PHYS 1444 - Lecture 1
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1 Electric Forces and Fields

- Electric forces are created by electric charges. Charges are a property of subatomic particles.
- There are two types of charges, positive and negative. Like charges repel, and opposites attract.
- Electric charge is **conserved** (net charge in the universe is always the same) and **quantized** (comes in discrete units).
  - Units used to be the Coulomb, but now it's e, the charge on an electron. $e = 1.602 \cdot 10^{-19}\ C$
  - Subatomic particles:
    * Electron ($-e$)
    * Proton ($+e$)
    * Neutron (no charge)

2 Atoms

Protons and neutrons bound by the strong force form the atoms nucleus, with a positive charge. The electrons orbit around the nucleus via electrical attraction, attracted because they have negative charge.

Atom width $\approx 10^{-10}\ m$

Nucleus $\approx 10^-15\ m$

(Spurlock tells lots of bad jokes)

3 Solids

Positively charged nuclei and inner (core) elections are bound tightly in place. The outer (valence) electrons aren't bound as tightly. The valence electrons determine the electric quality of the material. More conductive materials have "looser" valence electrons. Insulators have tighter valence electrons.

Semi-conductors are insulators that are combined with conductors, allowing you to control its conductivity. Silicon is an example.

4 Static Electricity

Electricity can be "waiting", static, then it can discharge. Rubbing two neutral objects together can displace electrons from one to the other. The charge will always be equal in magnitude and opposite in sign. If they have a path (through a conductor) to neutralize, they will, restoring equilibrium.

For example, on humid days, water molecules can strip electrons from the metal of a car, giving it a positive charge. Touching the metal could shock you as the electrons "swap" between you and the car to restore equilibrium.

Examples, Coulombs and e

- How many electrons does it take to make $-16\mu C$?

  This is basically a unit conversion.

$$-16 \cdot 10^{-6} \cdot \frac{1\ electron}{-1.6 \cdot 10^{-19}} = 10^{14}\ electrons$$

- What is the net charge of an object that is made of $8.7 * 10^{28}$ protons, $1.05 * 10^{29}$ neutrons, and $8.699 * 10^{28}$ electrons?

  Neutrons have no charge, so they can be ignored. We just need to add up all the charges. You can find the answer in e and convert, or just use Coulombs like this. We get 1.6 Mega Coulombs.

$$Q_{net} = (8.7 * 10^{28})(1.6 * 10^{-19}) + (8.699 * 10^{28})(-1.6 * 10^{-19})$$
$$Q_{net} = 1.6MC$$

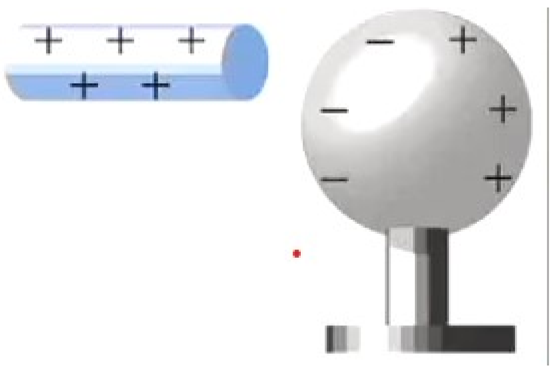
  This is equivalent to removing 1 out of every 8700 electrons from 5 kg of copper. 1.6 MC is about 10,000 lightning bolts worth of electricity.

5 Electric Forces vs. Gravity

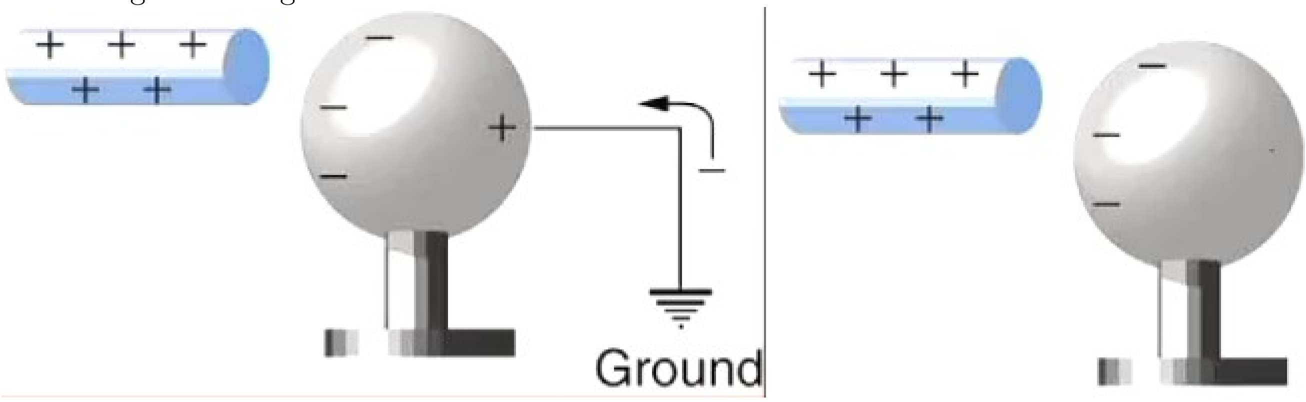
Apart from gravity, every force we studied in the first semester was electromagnetic in nature. Contact is an illusion, the outer electrons just repel each other. Electromagnetic forces are stronger than gravity.

6 Inducing Charge

Lets say we start with a charged object (rod) and move it near a conductor (sphere).



Positive charges on the sphere are going to repel from the rod and move to the far side, which polarizes the object. You can connect the side with the positive charge to ground, who's negative charge annihilates the positive charge and leaves the sphere with a negative charge.



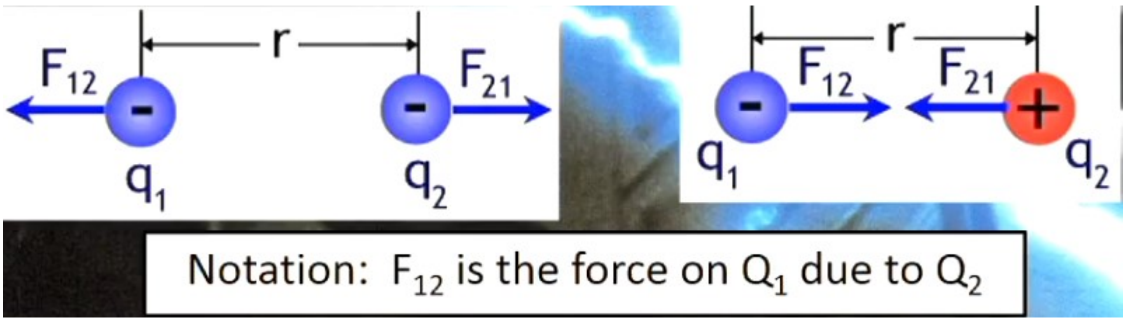
7 Coulomb's Law

$$F = k\frac{|Q_1|\,|Q_2|}{r^2}$$

- F is the magnitude of the force felt by both charges
- k is Coulomb's constant. $k = 9.0 \cdot 10^9\ Nm^2/C^2$
- Q_1 and Q_2 are the two charges
- r is the separation between the two charges

Coulomb's law is usually written without the absolute value signs, but you should only use the magnitude of the charges.

The forces are directed along the line connecting the point charges.



8 Coulomb vs. Newton

$$F = k\frac{|Q_1|\,|Q_2|}{r^2} \qquad F = G\frac{m_1 m_2}{r^2}$$

Masses in Newtons law are playing the part of charges in Coulomb's law. If you compare the gravitational and electric attraction between two protons separated by $1m$.

Gravity = $1.86 * 10^{-64}$
Electric = $2.3 * 10^{-28}$

The electric force is 36 orders of magnitude stronger. On a large scale, however, gravity is stronger. On a large scale, the electric forces are neutralized.

Examples, Coulombs Law

- Two tiny conducting spheres are identical but carry different charges of $-20.0\ \mu C$ and $50.0\ \mu C$. They are separated by a distance of $2.50cm$. (a) What is the magnitude of the force that each sphere experiences and is it attractive or repulsive? And (b) if the spheres are briefly brought into contact and the returned to a separation of 2.50 cm, what is the magnitude of the force that each sphere experiences and is it attractive or repulsive?

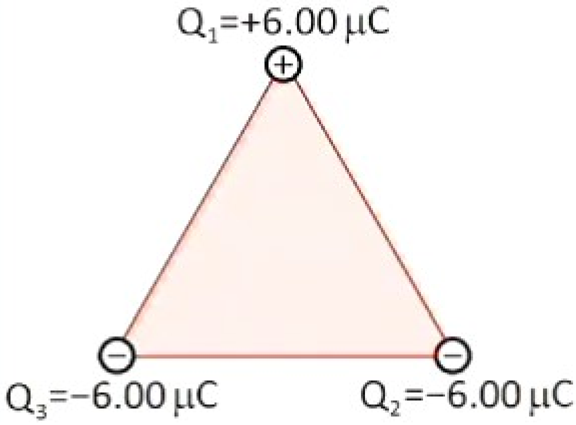
  a) In part A, we know that the first will be **attracted** because the particles have different charges. We can plug all our values into Coulomb's law to get a magnitude in Newtons.

  $$F = k\frac{|Q_1|\,|Q_2|}{r^2} = k\frac{|-20.0\ \mu C|\,|50.0\ \mu C|}{(0.025m)^2} = 14.4\ kN$$

  b) In part B, the particles touch, so the charges will be neutralized. When $-20\ \mu C$ and $50\ \mu C$ touch, we're left with $30\ \mu C$, which is spread evenly between both particles. Because both particles now have positive charge, they will be **repulsive**. We can use Coulomb's law again with the new charges.

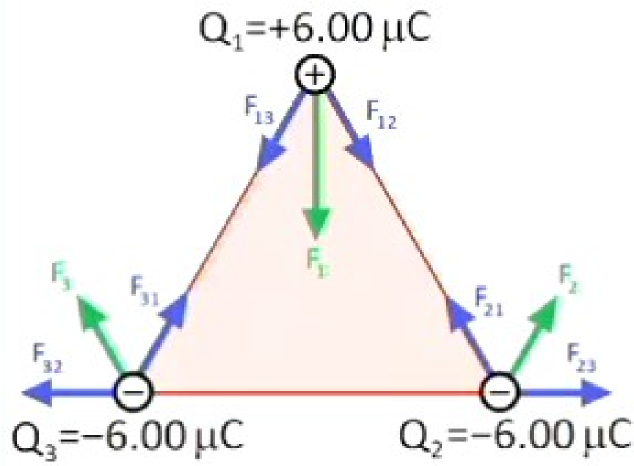
  $$F = k\frac{|15.0\ \mu C|\,|15.0\ \mu C|}{(0.025m)^2} = 3240\ N$$

- Determine the magnitude and direction of the net force on each of the three charges due to the other two. Each charge is at the corner of an equilateral triangle with sides of length 1.2 m.

  We can determine the vector force on each charge due to the other two with Coulomb's law. Each charge has the same magnitude, which will make calculation easier. We can draw a FBD to show each force. Q_1 will attract Q_2 and

Q_3, while Q_2 and Q_3 will repel. After drawing our forces (blue), we can add the vectors together (green).



Now we know which direction the forces point. We can do a single calculation to find the magnitude of all of the (blue) forces.

$$F = k\frac{(6.00 \cdot 10^{-6}\ C)^2}{(1.2\ m)^2} = 0.225\ N$$

For the force F_1 on Q_1, the resulting force (green) is vertical because of the symmetry. Also, because this is an equilateral triangle, we know the angle between F_{13} and F_{31} is 60°. We can add up the y components of F_{13} and F_{31} to get the magnitude of F_1.

$$F_1 = F_{13-y} + F_{12-y} = 2F_{13-y} = 2F\cos(30°) = 0.39\ N\ at\ 270°$$

For F_2 and F_3, notice that the angles between the blue force and the green forces form another equilateral triangle, meaning the magnitude of all forces in that triangle are the same. We already calculated that the magnitude of the blue forces is 0.225 N. Now we can do some basic trig to find the angles of F_2 and F_3, giving us $F_2 = (0.225, 60°)$ and $F_3 = (0.225, 120°)$.

- Having grown annoyed at Deadpool ($M_{deadpool} = 88.5\ kg$), Thanos uses the infinity gauntlet to separate deadpool into two parts. One part, composed of all his positively charged atomic nuclei, Thanos holds in his right hand. The other part, composed of all his negatively charged electrons, Thanos holds in his left hand. What force must Thanos apply to hold his hands 1 m apart? You may assume that in a human body there are 11 protons for every 9 neutrons.

  We know that Deadpool has a mass of 88.5 kg, and is composed of protons, neutrons, and electrons. We need to find the number of each in his body so we can calculate the charge. We'll need the masses of each, found on the formula sheet. Note that neutrons and protons weigh the same.

$$m_p = 1.67 \times 10^{-27}\ kg \qquad m_e = 9.11 \times 10^{-31}\ kg$$

Now that we know the masses, we can calculate how many of each is in the total mass. We have an equation relating protons to neutrons, and since Deadpool's net electric charge is 0 there are an equal amount of protons and electrons.

$$n = \frac{9}{11}p \qquad p = e$$

This equation is the sum of all the atomic nuclei times their weights, giving the total mass. We can then substitute and solve for p (amount of protons, and therefore electrons).

$$\begin{aligned}
pm_p + nm_p + em_e &= 88.5\ kg \\
pm_p + \left(\frac{9}{11}p\right) m_p + pm_e &= 88.5\ kg \\
p\left(m_p + \frac{9}{11}m_p + m_e\right) &= 88.5\ kg \\
p\left(\frac{20}{11}m_p + m_e\right) &= 88.5\ kg \\
p = e = \frac{88.5}{\frac{20}{11}m_p + m_e} &\approx 2.9138 \times 10^{28}
\end{aligned}$$

Now that have the amount of protons and electrons (p and e), we can find the two charges in Coulombs. They are exactly the same, except that the electrons have negative charge. This doesn't matter though, because Coulombs law uses the magnitude of the value.

$$\begin{aligned}
Q_p &= p \cdot (1.602 \times 10^{-19}\ C) \\
Q_e &= e \cdot (-1.602 \times 10^{-19}\ C)
\end{aligned}$$

Now we can use Coulombs law to find the magnitude of the force

$$k = 9.0 \times 10^9\ \frac{Nm^2}{C^2}$$

$$F = k\frac{|Q_1|\,|Q_2|}{r^2} = k\frac{|Q_p|\,|Q_e|}{(1\ m)^2} = k\,Q_p^2 = 1.956 \times 10^{29}\ N$$