ELECTRICITY AND MAGNETISM

Overview

- The physics of electromagnetism is the combination of electric and magnetic phenomena
- The basis of electronic devices: computers, TV, radio, telecommunications, lamps,…
- The basis of the nature phenomena: lightning, auroras

Electric Charge and the Coulomb's law

Electric Charge

"Electric charge is an intrinsic characteristic of the fundamental particles which combine to make objects"

It is a property that comes automatically with those fundamental particles wherever they exist.

- An everyday object usually contains equal amounts of the two kinds of charge:

positive charge and negative charge

Electrically neutral obj:

- With such an equality-or balance-of charge, the object is said to be electrically neutral; that is, it contains no net charge.

Electric Charge cont….

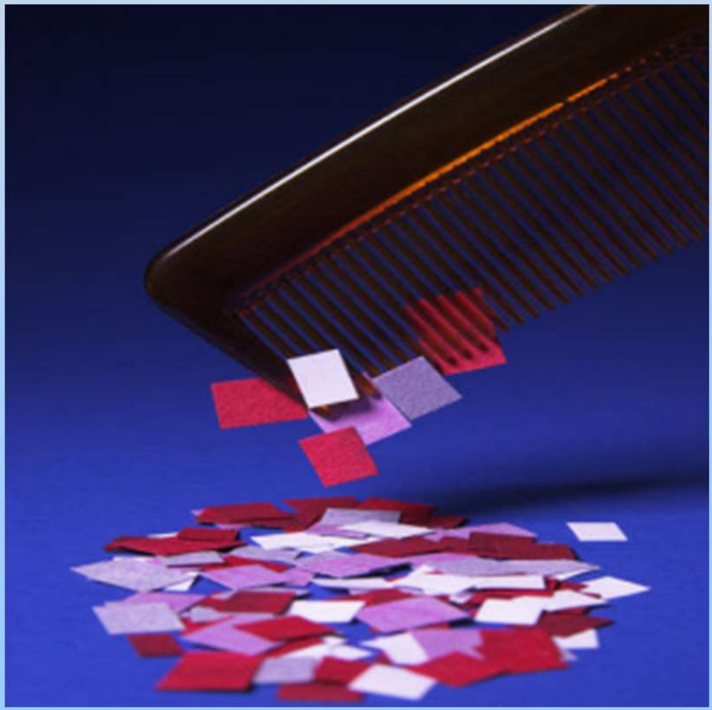
Charged objects:

- If the two types of charge are not in balance, then there is a net charge. We say that an object is charged to indicate that it has a charge imbalance, or net charge.

Experiment:

Rubbing a plastic comb with wool (dry weather), small pieces of paper can stick to the comb.

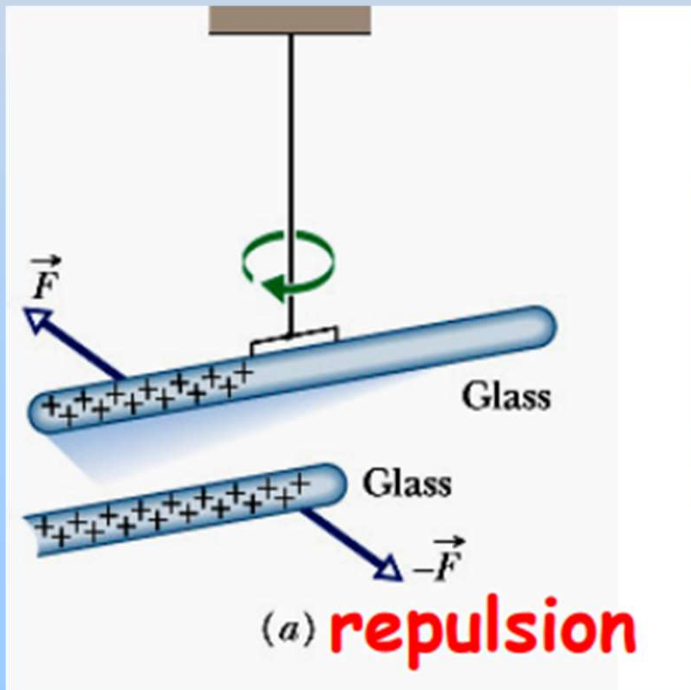
Why?

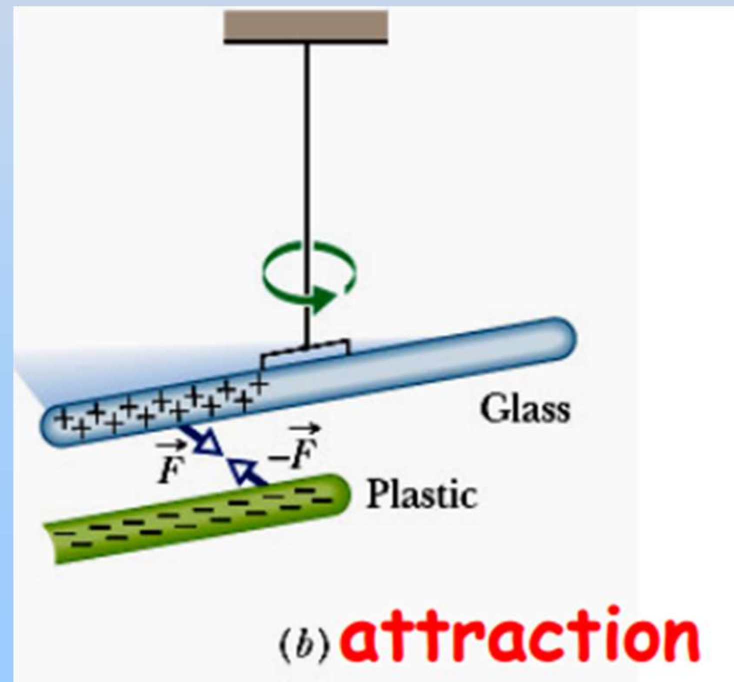


Electric Charge (Properties)

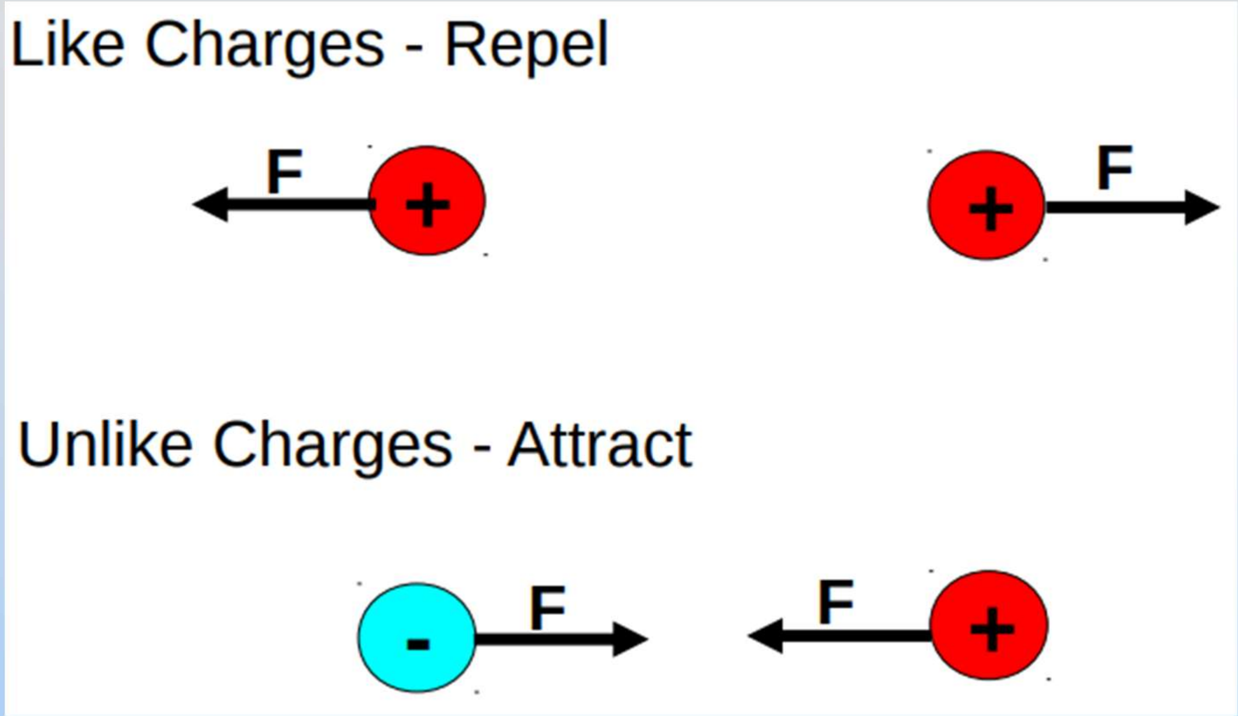
Charged objects interact by exerting forces on one another.

- **Charges with the same electrical sign repel each other, and charge with opposite signs attract each other**





Electric Forces



Quantization of charge

Any positive or negative charge q that can be detected can be written as

$$q = ne, n = \pm 1, \pm 2, \pm 3, \ldots$$
$$e = 1.602 \times 10^{-19}\ \text{C}$$

- **SI unit of charge: C (Coulomb),**
- **where e is the elementary charge**

Particle	Symbol	Charge
Electron	e or e^-	-e
Proton	p	+e
Neutron	n	0

Quantization of charge

- The elementary charge e is one of the important constants of nature.

- The electron and proton both have a charge of magnitude e.

- When a physical quantity such as charge can have only discrete values rather than any value, we say that the quantity is quantized.

- It is possible, for example, to find a particle that has no charge at all or a charge of + 10e or -6e, but not a particle with a charge of, say, 3.57e.

Conservation of Charge

- Charge can neither be created nor destroyed but it can be transfer from one object to the other.

- If you rub a glass rod with silk, a positive charge appears on the rod. Measurement shows that a negative charge of equal magnitude appears on the silk. This suggests that rubbing does not create charge but only transfers it from one body to another, upsetting the electrical neutrality of each body during the process.

Conservation of Charge Examples

- **Important examples** of the conservation of charge occur in the radioactive decay of nuclei, in which a nucleus transforms into (becomes) a different type of nucleus.

- **Example :1** A uranium-238 nucleus ^{238}U transforms into a thorium-234 nucleus (^{34}Th) by emitting an alpha particle.

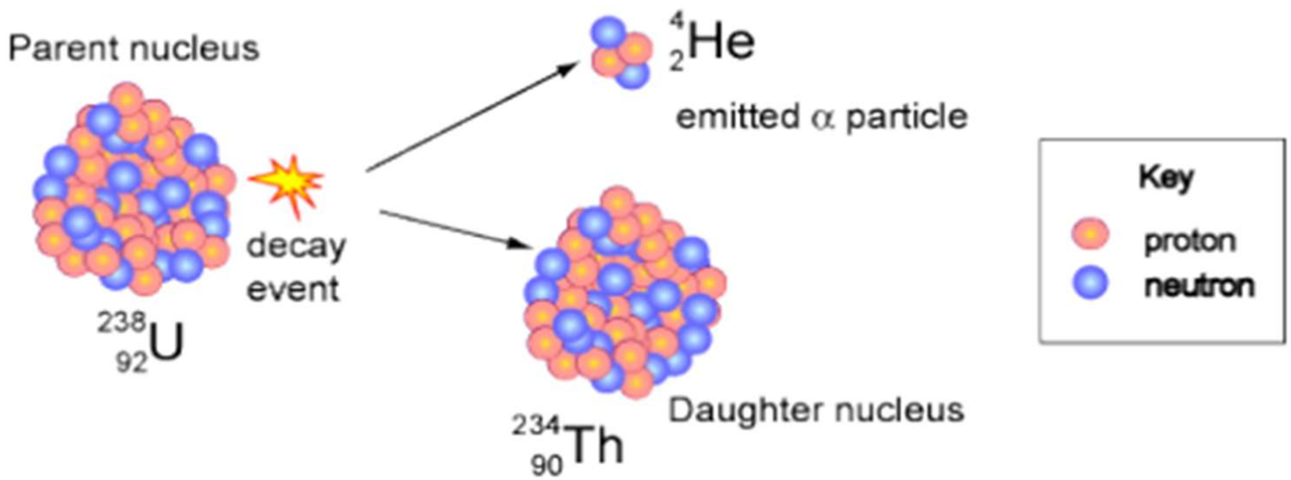
Conservation of Charge Examples

- **Example 1: Decay of $^{238}_{92}U$**

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$$

The total charge is +92e that is conserved

Alpha Decay of a Uranium-238 nucleus



- **Example 2: Annihilation of electron e^- and positron e^+ or pair production**

$$e^- + e^+ \rightarrow \gamma + \gamma : \text{annihilation}$$

$$\gamma \rightarrow e^- + e^+ : \text{pair production}$$

Important Note

- The term point charge refers to a particle of zero size that carries an electric charge.

  - The electrical behavior of electrons and protons is well described by modeling them as point charges.

- Remember the charges need to be in coulombs.
  e is the smallest unit of charge except quarks

$$e = 1.6 \times 10-19 \text{ C}$$

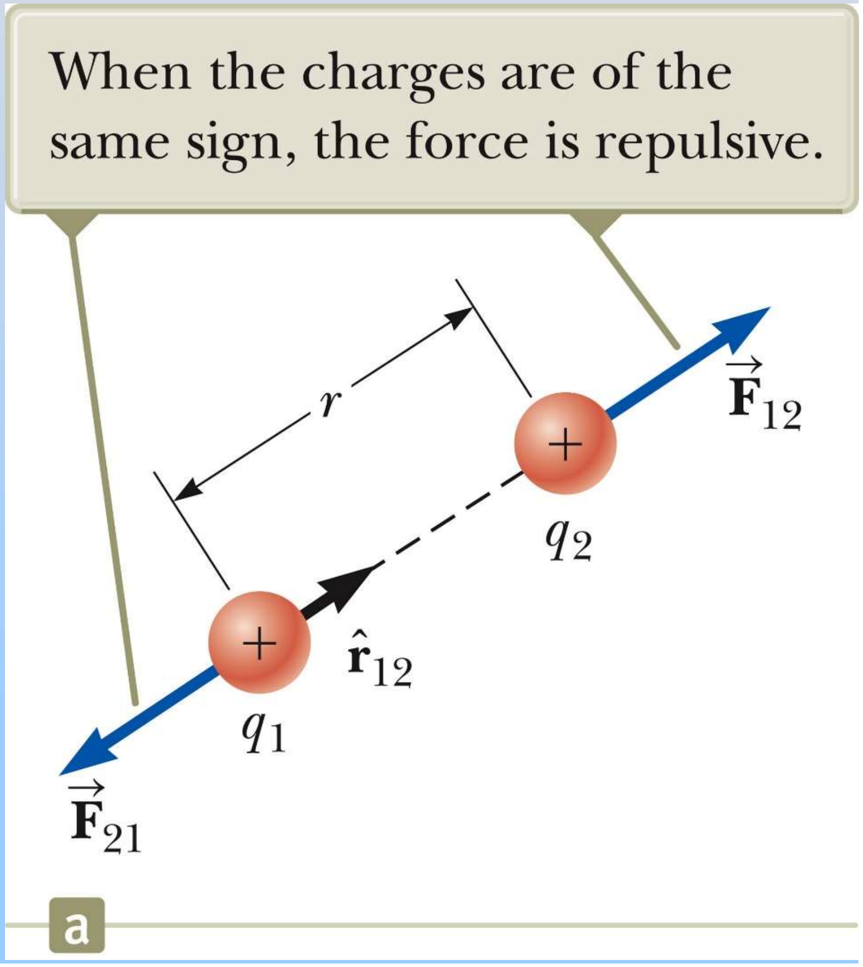
So 1 C needs 6.24×10^{18} electrons or protons
Typical charges can be in the µC range.

- Remember that force is a vector quantity.

Coulomb's Law

The Coulomb's law gives the electric force between two point charges

"The magnitude of the electric force between two point charges is directly proportional to the product of the charges and inversely proportional to the square of the distance between them"



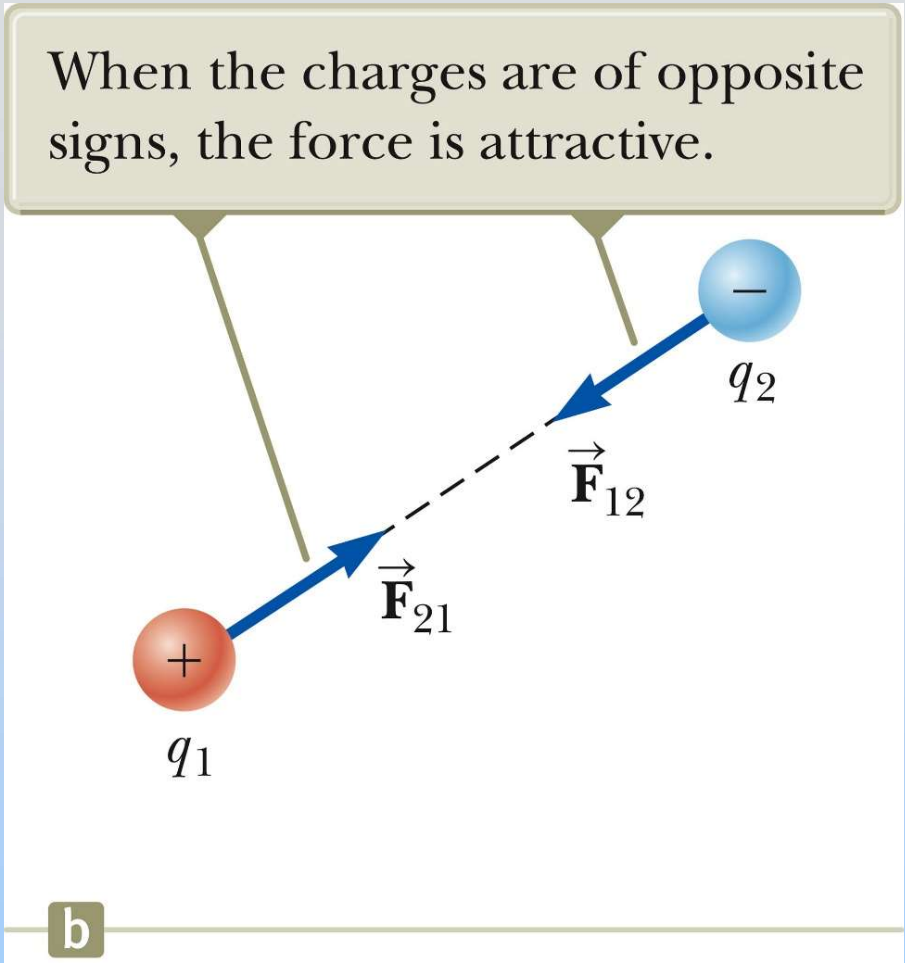
In vector form

$$\vec{\mathbf{F}}_{12} = k_e \frac{q_1 q_2}{r^2} \hat{\mathbf{r}}_{12}$$

Coulomb's Law

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

Inverse square law



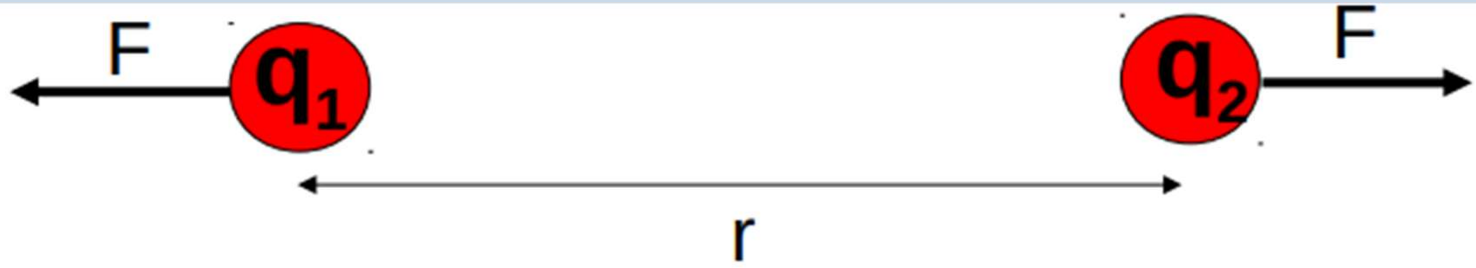
Coulomb's constant: $$k = 8.988\text{x}10^9 \frac{N - m^2}{C^2} \approx 9.0\text{x}10^9 \frac{N - m^2}{C^2} = \frac{1}{4\pi\varepsilon_o}$$

permittivity of free space: $$\varepsilon_o = \frac{1}{4\pi k} = 8.85\text{x}10^{-12} \frac{C^2}{N - m^2}$$

Coulomb's Law

Two charges are separated by a distance r and have a force F on each other.

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



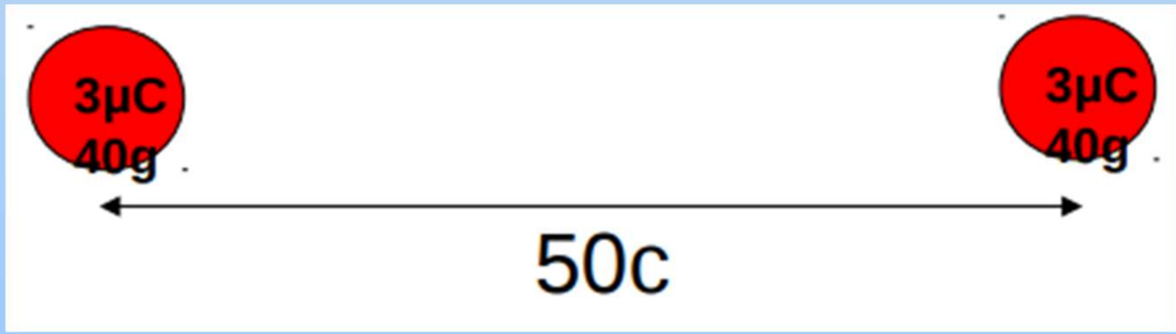
If r is doubled then F is : ¼ of F

If q_1 is doubled then F is : 2F

If q_1 and q_2 are doubled and r is halved then F is : 16F

Comparison of the Coulomb's force and gravitational force

Two 40 gram masses each with a charge of 3μC are placed 50cm apart. Compare the gravitational force between the two masses to the electric force between the two masses. (Ignore the force of the earth on the two masses)



Comparison of the Coulomb's force and gravitational force

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

$$= 6.67\times10^{-11}\frac{(.04)(.04)}{(0.5)^2} \quad 4.27\times10^{-13}N$$

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

$$= 9.0\times10^{9}\frac{(3\times10^{-6})(3\times10^{-6})}{(0.5)^2} \quad 0.324\,N$$

The electric force is much greater than the gravitational force

Effect of Medium on the Coulomb Force

Coulomb's Law in Vacuum

$$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_3}{r^2}$$

Relative Permitivity ε_r

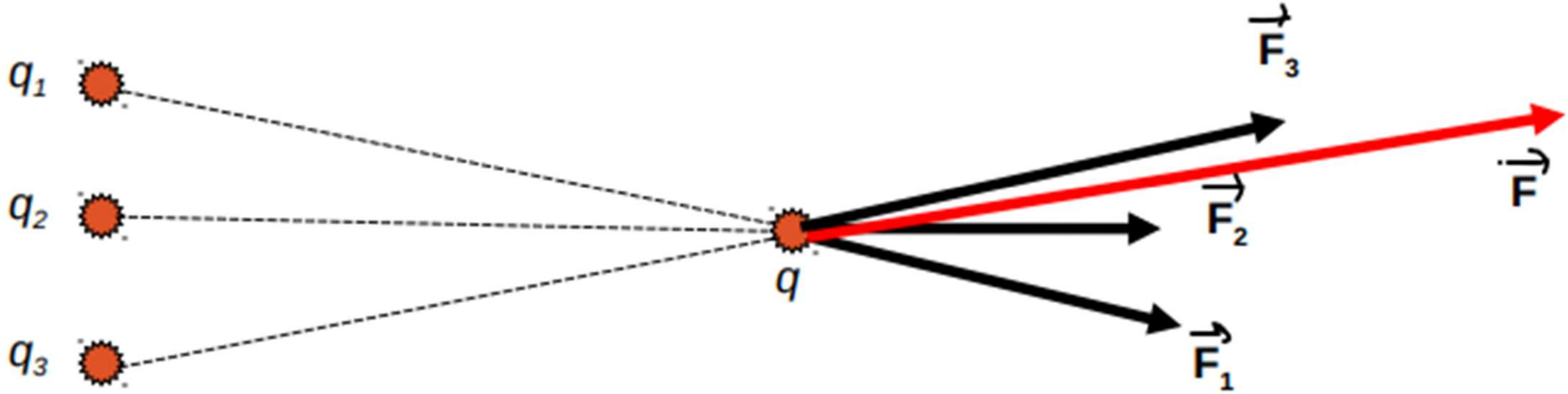
$$\varepsilon_r = \frac{\varepsilon_{med}}{\varepsilon_0}$$

$$F_{med} = \frac{1}{4\pi\varepsilon_{med}}\frac{q_1 q_3}{r^2}$$

$$=> F_{med} = \frac{F_{vac}}{\varepsilon_r}$$

Superposition of electric forces

Net force is the *vector sum* of forces from each charge

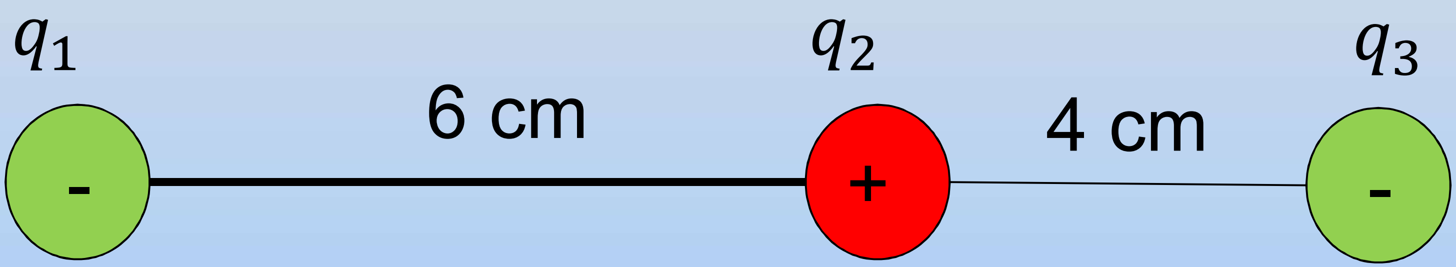


Net force on q

$$\vec{F} = \vec{F}_1 + \vec{F}_2\ \vec{F}_3$$

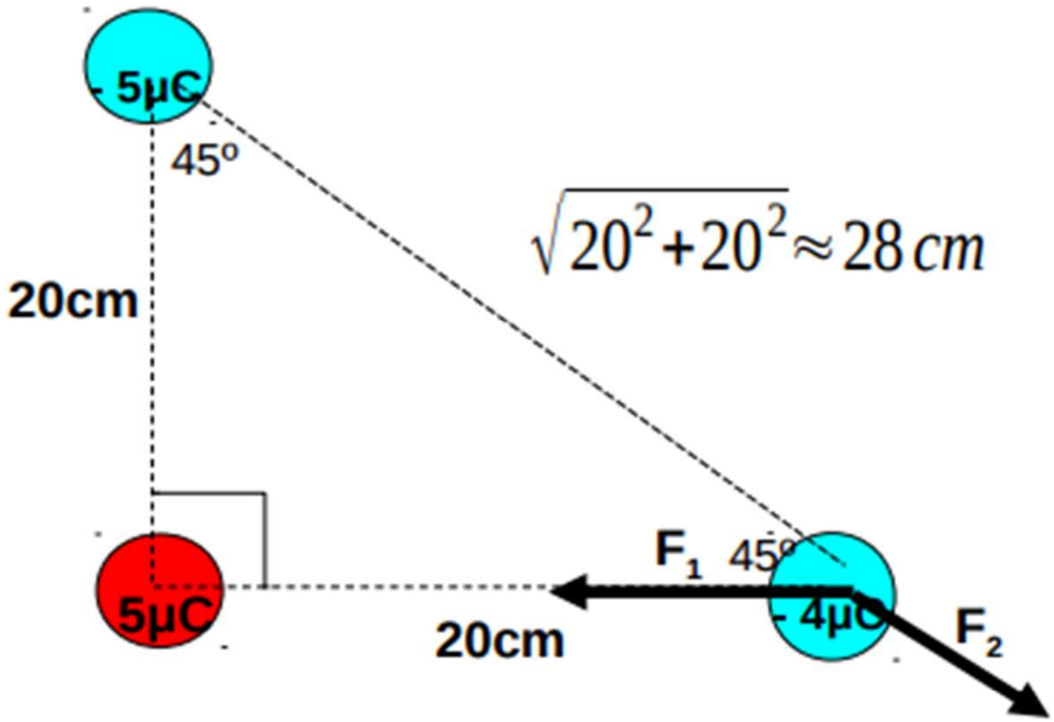
Problem:

Three charges q_1 = -5 μC, q_2= +10 μC and q_3 = -12 μC are placed in a line as shown in the figures. Calculate the net electrostatic force on q_2 due to other two charges.



Problem:
Three charged objects are placed as shown. Find the net force on the object with the charge of -4μC

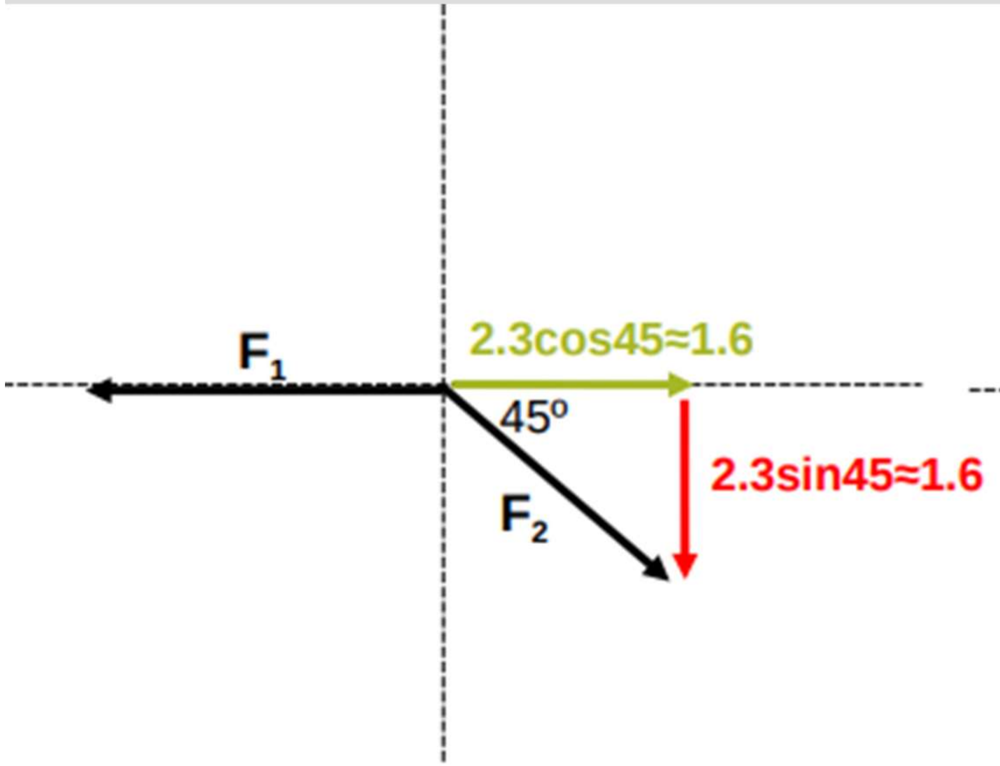
$$F = k\frac{q_1 q_2}{r^2}$$

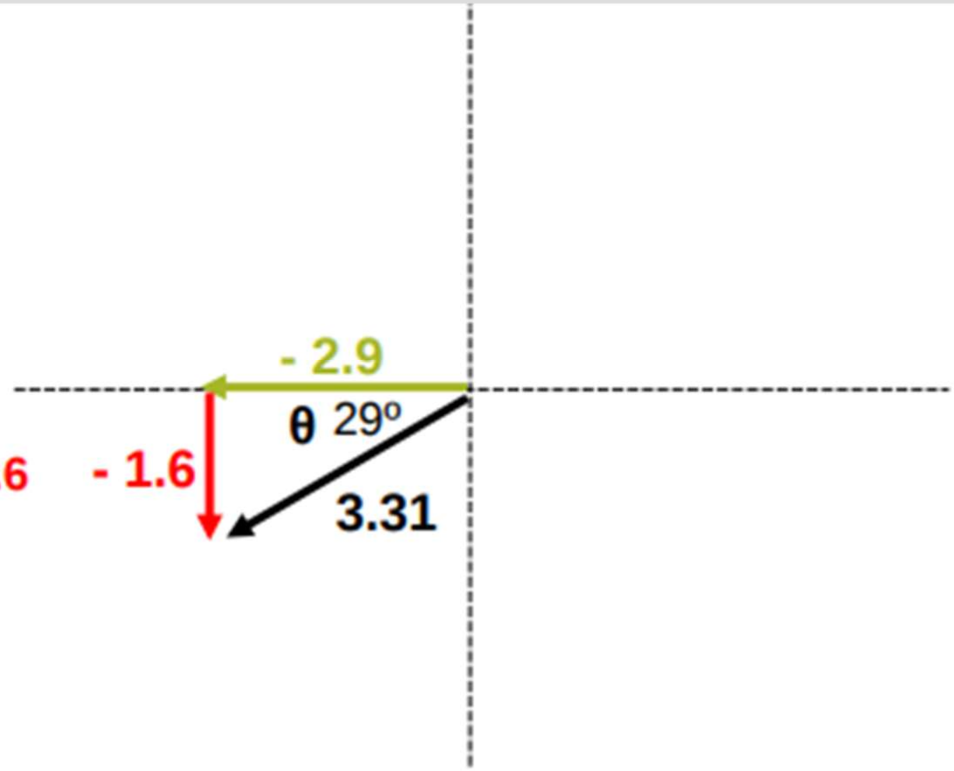


$$F_1 = 9\times10^9 \frac{(5\times10^{-6})(4\times10^{-6})}{(0.20)^2} = 4.5\,N$$

$$F_2 = 9\times10^9 \frac{(5\times10^{-6})(4\times10^{-6})}{(0.28)^2} = 2.30\,N$$

F_1 and F_2 must be added together as vectors.





$$F_1 = < -4.5\ ,\ \ 0.0 >$$

$$+\quad F_2 = < 1.6\ ,\ -1.6 >$$

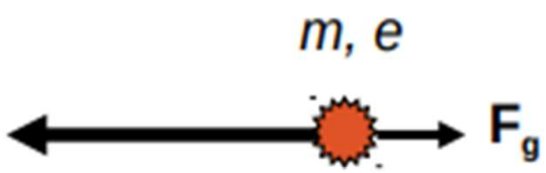
$$F_{net} = < -2.9\ ,\ -1.6 >$$

$$F_{net} = \sqrt{2.9^2 + 1.6^2} \approx 3.31\,N$$

$$\theta = \tan^{-1}\left(\frac{-1.6}{-2.9}\right) \approx 29^{\circ}$$

$$\boxed{3.31\text{N at } 29^{\circ}}$$

Example: Coulomb force *vs* gravity for electrons



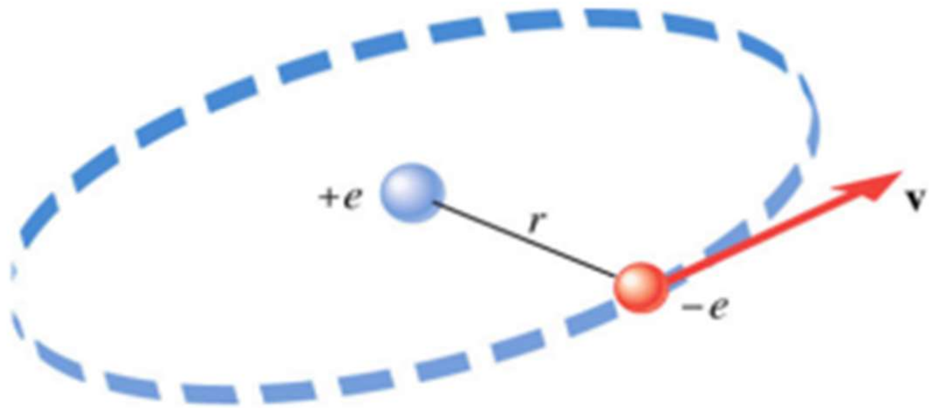
$$F_C = ke^2/r^2 \qquad\qquad F_N = Gm^2/r^2$$

Ratio:

$$\frac{F_C}{F_N} = \frac{ke^2}{Gm^2} = \frac{(9 \times 10^9)(1.6 \times 10^{-19})^2 N}{(6.7 \times 10^{-11})(9.1 \times 10^{-31})^2 N}$$

$$= 4 \times 10^{42}$$

Example: Velocity of an electron in the Bohr Atom



Coulomb force: $F = kq_1q_2/r^2$ (attractive)

Circular motion requires: $F = mv^2/r$

So,

$$v^2 = kq_1q_2/mr$$

For $r = 5.29 \times 10^{-11}$m, $v = 2.18 \times 10^6$ m/s