Applied Physics for Engineers (PHY121)

Electrostatics

LECTURE#1

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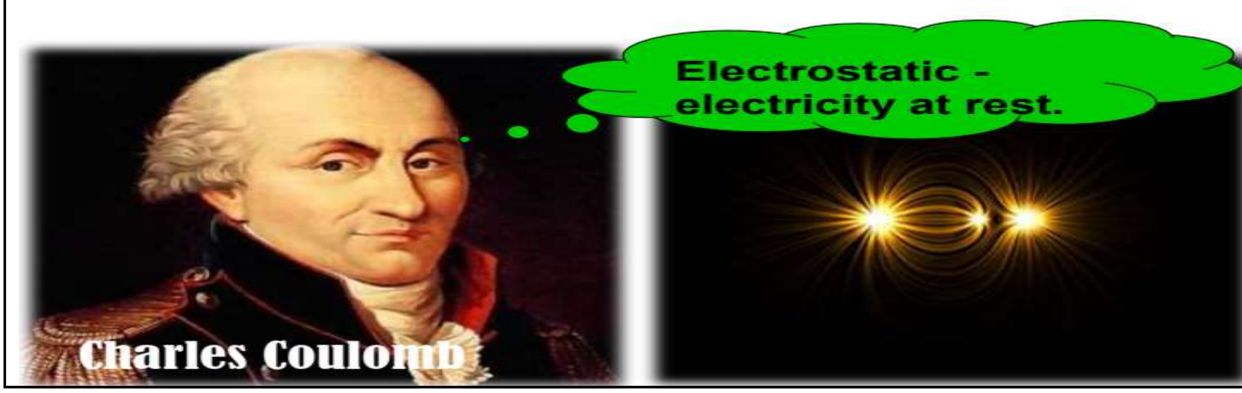
Outlines

1. Introduction to Electrostatics
2. Coulomb's Law

Electrostatics **is the branch of electromagnetics dealing with the effects of electric charges at rest.**

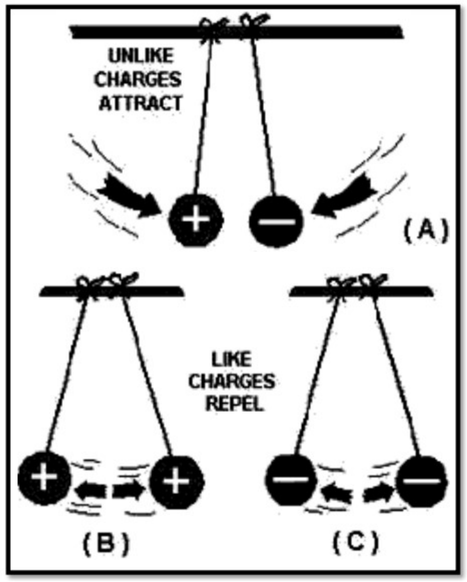


Electric charges , Q

There are two kinds of charges in nature – positive and negative charge.

Charges of opposite sign attract one another – attractive force.

Charges of the same sign repel one another – repulsive force.



Principle of conservation of charges state the total charge in an isolated system is constant (conserved).

Charge is quantized.

Electric charge exists as discrete "packets" and written as

$$\boxed{Q = ne}$$

Charge (C) = Current (A) x Time (s)
For example, if a current of ***10A*** flows for ***30s***, then 10 x 30 = **300 coulombs** of electrical charge moves.

n : positive integer number, 1, 2 …
e : 1.6×10^{-19} C

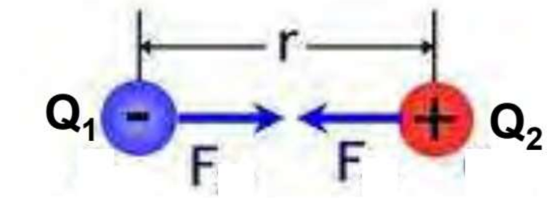
Charge, Q is a scalar quantity.

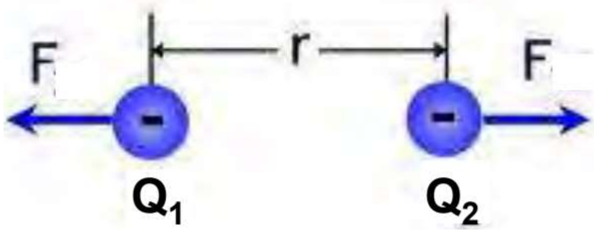
The S.I. unit of charge is coulomb (C).

It is the quantity of electricity carried in 1 **second** by a current of 1 **ampere**.

1 **C** = (1**A**) (1**s**)

1.1 Coulomb's Law





Coulomb's Law states that the **electrostatic force, F** between two charges separated by a distance, r, is

(i) **inversely proportional** to the **square of the separation, r** between the two charges, and ; **F α 1/r²**

(ii) **directly proportional** to the **product of the magnitudes of the charges**, Q_1 and Q_2 **F α Q_1Q_2**

Mathematically;

$$F = k\frac{Q_1Q_2}{r^2}$$

where :

k = Coulomb constant which has the value of 9×10^9 N m² C⁻²
Q_1 = magnitude of charge Q_1
Q_2 = magnitude of charge Q_2
r = separation distance between the two charges.

Coulomb constant k is given by

$$k = \frac{1}{4\pi\varepsilon_o} = 9.0 \times 10^9\,\mathrm{Nm^2C^{-2}}$$

where :

ε_o = permittivity of free space 8.85×10^{-12} $C^2N^{-1}m^{-2}$

Permittivity, also called electric **permittivity**, is a constant of proportionality that exists between electric displacement and electric field intensity.

The lowest possible permittivity is that of a vacuum. Vacuum permittivity, sometimes called the electric constant, is represented by ε_0 .

Figures (a) and (b) show the variation of electrostatic force with the distance between two charges.

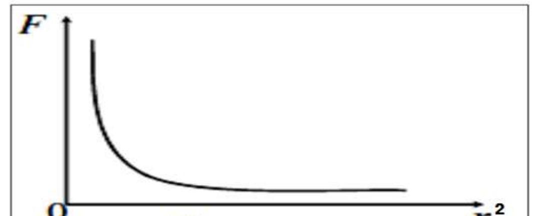


Figure a

- Force (**F**) is **inversely** proportional to distance (***r***^{2})

- Force (**F**) is **directly** proportional to the inverse of square of the distance (1/***r***^{2})

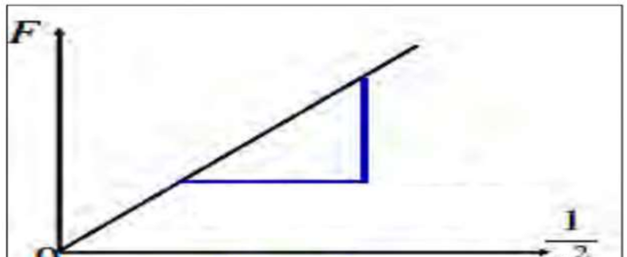
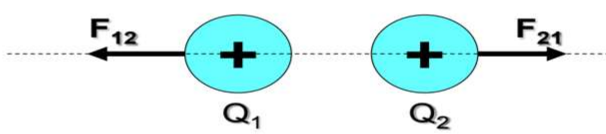


Figure b

This electrostatic force is directed along the line joining the charges.

The electrostatic force between two charges is attractive if the charges are of opposite sign and repulsive if the charges have the same sign.



The notation $\mathbf{F}_{12}$ denotes the force exerted on charge 1 by charge 2 and $\mathbf{F}_{21}$ is the force exerted on charge 2 by charge 1.

Since electric forces obey Newton's third law, therefore the forces F_{12} and F_{21} are equal in magnitude but opposite in direction.

Hence, it can be written as

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

Note :

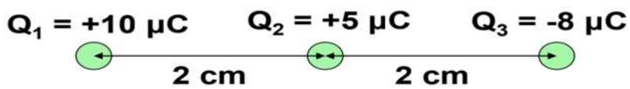
The sign of the charge can be ignored when substituting into the Coulomb's law equation.

The sign of the charges is important in distinguishing the direction of the electric force when we draw the electric force vector.

The electrostatic force is a vector quantity and has a direction as well as magnitude. When adding electrostatic forces, must take into account the directions of all forces, using vector components as needed.

Example 1 :

Three point charges are firmly held on a straight line of 4 cm in length as shown in the figure below.

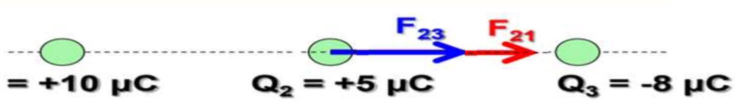


Find the resultant electric force acting on ;

(a) charge Q_2
(b) charge Q_1

Solution :

(a) **Step 1** : Draw the electric force vectors



The force acting on Q_2 due to Q_3 is attractive because Q_2 and Q_3 have the opposite sign, therefore the direction of F_{23} is also to the right.

The force acting on Q_2 due to Q_1 is repulsive because Q_1 and Q_2 have the same sign, therefore the direction of F_{21} is to the right.

Step 2 : Use Coulomb equation, find the magnitude of each of the electric forces.

The magnitudes of F_{21} and F_{23} are given by :

$$F_{21} = k\frac{Q_1Q_2}{r^2} \quad \& \quad F_{23} = k\frac{Q_2Q_3}{r^2}$$

$$F_{21} = (9\times10^9)\frac{(10\times10^{-6})(5\times10^{-6})}{0.02^2}$$

$$= 1125\ N$$

$$F_{23} = (9\times10^9)\frac{(5\times10^{-6})(8\times10^{-6})}{0.02^2}$$

$$= 900\ N$$

Step 3 : Electric force adds as vector (consider the direction)

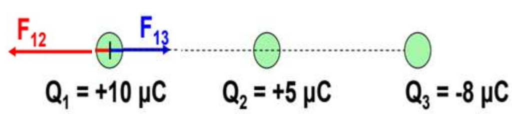
Therefore, the resultant electric force acting on charge Q_2 is ;

$F = F_{21} + F_{23}$

$= (+1125) + (+900)$

$=$ **2025 N** (to the right)

(b) Step 1 : Draw the electric force vectors



The force acting on Q_1 due to Q_2 is repulsive because Q_1 and Q_2 have the same sign, therefore the direction of F_{12} is to the left.

The force acting on Q_1 due to Q_3 is attractive because Q_1 and Q_3 have the opposite sign, therefore the direction of F_{13} is to the right.

Step 2 : Find magnitude of electric force

The magnitudes of F_{12} and F_{13} are given by;

$$F_{12} = k\frac{Q_1Q_2}{r^2}$$

$$F_{12} = (9\times10^9)\frac{(10\times10^{-6})(5\times10^{-6})}{0.02^2}$$

$$= 1125\ N$$

$$F_{13} = k\frac{Q_1Q_3}{r^2}$$

$$F_{13} = (9\times10^9)\frac{(10\times10^{-6})(8\times10^{-6})}{0.04^2}$$

$F_{13} = 450\ N$

Step 3 : Adds as vector (consider the direction)

Therefore, the resultant electric force acting on charge Q_1 is ;

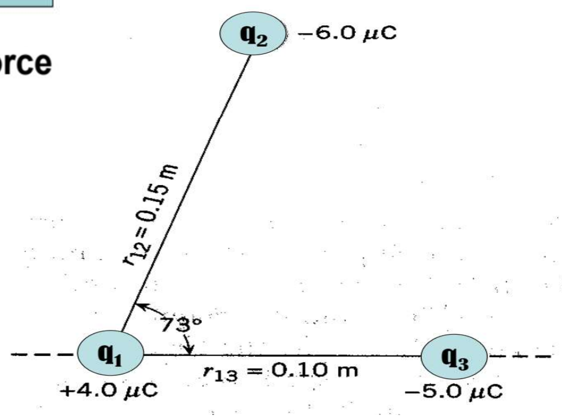
$F = F_{12} + F_{13}$

$= (-1125) + (+450)$

$= -675$ N (to the left)

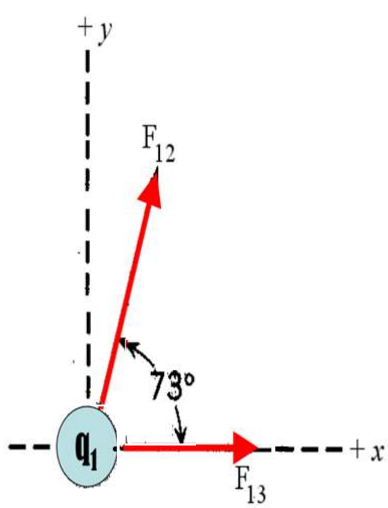
Example 2 :

Figure shows three point charges that lie in the x, y plane in a vacuum. Find the electrostatic force on q_1



Solution

Step 1 : Draw the electric force vectors



Step 2 : Find magnitude of electric force

$$F_{12} = k\frac{Q_1 Q_2}{r_{12}^{\ 2}} = (9\times10^9)\,\frac{(4\times10^{-6})(6\times10^{-6})}{(0.15)^2}$$

$$F_{12} = 9.6\ \text{N}$$

$$F_{13} = k\frac{Q_1 Q_3}{r_{13}^{\ 2}} = (9\times10^9)\,\frac{(4\times10^{-6})(5\times10^{-6})}{(0.10)^2}$$

$$F_{13} = 18\ \text{N}$$

Step 3 : Adds as vector (consider the direction)

Force	x - comp	y - comp
F_{12}	+9.6cos73 = +2.8 N	+9.6sin73 = +9.2 N
F_{13}	+ 18 N	0 N
F	F_x = + 21 N	F_y = +9.2 N

The electrostatic force acting on q_1 :

$$F = \sqrt{F_x^2 + F_y^2} = \sqrt{21^2 + 9.2^2} \boxed{= 23N}$$

$$\tan\theta = \frac{F_y}{F_x} = \frac{9.2}{21} \mapsto \boxed{\theta = 24^\circ \text{ above } + \text{x}}$$

Example 3

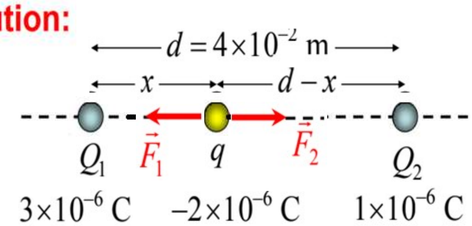
A −2 μC charge lies on the straight line between a 3 μC charge and a 1 μC charge. The separation between the 3 μC and 1 μC is 4 cm.

a) Draw the position of the three charges and show the forces acting on the −2 μC charge.

b) Calculate the distance of 3 μC from −2 μC where net force on −2 μC is zero.

Solution:

(a)



(b) Net force acting on q is zero,

$$F_1 = F_2$$

$$\frac{kQ_1 q}{r_1^2} = \frac{kQ_2 q}{r_2^2}$$

$$\frac{3\times10^{-6}}{x^2} = \frac{1\times10^{-6}}{\left(4\times10^{-2} - x\right)^2}$$

$$x = 2.53\times10^{-2}\text{ m}$$

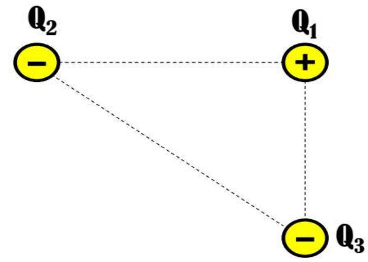
Home Assignment

For each of the diagram below, draw the direction of electric force acting on Q_1

1

2

3



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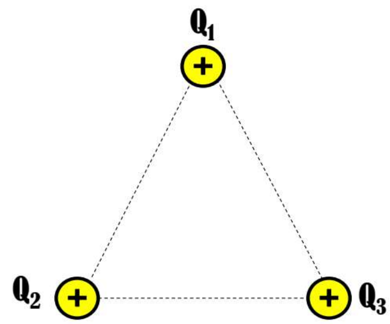

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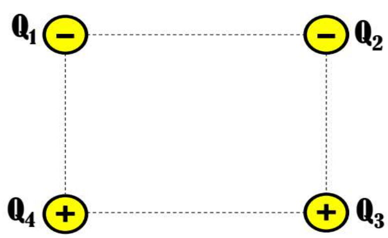

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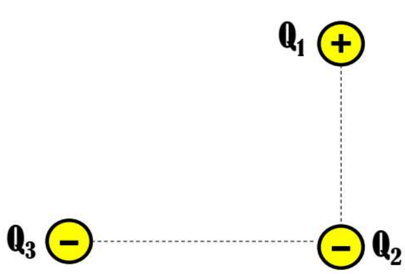
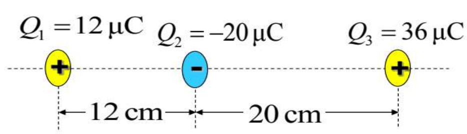


(7) Three point charges lie along the x-axis as shown in Figure below.



a. Calculate the magnitude and direction of the total electrostatic force exerted on Q_1.

b. Suppose the charge Q_2 can be moved left or right along the line connecting the charges Q_1 and Q_3. Determine the distance from Q_3 where Q_2 experiences a nett electrostatic force of zero.

Answer :

(a) 112 N towards Q_2

(b) 20.3 cm

8. What must be the distance between point charge q_1= 26.0 µC and point charge q_2= -47.0 µC for the electrostatic force between them to have a magnitude of 5.70 N?

Ans: 1.39 m

9. Two equally charged particles are held 3.2×10^{-3} m apart and then released from rest. The initial acceleration of the first particle is observed to be 7.0 m/s^2 and that of the second to be 9.0 m/s^2. If the mass of the first particle is 6.3×10^{-7} kg, what are (a) the mass of the second particle and (b) the magnitude of the charge of each particle?

Ans: (a) 4.9×10^{-7} kg (b) 7.1×10^{-11} C

10. In the return stroke of a typical lightning bolt, a current of 2.5×10^{4} A exists for 20 µs. How much charge is transferred in this event?

Ans: 0.50 C

11. Two small, positively charged spheres have a combined charge of 5.0×10^{-5} C. If each sphere is repelled from the other by an electrostatic force of 1.0 N when the spheres are 2.0 m apart, what is the charge on the sphere with the smaller charge?

Ans: 1.2×10^{-5} C

END OF LECTURE