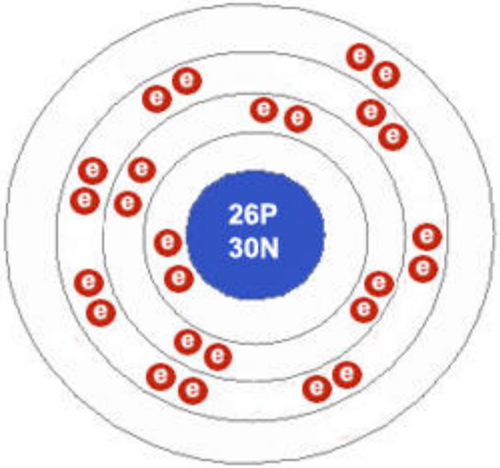
Physics 122: Electricity & Magnetism – Lecture 3
Electric Charge

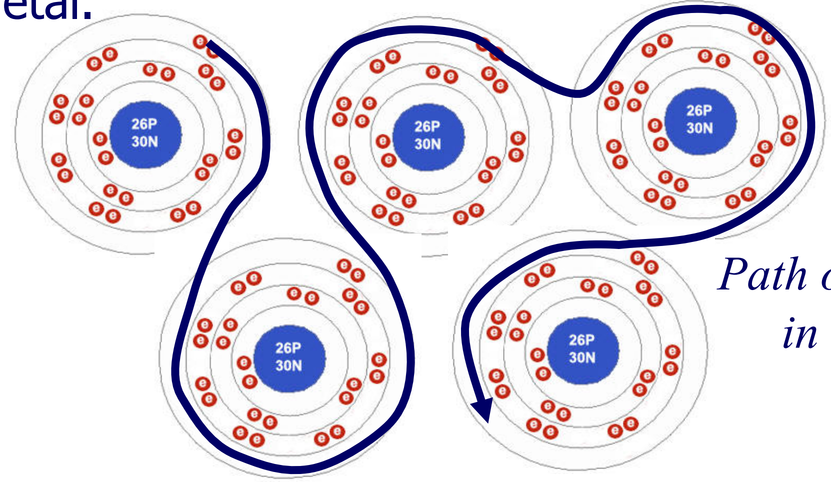
Baris EMRE

Metals and Conduction

- Notice that metals are not only good electrical conductors, but they are also good heat conductors, tend to be shiny (if polished), and are maleable (can be bent or shaped).
- These are all properties that come from the ability of electrons to move easily.

This iron atom (26 protons, 26 electrons) has two electrons in its outer shell, which can move from one iron atom to the next in a metal.

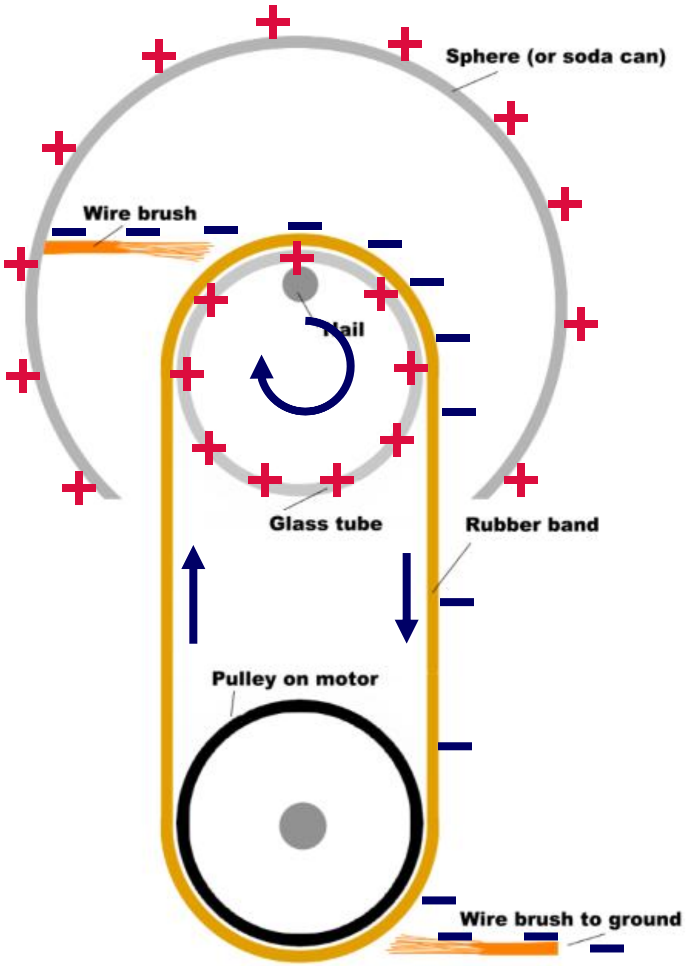




Path of electron in a metal

Van de Graaf Generator

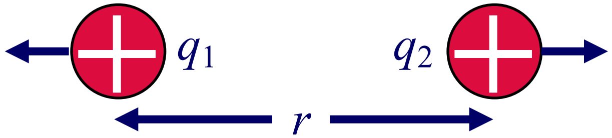
- Rubber band steals electrons from glass
- Glass becomes positively charged
- Rubber band carries electrons downward
- Positively charged glass continues to rotate
- Wire “brush” steals electrons from rubber band
- Positively charged glass steals electrons from upper brush
- Sphere (or soda can) becomes positively charged—to 20,000 volts!



[redacted]

Electric Force and Coulomb's Law

- We can measure the force of attraction or repulsion between charges, call them q_1 and q_2 (we will use the symbol q or Q for charge).



- When we do that, we find that the force is proportional to the each of the charges, is inversely proportional to the distance between them, and is directed along the line between them (along r).

- In symbols, the magnitude of the force is $F = k\frac{|q_1||q_2|}{r^2}$ where k is some constant of proportionality.
- This force law was first studied by Coulomb in 1785, and is called Coulomb's Law. The constant $k = 8.98755 \times 10^9$ N m^2/C^2 is the Coulomb constant.

Electric Force and Coulomb’s Law

- Although we can write down a vector form for the force, it is easier to simply use the equation for the magnitude, and just use the “like charges repel, opposites attract” rule to figure out the direction of the force.
- Note that the form for Coulomb’s Law is exactly the same as for gravitational force between two masses

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

$$G \Rightarrow k$$
$$m \Rightarrow q$$

Note BIG difference,
There is only one “sign”
of mass, only attraction.

- Note also that the mass is an intrinsic property of matter. Likewise, charge is also an intrinsic property. We only know it exists, and can learn its properties, because of the force it exerts.
- Because it makes other equations easier to write, Coulomb’s constant is actually written $k = \frac{1}{4\pi\varepsilon_0}$

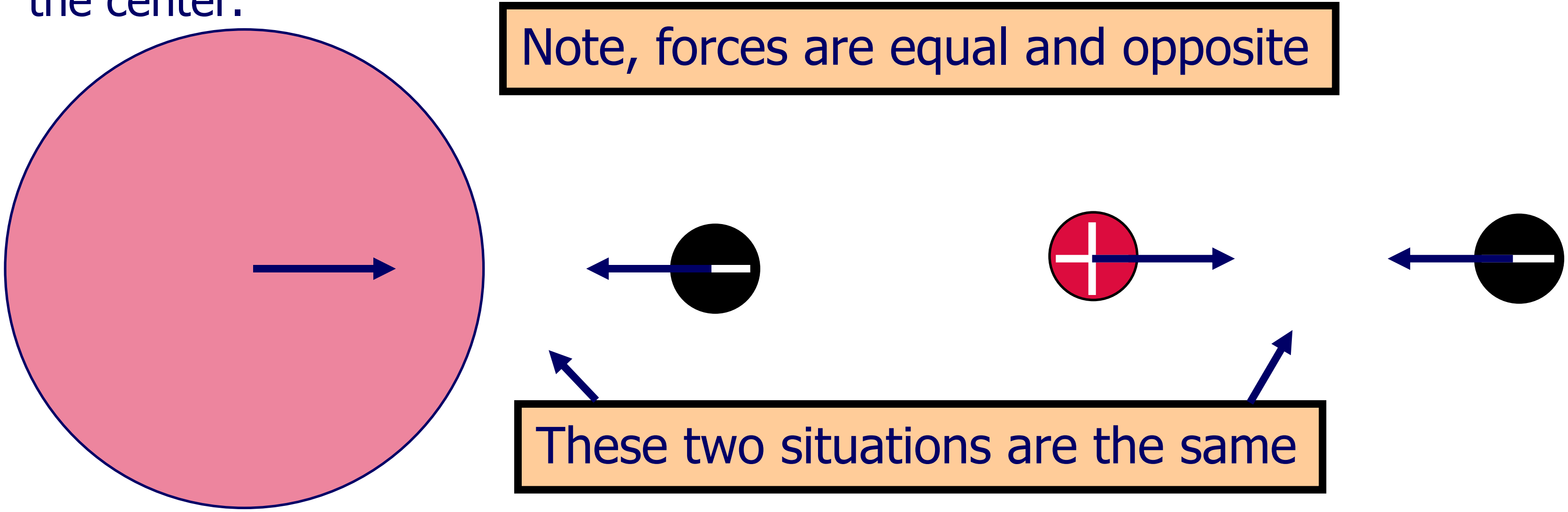
where $\varepsilon_0 = 8.85\times10^{-12}$ $C^2/N\text{-}m^2$ is called the permittivity constant.

Full form of Coulomb’s Law

$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}$$

Spherical Conductors

- Because it is conducting, charge on a metal sphere will go everywhere over the surface.
- You can easily see why, because each of the charges pushes on the others so that they all move apart as far as they can go. Because of the symmetry of the situation, they spread themselves out uniformly.
- There is a theorem that applies to this case, called the shell theorem, that states that the sphere will act as if all of the charge were concentrated at the center.



Note, forces are equal and opposite

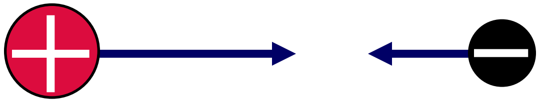
These two situations are the same

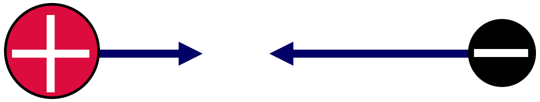
Insulators and Conductors

5. Two small spheres are charged with equal and opposite charges, and are placed 30 cm apart. Then the charge on sphere 1 is doubled. Which diagram could be considered to show the correct forces?

A. 

B. 

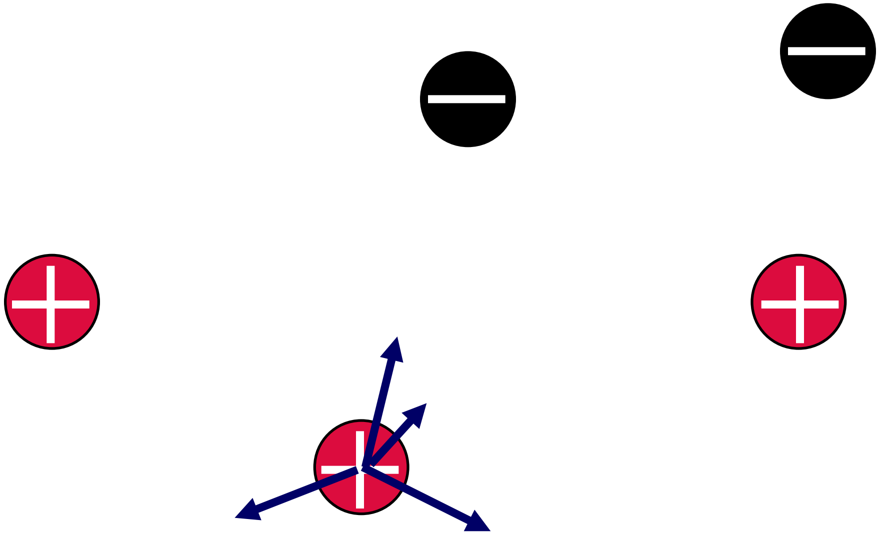
C. 

D. 

E. 

Case of Multiple Charges

- You can determine the force on a particular charge by adding up all of the forces from each charge.



Forces on one charge due to a number of other charges

Charges in a Line

6. Where do I have to place the + charge in order for the force to balance, in the figure at right?

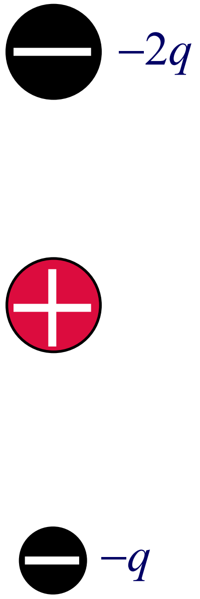
A. Cannot tell, because + charge value is not given.

B. Exactly in the middle between the two negative charges.

C. On the line between the two negative charges, but closer to the $-2q$ charge.

D. On the line between the two negative charges, but closer to the $-q$ charge.

E. There is no location that will give force balance.



Let’s Calculate the Exact Location

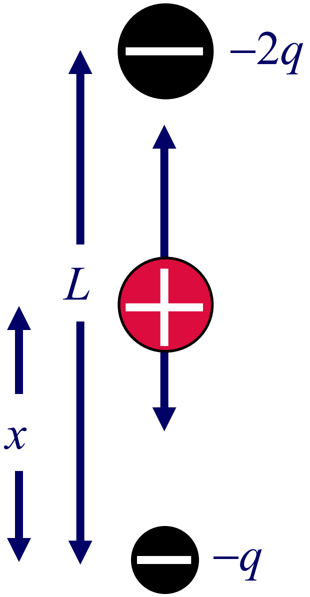
- Force is attractive toward both negative charges, hence could balance.
- Need a coordinate system, so choose total distance as L, and position of + charge from $-q$ charge as x.
- Force is sum of the two force vectors, and has to be zero, so

$$F = F_1 + F_2 = k\frac{2qQ}{(L-x)^2} - k\frac{qQ}{x^2} = 0$$

- A lot of things cancel, including Q, so our answer does not depend on knowing the + charge value. We end up with

$$\frac{2}{(L-x)^2} = \frac{1}{x^2} \qquad \frac{(L-x)^2}{x^2} = 2 \Rightarrow \frac{L-x}{x} = \sqrt{2}$$

- Solving for x, $x = \frac{L}{1+\sqrt{2}} = 0.412L$, so slightly less than half-way between.



Summary

- Charge is an intrinsic property of matter.
- Charge comes in two opposite senses, positive and negative.
- Mobil charges we will usually deal with are electrons, which can be removed from an atom to make positive charge, or added to an atom to make negative charge. A positively charged atom or molecule can also be mobil.
- There is a smallest unit of charge, e, which is $e = 1.602\times10^{-19}$ C. Charge can only come in units of e, so charge is *quantized*. The unit of charge is the Coulomb.
- Charge is *conserved*. Charge can be destroyed only in pairs (+e and –e can annihilate each other). Otherwise, it can only be moved from place to place.
- Like charges repel, opposite charges attract.
- The electric force is give by Coulomb's Law:

$$\boxed{F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}}$$

- Materials can be either conductors or insulators.
- Conductors and insulators can both be charged by adding charge, but charge can also be *induced*.
- Spherical conductors act as if all of the charge on their surface were concentrated at their centers.