جامعة الانبار
كلية العلوم التطبيقية – هيت
قسم البيئة
المرحلة الاولى

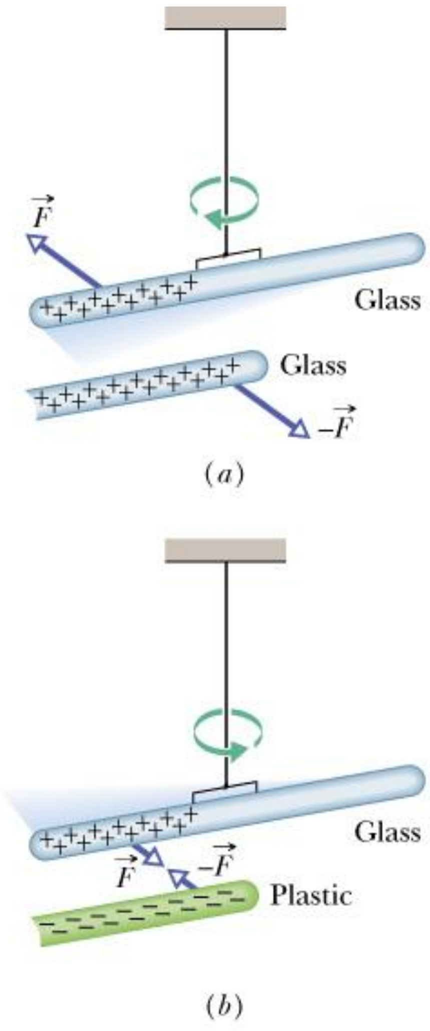
الفيزياء العامة

المحاضرة التاسعة : Coulomb’s Law

مدرس المادة : محمد قاسم طه

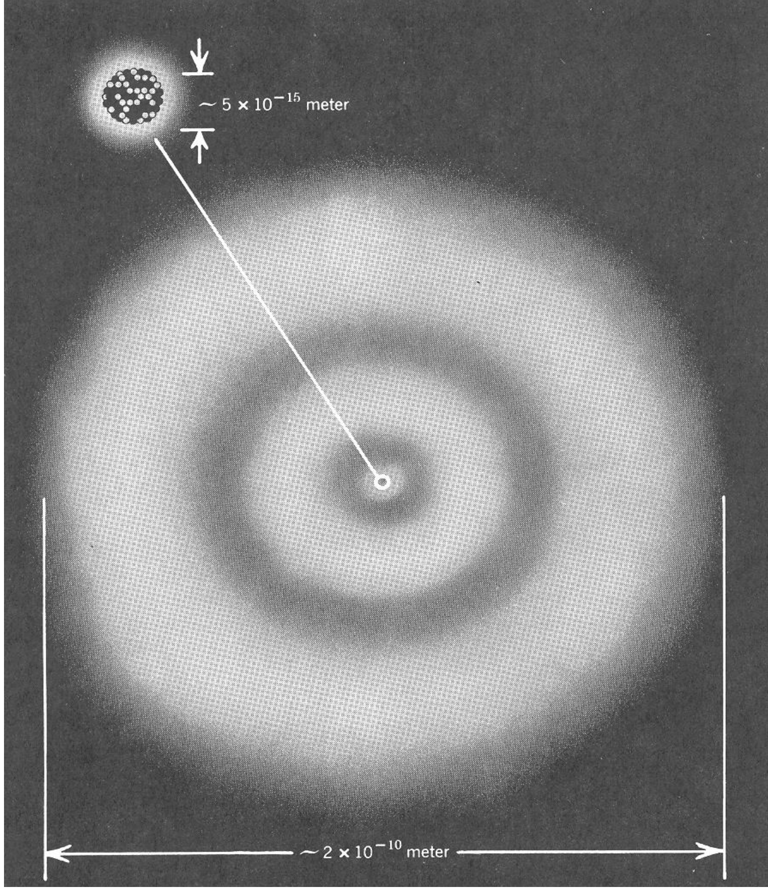
Force among two electric charges

- Experiments on charged objects show that
  - Charged objects with same sign repel each other
  - Charged objects with different sign attract each other



Atom

- In 18th century, it was assumed that electric charge is some type of weightless continuous fluid.
- Later on 20th century, Ernest Rutherford investigated structure of atom and revealed its constituents.



- Atom consists of electron and nuclei (proton and neutron).
  - Electron (e) is negatively charged.
  - Proton (p) is positively charged.
  - Neutron (n) is neutral (zero charge).

Charge quantization

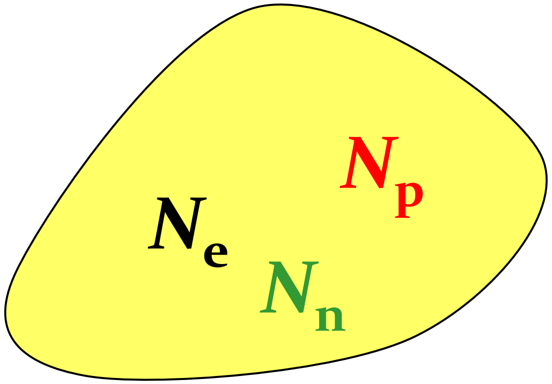
- The electric charge , q, is quantized : it exists as a discrete packets. (i.e. $q=\pm Ne$)
- The unit of charge is Coulomb (C).
- Neutron (n) : Mass $m = 1.675 \times 10^{-27}$ kg ; Charge $q = 0$
- Proton (p) : Mass $m = 1.673 \times 10^{-27}$ kg ; Charge $q = +1.602 \times 10^{-19}$ C
- Electron (e) : Mass $m = 9.11 \times 10^{-31}$ kg ; Charge $q = -1.602 \times 10^{-19}$ C
- **Note :** We use the symbol "-e" and "+e" for the electron and proton charge, respectively. This is known as the **elementary charge**

Example of charge quantization

- The net charge, Q_{net}, of any object is quantized (integral number of elementary charge)

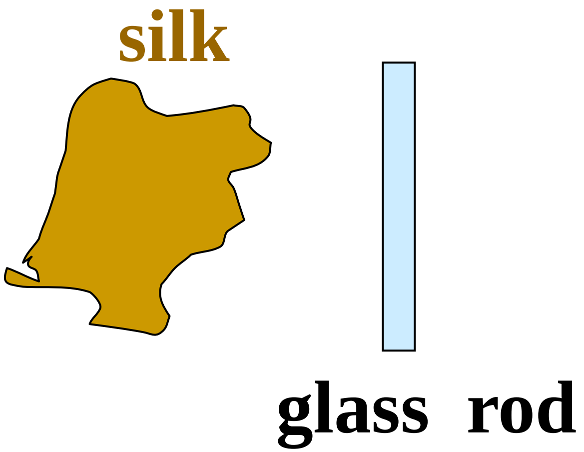
Q_{net} of an object that contains N_e electrons , N_p protons , and N_n neutrons is given by:

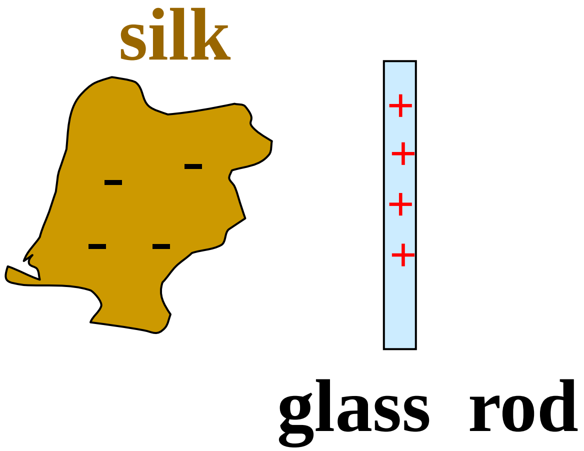
$$Q_{net} = -eN_e + eN_p + 0N_n = e\left(N_p - N_e\right) = ne$$



Conservation of charge

- Electric charge is always conserved in an isolated system
  - For example, charge is not created in the process of rubbing two objects together, it is just a transfer of charge.





Net charge before = Net charge after

$$Q_i = Q_f$$

Conductors, insulators, and semiconductors

- Electrical conductors are materials that have free electrons (electrons that can move freely in material), i.e. copper, iron.
- Electrical insulators are materials that most or all of there are bound electrons (electrons that are bound to atom and cannot move freely in material). i.e. glass, rubber
- Semiconductor are materials contain bound electrons that, under certain conditions, can turn into free electrons. i.e. silicon, germanium .

Charging a conductor by induction

- Can be done as follow:
  - Bring charged object close to a conductor.
  - Charged object will either repel or attract electrons of a conductor to the opposite end.
  - Connect a ground wire to the opposite end of a conductor causing electrons to go to ground(earth).
  - Disconnect ground wire.

Fig.a

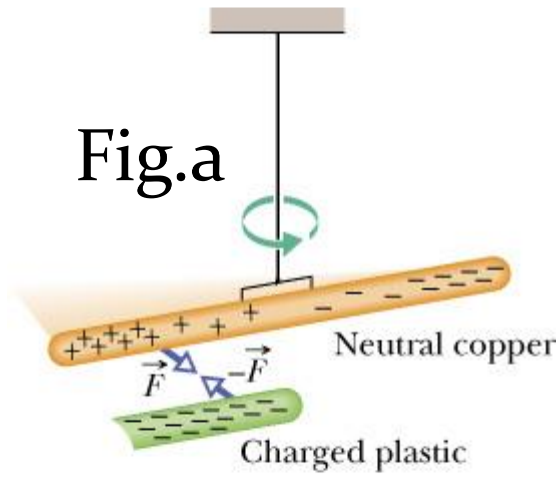
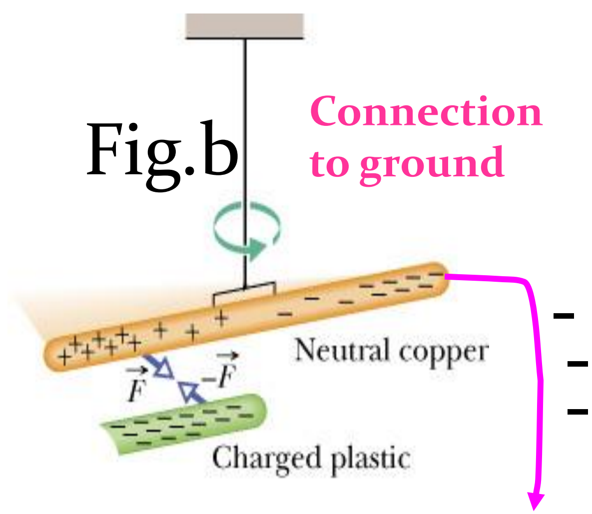


Fig.b

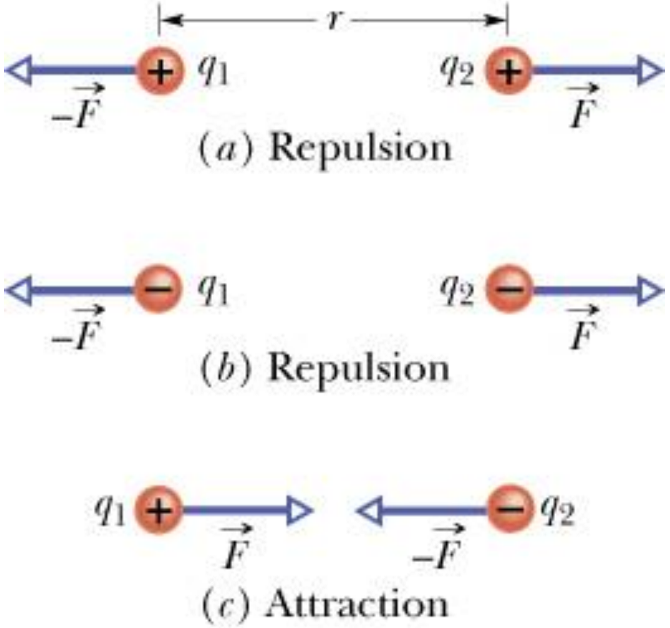


Coulomb's Law

- Charles Coulomb measured the magnitudes of electric forces between two small charged spheres
- He found the force depended on the charges and the distance between them
- The force has proportional correlation with the charges of the spheres
- The force has indirect correlation with the spacing of the sphere

Coulomb's Law

- Consider two point charges and placed at distance apart.
- The two charges exert force on each other along the line between them.
- The force is repulsion if the two charges are the same sign, the force is attraction if the two charges are the opposite sign.



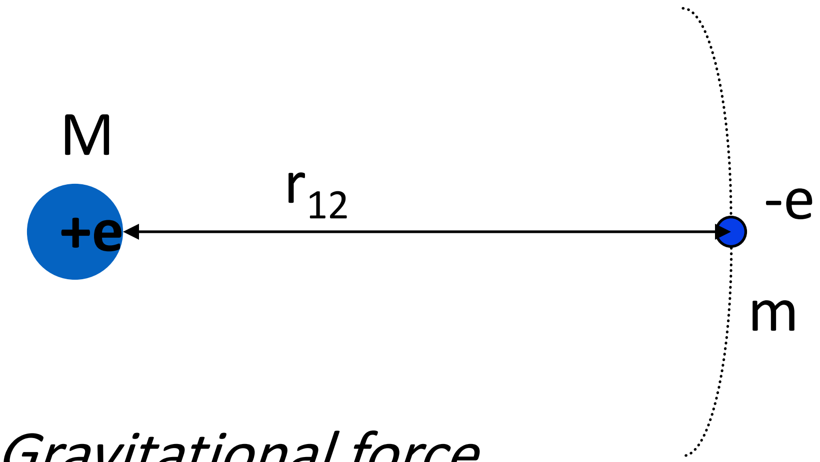
Coulomb's Law

- The magnitude of the force is given by:

$$F_e = k_e \frac{|q_1||q_2|}{r^2}$$

- k_e is called the **Coulomb constant**
  - $k_e = 8.9876 \times 10^9\ \mathrm{N{\cdot}m^2/C^2} = 1/(4\pi\varepsilon_o)$
  - ε_o is the **permittivity of free space**
  - $\varepsilon_o = 8.8542 \times 10^{-12}\ \mathrm{C^2 / N{\cdot}m^2}$

Gravitational and Electric Forces in the Hydrogen Atom



m = 9.1 10^{-31} kg
M = 1.7 10^{-27} kg
r_{12} = 5.3 10^{-11} m

Gravitational force

$$\vec{F}_g = G\frac{Mm}{r_{12}^2}\hat{r}$$

F_g = 3.6 10^{-47} N

Electric Force

$$\vec{F}_e = \left(\frac{1}{4\pi\varepsilon_0}\right)\frac{Qq}{r_{12}^2}\hat{r}$$

F_e = 3.6 10^{-8}N

Electrostatic force

- The electrostatic force is a vector, written $\vec{F}$
- Vectors have a magnitude and a direction. This may be indicated by components $\vec{F} = (F_x, F_y, F_z)$
- The magnitude is sometimes written as $\left|\vec{F}\right|$. It can be evaluated as $|\vec{F}| = \sqrt{F_x{}^2 + F_y{}^2 + F_z{}^2}$
- The direction can be indicated by a unit vector

Electrostatic force

Example

Two 0.5 kg spheres are placed 25 cm apart. Each sphere has a charge of 100 μC, one of them positive and the other negative. Calculate the electrostatic force between them, and compare it to their weight.

Coulomb's Law: $|F| = \frac{k\,|q_1|\,|q_2|}{r^2}$ $\quad k = 9 \times 10^9\ N\,m^2\,C^{-2}$

$$|q_1| = |q_2| = 100\ \mu C = 100 \times 10^{-6}\ C = 10^{-4}\ C$$

$$r = 25\ cm = 0.25\ m$$

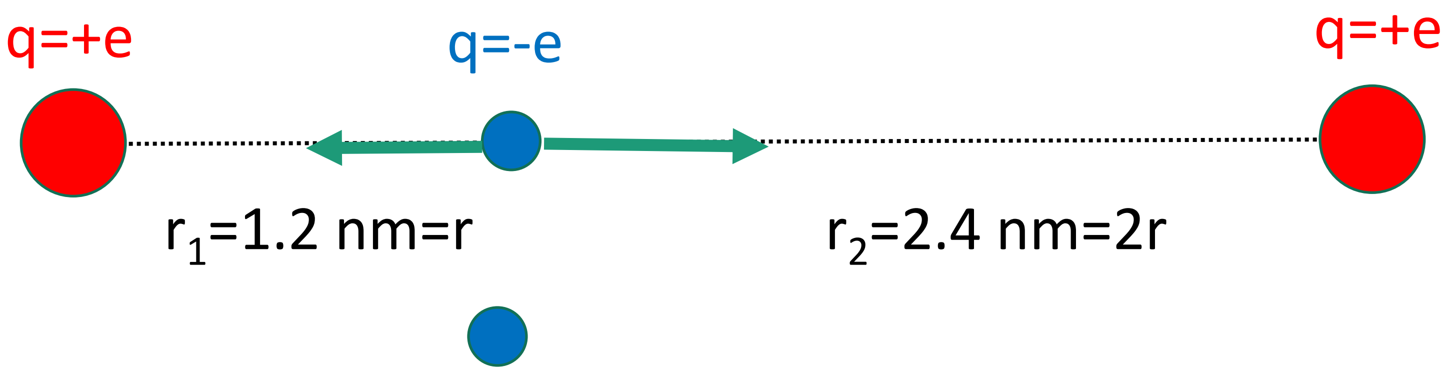
$$F_{electrostatic} = \frac{9 \times 10^9 \times 10^{-4} \times 10^{-4}}{0.25^2} = 1440\ N$$

$$F_{weight} = mg = 0.5 \times 9.8 = 4.9\ N$$

Electrostatic force

Example

Two protons are 3.6 nm apart. What is the total force on an electron located on the line between them, 1.2 nm from one of the protons? (elementary charge $e=1.6 \times 10^{-19}$ C)



$$|F_1| = \frac{k\,|q_1||q_2|}{{r_1}^2} = \frac{k\,e^2}{r^2} \qquad |F_2| = \frac{k\,|q_1||q_2|}{{r_2}^2} = \frac{k\,e^2}{(2r)^2}$$

$$|F_1| - |F_2| = \frac{ke^2}{r^2} - \frac{ke^2}{4r^2} = \frac{3ke^2}{4r^2} = \frac{3 \times 9 \times 10^9 \times (1.6 \times 10^{-19})^2}{4 \times (1.2 \times 10^{-9})^2} = 0.12\ nN$$

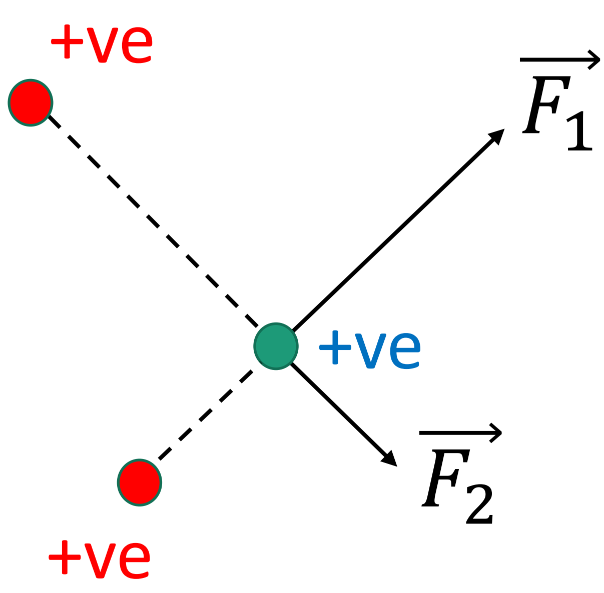
Superposition principle

- The resultant force on any one charge equals the vector sum of the forces exerted by the other individual charges that are present
    - Remember to add the forces *as vectors*
- The resultant force on q_1 is the vector sum of all the forces exerted on it by other charges:

$$\vec{\mathbf{F}}_1 = \vec{\mathbf{F}}_{21} + \vec{\mathbf{F}}_{31} + \vec{\mathbf{F}}_{41}$$

Superposition principle

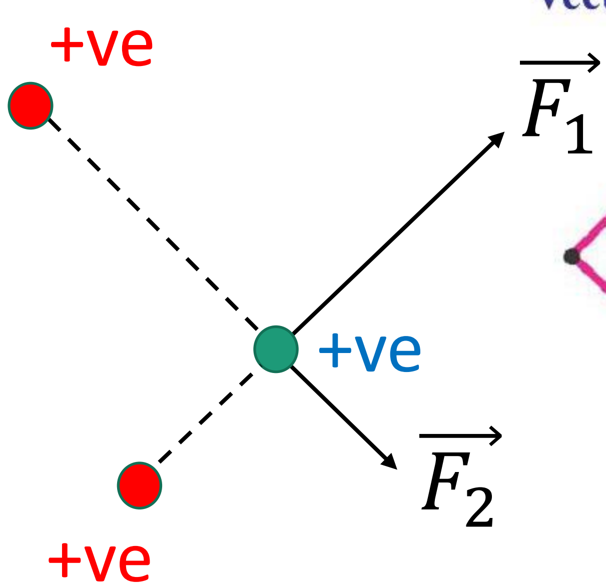
- Where multiple charges are present, the forces sum as vectors ("principle of superposition")

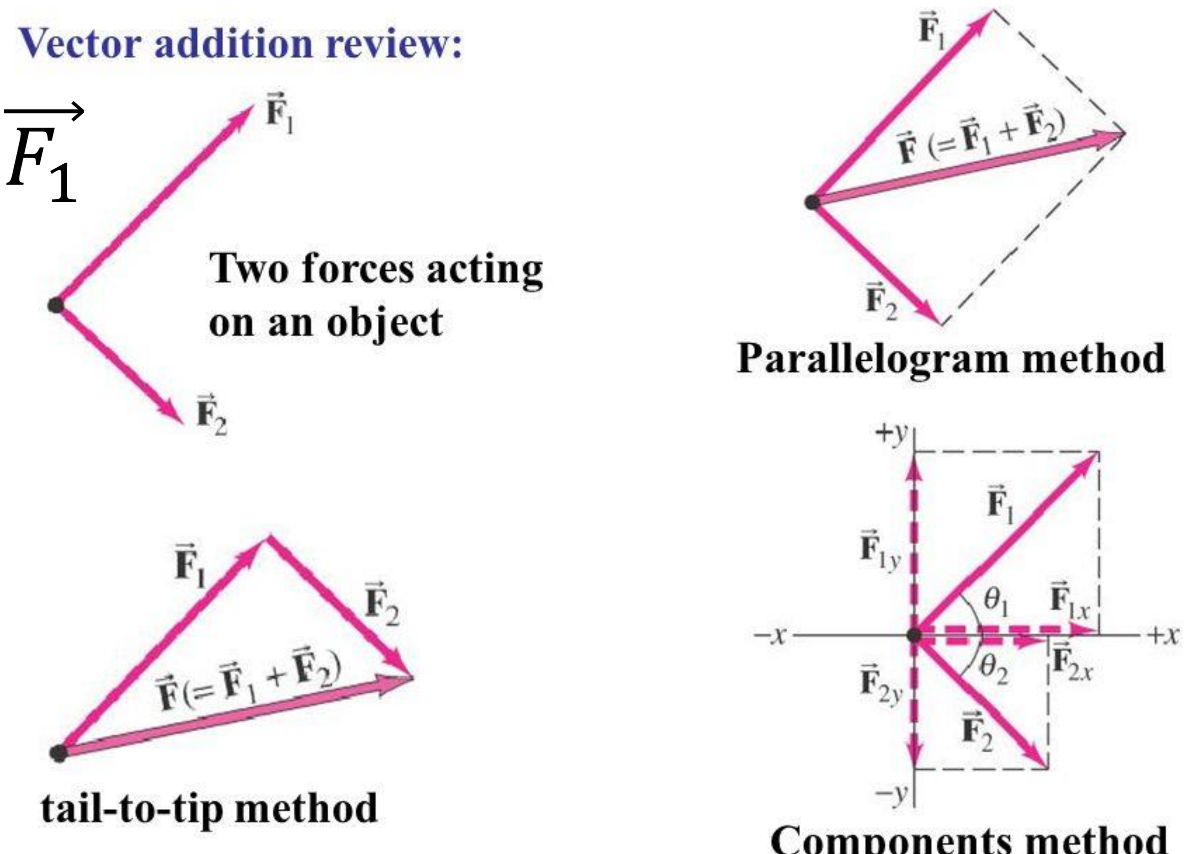


$$\overrightarrow{F_{total}} = \overrightarrow{F_1} + \overrightarrow{F_2}$$

Superposition principle

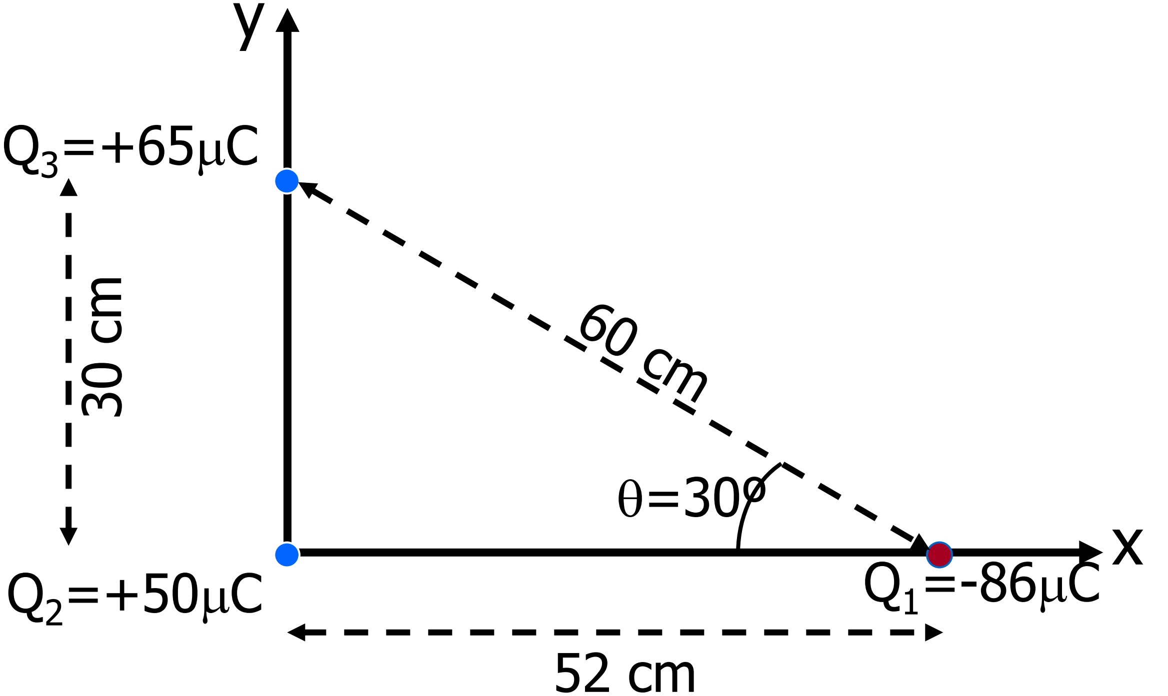
- Where multiple charges are present, the forces sum as vectors ("principle of superposition")





Solving Problems Involving Coulomb's Law and Vectors

Example: Calculate the net electrostatic force on charge Q_3 due to the charges Q_1 and Q_2.



Step 0: Think!

This is a Coulomb's Law problem (all we have to work with, so far).

We only want the forces on Q_3.

Forces are additive, so we can calculate $\vec{F}_{32}$ and $\vec{F}_{31}$ and add the two.

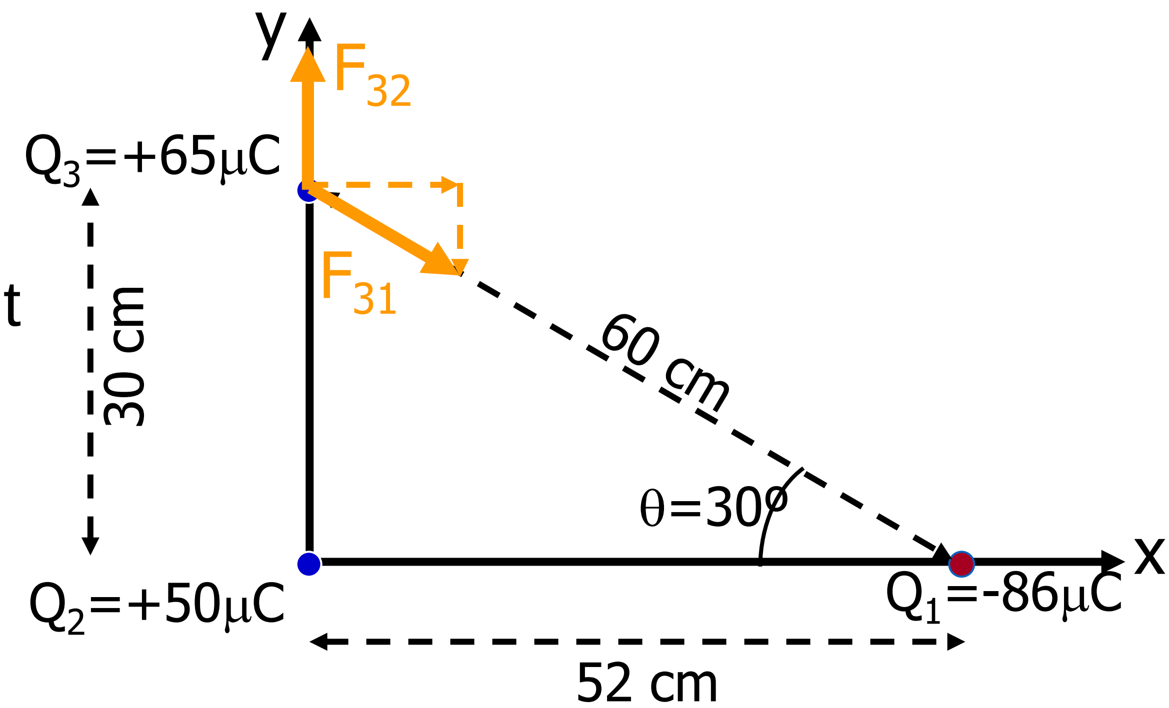
If we do our vector addition using components, we must resolve our forces into their x- and y-components.

Step 1: Diagram

Draw a representative sketch.

Draw and label relevant quantities.

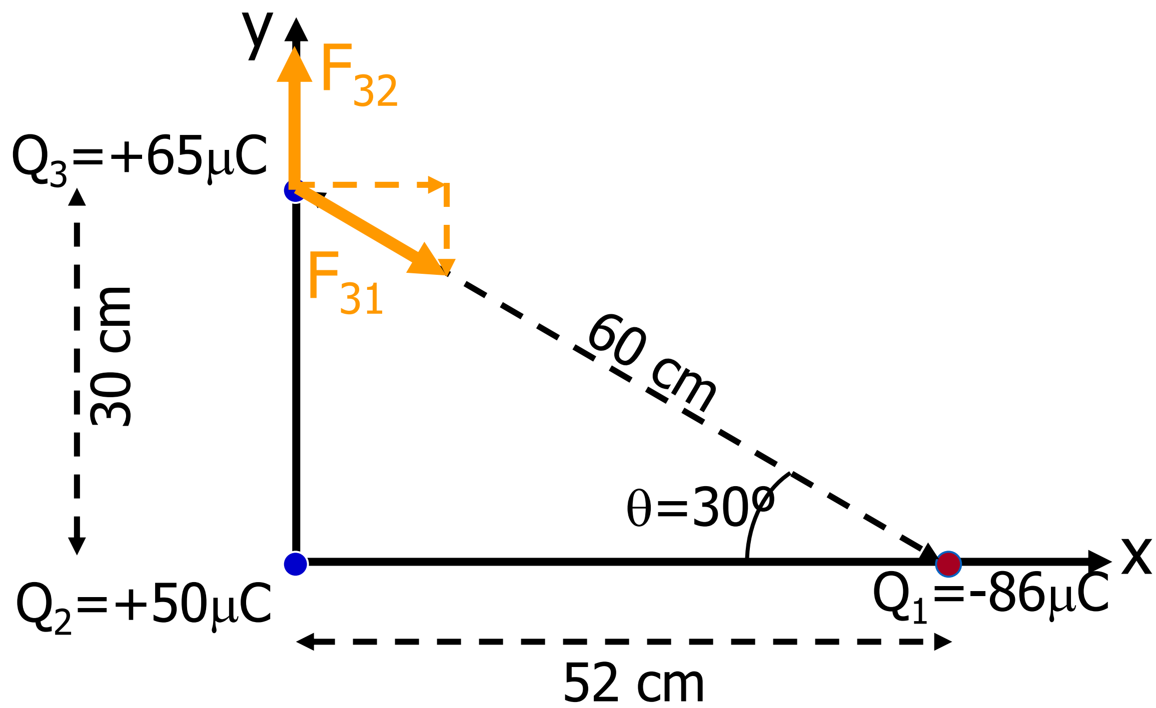
Draw axes, showing origin and directions.



Draw and label forces (only those <u>on</u> Q_3).

Draw components of forces which are not along axes.

Step 2: Starting Equation



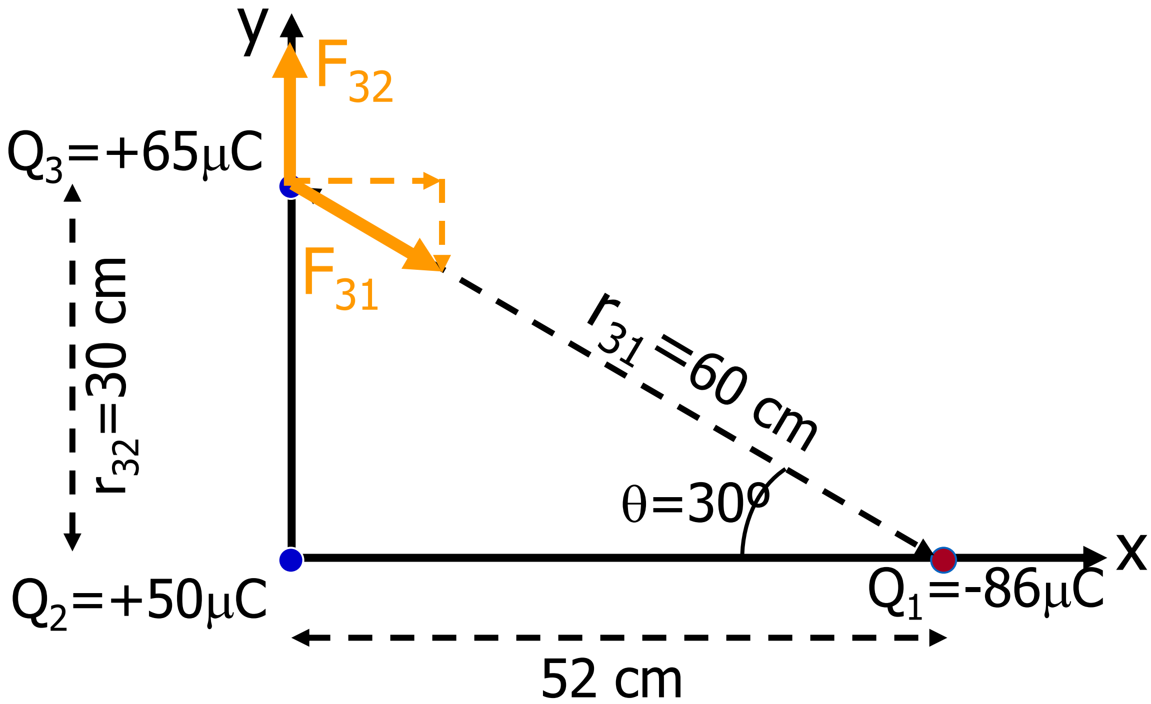
$$F_{12} = k\frac{|q_1 q_2|}{r_{12}^2}$$

"Do I have to put in the absolute value signs?"

Step 3: Replace Generic Quantities by Specifics

$$\vec{F}_{32} = k\frac{|Q_3 Q_2|}{r_{32}^2},$$

repulsive



$$F_{32,y} = k\frac{|Q_3 Q_2|}{r_{32}^2}$$

$$F_{32,x} = 0$$ (from diagram)

$F_{32,y}$ = 330 N and $F_{32,x}$ = 0 N.

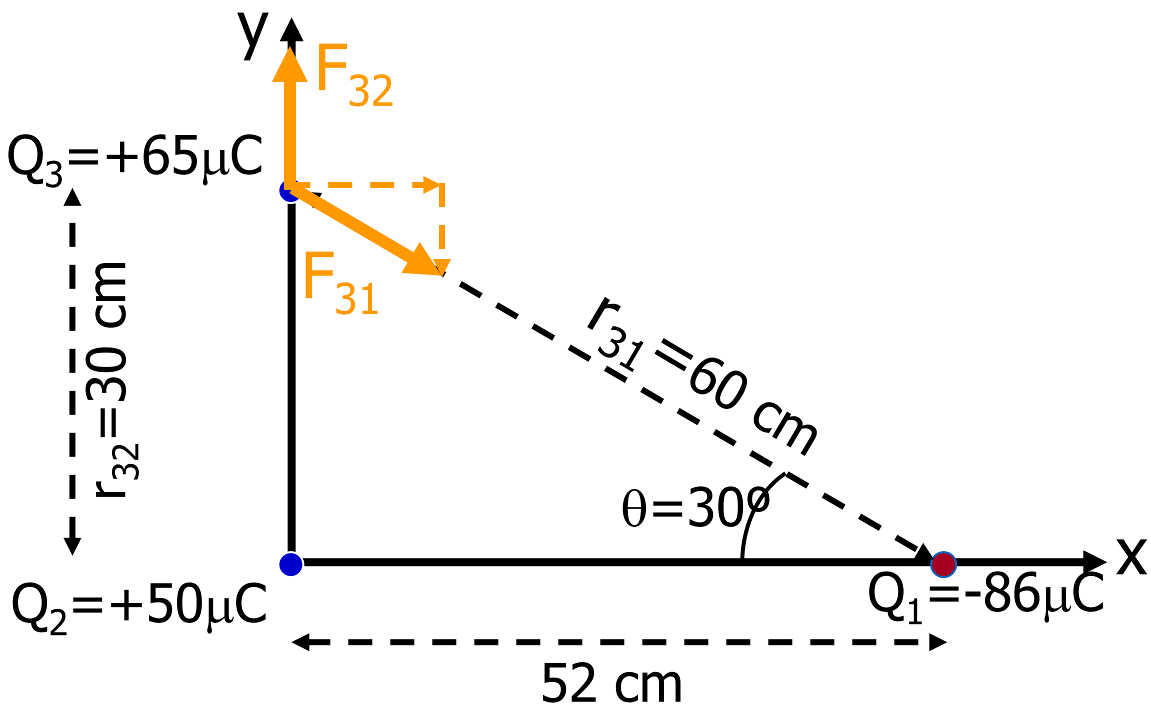
Step 3 (continued)

$$\vec{F}_{31} = k\frac{|Q_3Q_1|}{r_{31}^2},$$

attractive

$$F_{31,x} = +k\frac{|Q_3Q_1|}{r_{31}^2}\cos\theta$$

(+ sign comes from diagram)



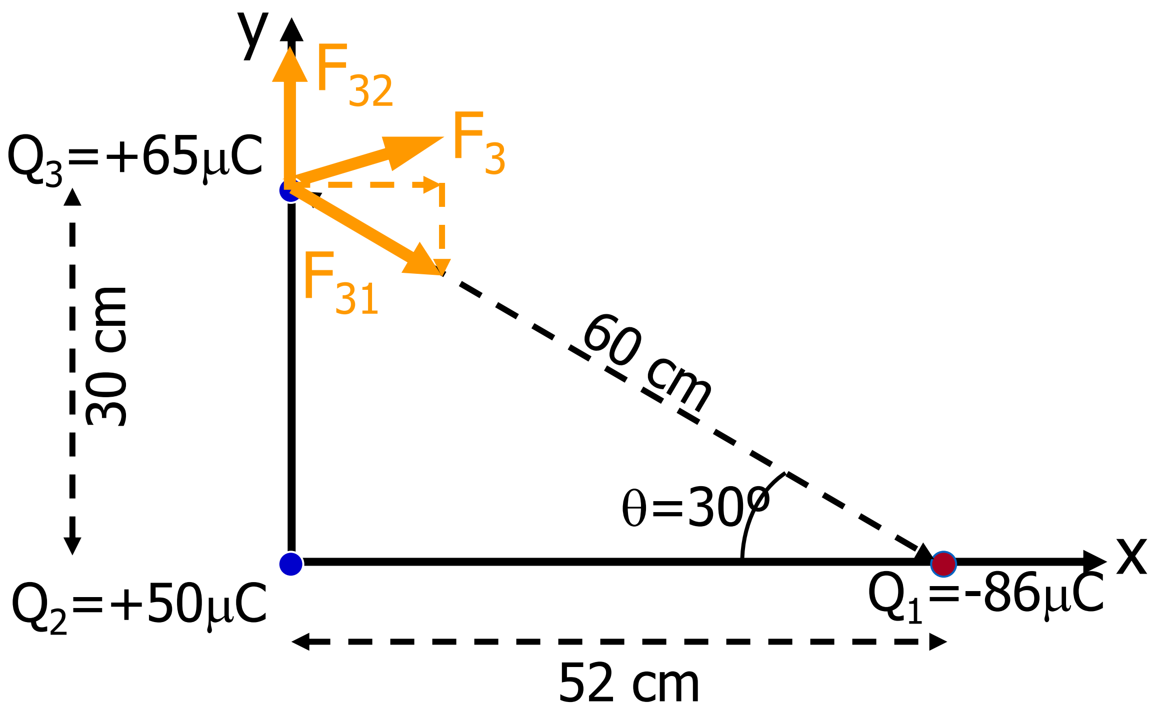
$$F_{31,y} = -k\frac{|Q_3Q_1|}{r_{31}^2}\sin\theta$$

(- sign comes from diagram)

You would get $F_{31,x}$ = +120 N and $F_{31,y}$ = -70 N.

Step 3: Complete the Math

The net force is the vector sum of all the forces on Q_3.



$F_{3x} = F_{31,x} + F_{32,x} = 120\text{ N} + 0\text{ N} = 120\text{ N}$

$F_{3y} = F_{31,y} + F_{32,y} = -70\text{ N} + 330\text{ N} = 260\text{ N}$

You know how to calculate the magnitude F_3 and the angle between $\vec{F}_3$ and the x-axis.

Homework

Find the position of q_3 so that it has net force equal to zero acting on it.