PHY1033C **Fall 2017**

Lecture W6

Electrical Charges and Coulomb Force

1. Electrical Charge and Coulomb Force

Imagine a day, way back several hundred thousand years ago, with a series of lightning bolt and thunder. People on a wide open field must have been scared and wondered what was going on. With no place to hide they probably witnessed wild fires and trees got hit by lightning. When they were able to hunt animals using tools and weapons, they could make covers using animal fur. One a dry cold night, they also saw statics from fur covers pop in a dark cave. Some people with keen observation skills who recognized the similarity between lightening and static sparks. Some people with a playful curiosity tried to make more sparks. More than 2500 years ago, people already knew how to generate and accumulate electric charges by rubbing fur against various materials.

A major scientific investigation on electric charges was done by Benjamin Franklin in the mid 18th century. Franklin, born in 1706, stopped his education at ten. Although his early success was as a publisher, throughout his life he retained his interest in all aspects of nature with a strong sense of curiosity. In 1746, Franklin witnessed a performance by Dr. Archibald Spencer in which he drew electric fire (sparks) from the extremities of a little boy suspended from the ceiling by silk threads. This event dragged him into studying and playing with electricity. He said "I never was before engaged in any study that so totally engrossed my attention and my time as this has lately done." [1] In his eighty-six page book entitled *Experiments and Observations on Electricity, Made at Philadelphia in America*, Franklin proposed a fluid which carries electricity: When the fluid flows out of a neutral body to another, the body in lack of fluid is negatively charged but the other in surplus is positively charged. This was against the traditional idea that electricity was of two types–vitrous and resinous. He also understood the notion of conservation of charge since the positive and negative charges are induced by the deficit or excess of the same amount of fluid.[1]

Franklin had qualitative understanding of the nature of forces between charges. About 40 years later Charles Coulomb was able to establish a formula for the force between charges based on his own experiments:

$$F_C = k\frac{qQ}{r^2}.$$

This is called Coulomb force between two charges of q and Q separated by a distance r. The proportional constant k is called Coulomb's constant ($k = 9 \times 10^9$ Nm^2/C^2). Here, a charge is expressed in C (coulomb). To give you a sense about the unit of charge C, one electron carries charge of $e = -1.6 \times 10^{-19}$ C. The mathematical structure of Coulomb force is identical to the gravitational force. However, there is one clear distinction: Coulomb force could be attractive or repulsive while the gravitational force is only attractive. For the pair of (+,+) or (-,-), Coulomb force is repulsive (positive sign) but for (+,-) or (-,+), it is attractive (negative sign).

Exercise Since the force between two masses and two charges have identical mathematical structure, let us make a comparison between two forces for two objects of 1 kg each of which carries 1 C of the same type of charge. They are apart by 1 m. Gravitational force is attractive but the Coulomb force in this case is repulsive.

$$F_G = 6.7 \times 10^{-11} \left(\frac{1 \cdot 1}{1^2} \right) \approx 6.7 \times 10^{-11} \mathrm{N},$$
$$F_C = 9 \times 10^{9} \left(\frac{1 \cdot 1}{1^2} \right) \approx 10^{10} \mathrm{N}.$$

The repulsive Coulomb force is much stronger than the attractive gravitational force. To make the gravitational force as strong as Coulomb force for this example, the mass has to be about 10^{10} kg. So when we consider a force between charged objects, we can simply ignore the gravitational part!

2. Charge, Conductor, and Insulator

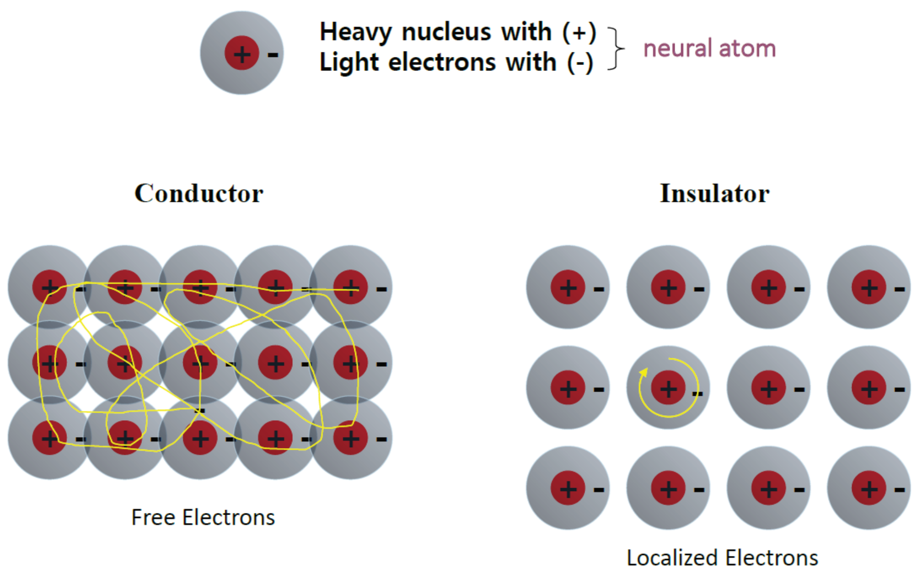

FIG. 1:

What is the nature of the fluid that Franklin envisioned? We now know that it is electrons which carry negative charges. Ordinary matter is composed of atoms. In a normal circumstance, atoms are electrically neutral in perfect balance between the positively charged heavy nucleus and negatively charged light electrons. Electrons are bound around the nucleus due to strong Coulomb force.

Q1 Consider a hydrogen atom. Both proton and electron have the same amount of charge $|e|$ and are separated by a distance of 3^{-11} m. How strong is the Coulomb force between them?

Q2 Each of three objects (A, B, and C) carries a net charge. A attracts B. Objects B and C attract each other. Which of the following configurations is a possible combination of three objects. (x,y,z) represents the type f charges on (A,B,C).
(1) (+,−,+)
(2) (+,−,−)
(3) (−,−,+)
(4) (0,−,+)

In a certain material, the electrons are very localized around their nuclei, maintaining the atomic structure. Electrons can only circulate only around the nuclei and cannot move to the neighboring atoms. This type of material is called an insulator. Wood, plastic, ceramic, and glass are a few examples of insulator. However, in some materials, the electrons around a nucleus are loosened up to freely move around the whole material, which is called a conductor. Metals are prime example of a conductor. Considering the ability of flowing electrons and the price, copper is the best choice for electrical wires.

Most of the electrostatic phenomena are caused by redistribution of electrons since positive charge is immobile. Here are a few examples of how we could manipulate charge.

[1] Gordon S. Wood, *The Americanization of Benjamin Franklin* (Penguin Books, 2005).