Lecture 1

Topics:

- some history
- electrostatic forces
- charge quantization and conservation
- Coulombs Law
- superposition principle

History

600 BC Thales of Maletus - rupped amber which attracted straw

? Observed naturally occurring magnetite attracts iron.

1706-1790 Ben Franklin identified charge deposited on glass +

1736 - 1806 Charles Coulomb - quantitative measurements of electrostatic force

1820 Hans Christian Oersted observed an electric current making a compass needle move

1791-1867 Michael Faraday - important series of experiments on electromagnetic phenomena.

1831-1879 James Clerk Maxwell - mathematical formulation of the laws of electromagnetism

The theory - called <u>classical electromagnetism</u> is responsible for most non-gravitational macroscopic physics.

<u>context</u>:

It is believed that there are four fundamental forces of nature

① gravitational force - weak, attractive long range - responsible for orbits of planets around sun.

② electromagnetic forces –
intermediate strength, long range,
attractive and repulsive

③ weak force – weak strength –
short-range

responsible for radiative decay

$$n \rightarrow p_+ + e_- + \nu$$

④ strong force – strong, short range
attractive

responsible for keeping atomic
nucleus together.

* electromagnetic force responsible
for light, radio waves, chemical
reactions, ...

Observations – <u>electrostatic forces</u>

rub glass with silk
rub plastic with fur

2 glass rods repel

2 plastic rods repel

1 plastic + 1 glass rod attract.

conclusion

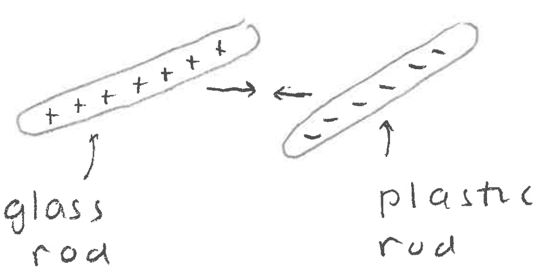
something is deposited on the rods that causes them to repel.

what is deposited on the glass and plastic rods are different

What is deposited on each rod is called electric charge

The exercise suggests that there are 2 kinds of charges. They are labeled + = positive charge
− = negative charge

By convention the charge on the glass is called positive charge, the charge on the plastic is called negative charge



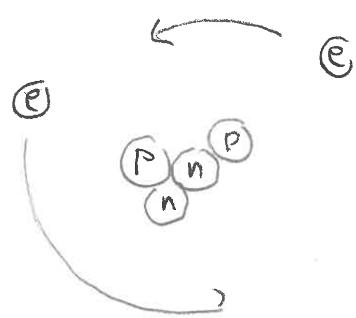
There are 2 types of electri charge - positive and negative

like charges repel

unlike charges attract

What is going on ?

Most visible matter is made of atoms. Atoms have a core consisting of protons and neutrons. Electrons orbit outside of the core



It has been determined that each proton has a unit of positive charge, and each electron has a corresponding unit of negative charge.

A typical atom has the same numbers of electrons and protons. The total amount of positive charges = the total amount of negative charge. When the numbers of positive charges is equal to the number of negative charges the object the object is electrically neutral.

If we bring a positive charge near a neutral atom it will not move because the attractive forces due to the electrons cancel the repulsive forces due to the protons

The nucleus of the atom looks like it should not be stable because the protons repel each other. The reason that the nucleus stays together-is because there is another stronger attractive force. It is called the strong force — it is much stronger than the electric force, but it has a very short range (about 10^{-15} meters)

what happened with the glass and plastic rods?

Both start out being electrically neutral — having approximately equal numbers of protons and electrons.

when the glass is rubbed with silk electrons in the glass get transferred to the silk, leaving the glass with an <u>exess of positive charge</u>

Similary — when the plastic rod is rubbed with fur, the fur deposits electrons on the plastic and it gets an <u>excess of negative charge</u>

In most cases it is the electrons that move. The protons are more tightly bound in the atomic nucleus, in addition the mass of an electron is about 1/2000 × the mass of a proton

$$m_e \approx 9.1 \times 10^{-31} \text{ kg}$$

$$m_p \approx 1.67 \times 10^{-27} \text{ kg}$$

$$\frac{m_e}{m_p} \simeq 5.45 \times 10^{-4} = \frac{1}{1835}$$

charge quantization - conservation

* charge quantization

  electric charge has only been observed in integer multiples of the charge of an electron or proton.

* protons and neutrons are believed to be composed of quarks that have charges

  $u_q = +\frac{2}{3} q_p \qquad d_q = -\frac{1}{3} q_p$

  $p = uud$

  $n = ddu$

  (up and down quarks). The quarks are believed to permanetly confined in observable particles free quarks have never been seen.)

② the net electric charge is always conserved.

$$n \rightarrow p + e + \nu$$
$$\quad\;\; + \quad -$$

a free neutron is unstable - it decays into a proton, electron and neutrino. - the net charge of $p + e + \nu$ is 0 which is the same as the net charge of the neutron.

$$e^+ + e^- \rightarrow 2\gamma$$

an electron and positron (positively charged electron) decay into 2 photons each with energy $E_\gamma = m_e c^2$. this mechanism is important in positron emission tomography (at UIHC)

unit of electric charge

1 Coulomb = the amount of charge transported in 1 second by a 1 ampere current = charge of

624 150 907 446 076 2607.776 protons

$\simeq 6.24 \times 10^{18}$ protons

conductors and insulators

insulators - these are substances where the electrons are tighty bound to the positive charges

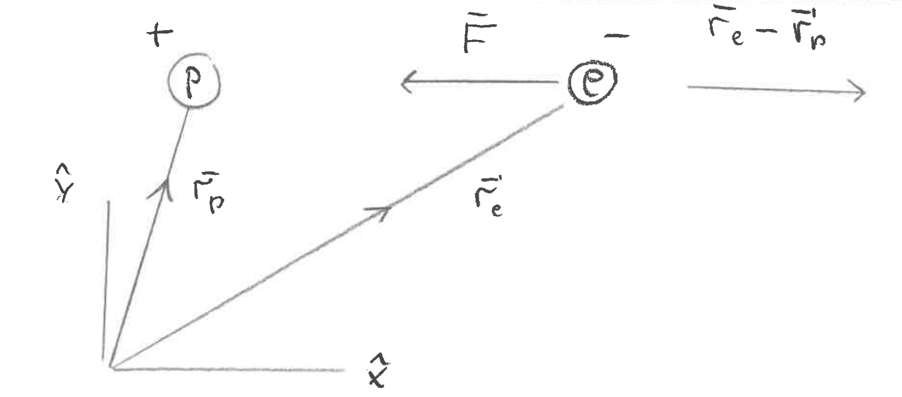
conductors - these substances have sum electrons that are weekly bound. - electrons move more freely in conductors.

Copper, Silver, Aluminum are good conductors

plastic, wood, glass are good insulators.

Coulomb's Law and the superposition principle.

What is the force on an electron due to a proton



$$\vec{F}_{ep} = \text{constant} \times q_p q_e \frac{\vec{r}_e - \vec{r}_p}{|\vec{r}_e - \vec{r}_p|^3}$$

* the force is a vector quantity
* here $\vec{F}$ points in the opposite direction to the vector $\vec{r}_e - \vec{r}_p$ because q_e and q_p have different signs.

remarks

① the force on the electron is proportional to both the charge of the electron and the charge of the proton

② the direction of the force is along the line between the charges (repulsive for like charges - attractive for unlike charges.

③ the magnitude of the force falls off like the inverse square of the distance between the charges

④ the constant is

$$k = \frac{1}{4\pi\epsilon_0} = 8.99 \times 10^9 \ N \cdot m^2 / C^2$$

$$\epsilon_0 = 8.854 \times 10^{-12} \ C^2 / N \cdot m^2$$

C = coulombs

m = meters

N = Newtons

<u>k</u> is called the Coulomb constant

<u>ϵ_0</u> is called the permittivity of free space

The general form of <u>Coulombs Law</u>

$$\vec{F}_{12} = k q_1 q_2 \frac{\bar{r}_1 - \bar{r}_2}{|\bar{r}_1 - \bar{r}_2|^3}$$

= force on particle 1 due to particle 2

From this definition

$$\bar{F}_{12} = -\bar{F}_{21}$$

which is Newton's third law.

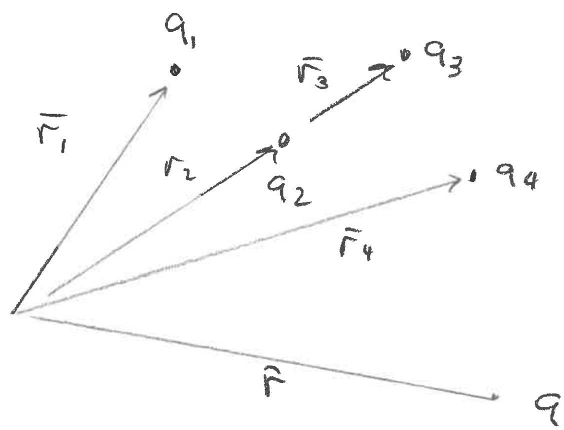
$$q_e = -1.602 \times 10^{-19}\, C$$

$$q_p = 1.602 \times 10^{-19}\, C$$

This means that the <u>net force</u> on any pair of charges is zero.

superposition principle

consider charges $q_1 \cdots q_N$ at positions $\bar{r}_1 \cdots \bar{r}_N$

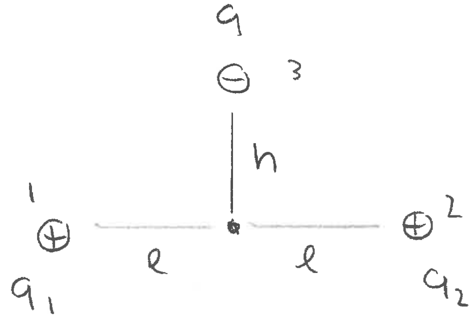


the force on charge q at $\bar{r}$ due to the charges $q_1 \quad q_N$ at $\bar{r}_1 \cdots \bar{r}_N$ are the <u>sum</u> of the forces on q due to the other charges

$$\bar{F}_q = \sum_{n=1}^{N} k q q_n \frac{\bar{r}-\bar{r}_n}{|\bar{r}-\bar{r}_n|^3} = \sum_{n=1}^{N} \bar{F}_{qq_n}$$

This is called the superposition principle.

example: superposition principle



what is the force on particle 3 due to the charges on particles 1 an 2

superposition implies:

$$\vec{F}_{q_3} = \vec{F}_{q_3 q_1} + \vec{F}_{q_3 q_2}$$

since the forces are vectors we have to use vector addition

choose a coordinate system

- above = origin

$$\bar{r}_1 = (-\ell, 0)$$

$$\bar{r}_2 = (+\ell, 0)$$

$$\bar{r}_3 = (0\ h$$

$$(\bar{r}_3 - \bar{r}_1) = (\ell, h) \quad |\bar{r}_3 - \bar{r}_1| = \sqrt{\ell^2 + h^2}$$

$$(\bar{r}_3 - \bar{r}_2) = (-\ell, h) \quad |\bar{r}_3 - \bar{r}_2| = \sqrt{(-\ell)^2 + h^2}$$

using coulams law

$$\bar{F}_{q_3} = k q_3 q_1 \frac{\bar{r}_3 - \bar{r}_1}{|\bar{r}_3 - \bar{r}_1|^3} + k q_3 q_2 \frac{\bar{r}_3 - \bar{r}_2}{|r_3 - r_2|^2}$$

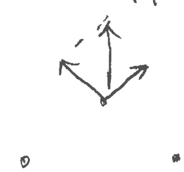
$$= k q_3 q_1 \frac{(\ell, h)}{(\ell^2 + h^2)^{3/2}} + k q_3 q_2 \frac{(-\ell\, h)}{|\ell^2 + h^2|^{3/2}}$$

$$= \frac{k q_3}{(\ell^2 + h^2)^{3/2}} \left((q_1 - q_2)\ell \,,\, (q_1 + q_2) h \right)$$

consider the case where $q_1 = q_2$

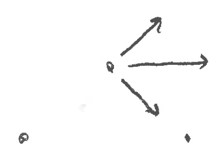
then

$$\bar{F}_{q_3} = \frac{2 k q_3 q_1}{(\ell^2 + h^2)^{3/2}} \cdot (0, h)$$



if $q_1 = -q_2$

$$\bar{F}_{\bar{q}_3} = \frac{2 k q_3 q_1}{(\ell^2 + h^2)^{3/2}} (\ell, h)$$



numerically

$q_1 = q_2 = q_3 = 1$ coulomb

$\ell = h = 1$ meter

$$\bar{F}_{q_3} = \frac{2k}{(2^{3/2})} (0, 1) \approx \frac{2 \times 9 \times 10^9}{2\sqrt{2}} (0, 1)$$

$$= \left(0, \frac{9}{\sqrt{2}} \times 10^9 \text{ N} \right)$$

In this case the force is a vector in the "y" direction with magnitude $\frac{9}{\sqrt{2}} \times 10^9 N \cong 6.36 \times 10^9 N$

comparison of the strength of the strong, coulomb and gravitational forces between 2 protons separated by 10^{-15} meters

Gravity

$$|\vec{F}| = \frac{G m_p^2}{r^2} \approx \frac{(6.67 \times 10^{-11})(1.7 \times 10^{-27})^2}{(10^{-15})^2} \simeq 19.3 \times 10^{-35} N$$

Coulomb

$$|F| = \frac{k q_p^2}{r^2} \approx (9 \times 10^9) \frac{(1.6 \times 10^{-19} c)^2}{(10^{-15})^2} \approx 2.3 \times 10^2 N$$

strong

$$|F| \cong \lambda \frac{e^{-ur}}{r^2} \approx (3.4 \times 10^{-26}) \frac{e^{-10^{-15}/1.5 \times 10^{-15}}}{(10^{-15})^2} \approx 1.7 \times 10^4 N$$

$$\frac{F_s}{F_c} \text{ at } 10^{-15} m \simeq 60.1 \qquad \frac{F_g}{F_c} \text{ at } 10^{-15} m \simeq \approx 8.4 \times 10^{-37} N$$