PHYSICS 632 SUMMER 2006
Orientation
8:30 – 10:30 Room 203
Electricity & Magnetism

Richard A. Lindgren, Office Room 302

Your Goals: Get a degree, crossover teaching, fill in knowledge gaps, review, learn new teaching ideas, peer learning, modeling, inquiry learning, group learning, new demos, computer technology, solidify concepts, learn how to do problems.

Format: Daily graded homework focuses on problems solving using WebAssign. Work on problems in recitation before lecture, discuss with TA's and others in the apartments at night. Due at 8:00 am next day. Math review in recitation. Trigonometry, unit vectors and vectors, derivatives and integration. How do you improve problem-solving skills. Lots of practice and more practice. Test on first three Tuesdays fourth test and final on WebAssign, 30% conceptual questions, 70% problem oriented. There will also be 4 homework assignments due in August, September, and October. Final exam in October on WebAssign.

Class organization

Cartoon
Demonstrations
Graded problems due 8:00 AM
Warm-up problems due 8:00 AM. Not graded.
Lecture and discussion
Demos with explanations
Handworked Problems on Elmo
Misconception/Polling problems
Physlets

Text: Halliday, Resnick, and Walker 7'th edition, extended, Sarting with chapter 21.

Lecture 1 Charge Chp. 21

- Cartoon - Charge is analogous to mass
- Opening Demo - Large Van de Graaff
- Warm-up problems
- Topics
  - What is electric charge? Point objects, Size. Atomic model
  - Methods of charging objects. Friction,Contact, Induction, Machines
  - Instruments to measure charge
  - Quantization of charge and conservation of charge
  - Coulombs Law and examples
  - Principle of superposition and examples
- Example problems
- Clicker Misconception/polling problems
- Demonstrations
- Physlets

Introduction

- **"In the matter of physics, the first lessons should contain nothing but what is experimental and interesting to see. A pretty experiment is in itself more valuable than 20 formulae." Albert Einstein**

$$F = kq_1q_2 / r^2$$
$$k = 1/4\pi\varepsilon_0$$

Charged Hair Van de Graaff Demo

- Need a female teacher to come forward.

- How does this gadget produce a mini-lightning bolt?
- What upward forces are keeping your hair up?
- How are these forces produced?
- Why do the hair strands spread out from each other?
- Why do they spread out radially from the head?
- Is hair a conductor or insulator? How can we find out? Does it depend if is wet or dry.
- To understand what is going on we need a model of electricity.

Introduction Continued

- What is charge?
- How do we visualize it.
- What is the model.
- We only know charge exists because in experiments electric forces cause objects to move.
  - Show cartoon comparing mass and charge

- Electrostatics: study of electricity when the charges are not in motion. Good place to start studying E&M because there are lots of demonstrations.

- Atomic Model:

Some preliminaries

- **Electron**: Considered a point object with radius less than 10^{-18} meters with electric charge e= -1.6 x 10^{-19} Coulombs (SI units) and mass m_e= 9.11 x 10^{-31} kg

- **Proton**: It has a finite size with charge +e, mass m_p= 1.67 x 10^{-27} kg and with radius
  - 0.805 +/-0.011 x 10^{-15} m scattering experiment
  - 0.890 +/-0.014 x 10^{-15} m Lamb shift experiment

- **Neutron**: Similar size as proton, but with total charge = 0 and mass m_n=
  - Positive and negative charges exists inside the neutron

- **Pions:** Smaller than proton. Three types: + e, - e, 0 charge and radius
  - 0.66 +/- 0.01 x 10^{-15} m

- **Quarks**: Point objects. Confined to the proton and neutron,
  - Not free
  - Proton (uud) charge = 2/3e + 2/3e -1/3e = +e
  - Neutron (udd) charge = 2/3e -1/3e -1/3e = 0

  - An isolated quark has never been found

Methods of Charging Objects: Friction, Contact, and Induction

- Normally atoms are in the lowest energy state. This means that the material is electrically neutral. You have the same number of electrons as protons in the material.

- How do we change this?

- How do we add more electrons than protons or remove electrons?

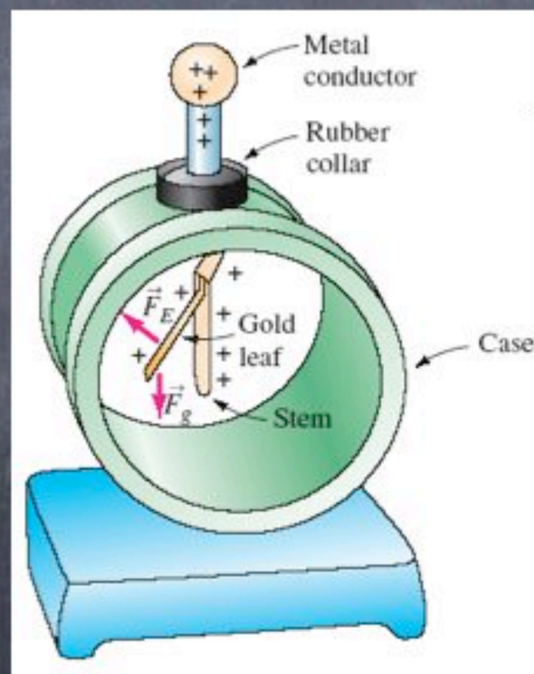
Different Methods for Charging

Friction

e.g. rubbing a balloon with wool

Conduction

e.g. touching an electroscope



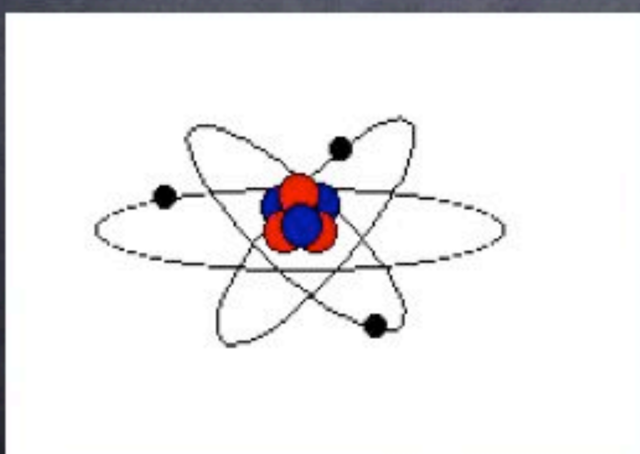
Induction

e.g. balloon sticking to a wall

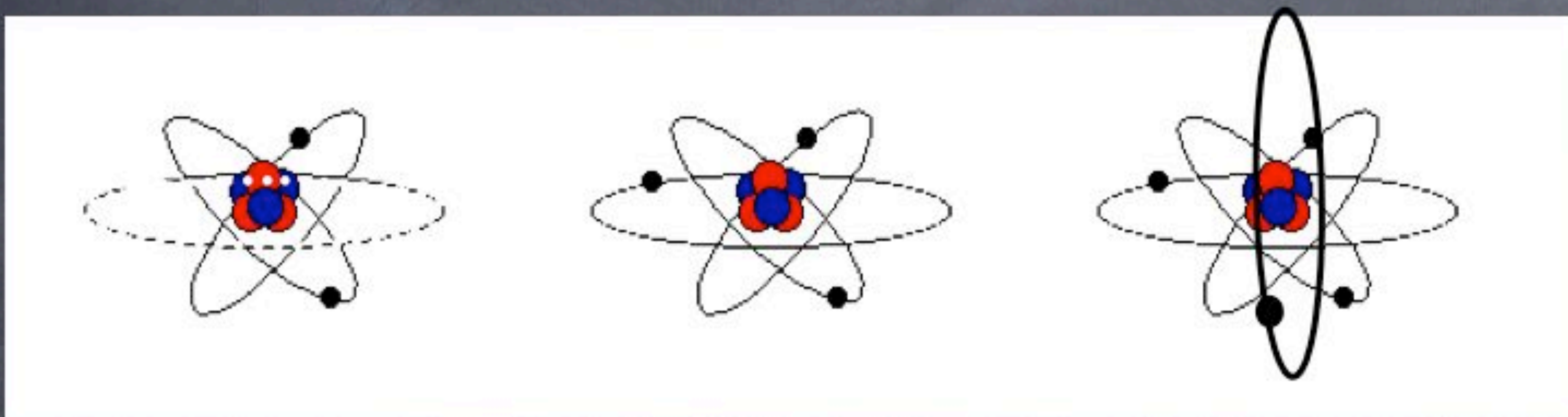
Microscopic explanation of "charging"

Previously we have looked at the "macroscopic" behaviour of charge (e.g. balloons)

Need to look at a simple model of the atom, the Bohr model



Atoms & Ions



Removing an electron
Leaves us with a net +ve ion

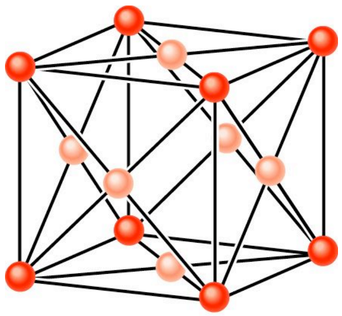
Adding an electron
Leaves us with a net -ve ion

3+ve Protons and 3 -ve electrons
means a neutral atom

Model of electricity

Consider solid material like a piece of copper wire. The proton core is fixed in position in a lattice like structure. In a conductor, some electrons are free to move about. How many electrons are there free to move about?

1cm long and a radius of 0,005 cm

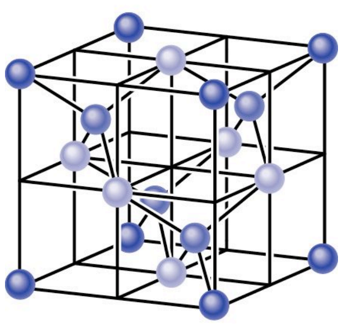


(a)

Copper (Face Centered Cube)

Question: What is the electrical charge in the material that we are talking about? What is responsible for the conduction of electricity? How many electrons are moving about?

Copper atom:
Z=29(protons), N= 34(neutrons),
29 Electrons



(b)

Carbon or diamond

Charging Insulators by Friction/Rubbing

- Electrostatics Kit
  - Click on Demo Explanations

Summary Comments

- Silk(+) on teflon(-)
- Silk (-) on acrylic (+)
- Wood doesn’t charge
- Charged objects always attract neutral objects

- Show Triboelectric series
- Not only chemical composition important, structure of surface is important - monolayer of molecules involved, quantum effect. (nanotechnology)

Triboelectric series

http://www.sciencejoywagon.com/physicszone/lesson/07elecst/static/triboele.htm

Positive (Lose electrons easily)
Air
Human Hands
Asbestos
Rabbit Fur
Glass
Mica
Acrylic
Human Hair
Nylon
Wool
Fur
Lead
Silk
Aluminum
Paper
Cotton
Steel
Wood
Amber
Sealing Wax
Hard Rubber
Nickel, Copper
Brass, Silver
Gold, Platinum
Sulfur
Acetate, Rayon
Polyester
Styrene
Orlon
Saran
Balloon
Polyurethane
Polypropylene
Vinyl (PVC)
Silicon
Teflon
Negative (Gains electrons easily)

Summary: Electrostatics is based on 4 four empirical facts

- Conservation of charge
- Quantization of charge
- Coulombs Law
- The principle of superposition

Conservation of charge

- Rubbing does not create charge, it is transferred from object to another

- Teflon negative - silk positive
- Acrylic positive - silk negative

  Demo: Show electronic electroscope with cage: gives magnitude and sign of charge. Use teflon and silk to show + and -.

- Nuclear reactions $\gamma^0 = e^+ + e^-$

- Radioactive decay $^{238}U_{92} = {}^{234}Th_{90} + {}^{4}He_2$

- High energy particle reactions $e^- + p^+ = e^- + \pi^+ + n^0$

What is meant by quantization of charge?

- Discovered in 1911 by Robert A. Millikan in the oil drop experiment
- The unit of charge is so tiny that we will never notice it comes in indivisible lumps.
- Example: Suppose in a typical experiment we charge an object up with a nanoCoulomb of charge (10^{-9} C). How many elementary units of charge is this?

$$Q = N \times e \quad \textbf{so} \quad N = \frac{Q}{e} = \frac{10^{-9}\,C}{1.6 \times 10^{-19}\,C} = 6 \times 10^{9}$$

= six billion units of charge or 6 billion electrons.

Coulombs Law

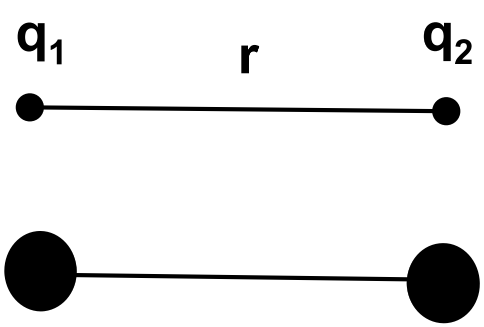
Lab Experiment

In 1785 Charles Augustin Coulomb reported in the Royal Academy Memoires using a torsion balance two charged mulberry pithballs repelled each other with a force that is inversely proportional to the distance.

$$F = \frac{kq_1q_2}{r^2}$$

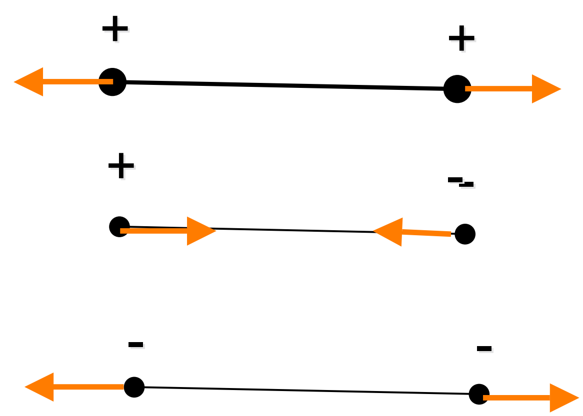
where $k = 8.99 \times 10^9 \ Nm^2/C^2$ in SI unit

$k \sim 10^{10} \ Nm^2/C^2$



Point charges

Spheres same as points

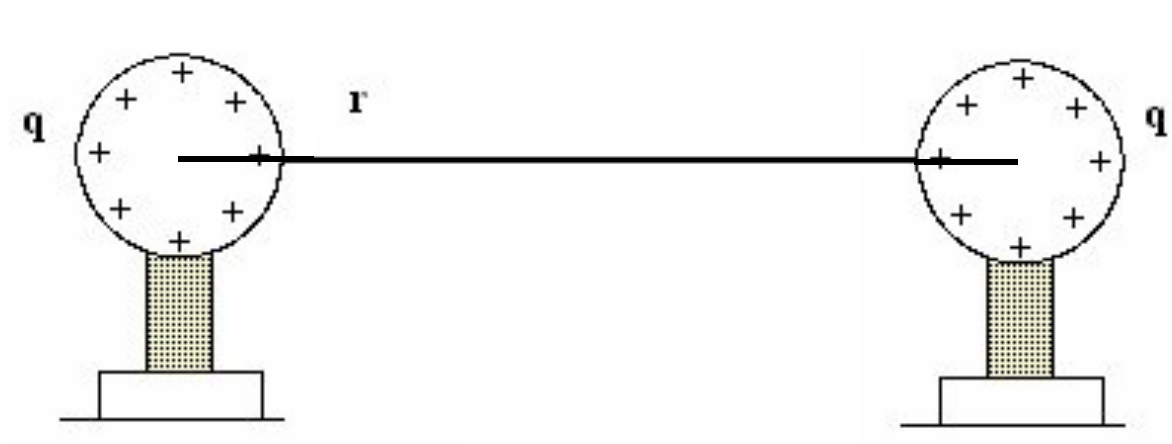


Repulsion

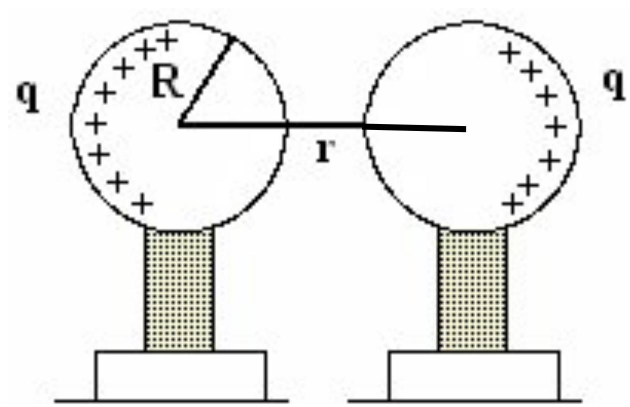
Attraction

Repulsion

Uniformly charged metal spheres of Radius R



$$F=\frac{kq^2}{(r)^2}$$

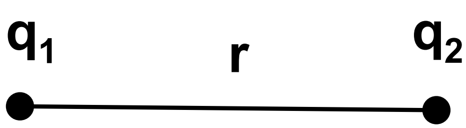


$$F\approx\frac{kq^2}{(r+2R)^2}$$

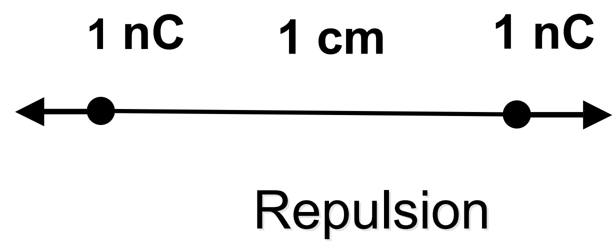
Demo: Show uniformity of charge around sphere using electrometer.
Demo: Show charging spheres by induction using electrometer

Coulombs Law
Two Positive Charges

•What is the force between two positive charges each 1 nanoCoulomb 1cm apart in a typical demo? Why is the force so weak here?



$$F = \frac{kq_1q_2}{r^2}$$



$$F = \frac{\left(10^{10}\ \frac{Nm^2}{C^2}\right)\left(10^{-9}\,c\right)^2}{\left(10^{-2}\,m\right)^2} = 10^{-4}\,N$$

(equivalent to a weight of something with a mass of 10^{-5} kg = 10^{-2} gm or 10 mg - long strand of hair)

Coulombs Law
Two Pennies without electrons

What is the force between two 3 gm pennies one meter apart if we remove all the electrons from the copper atoms? (Modeling)

$$F=\frac{kq_1q_2}{r^2}=\frac{\left(10^{10}\ \frac{Nm^2}{C^2}\right)q^2}{(1m)^2}$$

The force is $$F=\frac{\left(10^{10}\ \frac{Nm^2}{C^2}\right)\left(1.4\ \times 10^5 C\right)^2}{1m^2}=2\times 10^{20}N$$

The atom Cu has 29 protons and a 3 gm penny has

$$=\left(\frac{3gm}{63.5gm}\right)\times 6\times 10^{23}\,atoms=3\times 10^{22}\,atoms$$

The total charge is $q=29\times 3\times 10^{22}\,atoms\times 1.6\times 10^{-19}C=1.4\times 10^5 C$

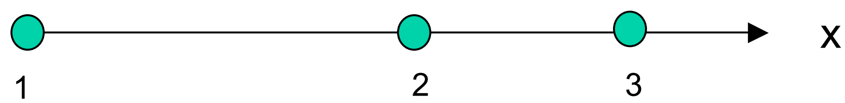
What is their acceleration as they separate?

$$a=\frac{F}{m}=\frac{2x10^{20}N}{3x10^{-3}kg}=7x10^{22}\,\frac{m}{s^2}$$

Principle of Superposition
Three charges In a line

- In the previous example we tacitly assumed that the forces between nuclei simply added and did not interfere with each other. That is the force between two nuclei in each penny is the same as if all the others were not there. This idea is correct and is referred to as the Principle of Superposition.

- Example of charges in a line



  - Three charges lie on the x axis: q_1=+25 nC at the origin, q_2= -12 nC at x =2m, q_3=+18 nC at x=3 m. What is the net force on q_1? We simply add the two forces keeping track of their directions. Let a positive force be one in the + x direction.

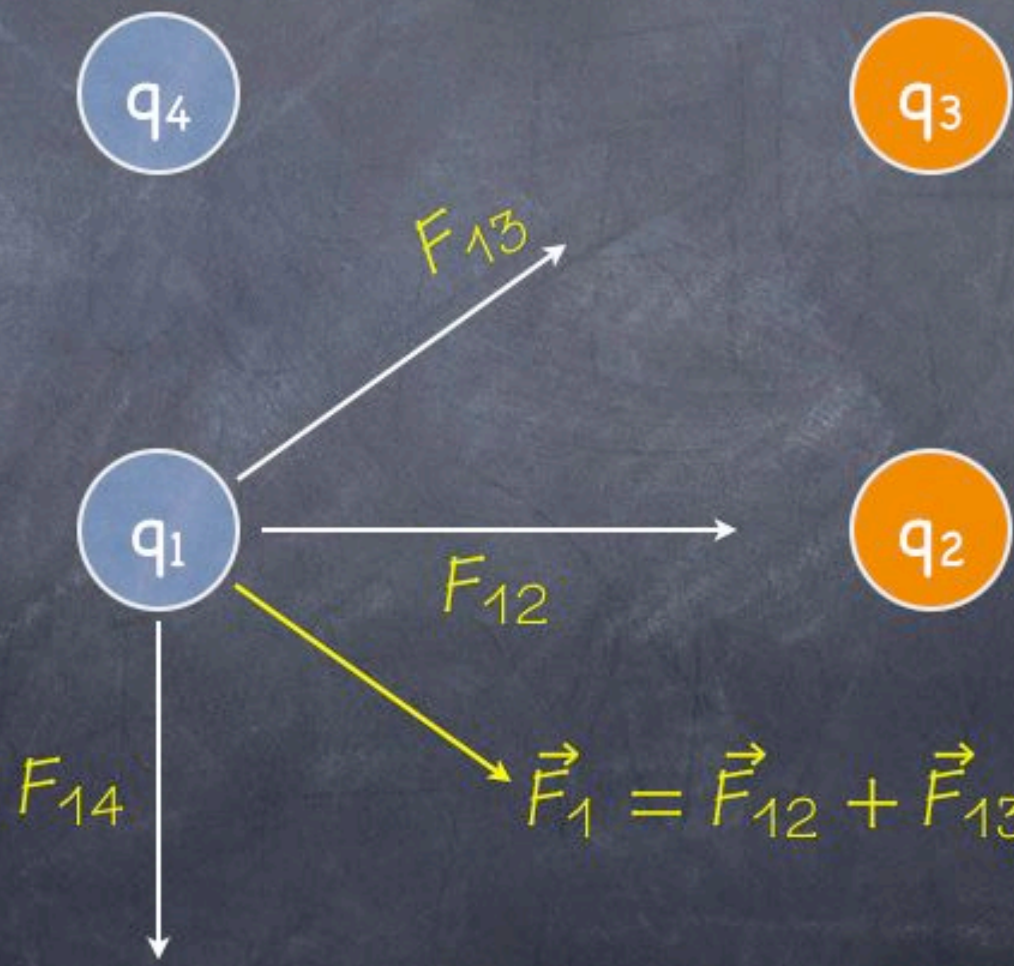
$$F=-kq_1\left(\frac{q_2}{(2m)^2}+\frac{q_3}{(3m)^2}\right)$$

$$=-\left(10^{10}\,\tfrac{Nm^2}{C^2}\right)(25\times10^{-9}\,C)\left(\frac{-12\times10^{-9}\,C}{(2m)^2}+\frac{18\times10^{-9}\,C}{(3m)^2}\right)$$

$$=2.5\times10^{-7}\,N$$

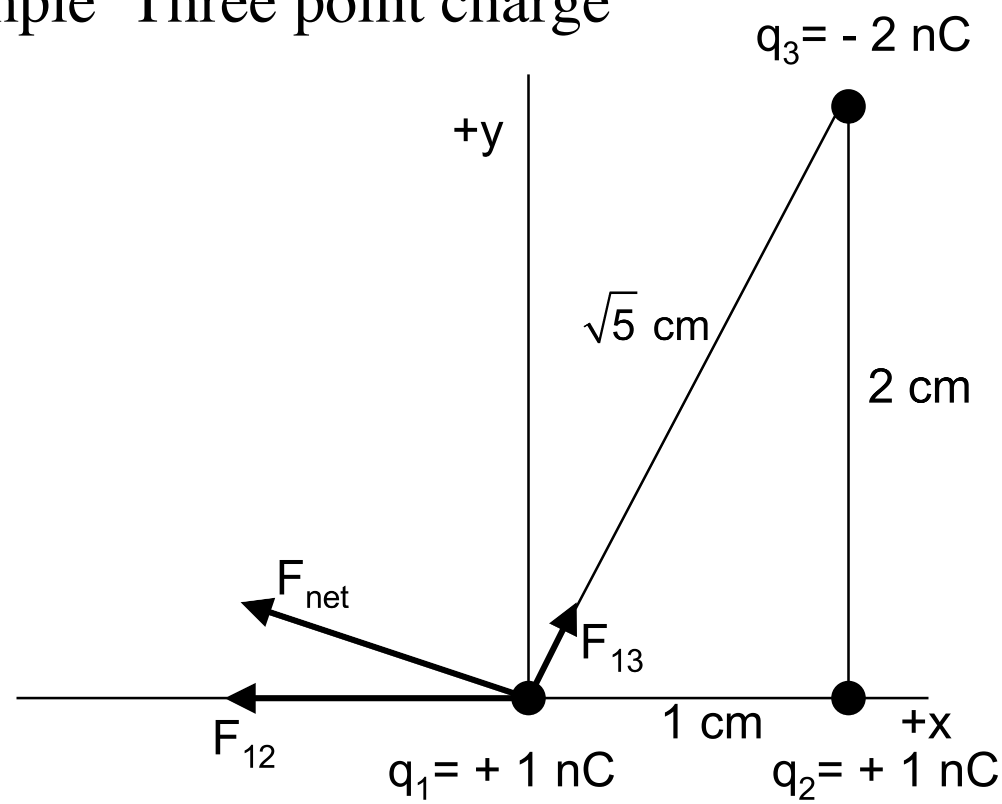
Superposition - Force from many charges

$$\vec{F} = \sum_{i=1}^{N} \vec{F}_i = \frac{q}{4\pi\varepsilon_0} \sum_{i=1}^{N} \frac{q_i}{r_i^2} \hat{r}_i$$



$$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14}$$

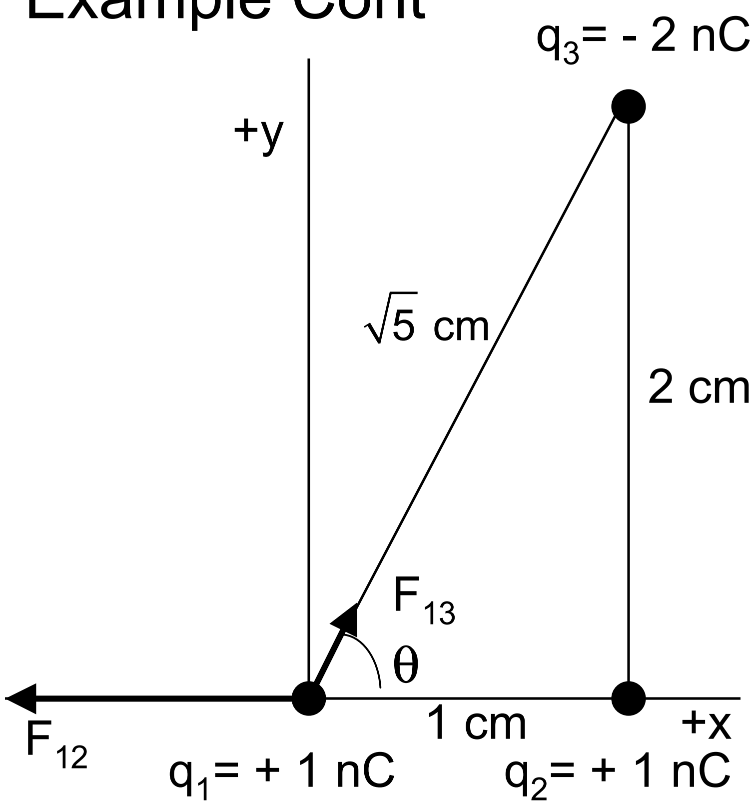
Example Three point charge



Question: What is the net force on q_1 and in what direction?

Hint : Find x and y components of force on q_1 due to q_2 and q_3 and add them up.

Example Cont



x and y Components of force due to q_2

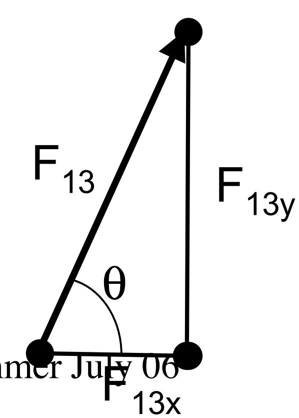
$$F_{12x} = -10^{10}\,\tfrac{\mathrm{Nm}^2}{\mathrm{C}^2}\frac{(10^{-9}\,\mathrm{C})^2}{(10^{-2}\,\mathrm{m})^2} = -1\times 10^{-4}\,\mathrm{N}$$

$$F_{12y} = 0$$

x and y Components of force due to q_3

Magnitude of Force due to q_3

$$\left|F_{13}\right| = 10^{10}\,\tfrac{\mathrm{Nm}^2}{\mathrm{C}^2}\frac{(2\times 10^{-9}\,\mathrm{C})(1\times 10^{-9}\,\mathrm{C})}{(\sqrt{5}\times 10^{-2}\,\mathrm{m})^2} = 0.40\times 10^{-4}\,\mathrm{N}$$

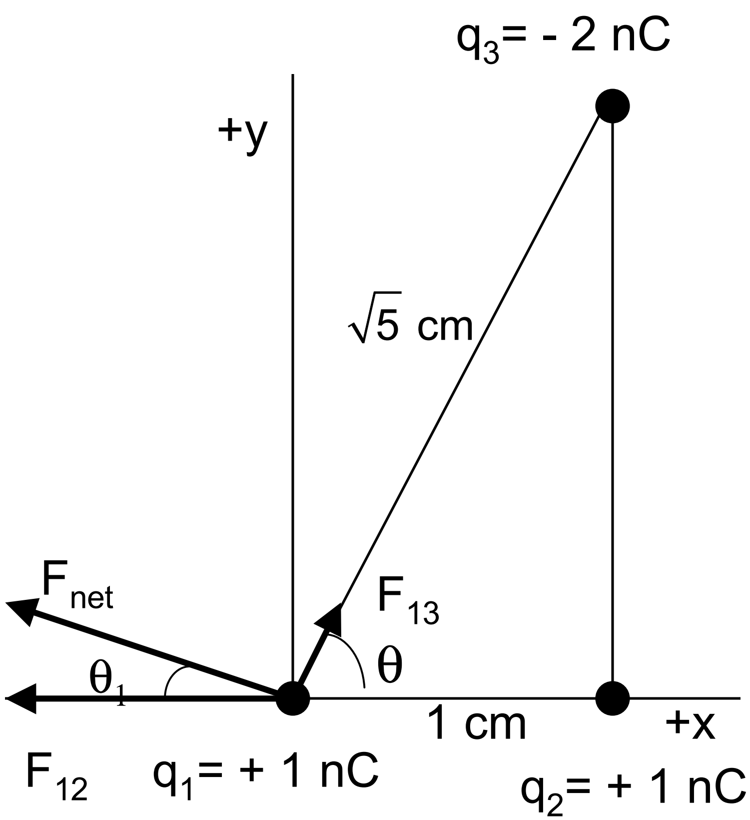


$$\tan\theta = \frac{\text{y - axis value}}{\text{x - axis value}} \quad \Rightarrow \theta = \tan^{-1}(\tfrac{2}{1}) = 63.43\ \mathrm{deg}$$

$$F_{13x} = F\cos\theta = (0.40\mathrm{N})(\cos 63.43) = 0.179\times 10^{-4}\,\mathrm{N}$$

$$F_{13y} = F\sin\theta = (0.40\mathrm{N})(\sin 63.43) = 0.358\times 10^{-4}\,\mathrm{N}$$

Example Cont.



Total force along the x-axis

$$F_{x_{net}} = F_{12x} + F_{13x} = (-1\times10^{-4} + 0.179\times10^{-4})N = -0.821\times10^{-4}N$$

Total force along the y-axis

$$F_{y_{net}} = F_{12y} + F_{13y} = (0 + 0.358\times10^{-4})N = 0.358\times10^{-4}N$$

$$F_{net} = \sqrt{F_{x_{net}}^2 + F_{y_{net}}^2} = \sqrt{((0.821)^2 + (0.358)^2)\times(10^{-4})^2}N$$

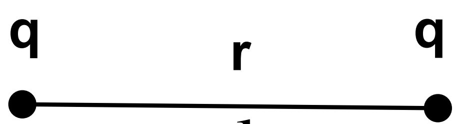
$$F_{net} = +0.802\,10^{-4}N$$

$$\tan\theta_1 = \frac{F_y}{F_x}$$

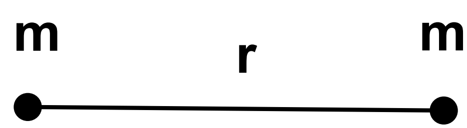
$$\theta_1 = \tan^{-1}\left(\frac{F_y}{F_x}\right) \qquad \theta_1 = \tan^{-1}\left(\frac{0.358\times10^{-4}N}{-0.821\times10^{-4}N}\right)$$

$$\theta_1 = 23.6^\circ \text{ from the } -x \text{ axis}$$

In an atom can we neglect the gravitational force between the electrons and protons? What is the ratio of Coulomb's electric force to Newton's gravity force for 2 electrons separated by a distance r ?



$$F_c = \frac{kee}{r^2}$$



$$F_g = \frac{Gmm}{r^2}$$

$$\frac{F_c}{F_g} = \frac{ke^2}{Gm^2}$$

$$\frac{F_c}{F_g} = \frac{\left(10^{10}\, Nm^2/C^2\right)\left(1.6\times10^{-19}\,C\right)^2}{\left(6.67\times10^{-11}\, Nm^2/kg^2\right)\left(9.1\times10^{-31}\,kg\right)^2}$$

$$= 4.6\times10^{42}$$

Huge number, pure ratio

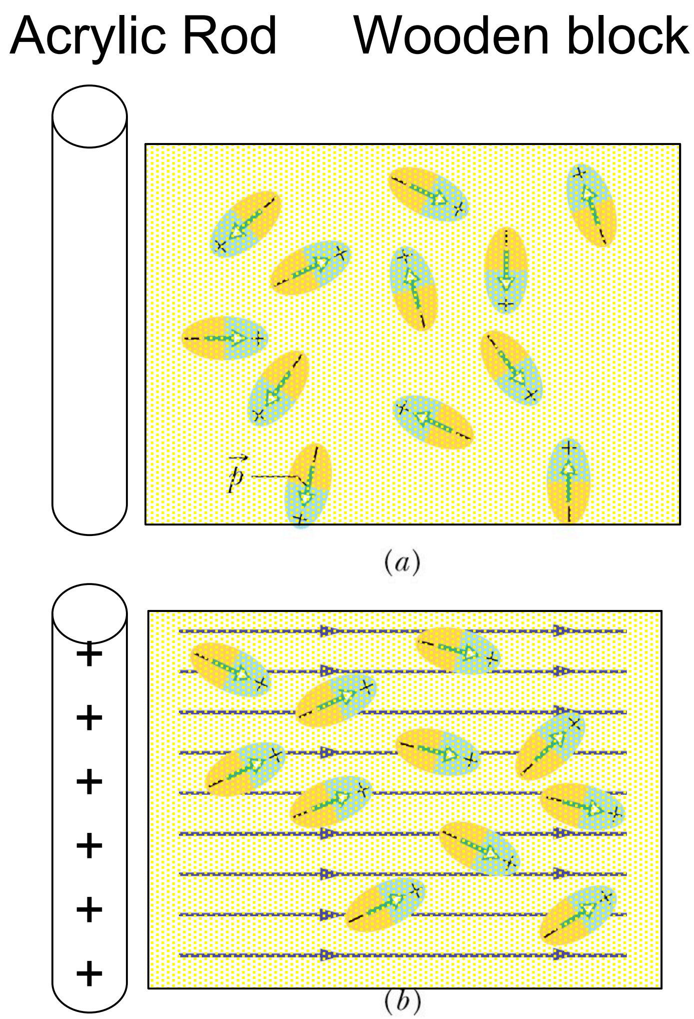
Why are neutral objects always attracted to positive or negative charged objects.

For example:
•Rubbed balloon is attracted to wall
•Comb is attracted to small bits of paper
•Clothes in the dryer stick together.

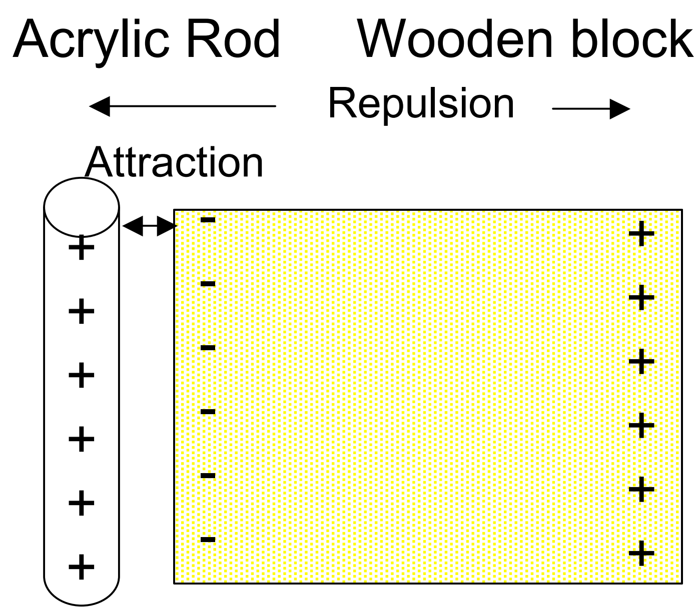
Demo: Put wood on the spinner and place charged teflon and plastic rods near it.

What is the explanation of all of these phenomena?

Explanation: The neutral objects atoms and molecules orient themselves in the following way so that the Coulomb forces due to attraction are greater than those due to repulsion because the latter are further away. (Inverse square Law)



$$F = \frac{kq_1q_2}{r^2}$$



Attractive forces >> Repulsive Forces

- Show induction: Click on demos
    - -- Demo: Using conducting spheres and electrometer
    - – Demo: Electrophorus
    - – Demo: Electroscope

    - – Demo: hanging charged/conducting pith ball- first attraction by induction, then contact, then conduction of charge, then repulsion

Problem: Two equally charged hanging pith balls