PHYS 1441 – Section 002
Lecture #3

Wednesday, Sept. 5, 2018

Dr. Jaehoon Yu

- Ch 21
  - Static Electricity and Charge Conservation
  - Charges in Atom, Insulators and Conductors & Induced Charge
  - Coulomb's Law
  - The Electric Field & Field Lines
  - Electric Fields and Conductors

Announcements

- There are still one of you who haven't registered for homework system
  - It will be very hard to pass this course without the homework!
  - I strongly suggest you to register ASAP!
- 1st Term exam
  - In class, Wednesday, Sept. 19: DO NOT MISS THE EXAM!
  - CH1.1 to what we learn on Monday, Sept. 17 + Appendices A1 – A8
  - You can bring your calculator but it must not have any relevant formula pre-input
  - BYOF: You may bring a one 8.5x11.5 sheet (front and back) of handwritten formulae and values of constants for the exam
  - No derivations, word definitions, or solutions of any problems !
  - No additional formulae or values of constants will be provided!
- Colloquium today at 4pm! Physics faculty expo!
- Submit the special project now!

Physics Department
The University of Texas at Arlington
COLLOQUIUM

Physics Faculty Research Expo

Wednesday September 5, 2018
4:00p.m. Rm. 100SH

SPEAKERS:

Kaushik De

Particle physics is not dead - it is just beginning

"The story of how we got the Nobel Prize in 2013 for explaining everything about mass, while only 5% of the mass in the universe is known to us - will the Large Hadron Collider come to the rescue again?"

Muhammad N Huda

What is an insulator?

This is one of the most fundamental questions in solid state physics based on which there has been a revolutionary progress in Physics in the last few decades. Both symmetry and topology are found to play key roles in defining insulating states. I'll outline very briefly some of these progresses, and few of their relevance with our research.

Daniel Welling

Space Weather Research Opportunities at UTA

The Sun floods the solar system with super-sonically flowing particles, called the solar wind. The solar wind, along with its embedded magnetic field, interacts with the Earth's magnetic field and upper atmosphere. This interaction creates a natural plasma physics laboratory to explore. It also can impair and destroy technological systems on which we all depend. This interaction is known as "space weather" and is a growing topic on the national and international stage. This talk introduces space physics and space weather, as well as research projects commencing here at UT Arlington. Opportunities to join these efforts will also be presented.

Refreshments will be served at 3:30 p.m. in the Physics Library

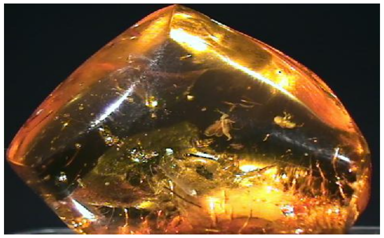
What does the Electric Force do?

- Electric force is the bases of modern technology
  - Virtually everything we use every day uses electric force
    - Can you give a few examples?

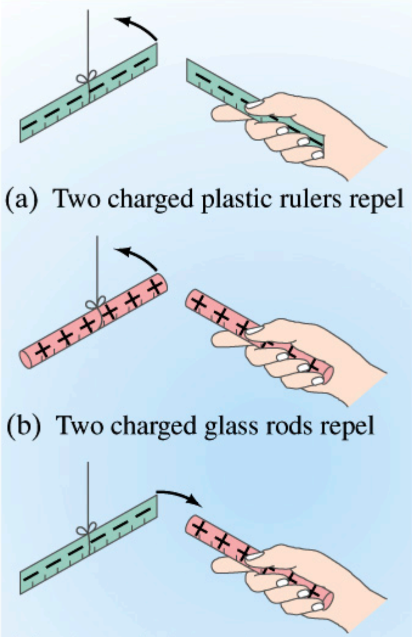
- But this force also affects many others
  - Making up materials with atoms and molecules
  - Biological metabolic processes
    - Nerve signals, heart pumping, etc
- Virtually all the forces we have learned in Physics I:
  - Friction, normal force, elastic force and other contact forces are the results of electric forces acting at the atomic level

Static Electricity; Electric Charge and Its Conservation

- Electricity is from Greek word *elecktron*=amber, a petrified tree resin that attracts matter if rubbed



- Static Electricity: an amber effect
  - An object becomes charged or "posses a net electric charge" due to rubbing
  - Can you give some examples?
- Two types of electric charge
  - Like charges repel while unlike charges attract
  - Benjamin Franklin referred the charge on glass rod as the positive, arbitrarily. Thus the charge that attracts glass rod is negative. ➔ This convention is still used.



(a) Two charged plastic rulers repel

(b) Two charged glass rods repel

(c) Charged glass rod attracts charged plastic ruler

Static Electricity; Electric Charge and Its Conservation

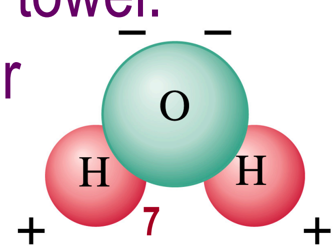
- Franklin argued that when a certain amount of charge is produced on one body in a process, an equal amount of opposite type of charge is produced on another body.
  - The positive and negative are treated algebraically so that during any process the net change in the amount of produced charge is 0.
    - When you comb your hair with a plastic comb, the comb acquires a negative charge and the hair an equal amount of positive charge.
- This is the **law of conservation of electric charge.**
  - **The net amount of electric charge produced in any process is ZERO!!**
    - If one object or one region of space acquires a positive charge, then an equal amount of negative charge will be found in neighboring areas or objects.
    - No violations have ever been observed.
    - This conservation law is as firmly established as that of energy or momentum.

Electric Charge in an Atom

- It has been understood through the past century that an atom consists of
  - A positively charged heavy core ← What is the name?
    - This core is the nucleus and consists of neutrons and protons.
  - Many negatively charged light particles surround the core ← What is the name of these light particles?
    - These are called electrons
    - How many of these in an atom?

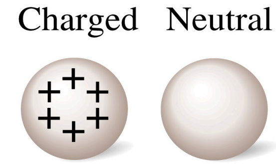
As many as the number of protons in the nucleus!!

- So what is the net electrical charge of an atom?
  - Zero!!! Electrically neutral!!!
- Can you explain what happens when a comb is rubbed on a towel?
  - Electrons from the towel get transferred to the comb, making the comb negatively charged while leaving positive ions on the towel.
  - These charges eventually get neutralized primarily by water molecules in the air.

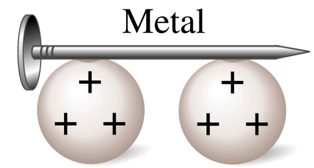


Insulators and Conductors

- Let's imagine two metal balls of which one is charged

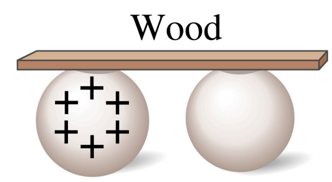


- What will happen if they are connected by
  - A metallic object?
    - Some charge is transferred.
    - These objects are called <u>**conductors of electricity**</u>.



(b) Conductor

  - An wooden object?
    - No charge is transferred
    - These objects are called <u>**nonconductors or insulators**</u>.

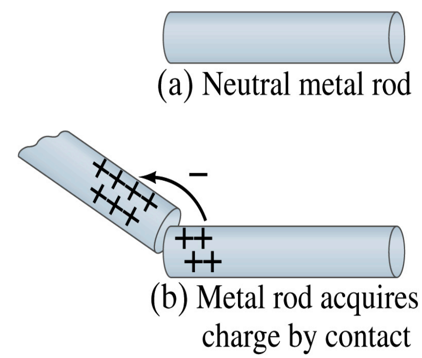


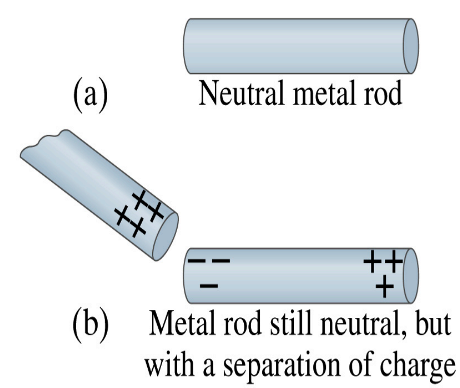
(c) Insulator

- Metals are generally good conductors whereas most other materials are insulators.
  - There are third kind of materials called, semi-conductors, like silicon or germanium → conduct only in certain conditions
- Atomically, conductors have loosely bound electrons while insulators have them tightly bound!

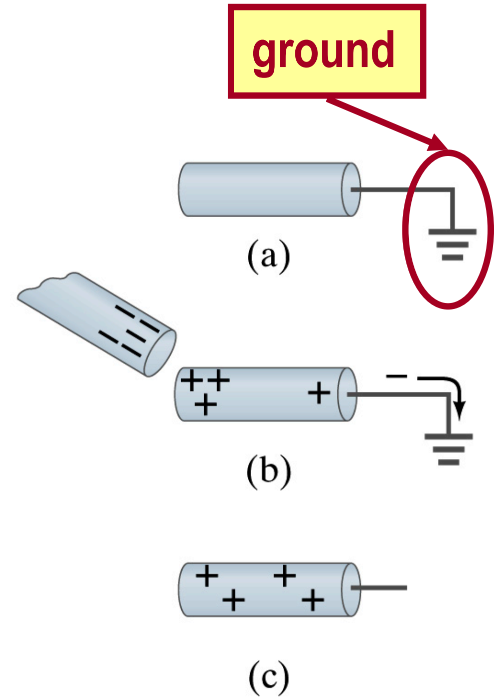
Induced Charge

- When a positively charged metal object is brought close to an uncharged metal object
  - If two objects touch each other, the free electrons in the neutral one are attracted to the positively charged object and some will pass over to it, leaving the neutral object positively charged ➔ Charging by conduction
  - If the objects get close, the free electrons in the neutral one still move within the metal toward the charged object leaving the opposite side of the object positively charged.
    - The charges have been "induced" in the opposite ends of the object.

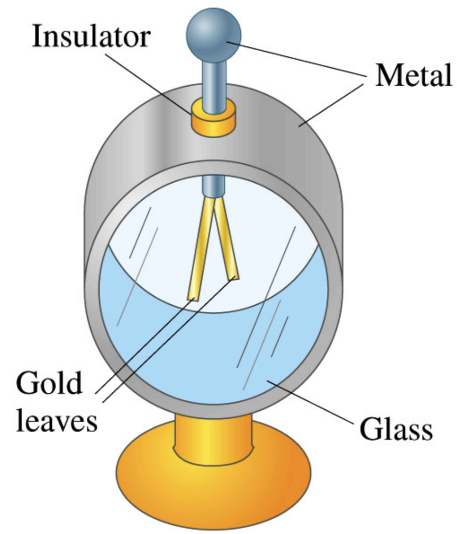




Induced Charge



- We can induce a net charge on a metal object by connecting a wire to the ground.
  - The object is "grounded" or "earthed".
- Since the Earth is so large and conducts, it can give or accept charge.
  - The Earth acts as a reservoir of electric charge.
- If negative charge is brought close to a neutral metal
  - Positive charge will be induced toward the negatively charged metal.
  - The negative charges in the neutral metal will be gathered on the opposite side, transferring through the wire to the Earth.
  - If the wire is cut, the metal bar has net positive charge.
- An **electroscope** is a device that can be used for detecting charge and signs.
  - How does this work?



Coulomb's Law

- Charges exert force to each other. What factors affect the magnitude of this force?
  - Any guesses?
- Charles Coulomb figured this out in 1780's.
- Coulomb found that the electric force is
  - Proportional to the multiplication of the two charges
    - If one of the charges doubles, the force doubles.
    - If both the charges double, the force quadruples.
  - Inversely proportional to the square of the distances between them.
  - Electric charge is a fundamental property of matter, just like mass.
- How would you put the above into a formula?

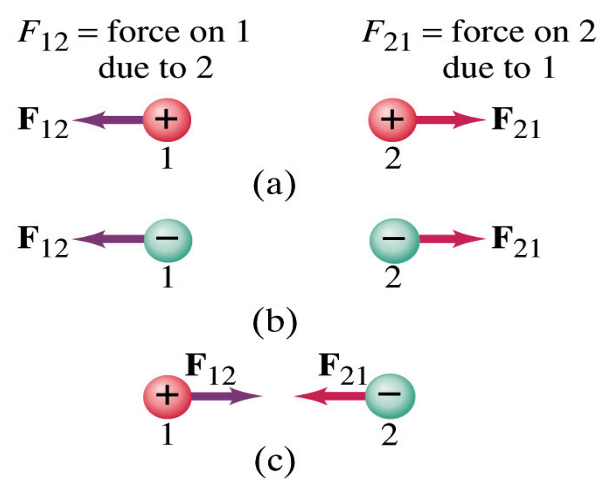
Coulomb's Law – The Formula

$$F \propto \frac{Q_1 \times Q_2}{r^2}$$

Formula

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

- Is Coulomb force a scalar quantity or a vector quantity? Unit?
  - A vector quantity. The unit is Newtons (N)!
- The direction of electric (Coulomb) force is always along the line joining the two objects.
  - If the two charges are the same: forces are directed away from each other.
  - If the two charges are opposite: forces are directed toward each other.
- Coulomb force is precise to 1 part in 10^{16}.
- Unit of charge is called Coulomb, C, in SI.
- The value of the proportionality constant, k, in SI unit is $k = 8.988 \times 10^9 \ \mathrm{N \cdot m^2}/C^2$
- Thus, 1C is the charge that gives **F~9x10^{9}N** of force when placed 1m apart from each other.



Electric Force and Gravitational Force

$$F = k\frac{Q_1 Q_2}{r^2} \iff F = G\frac{M_1 M_2}{r^2}$$

Extremely Similar

- Does the electric force look similar to another force? What is it?
  - **Gravitational Force**
- What are the sources of the forces?
  - Electric Force: Electric charges, fundamental properties of matter
  - Gravitational Force: Masses, fundamental properties of matter
- What else is similar?
  - Inversely proportional to the square of the distance between the sources of the force ➔ What is this kind law called?
    - Inverse Square Law
- What is the difference?
  - Gravitational force is always attractive.
  - Electric force depends on the type of the two charges. (must pay good attention to the signs due to the sign of the charge and the vector force directions!!)

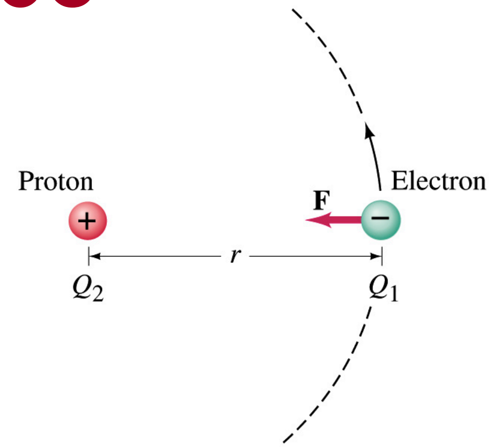
The Elementary Charge and Permittivity

- Elementary charge, the smallest charge, is that of an electron: $e = 1.602 \times 10^{-19} C$
  - Since electron is a negatively charged particle, its charge is $-e$.
- Object cannot gain or lose fraction of an electron.
  - Electric charge is quantized.
    - It changes always in integer multiples of e.
- The proportionality constant k is often written in terms of another constant, ε_0, the permittivity* of free space. They are related $k = 1/4\pi\varepsilon_0$ and $\varepsilon_0 = 1/4\pi k = 8.85 \times 10^{-12}\, C^2/N \cdot m^2$.
- Thus the electric force can also be written as: $F = \frac{1}{4\pi\varepsilon_0}\frac{Q_1 Q_2}{r^2}$
- Note that this force is for "point" charges at rest.

***Mirriam-Webster, Permittivity: The ability of a material to store electric potential energy under the influence of an electric field**

Example on Coulomb Force

- **Electric force on electron by proton.** Determine the magnitude of the electric force on the electron of a hydrogen atom exerted by the single proton (Q_2=+e) that is its nucleus. Assume the electron "orbits" the proton at its average distance of r=0.53×10^{-10}m.



Using Coulomb's law $$F=\frac{1}{4\pi\varepsilon_0}\frac{Q_1Q_2}{r^2}=k\frac{Q_1Q_2}{r^2}$$

Each charge is $Q_1=-e=-1.602\times10^{-19}C$ and $Q_2=+e=1.602\times10^{-19}C$

So the magnitude of the force is

$$F=\left|k\frac{Q_1Q_2}{r^2}\right|=9.0\times10^9\ N\cdot m^2/C^2\frac{\left(1.6\times10^{-19}C\right)\left(1.6\times10^{-19}C\right)}{\left(0.53\times10^{-10}m\right)^2}$$
$$=8.2\times10^{-8}N$$

Which direction? Toward each other…