جامعة الملك سعود

كلية العلوم

قسم الفيزياء والفلك

مذكرة المقرر 104 فيز

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الباب 23

محاضرة رقم 1 (صيفي)

أجزاء كبيرة من هذه المذكرة معتمدة على عروض الأستاذة نورة علي المنيف ـ قسم الفيزياء.

2019

Physics 104
Course Outline

Chapter 23: Electric Fields
Chapter 24. Gauss's Law
Chapter 25. Electric Potential
Chapter 26. Capacitance and Dielectrics
Chapter 27. Current and Resistance
Chapter 28. Direct Current Circuits
Chapter 29. Magnetic Fields
Chapter 30. Sources of Magnetic Field
Chapter 31. Faraday's Law
Chapter 32. Inductance
Chapter 33. Alternating Current Circuits

Physics 104
Chapter 23

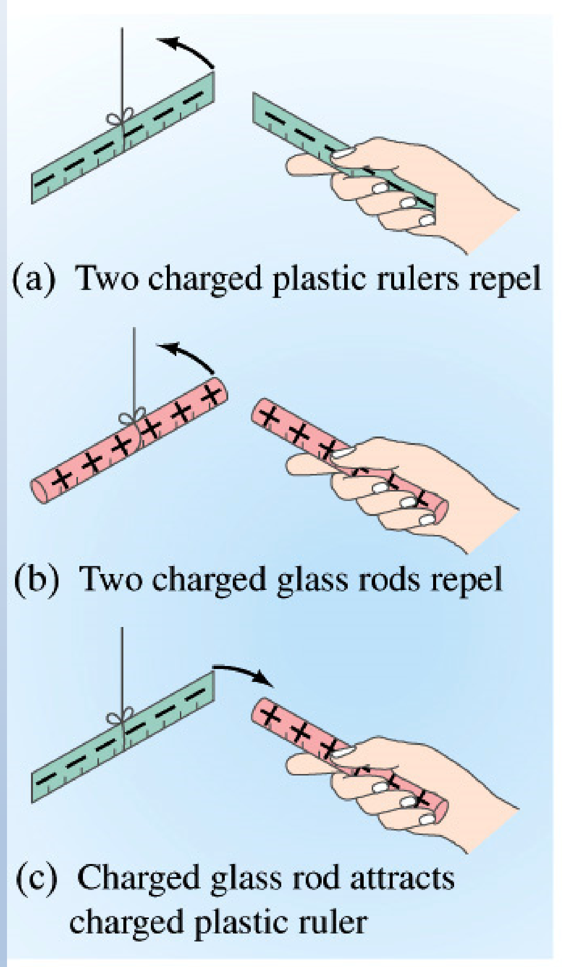
Chapter 23 electric field

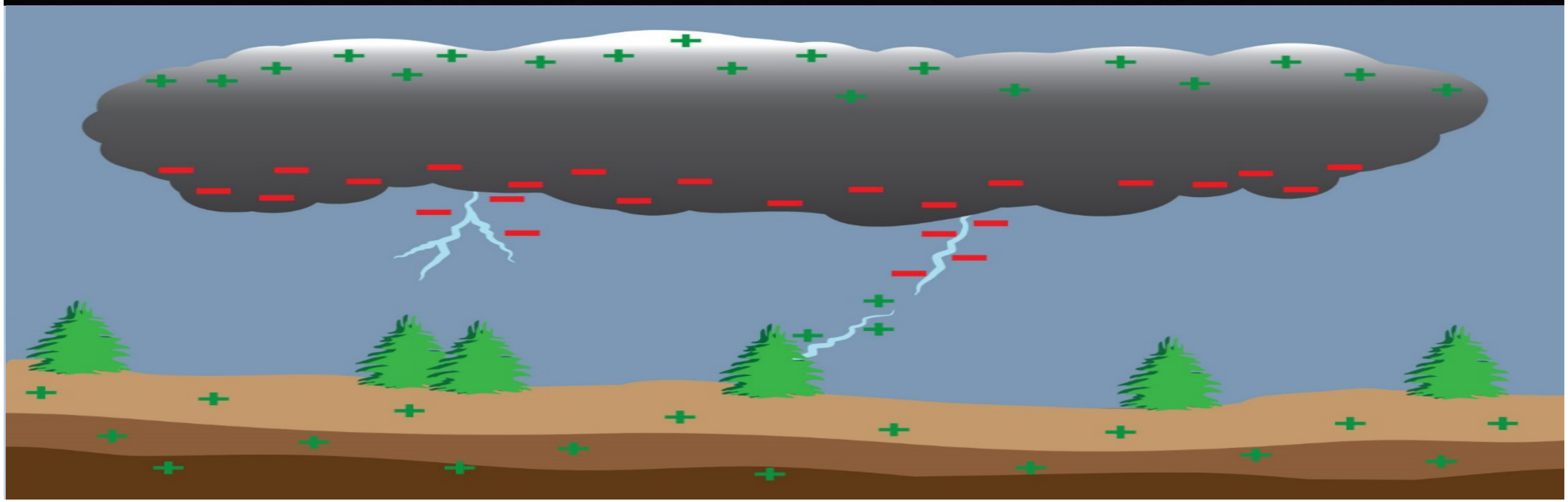
23.3 Coulomb’s Law
23.4 The Electric Field
23.6 Electric Field Lines
23.7 Motion of Charged Particles in a Uniform Electric Field

Lecture No. 01

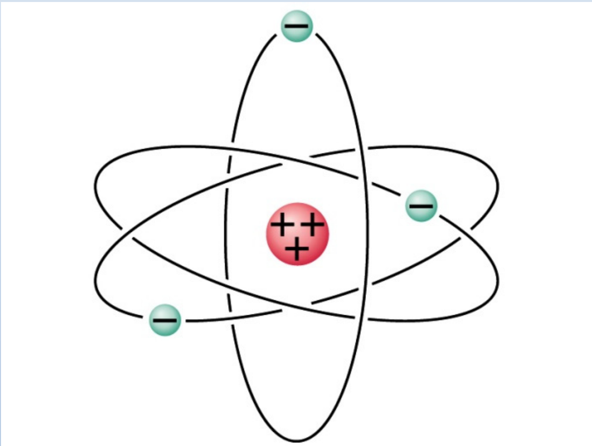
Electric Charge

- Types:
  - **Positive**
    - Glass rubbed with silk
    - Missing electrons
  - **Negative**
    - Rubber/Plastic rubbed with fur
    - Extra electrons
- Arbitrary choice
  - convention attributed to ?
- Units: amount of charge is measured in [Coulombs]
- Empirical Observations:
  - Like charges repel
  - Unlike charges attract

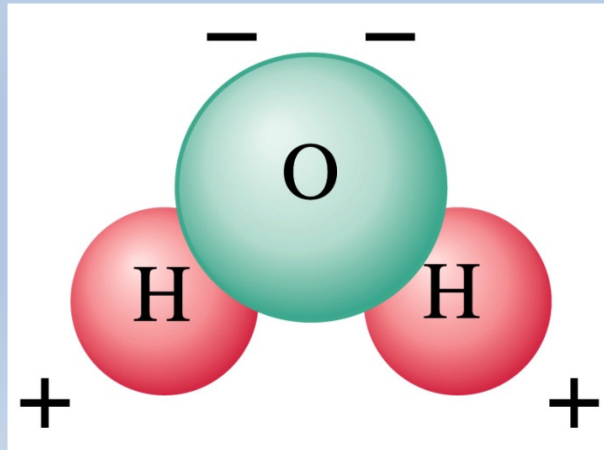




Charge in the Atom

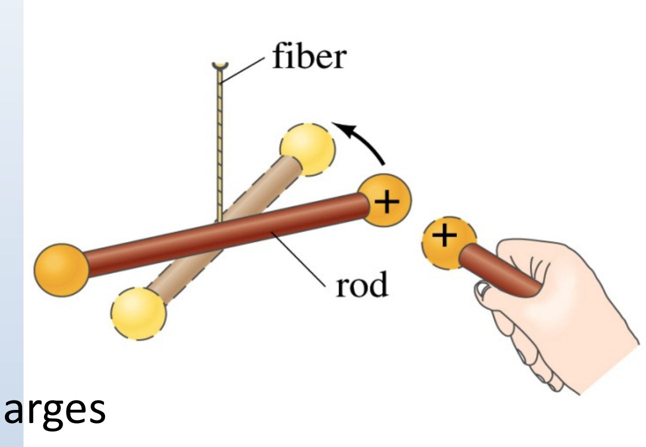


- Protons (+)
- Electrons (-)
- Ions
- Polar Molecules



23-3 Coulomb's Law

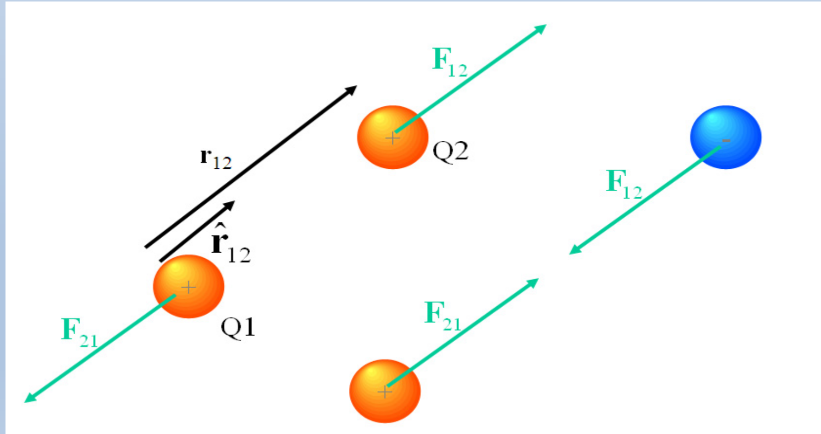
- Empirical Observations



$$F \propto q_1 q_2 \qquad\qquad F \propto \frac{1}{r^2}$$

Direction of the force is along the line joining the two charges

- Formal Statement



$$\mathbf{F}_{12} = k\frac{q_1 q_2}{r_{21}^2}\hat{r}_{21}$$

- Consider two electric charges: q_1 and q_2
- The electric force **F** between these two charges separated by a distance *r* is given by Coulomb's Law

$$F = k\frac{q_1 q_2}{r^2}$$

- The constant k is called Coulomb's constant and is given by $k = 9\times10^9\ \mathrm{Nm^2/C^2}$

- The coulomb constant is also written as

$$k = \frac{1}{4\pi\,\varepsilon_0} \quad \text{where} \quad \varepsilon_0 = 8.85\times10^{-12}\ \frac{\mathrm{C^2}}{\mathrm{Nm^2}}$$

- ε_o is the "electric permittivity of vacuum"
  - A fundamental constant of nature

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$$

- Double one of the charges
  - force doubles
- Change sign of one of the charges
  - force changes direction
- Change sign of *both* charges
  - force stays the same
- Double the distance between charges
  - force four times weaker
- Double both charges
  - force four times stronger

Quick Quiz 23.4 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) $F_{AB} = F_{BA}$ (f) $3F_{AB} = F_{BA}$

Coulomb's Law using vectors

- When dealing with Coulomb's law, you must remember that force is a vector quantity and must be treated accordingly

$$\mathbf{F}_{12} = k\frac{q_1 q_2}{r^2}\hat{r} \qquad (23.6)$$

Quick Quiz 23.5 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) $3\mathbf{F}_{AB} = \mathbf{F}_{BA}$

Example:

What is the force between two charges of 1 C separated by 1 meter?

$\because F = k \frac{q_1 q_2}{r^2} \qquad q_1 = q_2 = 1\,C,\; r = 1\,m$

$\Rightarrow F = 9 \times 10^9 \times \frac{1 \times 1}{1^2} = 9 \times 10^9\ N$

Coulomb's Law Example

What is the magnitude of the electric force of attraction between an iron nucleus (q=+26e) and its innermost electron if the distance between them is 1.5×10^{-12} m

الشحنة الأولى : q_1 شحنة النواة :

$26e = 26 \times 1.6 \times 10^{-19}$

$= 4.16 \times 10^{-18}$ C

الشحنة الثانية : q_2 شحنة الإلكترون

1.6×10^{-19} C

المطلوب : القوة بين شحنة النواة وشحنة الإلكترون :

$$\therefore F = k\frac{q_1 q_2}{r^2} = 9 \times 10^{9} \times \frac{4.16 \times 10^{-18} \times 1.6 \times 10^{-19}}{(1.5 \times 10^{-12})^2}$$

$$= 3 \times 10^{-3} \text{ N} \quad \#$$

Example 23.1 The Hydrogen Atom

The electron and proton of a hydrogen atom are separated by a distance of approximately 5.3×10^{-11} m. Find the magnitudes of the electric force and the gravitational force between the two particles.

1st: electric force:

$q_1 = +1.6 \times 10^{-19}$ C $\quad q_2 = -1.6 \times 10^{-19}$ C

$\therefore F_e = k \frac{q_1 q_2}{r^2} = \frac{1.6 \times 10^{-19} \times (-1.6 \times 10^{-19})}{(5.3 \times 10^{-11})^2}$

$= -8.2 \times 10^{-8}$ N

But we need magnitude

$\vec{F}_e = 8.2 \times 10^{-8}$ N #

2nd: gravitational force

$F_g = G \frac{m_1 m_2}{r^2}$

$m_p = 1.67 \times 10^{-27}$ kg, $m_e = 9.11 \times 10^{-31}$ kg

$G = 6.67 \times 10^{-11}$ N.m²/kg²

$\therefore F_g = 6.67 \times 10^{-11} \frac{1.67 \times 10^{-27} \times 9.11 \times 10^{-31}}{(5.3 \times 10^{-11})^2}$

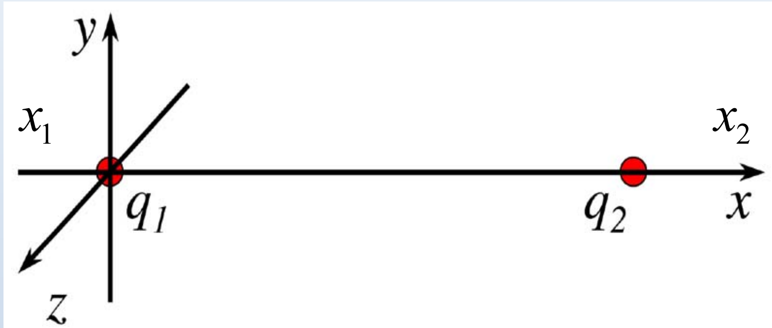
$= 3.6 \times 10^{-47}$ N #

$\rightarrow F_e / F_g \simeq 2 \times 10^{39}$

أي أن قوى التجاذب الكوني لا شيء
مقارنة بالتجاذب الكولومي.

Example - Equilibrium Position

- Consider two charges located on the x axis
- The charges are described by
  - $q_1 = 0.15\ \mu C$ $x = 0.0$ m
  - $q_2 = 0.35\ \mu C$ $x = 0.40$ m



- Where do we need to put a third

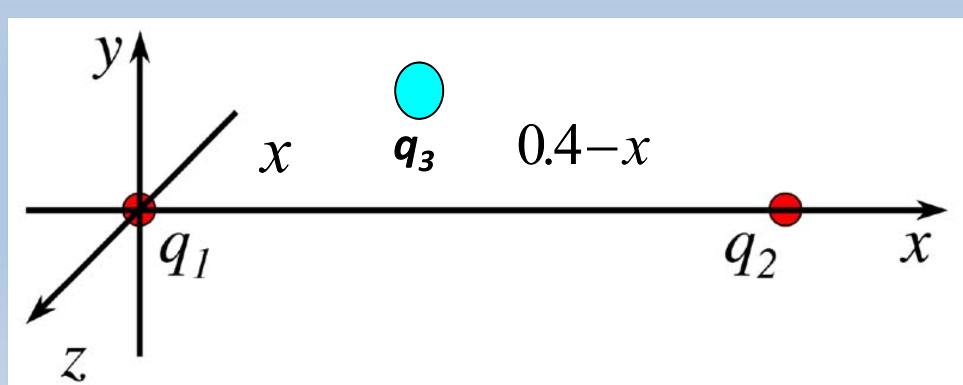
charge for that charge to be at an equilibrium point?

At the equilibrium point, the forces from the two charges will cancel.

Here the forces from q_1 and q_2 can balance.

$$k\frac{q_1 q_3}{(x)^2} = k\frac{q_2 q_3}{(0.4 - x)^2}$$

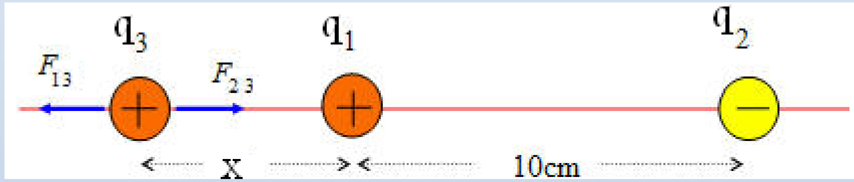
$$x = 0.16\ m$$



Zero Resultant Force, Example

Two fixed charges, 1mC and -3mC are separated by 10cm as shown in the figure (a) where may a third charge be located so that no force acts on it?

- The magnitudes of the individual forces will be equal
- Directions will be opposite
- Will result in a quadratic
- Choose the root that gives the forces in opposite directions



$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

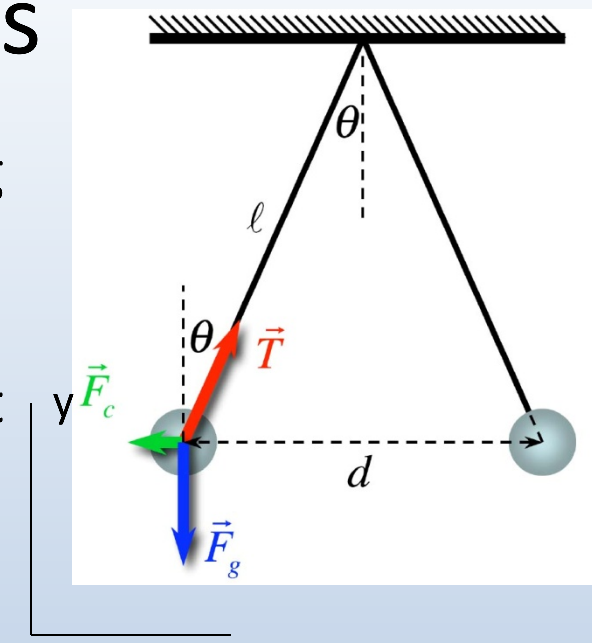
$$k\frac{q_1 q_3}{(x)^2} = k\frac{q_2 q_3}{(10 + x\ )^2}$$

$$\frac{1\times10^{-6}}{(x)^2} = \frac{3\times10^{-6}}{(x+10)^2}$$

$$x = 13.7cm$$

Example - Charged Pendulums

Consider two identical charged balls hanging from the ceiling by strings of equal length 1.5 m (in equilibrium). Each ball has a charge of 25 μC. The balls hang at an angle θ = 25° with respect to the vertical. What is the mass of the balls?



Step 1: Three forces act on each ball: Coulomb force, gravity and the tension of the string.

Ball on left :

$$F_x = T \sin\theta - \frac{kq^2}{d^2}$$

$$F_y = T \cos\theta - mg$$

Example - Charged Pendulums (2)

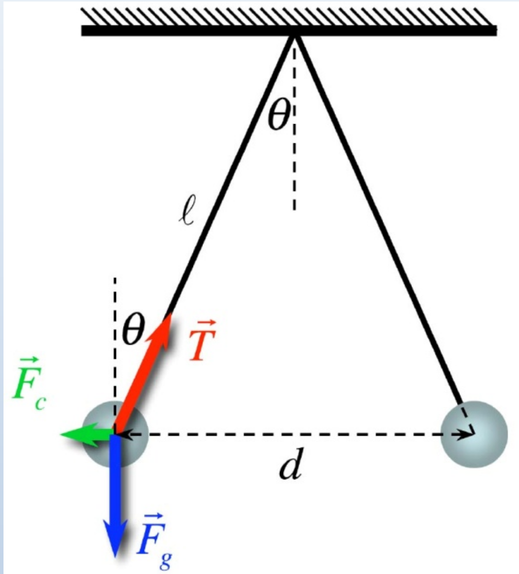
Step 2: The balls are in equilibrium positions. That means the sum of all forces acting on the ball is zero!

$$T \sin \theta = \frac{kq^2}{d^2}$$

$$T \cos \theta = mg$$

$$\frac{T \sin \theta}{T \cos \theta} = \frac{kq^2 / d^2}{mg}$$

$$mg = \frac{kq^2}{d^2 \tan \theta}$$



d=2ℓ sin 25

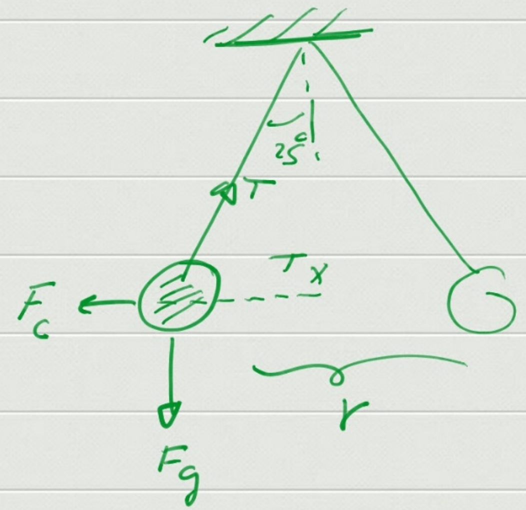
Answer: m = 0.76 kg

A similar analysis applies to the ball on the right.

Example - Charged Pendulums solution

∵ الكتلتين في حالة اتزان

∴ القوى يلغي بعضها بعضاً



$x:\quad T_x = T\sin 25 \quad , F_c = k\frac{q_1 q_2}{r^2}$

$y:\quad T_y = T\cos 25 \quad , F_g = mg$

$\therefore x:\quad T\sin 25 - k\frac{q_1 q_2}{r^2} = 0 \quad ① \rightarrow T\sin 25 = k\frac{q_1 q_2}{r^2} \quad ③$

$y:\quad T\cos 25 - mg = 0 \quad ② \rightarrow T\cos 25 = mg \quad ④$

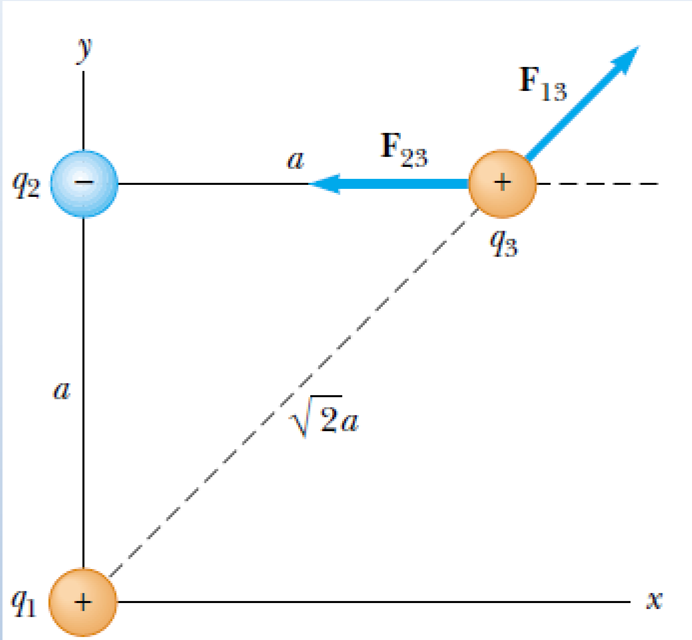
$③ \div 4:\quad \tan 25 = k\frac{q_1 q_2}{r^2} / mg \rightarrow m = k\frac{q_1 q_2}{r^2} / g\tan 25$

$\because r = 2 \times l\sin 25 = 2\times 1.5 \times \sin 25 = 1.267\ m$

$\therefore m = \frac{9\times 10^9 \times (25\times 10^{-6})^2}{(1.267)^2} \div (9.8\times \tan 25) = 0.77\ kg$

Example 23.2 **Find the Resultant Force**

Consider three point charges located at the corners of a right triangle, where $q_1 = q_3 = 5\ \mu C$, $q_2 = -2\mu C$, and $a = 0.10$ m. *Find the resultant force exerted on q_3.*



Example 23.2: Solution

We have x-y plane

∴ we must find F_x and F_y:

① F_x: $F_{13}^{x} = F_{13}\cos 45 = +k\frac{q_1 q_3}{(\sqrt{2}a)^2}\cos 45$ ①

$F_{23}^{x} = -k\frac{q_2 q_3}{a^2}$ —— ②

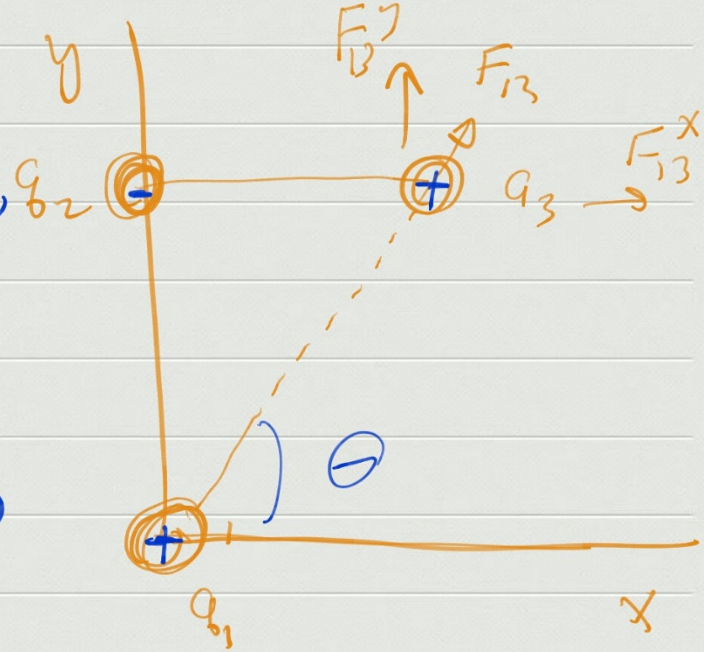
$F_{13}^{x} = 9\times10^{9}\times\frac{5\times10^{-6}\times5\times10^{-6}}{2(0.1)^2}\cos 45 = 7.95\ N.$ ③

$F_{23}^{x} = -9\times10^{9}\times\frac{2\times10^{-6}\times5\times10^{-6}}{0.1^2} = -9\ N$ ④

∴ $F_x = 7.95 - 9 = -1.05\ N$ ⑤

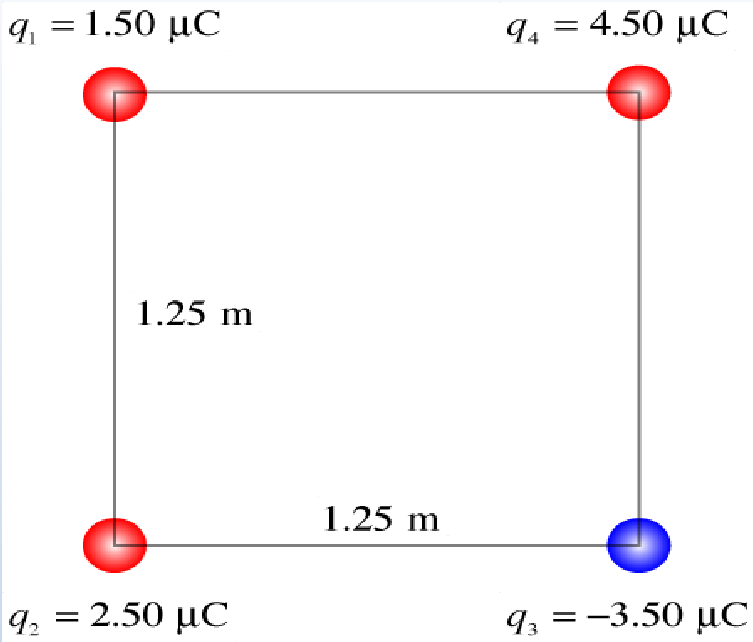
② $F_y = F_{23}^{x} = 7.95\ N$ ⑥

∴ $F_3 = (-1.05\,\hat{i} + 7.95\,\hat{j})$ ##



Example - Four Charges

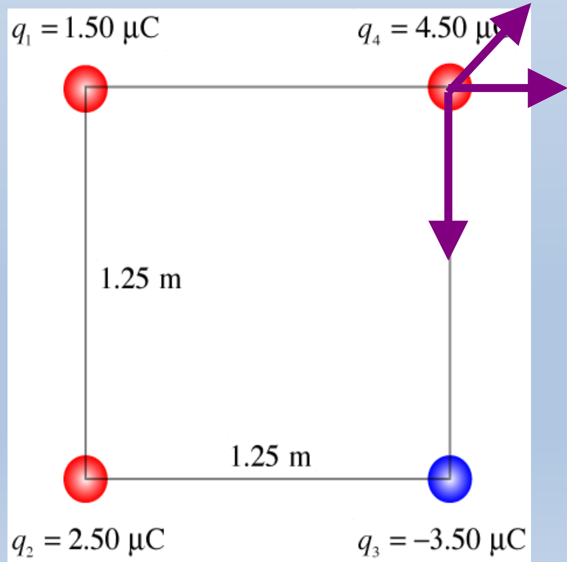
Consider four charges placed at the corners of a square with sides of length 1.25 m as shown on the right. What is the magnitude of the electric force on q_4 resulting from the electric force from the remaining three charges?



Answer:

F (on q_4) = 0.0916 N

… and the direction?



23-4 The Electric Field

We define the electric field by the force it exerts on a test charge q_0: $$\mathbf{E} = \frac{\mathbf{F}_0}{q_0}$$

This is your second starting equation. By convention the direction of the electric field is the direction of the force exerted on a POSITIVE test charge. The absence of absolute value signs around q_0 means you must include the sign of q_0 in your work.

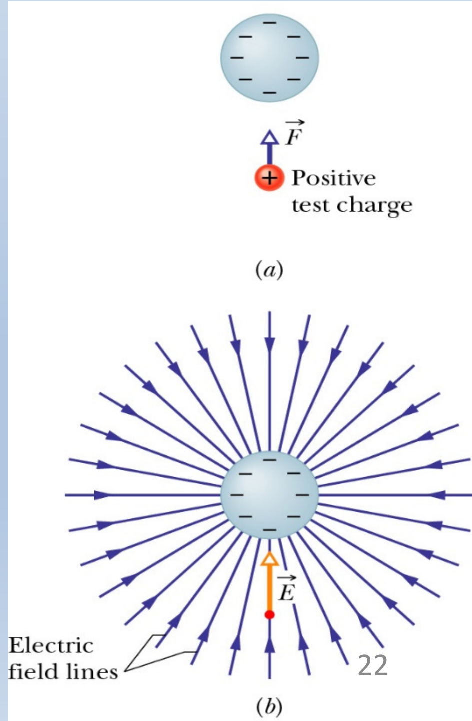
Any time you know the electric field, you can use this equation to calculate the force on a charged particle in that electric field. $\mathbf{F} = q\mathbf{E}$

The units of electric field are Newtons/Coulomb.

Later you will learn that the units of electric field can also be expressed as volts/meter:

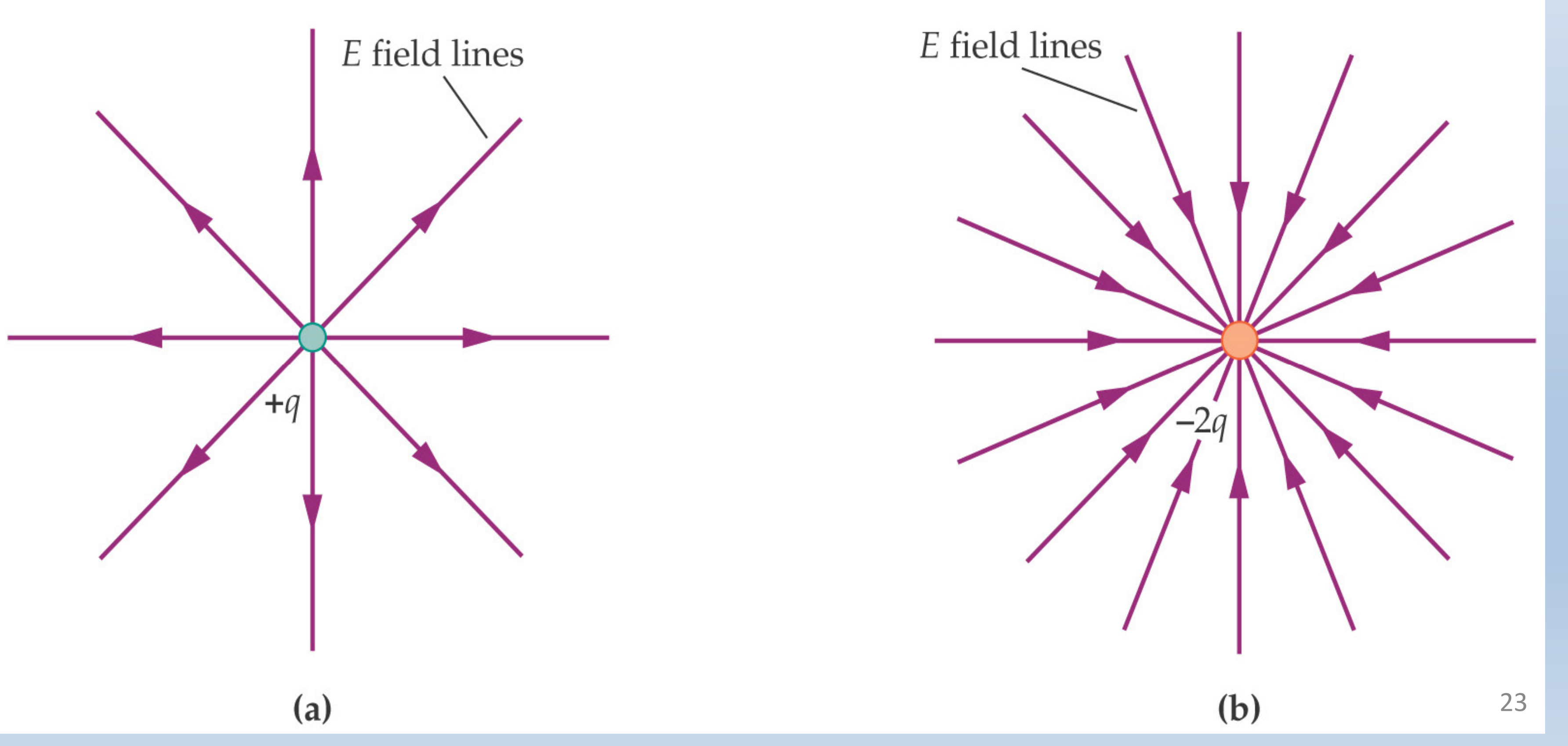
$$[E] = \frac{N}{C} = \frac{V}{m}$$

The electric field exists independent of whether there is a charged particle around to “feel” it.

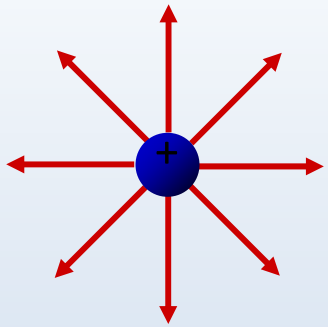


23-6 Electric Field Lines

The charge on the right is twice the magnitude of the charge on the left (and opposite in sign), so there are twice as many field lines, and they point towards the charge rather than away from it.



Remember: the electric field direction is the direction a + charge would feel a force.

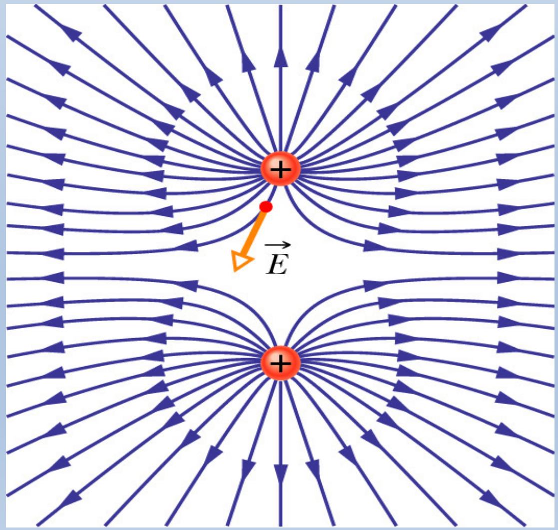


A + charge would be repelled by another + charge.

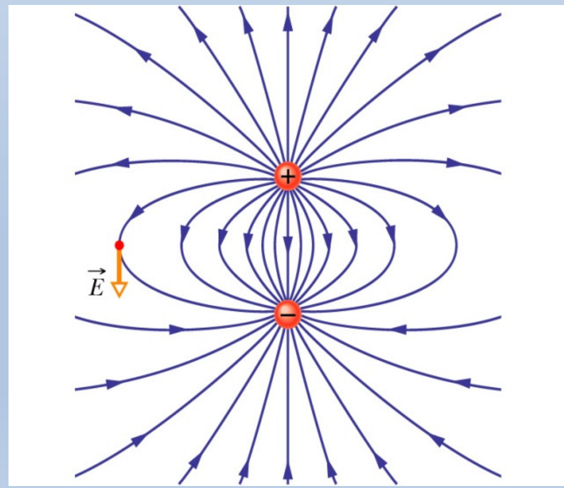
Therefore the direction of the electric field is away from positive (and towards negative).

Electric Field Lines

Like charges (++)



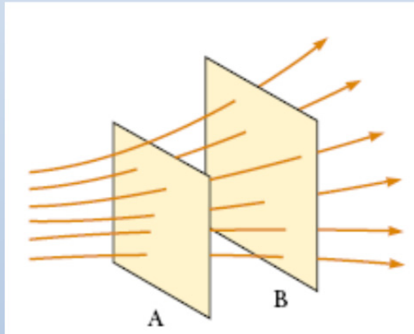
Opposite charges (+ -)



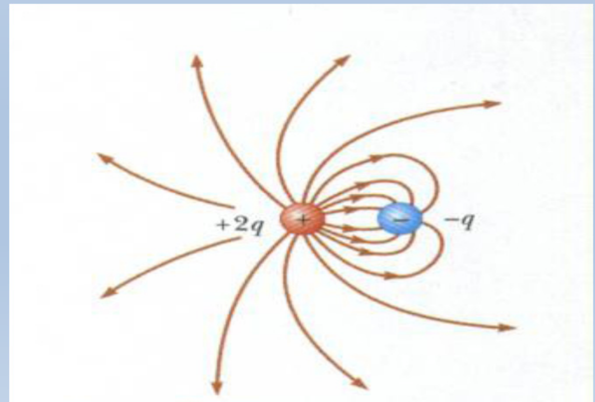
Electric Field Lines: a graphic concept used to draw pictures as an aid to develop intuition about its behavior.

The text shows a few examples. Here are the drawing rules.

- E-field lines begin on + charges and end on - charges. (or infinity).
- They enter or leave charge symmetrically.
- The number of lines entering or leaving a charge is proportional to the charge
- The density of lines indicates the strength of E at that point.
- No two field lines can cross.

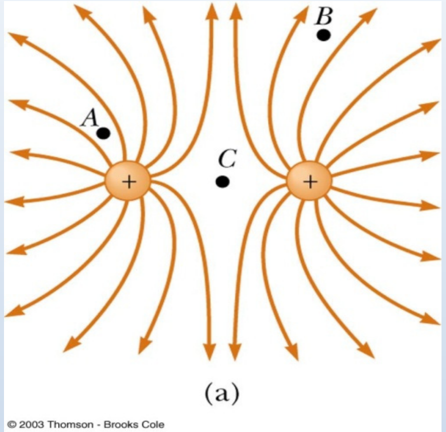


The spacing of the lines indicates the strength of the electric field.



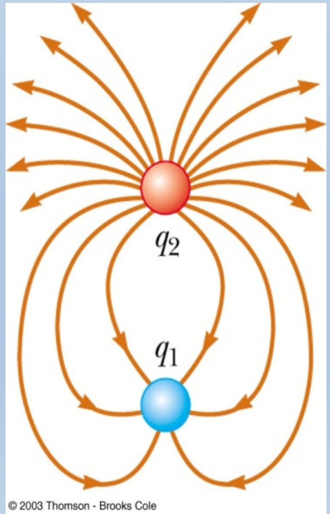
QUICK QUIZ 1

Rank the magnitudes of the electric field at points *A*, *B*, and *C* in the figure below, largest magnitude first.



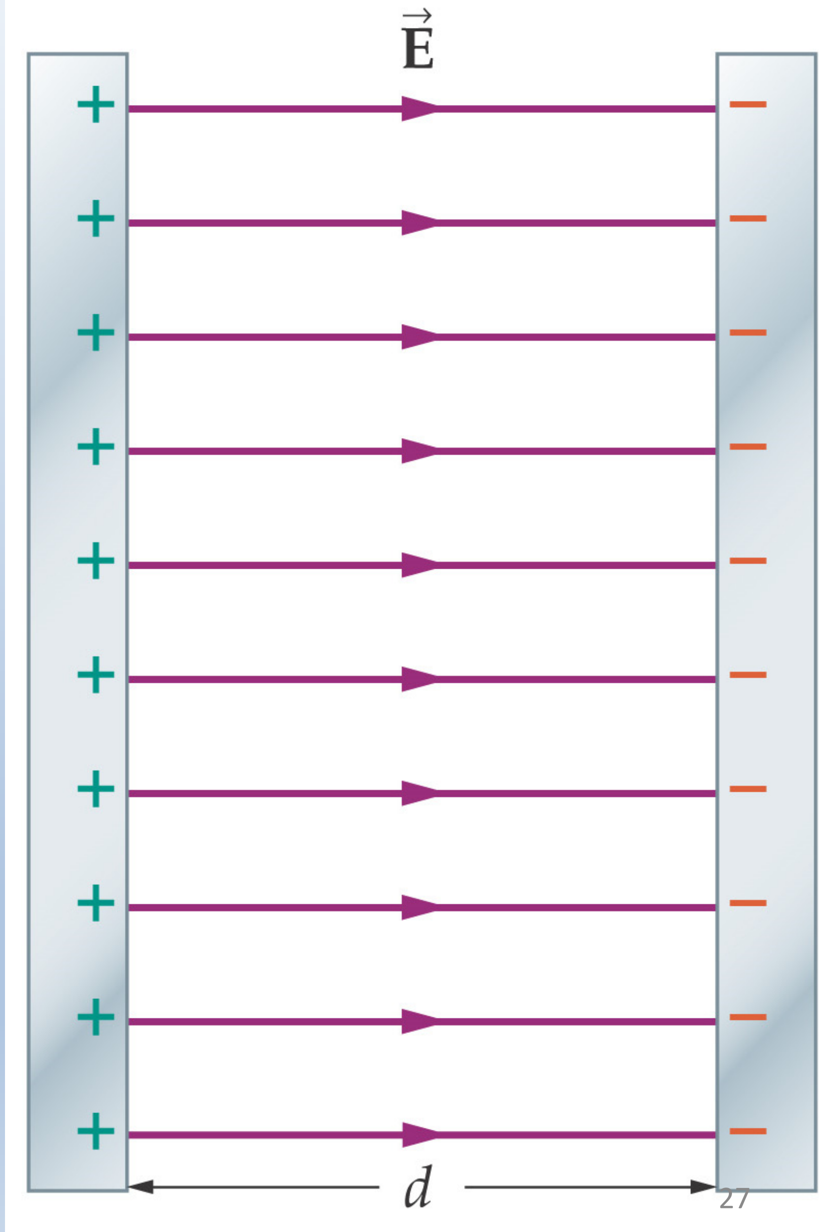
QUICK QUIZ 2

Figure shows the electric field lines for two point charges separated by a small distance. (a) Determine the ratio q_1/q_2. (b) What are the signs of q_1 and q_2?



Electric Field Lines

A parallel-plate capacitor consists of two conducting plates with equal and opposite charges. Here is the electric field:



The Electric Field Due to a Point Charge

Coulomb's law says

$$F_{12} = k\frac{|q_1 q_2|}{r_{12}^2},$$

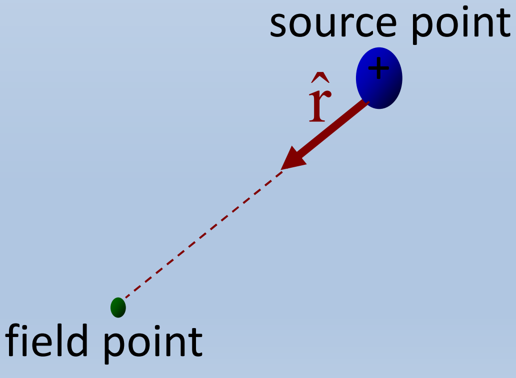
... which tells us the electric field due to a point charge q is

$$E_q = k\frac{|q|}{r^2}\text{ , away from +}$$

...or just...

$$E = k\frac{|q|}{r^2}$$

We define $\hat{r}$ as a unit vector from the source point to the field point:



The equation for the electric field of a point charge then becomes:

$$\mathbf{E} = k\frac{q}{r^2}\hat{r}$$

Example

Find the electric force on a proton placed in an electric field of 2.0 X 10^4 N/C

$$E = \frac{F}{q}$$

$$F = qE = \left(1.6\times10^{-19}C\right)\left(2\times10^{4}N/C\right)$$

$$F = 3.2\times10^{-15}N$$