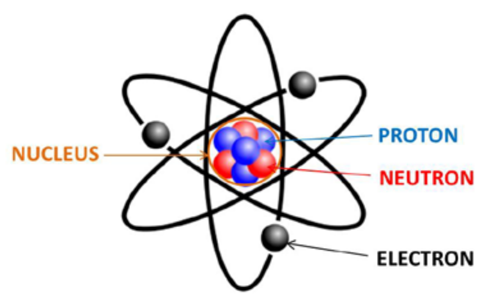
UNIT 5 ELECTRICITY AND MAGNETISM

PHYS:1200 LECTURE 23 — ELECTRICITY AND MAGNETISM (1)

Thus far in this course we have considered only one of the basic properties of matter – mass. Mass is the property of matter that enables it to interact with other matter by the gravitational force. The Universe is held together by gravity, and the Sun's gravity holds the solar system together. But what holds the atoms in matter together? It is not the gravitational attraction between individual atoms, because on the microscopic scale, the gravitational force is too weak. The gravitational force between atoms is negligible because the masses are very small. However, atoms are composed of particles (electrons and protons) that have, in addition to mass, **electric charge**, and electric charges experience electric and magnetic forces. Electricity and magnetism is the branch of physics dealing with the behavior of electric charges. We will explore the phenomena associated with electric charge in this and the next five lectures.

23-1. Electric Charge.—There are **two types** of electric charge: positive charge and negative charge. The effects of electric charge are not as apparent as the effect of mass because, charge is bound up inside of atoms. Masses only experience attractive forces, whereas electric forces can be both attractive and repulsive. Usually, matter has equal numbers of positive and negative charges, so that it is **electrically neutral**. Even at the microscopic level of atoms, atoms have equal numbers of positive and negative charges, so they are electrically neutral. We must look inside the atom to see the charges. Atoms are the most basic units of matter. In other words, when you break a piece of say, copper down to its smallest part, you find single copper atoms. All atoms have a nucleus and electrons.



The nucleus is composed of two types of elementary particles – protons which have a positive charge, and neutrons which have no electric charge. The nucleus of protons and neutrons is at the center of the atom, and the electrons move around on the outside of the nucleus, and have a negative charge. The proton charge and electron charge have the same magnitude of charge, we call this one unit of elementary charge, but opposite sign. Under normal conditions, the number of protons in the nucleus is equal to the number of electrons, so the atom is electrically neutral—no net charge. For example, the simplest atom – hydrogen, has one proton, no neutrons, and one electron, so the net charge is zero. The number of protons in the nucleus is the distinguishing characteristic of an atom. Hydrogen has 1 proton, helium has two protons, lithium has three protons, beryllium has 4 protons (shown in the figure above), etc. We will discuss the properties of the nucleus in the last unit of this course.

Electric charge is measured in units of **Coulombs** (C). The proton has one basic unit of positive charge $+e,$ and the electron has one negative unit of charge $-e,$ where $e = 1.6 \times 10^{-19}\ C.$ The letter $q\ or\ Q,$ is used to symbolize electric charge.

EXAMPLE 23-1: How many electrons are needed to produce a charge of $-1\ C$?

Solution- One electron has a charge $-e = -1.6 \times 10^{-19}\ C.$ Suppose the number required is N,

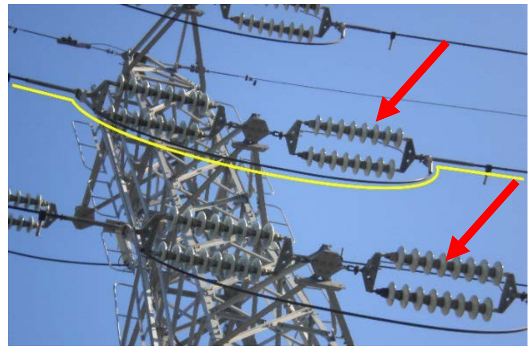
then we require that $N\left(-1.6 \times 10^{-19} C\right) = -1C$ so that $N = \dfrac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}\ electrons.$

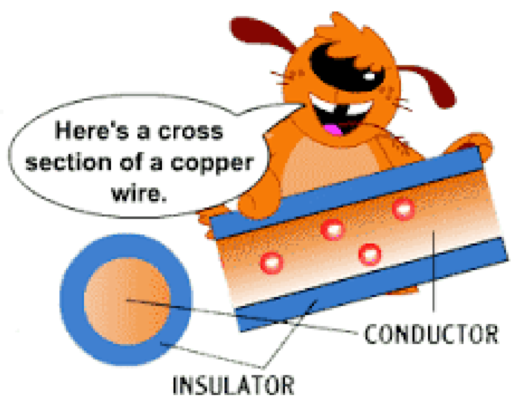
23-2. The Electric Force: Coulomb's Law—The force between two charges, $q_1\ and\ q_2,$ is given by Coulomb's Law:

- Like charges (two positive or two negative) repel (push each other away).
- Unlike charges (one positive and one negative) attract (pull each other together).
- The magnitude of the electric force $\left(F_e\right)$ between two charges, $q_1\ and\ q_2,$ is directly proportional to the product of the charges and inversely proportional to the square of the distance $\left(r\right)$ separating them: $F_e = k_e \dfrac{q_1 q_2}{r^2},$ where k_e is a constant. (**slide 5**).

The attractive electric force between the protons in the nucleus and the electrons is the force that binds the atom together.

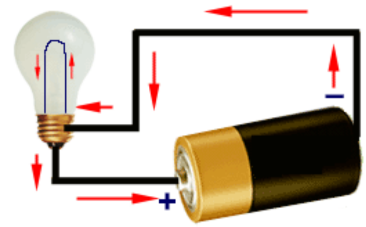
23-3. Conductors and Insulators.—The electrical properties of materials are broadly classified as **conductors or insulators (non-conductors).** This classification is based on the extent to which the material **will allow electric charge to move through them**, or, in other words to allow **electric current** to pass through it. **Electric current is a flow of charge.** Electric current can flow through a conductor but cannot flow through a non-conductor. Conductors include the metals- copper, aluminum, fold, silver, steel, etc., as well as some liquids like salt water. Pure water is generally a non-conductor, but becomes conducting if some salt (NaCl) is dissolved in it. The non-conductors include glass, plastics, ceramics, dry air, etc. The wires that carry electricity in your home are made of copper and are contained within a plastic (nylon or Teflon) sheath to insulate them. High voltage power lines which carry power over long distanced are supported by huge metal towers. Ceramic insulators are used to prevent the high voltage lines from coming into contact with the towers.





What makes a conductor conduct and a non-conductor not conduct? First, it is important to emphasize that both conductors and non-conductors are electrically neutral in their normal state – they have no **net** charge. A conductor does not need to have a net charge for current to flow through it. In a conductor, such as copper, there are electrons that are not bound to any particular atom, and are free to move about. Each Cu atom has one electron that is not bound to it. We call this collection of “homeless” electrons, free electrons, and it is these free electrons that are able to carry the current. Non-conductors have no free electrons. Every electron is tightly bound to an atom, so there are no free charges which can carry currents.

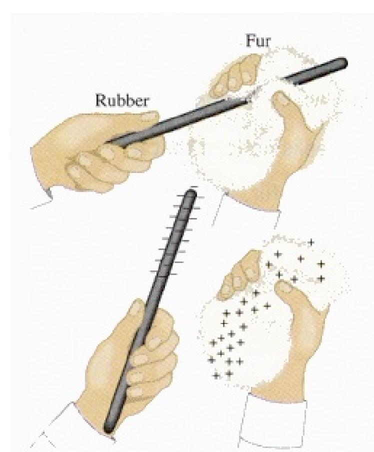
Under normal conditions the free electrons in a conductor move about in random directions but there is no current associated with this random motion of the free electrons. However, when a battery is connected to the ends of the conductor, a current flows. A battery is like a pump for charge which makes the electrons flow in the direction toward the positive terminal. We will discuss this process in more detail when we introduce the concept of resistance in another lecture.



Simple circuit with light

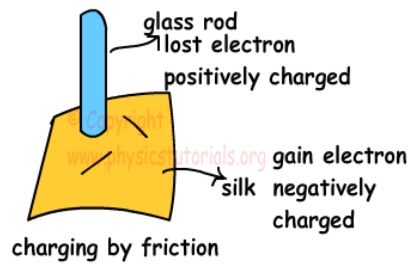
It was easy to visualize free fall – you release an object and it falls to the ground. Electrical phenomena is more difficult to visualize because the charges are usually stuck inside the conductors. We experience the effects of electric charge directly when we observe a spark. A spark is a rapid discharge of electric charge through the air. A spark occurs when the voltage difference between two objects is high enough that some of the electrons in the oxygen and nitrogen molecules of the air are ripped out of the atoms, producing a temporary supply of free charges. The molecules are excited in this process and give off the characteristic light flash that is the spark. Similar processes occur in a lightning discharge on a much larger scale. The van de Graff generator is a device which produces larger amounts of charge and enough voltage to cause sparking through the air.

23-4. Charging Processes.—Most of us have experienced the phenomenon referred to as **static electricity**. In the winter months when the air is dry, it is common to "get a shock" when touching a door or another person after walking across a carpet. You might also notice that clothes are stuck together when you remove them from a dryer. These effects are due to frictional charging (the technical term is the triboelectric effect). When two materials are rubbed against each other, charge from one can flow to the other, leaving one positive and one negative. Although conductors have no free charges, they can still be "charged." Which means than charges can be transferred or taken away from them. This can also occur with conductors, but when charges are placed on a non-conductor, they remain in the place where they were placed and do not move around. Charges placed

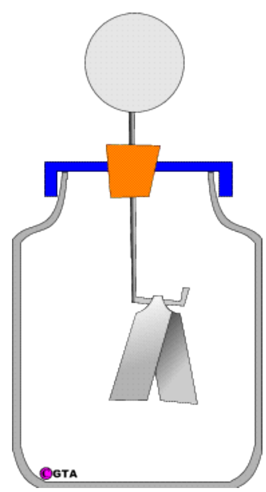


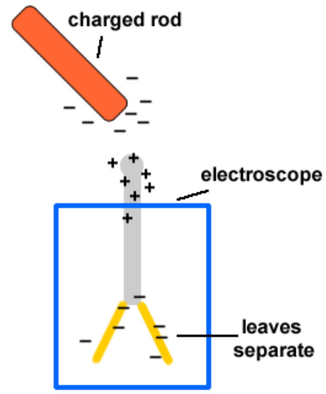
on conductors can move around and usually redistribute themselves on the surface of the conductor.

The basic rules of frictional charging are: (a) When plastic (or rubber) is rubbed with fur, electrons are transferred from the fur to the plastic, making the plastic negative and leaving the fur positive. (b) When glass is rubbed with silk, electrons are transferred from the glass to the silk, making the glass positive and the silk negative. These rules are known by observation. As a general rule in the charging process (there are exceptions however), it is the electrons (negative charges) that are transferred from one object to another, the positive charges are not transferred (there are some materials where positive charges are transferred, but we will not consider those.). So an object is charged negatively by adding electrons to it; and charged positively by removing electrons from it. Remember that before the charging occurs, the objects are electrically neutral. The total amount of charge is always conserved in the charging process, charge is not lost, just transferred. In the charging process, the charge lost by one object = the charge gained by the other object.



A piece of plastic can be charged negatively by rubbing it with fur, and then some of the negative charged can be transferred to a conductor. A device called an electroscope is used to quantify the amount of charge on a conductor. It consists of a metal ball connected to a metal rod which has two thin gold foil leaves attached to it. When negative charged is placed on the ball some of it is redistributed to the gold leaves, which then repel each other. The amount by which the leaves repel is a measure of the amount of charge. The effect of charge on a charged rod can be observed with the electroscope even before the charge id transferred to the ball. When a negatively charged rod is brought near the ball at the top of the electroscope, it will cause electrons in the ball to move downward to the leaves, which then separate. The closer the rod is brought to the ball, the more the leaves separate.





Because a metal sphere has free electrons it will be attracted to a negatively charged plastic rod as illustrated on slide 16. The negative charges on the plastic will cause some of the electrons in the metal sphere to move away to the other side of the sphere. This leaves the side of the sphere closest to the rod with a positive charge which is attracted to the negative rod because they are closer than the negative charges on the other side of the sphere.

Uncharged non-conductors like wood or water can also be attracted to a charged rod. This is due to a process called ***polarization***, which is explained on slides 17-19, and will be demonstrated in class.

23-5. Electric Potential.—We have used this term but not defined it. **Electric potential** (or simply, voltage) is a difficult quantity to grasp because we can't see the charges or sense the energy involved with them. However, there is energy involved with electric charge just like there is energy involved with masses and gravity. Work is required to lift a weight to a certain height and that work is stored as gravitational potential energy. Similarly, work is required to separate a positive and negative charge or to bring two like charges together. When this work is done, it is stored as electric potential energy. Now mostly for reasons of convenience, people who worked on electricity preferred to deal with a related quantity called **potential or voltage, which is defined as the electric potential energy per unit of charge.** Just as a weight always falls to a point of lower gravitational potential energy, a positive electric charge will fall (accelerate) to a point of lower electric potential energy or lower potential. Potential, or voltage is the more practical quantity and is measured in volts (V). A battery is quantified in terms of its ability to move charges. A battery with a higher voltage, can provide more potential energy per Coulomb.

The amount of charge on a conductor determines its voltage. If the positive side of a battery is connected to a conducting sphere (**see diagram below**) and the other side connected to the earth (ground), electrons are drawn from the sphere to the earth. This leaves the sphere with a positive charge and a positive potential relative to the earth. The earth (ground) is used as a reference level for potential because it is so huge, that its potential remains more or less the same regardless of how much charge is placed on it. In the figure below, the battery will transfer as many electrons to the ground as is necessary to raise the potential of the sphere to the voltage of the battery.