{توحيد مقامات}} \left[\frac{1}{a} - \frac{1}{a+L}\right] = \frac{\cancel{a} + L - \cancel{a}}{a(a+L)}$$

$$E = k \cdot \lambda \cdot \left[\frac{L}{a(a+L)}\right]$$

Electric field of a continuous charge distribution

- **Example 5 : The electric field of a uniform ring of charge**



$$r = \sqrt{a^2 + x^2} \Longrightarrow r^2 = a^2 + x^2$$

$$\cos\theta = \frac{\text{المجاور}}{\text{الوتر}} = \frac{x}{r} = dE_x$$

$$dE_x = dE\cos\theta$$

$$dE = \frac{k \cdot dq}{r^2} \Longrightarrow dE = \frac{k \cdot dq}{a^2 + x^2} \Longrightarrow dE_x = dE\cos\theta$$

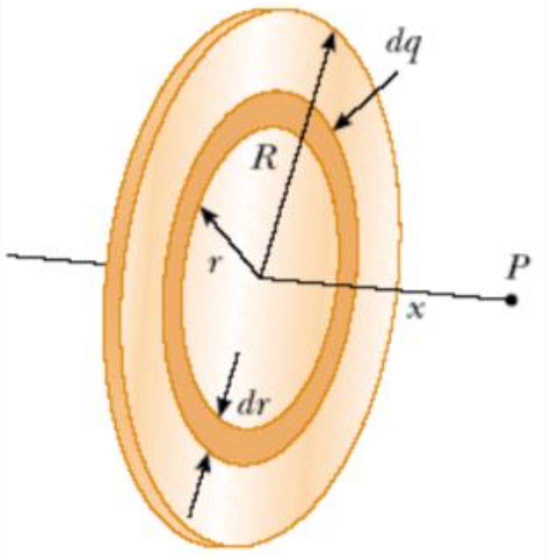
$$dE_x = \left(\frac{k \cdot dq}{a^2 + x^2}\right)\left(\frac{x}{(a^2+x^2)^{1/2}}\right) \Longrightarrow E = \int \frac{k \cdot dq \cdot x}{(a^2+x^2)(a^2+x^2)^{1/2}} \rightarrow (a^2+x^2)^{3/2}$$

$$E = \frac{k \cdot x}{(a^2+x^2)^{3/2}} \int dq \Longrightarrow E = \frac{k \cdot q \cdot x}{(a^2 + x^2)^{3/2}}$$

$E = \text{zero}$ at $x = 0$

Electric field of a continuous charge distribution

- **Example 5 : The electric field of a uniformly charged disk**



$$dE_x = K_e \frac{x}{\left(x^2+r^2\right)^{3/2}} (2\pi \ \sigma r \ dr)$$

$$E_x = K_e \ x \ \pi \ \sigma \int_0^R \frac{2rdr}{\left(x^2+r^2\right)^{3/2}}$$

$$= K_e \, 2 \ \pi \ x \ \sigma \int_0^R \left(x^2+r^2\right)^{-3/2} d\left(r^2\right)$$

$$= \frac{1}{2 \ \pi \ \varepsilon_o} \ 2 \ \pi \ x \ \sigma \int_0^R \left(x^2+r^2\right)^{-3/2} d\left(r^2\right)$$

$$= \left(\frac{x\sigma}{4\varepsilon_0}\right) \int_0^R \left(x^2+r^2\right)^{-3/2} d\left(r^2\right)$$

$$= \left(\frac{x \ \sigma}{4 \ \varepsilon_0}\right) \left[\frac{\left(x^2 + r^2\right)^{-1/2}}{-1/2} \right]_0^R$$

Then, $E_x = \left(\frac{\sigma}{2\varepsilon_0}\right) \left[1 - \frac{x}{\left(x^2+R^2\right)^{1/2}} \right]$

When x→ 0 or R → ∞ $\quad E_x = \frac{\sigma}{2 \ \varepsilon_0}$

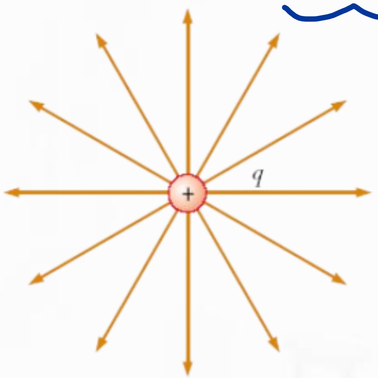
محذوف

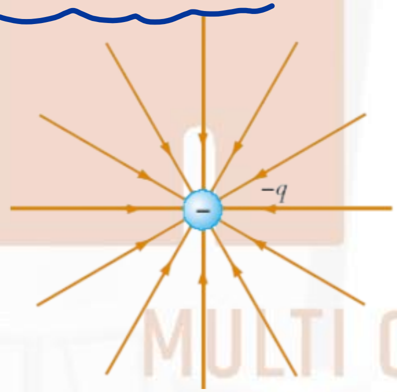
Electric field lines

Electric field lines

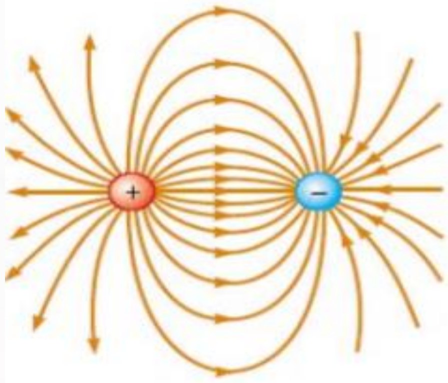
تنتهي

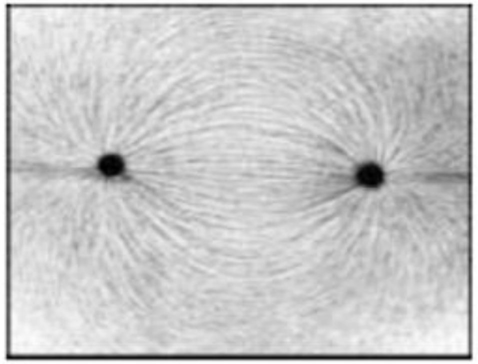
- The lines must begin on a positive charge and terminate on a negative charge .





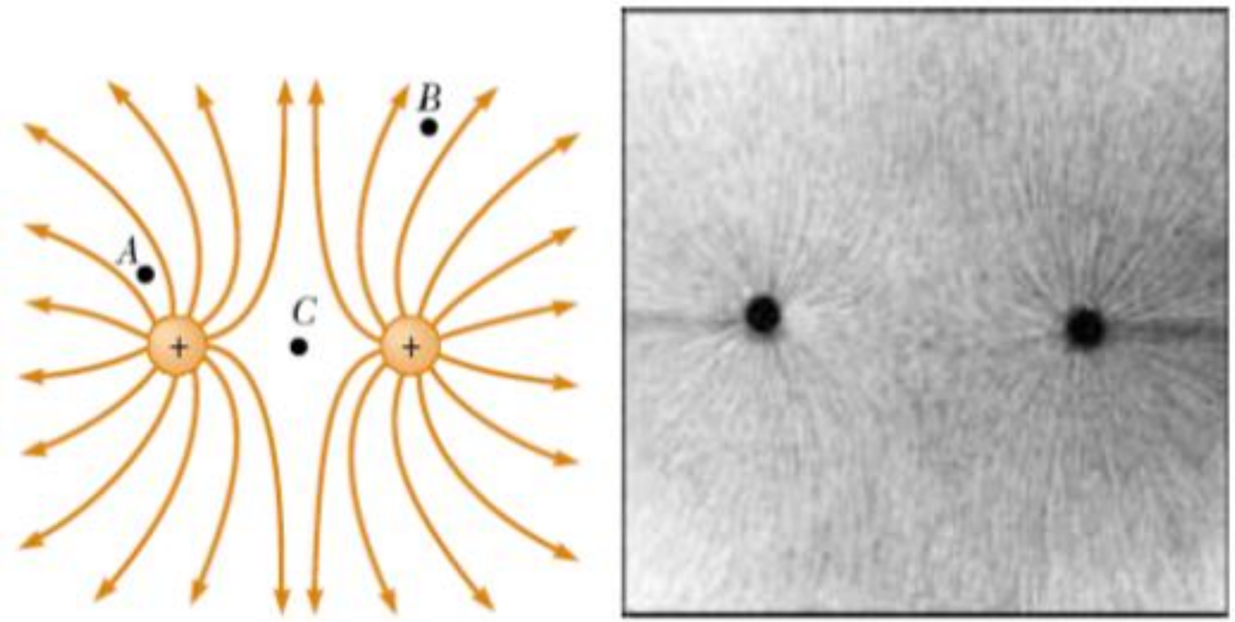
- The number of lines drawn leaving a positive charge or approaching a negative charge is proportional to the magnitude of the charge.





Electric field lines

- No two field lines can cross .



Motion of Charged Particles in a Uniform Electric Field

Motion of Charged Particles in a Uniform Electric Field

مجال كهربي

كتلة

شحنة $\boxed{q\,E = m\,a}$ تسارع

The acceleration is $\boxed{a = \dfrac{q\,E}{m}}$

مهم

- If E is uniform (that is, constant in magnitude and direction), then the acceleration a is constant

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$$x_f = x_i + v_i t + \frac{1}{2}at^2$$

$$v_f = v_i + at$$

$$v_f^2 = v_i^2 + 2a(x_f - x_i)$$

$$K = \frac{1}{2}mv_f^2 = \frac{1}{2}m\left(\frac{2qE}{m}\right)\Delta x = qE\Delta x$$

THE END

End of Chapter 1

Chapter 1 – Electric force and electric field

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