IIIT-H

VIRTUAL LABS

Manual for Columb's Law

Introduction:

Coulomb's law is a law of physics describing the electrostatic interaction between electrically charged particles. It was studied and first published in 1783 by French physicist Charles Augustin de Coulomb and was essential for the development of the theory of electromagnetism.

It deals with the force a point charge exerts on another point charge. A point charge means a charge that is located on a body whose dimensions are much smaller than other relevant dimensions. For example, a collection of electric charges on a pinhead can be regarded as a point charge. Charges are generally measured in coulombs(C). One coulomb is approximately equivalent to 6 X 10^{18} electrons; it is a very large unit of charge because one electron charge e= -1.6019x10^{-19} C.

Coulomb's law states that the force between two point charges Q_1 and Q_2 is:
1. Along the line joining them
2. Directly proportional to the product Q_1Q_2 of the charges
3. Inversely proportional to the square of the distance R between them.

Objectives:

The main objectives of this experiment are the following:

1. To Verify the Inverse Square Law: F ~ $1/R^2$
2. To Verify the Force and Charge Relationship: F ~ q_1q_2
3. To Determine Coulomb's constant: k for free space.
4. Neutralize force on a test charge by introducing another other charge

Theory:

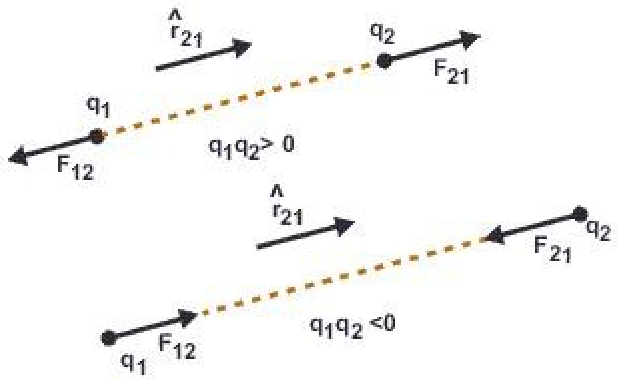
1. Coulomb's law

In order to obtain both the magnitude and direction of the force on a charge, q1 at position r1, experiencing a field due to the presence of another charge, q2 at position r2, in free space, the Coulomb's law is stated as below.

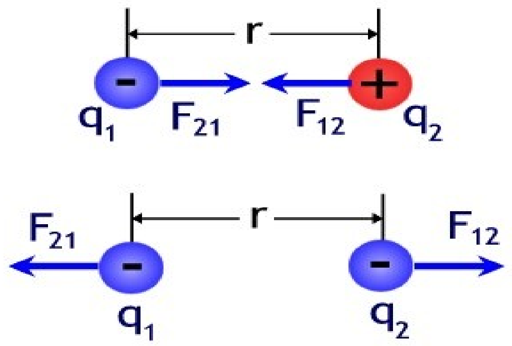
$$\mathbf{F} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2(\mathbf{r}_1 - \mathbf{r}_2)}{|\mathbf{r}_1 - \mathbf{r}_2|^3} = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}\hat{\mathbf{r}}_{21},$$

where r is the separation of the two charges. This is simply the scalar definition of Coulomb's law with the direction given by the unit vector $\hat{\mathbf{r}}_{21}$, parallel with the line from charge q2 to charge q1.

If both charges have the same sign (like charges) then the product q1q2 is positive and the direction of the force on q1 is given by r21; the charges repel each other. If the charges have opposite signs then the product q1q2 is negative and the direction of the force on q1 is given by -r21; the charges attract each other.



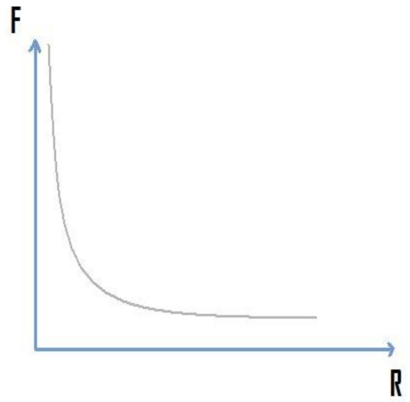
The proportionality constant $1/4\pi\varepsilon_0$, called the Coulomb constant (k) (sometimes called the Coulomb force constant), is related to defined properties of space.
$k = 1/4\pi\varepsilon_0$
$\varepsilon_0=8.85\text{x}10^{-12}\ C^2/N\text{-}m^2$ (ε_0 is the "permittivity of free space")
hence $k=9\text{x}10^9$



If both charges have the same sign (like charges) then the product q_1q_2 is positive and the direction of the force on q_1 is shown in above figure and the charges repel each other. If the charges have opposite signs then the product q_1q_2 is negative and the direction of the force on q_1 is shown in above figure and the charges attract each other.
force on q_2 due to q_1 is $F_{21} = -F_{12}$ and it is consistent with Newtons 3rd law.

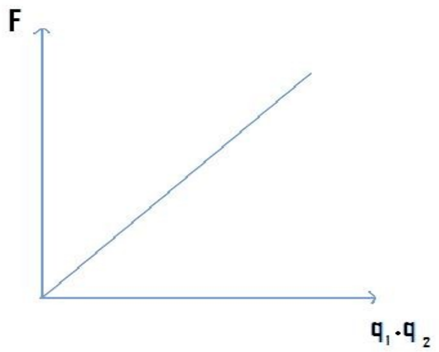
In this experiment, initially $F \sim 1/R^2$ will be verified using graph :

On keeping the value of charges fixed, if value of R ,i.e. distance between 2 point charges is changed we get a graph which shows F ~ $1/R^2$



Hence it can be easily seen that F ~ $1/R^2$
After verifying F ~ $1/R^2$, now F ~ q_1q_2 will be verified:

On keeping R, i.e. distance between 2 point charges constant, now if values of q_1 or q_2 or both are varied it can be seen from the graph that change in value of F will be according to the change in product of charges.



It can be seen that F ~ q_1q_2
Now concept of Principle of Superposition will be discussed

2. Principle of Superposition

Coulomb's law can be applied to any pair of point charges. When more than 2 charges are present, the net force on any one of the charge is the vector sum of forces exerted on it by other charges.

For example:

If 3 charges are present the net force experienced by q_3 due to q_2 and q_1 will be

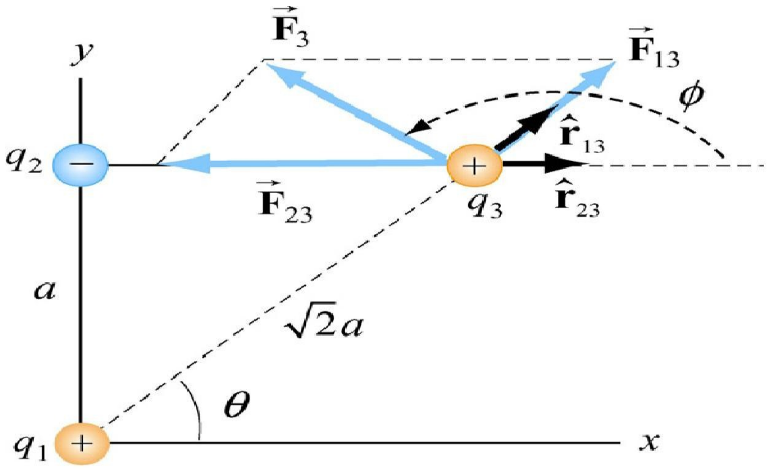
$$F_3=F_{13} + F_{23}$$

For a system of N charges the net force by the j th particle would be

$$F_j = \sum_{\substack{i=0 \\ j>0}}^{N} F_{ij}$$

where F_{ij} denotes the force between particle i and j.

Example 1) Three charges are arranged as shown in the figure. Find force on the charge $q_3$assuming that q_1 = 6.0x10^6 ,q_2=-q1, q_3= q_1/2 , and r=2.0x10^{-2} m.



$F_3 = F_{13} + F_{23}$

$$F_3 = \frac{1}{4\pi\epsilon_0\left(q_1 q_3 \frac{a_{13}}{r_{13}^2} + q_2 q_3 \ \frac{a_{23}}{r_{23}^2}\right)}$$

a_{r13} = cosθ a_x + sinθ a_y,

a_{r13} = (a_x +a_y)/$2^{1/2}$,

a_{r23}=a_x

Hence F_3=3.0N

φ=$\tan^{-1}(F_{3,y}/F_{3,x})$ =151.3^0.

Procedure:

This experiment consists of four stages and each stage will teach you a new concept.

The experiment was designed in a way, so that you can quickly change the parameters and observe the results. This makes you to have a more clear picture of the concepts.

Start the experiment by clicking on *start* button on the top of window.

- STAGE 1:

  In stage 1, we will see the force between two charges q1 and q2, seperated by distance r. Here, you can change the values q1, q2 and r by using sliders provided at the bottom of window. You have to observe the output values provied at the middle of window. Try to reason the observed values. You can pictorially see the variations in the graph provided at the right of window.
  So in the graph you should observe the fact that force is inversely proportional to square of the distance. To move on to next stage press *next* button on the top of window.

- STAGE 2:

  In stage 2, the concept is that Force is proportional to product of charges. This you can observe by changing parameters q1 and q2 by using sliders provided at the bottom of window. See the graph whether it was giving the same information to you or not. Also, you can conclude the fact that k remains constant.

- STAGE 3:

  In stage 3, observe the k value for free space by varying the charge values. Try to figure it out whether k for free space remains constant or not. See the graph between k for free space and F.

- STAGE 4:

  In this stage we see an interesting experiment. Try to add charges n to the screen by clicking mouse anywhere on the screen. Now you can see the resulting force on a charge due to other charges. We use the principle of superposition,
  $F_3=F_{13} + F_{23}$