Electric Charge and Electric Field

Static Electricty, Charge, Conductors and Insulators

Sections 16-1 to 16-3

We recognize, from a few basic experiments in static electricity that two types of charges exist, which we call positive and negative. Benjamin Franklin recognized this based on certain things:

1. Charged (or electrified) objects attract uncharged ones.
2. Charged objects can either attract or repel.

Franklin defined the negative charge as being the charge on amber (when rubbed with wool) and the positive charge as the charge on glass (when rubbed with silk). This was an arbitrary decision, but is a convention we still hold today.

Franklin argued that we could not create charge, but could merely transfer it. That is the total amount of charge remains unchanged. Formally

the net amount of charge created in any process is zero

is known as the law of conservation of charge.

Looking at our knowledge of the atom, we understand (in simplified form) that it is made up of a core of positive charges (protons) surrounded by negatively charged electrons. The question is, while transferring charge, which is actually transferred? Based on our understanding of chemistry we realize it is the electrons (when they transfer they form ions).

Conductors and Insulators

We start by defining a conductor and an insulator:

Conductor - an object which allows charges to flow easily

Insulator - an object which does not allow charges to flow easily

Notice that these definitions are relative definitions. Wood is a good insulator - so why don't we stand under a tree in a thunderstorm? Because wood is a better conductor than air, and so the charge is more likely to travel through the tree than through the air.

From an atomic point of view, electrons in an insulator are bound tightly to the nucleus, while in a good conductor, some of the electrons are bound very loosely. These electrons are known as free electrons or conduction electrons.

Charging Objects and Coulomb's Law

Sections 16-4 to 16-5

Charging by Friction

Charging by friction occurs when two different substances rub together. This is due to the different atomic or molecular affinities for electrons and electron configuration in the shells. One substance will have a greater affinity for electrons than the other, and so, when rubbed together, one takes electrons away from the other becoming negative. This leaves the second object electron deficient or positively charged.

Charging by Conduction

If a charged object contacts another object and there is transfer of electrons between the objects, the second object is said to be charged by conduction. For example, if a negatively charged sphere is allowed to touch an identical, but neutral sphere, the two will become negatively charged, but each will have a charge only half of the original.

If a charged object and neutral object make contact, the neutral object will take a charge of the same sign as the first object.

It is not necessary for the two objects to touch. They simply need to be close enough for the charge to arc from one to the other (as is the case with lightning).

Charging By Induction

Charging by induction involves 3 steps:

1. Bringing a charged object near (but not touching) the neutral object.
2. Grounding the neutral object (providing a path for electrons to pass to or from a massive object - such as the earth - from or to the object).
3. Removing the ground.

When this happens, the "neutral" object obtains the opposite charge of the charged object. (See p. 480 of Giancoli for further details - this will be discussed more in class).

Coulomb's Law

Coulomb had an apparatus similar to Cavendish's apparatus for measuring the force of gravity, involving an insulating rod suspended from a string with two spheres (one on each end of the rod). By changing the charges on the rod by factors of 2 (which is easy to do when sharing charge between two objects) he was able to determine the relationship between the size of the charges, the separation and the force. This took the form of

$$F = \frac{kQ_1Q_2}{r^2} \tag{6.1}$$

where Q_1 and Q_2 are the charges in Coulombs (or elementary charges) and k is the Coulomb constant (and $k = 8.988 \times 10^9 \frac{\text{Nm}^2}{\text{C}^2}$ in a vacuum).

The Coulomb (C) is the SI unit of charge. 1 C is equal to the charge on 6.24×10^{18} protons, or likewise, one proton has a charge of 1.602×10^{-19} C. This is often written as

$$e = 1.602 \times 10^{-19}$$

where e is an elementary charge. Therefore the charge on an electron is $-e$ and the charge on a proton is $+e$.

The Coulomb constant, k, is dependent upon the material through which the force acts. For this reason, k is often defined in terms of the *permittivity of free space*, ϵ_0, so $k = \frac{1}{4\pi\epsilon_0}$. Coulomb's law then takes the form

$$F = \frac{1}{4\pi\epsilon_0}\frac{Q_1 Q_2}{r^2}. \tag{6.2}$$

If the force is not acting through free space (i.e., a vacuum), the permittivity changes, so then

$$F = \frac{1}{4\pi\epsilon}\frac{Q_1 Q_2}{r^2}. \tag{6.3}$$

where ϵ is the permittivity of the substance (see p. 514 of Giancoli for a list of permittivities).

We will compare the size of the electrical force with that of the gravitational force between a proton and an electron in class.

Multiple Charges and Electric Field

Sections 16-6 to 16-7

Multiple Charges

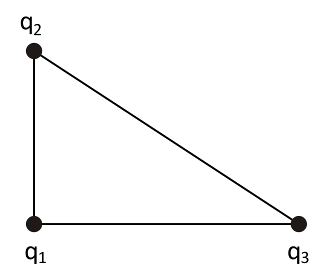

Figure 6.1: Example of multiple charges

WE DEAL WITH MULTIPLE POINT CHARGES and the forces between them by summing the forces on a single charge. For example, if we have three point charges as in figure 6.1, to find the total force acting on q_1, we find the force that q_2 puts on it and the force q_3 puts on it and add them together as vectors.

So $\vec{F}_1 = \vec{F}_{21} + \vec{F}_{31}$ where $\vec{F}_1$ is the total force on charge 1, and $\vec{F}_{21}$ and $\vec{F}_{31}$ are the forces charge 2 puts on charge one and charge 3 puts on charge 1 respectively. In general, we write this as

$$\vec{F}_i = \sum_j \vec{F}_{ji}$$

We will look at specific examples of these in class.

Electric Fields

The electric field is defined as the limit of the electrical force acting on a charge as the charge approaches zero. In practical terms, we define the electric field to be

$$\vec{E} = \frac{\vec{F}}{q} \tag{6.4}$$

where the direction of the electric field is defined to be in the direction of a force acting on a positive charge and q is the charge experiencing the force.

By substituting Coulomb's law for force from equation 6.1, we obtain

$$E = \frac{kQ}{r^2} \tag{6.5}$$

where Q is the charge causing the electric field and the direction of the field is radial (outward for a $+$ charge and inward for a $-$ charge).

Between two parallel plates, the electric field is constant.

The properties of field lines can be summarized as follows:

1. *The field lines indicate the direction of the electric field; the field points in the direction tangent to the field line at any point.*
2. *The lines are drawn so that the magnitude of the electric field, E, is proportional to the number of lines crossing unit area perpendicular to the lines. The closer the lines, the stronger the field.*
3. *Electric field lines start on positive charges and end on negative charges; and the number starting or ending is proportional to the magnitude of the charge.*
4. *The electric field lines are always perpendicular to the surface of a conductor.*[5]

The total electric field inside a conductor in a static situation is always zero. We will look at some examples of this in class.

[5] Giancoli, D. *Physics,* 5*th ed.*, p. 491.