Electrostatics

Electricity is an aspect of modern society that many of us take for granted – until the lights go out. Power outages have a wide range of effects: disappointment when you can't see your favorite show or play a new video game, annoyance that supper will not be ready and food may spoil, financial woes because data is lost when computers suddenly go blank, panic when hospital equipment stops working during an operation.

Forms of Electricity Electricity occurs in two forms – static electricity and current electricity. Static electricity is due to the buildup of stationary positive or negative charges on electrified substances. For example, as you pull a sweater over your head, electrons (tiny negative particles on the outside of atoms) are transferred between the fibers of the sweater and your hair. The result is static charges that build up on the sweater fibers and on your hair. This makes your hair stand on end. If the sweater fibers are long enough, they will also stand on end.

Current electricity is the result of moving streams of electrons flowing from a power supply, e.g., a battery, a solar cell, a nuclear power plant.

Static Electricity As far back as 600 BC, static electricity was being demonstrated (but not understood) by rubbing a piece of amber (solidified tree sap) across a piece of fur. Both the amber and the fur were then able to attract small pieces of cloth and wood shavings. Hundreds of years later, in the 1600's, William Gilbert made a methodical study of amber, fur and other substances that, when rubbed with a cloth, attract tiny bits of matter. He called materials like amber and fur "electrics" because of their ability to attract tiny bits of materials.

Recall static charges are produced when electrons move from one body to another. When smooth cloth, e.g., silk, is wiped over glass, electrons transfer from the surface of the glass rod to the cloth. The cloth becomes negative and the glass becomes positive. Since the electrons are negatively charged, they make the body to which they move, negative, and the area which they leave becomes positive. Another example: if a plastic rod is scraped across a piece of fuzzy cloth, electrons transfer from the surface of the fuzzy material to the plastic. The plastic becomes negative and the fuzzy cloth becomes positive. Again, since the electrons are negatively charged, they make the body to which they move, negative, and the area which they leave becomes positive. Note: once static charges are created, the law of charges states that like charges repel while opposite charges attract. This is why, in the sweater example above, your hair lifts out toward the sweater as you pull it up away from your head – your hair and the sweater have opposite charges.

Conductors A conductor allows electrons to easily move around on its surface. A common example of a conductor is metal. Think of all the copper wire snaking around your house, hidden inside the walls. The wires carry electricity to the various wall sockets located around your house. Other examples are metals, carbon, ionic and polar covalent solutions, e.g., salt water.

Electrons move easily between conductors that are in direct contact so when you join two lengths of copper wire by twisting the ends together, electric current easily moves through one length and into the next. Because electrons can move around so easily, negative charges can not build on the wire. If you put a large number of electrons onto a spot on a wire, there would be a large negative charge there. But, an instant later, the electrons would just spread out all over the surface of the wire and the negative charge would fade away.

Insulators An insulator is a substance that prevents electrons from moving around. Common examples are glass, plastic, rubber, and air. When electrons get onto a spot on the surface of an insulator, they are stuck there and so a negative charge builds up at that location. In fact, negative charges can build up at many different areas on the surface of an insulator. The electrons try to spread out and reduce the charges (like they do on metals) but the insulator holds them in place and so the charges remain on the surface of the insulator. Note: if two insulators touch or a conductor and an insulator touch, electrons can move to or from the surface of the insulator but only at the point where it is touching the other insulator or the conductor. If electrons leave that spot on the insulator, the negative charge there will decrease; if electrons move onto that spot on the insulator, the negative charge there will increase.

Charge Balance A material is usually neutral because the positive and negative charges in its atoms balance. An atom is something like a miniature solar system: the planets are like electrons (e^-) circling the sun which is like the nucleus. The nucleus contains protons (p^+) and neutrons (n^0). Normally, the number of electrons = the number of protons. For example, an atom with 10 protons and 10 electrons will be neutral.

Whenever the atoms absorb extra electrons, the charge balance is upset and the matter becomes negatively charged because the extra electrons bring in their extra negative charges with them. If the atom with 10 protons (10^+) and 10 electrons (10^-) takes in 2 <u>extra</u> electrons, it will have a total of 12 electrons and, 10^+ plus 12^- gives a total charge of 2^-. Now, the whole atom takes on a negative charge. The extra electrons, all being negative, exert a <u>repulsive</u> force on each other and try to push away from each other. If there is an escape route, called a <u>ground</u>, the two extra electrons will use it to rush <u>away</u> from the atom. The atom becomes neutral again.

Note: a ground is any material that can loose or gain electrons without experiencing a charge change. When paper comes out of a photocopier or printer, it often has an electrical charge. To keep the machine from jamming if the static charge causes three or four pages to stick together, each page passes under a “brush” made of conductive hairs. Each hair is a tiny ground and as it moves across the surface of the paper, it allows some of the static charge to leave the paper. Each sheet of paper is brushed by dozens of hairs and the result is: no static charge left on the paper, no jamming. In some situations, a ground could be just a piece of copper wire or even yourself.

But, what if a <u>neutral</u> atom <u>loses</u> some electrons? If an atom with 10 protons (10^+) and 10 electrons (10^-) <u>loses</u> 3 electrons for example, it will have a total of just 7 electrons and, 10^+ plus 7^- gives a total charge of 3^+. So, if the atoms of a substance <u>lose</u> some electrons, the charge balance is upset and the matter becomes <u>positively</u> charged. Note: the 3^+ charge on the atom would exert a pull on the negative electrons in surrounding materials and, in this situation, the ground would be a route for electrons to <u>enter</u> the atom to reestablish the charge balance.

Measuring Static Charge

The Electroscope This device, made of metal, is used to demonstrate the magnitude and sign of static charges. It consists of a stem connecting a knob to a pair of flexible leaves. See Fig. 20 – 4, p 397. It can be used in five different situations to demonstrate the behavior of static electricity. *Home made electroscope*

Summary Description of Electroscope Behavior

1. Temporary Charging: A charged object approaches the electroscope, driving <u>like</u> charges down to the leaves which open. When the object retreats, the charges ascend from the leaves which then collapse.

2. Contact Charging: If a charged object touches the disc, some of its charge moves onto the electroscope and down to the leaves, causing them to stay open with the <u>same</u> charge as the object.

3. Induction Charging: This 4 - step process always leaves a charge on the electroscope opposite

to that on the rod. a) A charged object approaches the electroscope causing its leaves to open. b) A ground is attached to the disc, electrons flow through it, and the leaves close. c) The ground is removed. d) The charged object moves away and the leaves open, but with a charge opposite to that of the object.

4. Charge Intensification: The electroscope's leaves are forced to open more if a like charge is held near it.

5. Charge Neutralization: The electroscope's leaves close some if an opposite charge is held near it.

Detailed Description of Electroscope Behavior

1. Temporary Charging: This process creates a temporary charge on the leaves the same as that on a charged rod.

a) A negative rubber rod is held close to the knob of the electroscope. Some of its electrons are forced down into the leaves which become temporarily negative, and open. The upper portion is left positive. When the rod is removed, the electrons crowded into the leaves ascend. The leaves become neutral and collapse. The upper portion likewise regains its neutrality.

b) A positive glass rod is held next to the knob. Some of the electrons in the electroscope move to the knob, attracted there by the positive rod. The lower portion becomes positively charged. The leaves separate. When the rod is removed, the electrons move back down the electroscope, the whole of which regains its charge balance. The leaves collapse.

2. Contact Charging: This process creates a permanent charge on the leaves the same as that on a charged rod.

a) If a negative rubber rod is touched to the knob, some of its excess electrons move to the electroscope. It becomes negatively charged as the incoming electrons evenly distribute themselves. The leaves separate. If a ground is established, it allows the extra to depart, returning the electroscope to neutrality.

b) If a positive glass rod is touched to the knob, some of the electrons move to the rod, drawn there by its electron hungry protons. The remaining electrons evenly distribute themselves throughout the electroscope which is left positively charged. The leaves separate. A ground will allow electrons to enter the electroscope, thereby returning it to the neutral state. The leaves collapse.

3. Induction Charging: This process creates a permanent charge on the leaves the opposite to that on a charged rod.

a) A negative rubber rod is held close to the knob of the electroscope. Some of its electrons are driven into the leaves which become negative and separate. Its upper portion is left positive. A ground is attached to the knob. The charge pressure created by the negative rod drives some electrons from the electroscope into the ground. Those electrons originally forced into the leaves move up the stem to replace those leaving through the ground. The now neutral leaves collapse. The ground is removed so the escaped electrons can not return and then the rod is removed. The remaining electrons evenly distribute themselves throughout the electroscope. Since it has lost some electrons through the ground, it shows a positive charge which separates the leaves.

b) A positive glass rod is held close to the knob to which some electrons are attracted. The leaves, becoming positive as they lose electrons, separate. The upper portion of the electroscope is negatively charged. When the ground is connected to the knob, electrons are drawn there, attracted by the positive rod. The influx of new electrons pushes back down to the leaves those electrons that were originally drawn came up from there. The leaves return to neutrality and collapse. The ground and then the rod are removed. The electrons evenly distribute themselves throughout the electroscope. Since it gained electrons through the ground, it shows a negative charge which forces apart the leaves.

4. Charge Intensification: This process magnifies the effect of the charge on the leaves.

a) If a negative rubber rod is held next to the knob of an already negatively charged electroscope, even more excess electrons are driven into the leaves which separate still wider.

b) If a positive glass rod is held next to the knob of an already positively charged electroscope, it will draw up from the opened leaves still more electrons. This increases their charge and they open still more.

5. Charge Neutralization: This process minimizes the effect of the charge on the leaves.

a) If a negative rubber rod is held next to the knob of an already positively charged electroscope, electrons are driven into the leaves which are neutralized and collapse.

b) If a positive glass rod is held next to the knob of an already negatively charged electroscope, it will draw up from the opened leaves some of the excess electrons. This reduces their negative charge and they close.

Static Charge Attraction

Induction Attraction: A charged object creates its opposite charge in the closest portion of a nearby object which is then attracted to the object. *Balloon on wall or hair, clinging clothing,* H_2O *spray*

a) Rod and Conductor: The rod induces the opposite charge in the nearby conductor, the electrons of which are either attracted or repelled. The conductor is polarized. The oppositely charged bodies then attract each other.

b) Rod and Insulator: The electrons in the insulator can not move, so its end close to the rod does not lose nor gain electrons. The electrons can, however, move within each of the insulator's tiny molecules, polarizing them. The oppositely charged molecules and the rod then attract each other

Coulomb's Law and Electric Fields

Electric Force Fields Force fields are a common thing in science fiction stories – invisible prison doors, tractor beams pulling objects into spaceships. In reality, invisible electric force fields do surround electric charges and they are responsible for the following phenomena:
a) cohesion – things sticking to themselves, e.g., tape sticking to itself
b) adhesion – things sticking to other things, e.g., tape sticking to paper
c) friction – things not sliding, e.g., sand on slippery roads
d) chemical bonds – atoms sticking together to form molecules.

If two charges are adjacent, their fields interact with each other and, as a result, the two charges attract or repel each other. A magnet's invisible force field can be easily mapped out by putting it under a piece of looseleaf and sprinkling the page with iron filings. The shape of electric force fields around electric charges can not be seen so simply – mathematical equations must be changed into complex but beautiful 3-

D graphs. Groups of charges create complicated looking electric force fields.

Coulomb's Law The details of electric fields were studied in 1785 by Coulomb. He measured charge magnitude and sign. He developed an equation that predicts the strength of interaction between two charges. $F = K q_1 q_2 / r^2$, where F = force in newtons, N, between two charges; $K = 9 * 10^9 \mathrm{Nm}^2 / \mathrm{C}^2$ (an experimentally derived constant); $q_{1,2}$ = charges in coulombs, C; the r = intercharge distance in meters, m. His law makes accurate predictions when the charged bodies, called point charges, are tiny compared to the intercharge distance.

Lines of Force Drawing "lines of force" around electric charges is a way of showing the shape of the force field. (The behavior of an imaginary + charge called a test charge is used to trace electric fields.) These are a visual representation of a field's intensity and direction of force. The spacing of the lines is proportional to the field intensity. The potential will differ at each spot in the field. There are five basic shapes of force field diagrams. Groups of charges create complex combined fields. Note the shape <u>and</u> direction of the force field lines.

1. Point Charges

a) the shape of the force field around
an individual point positive charge

b) the shape of the force field around
an individual point negative charge

c) the shape of the force field around
a pair of point positive charges

d) the shape of the force field
around a pair of point negative charges.

e) the shape of the force field around
a pair of opposite point charges.

The effect of an electric field on a nearby charge is described by $E = F/q$ where E = electric field intensity (N/C), F = the force (N) exerted by the electric field, q = the magnitude of the charge (C).

2. Parallel Plates: There is one type of diagram. Note the uniformity of the field intensity except at the plate margins. The field intensity is found by $E = V / d$ where V = the electric potential difference in V between the plates, the d = the distance in m between them.
Note that an E of 1 N/C = an E of 1V/m.

3. Conductors: There is one type of diagram. There is no field inside the conductor, so there can be no unbalanced internal charges. Since all unbalanced charges stay on its surface, the force

lines leave there at 90^0. If there were an internal
field or force lines parallel to the surface,
current would flow without a battery present!

Work and Potential Energy Because N or S poles of adjacent magnets repel, work would have to be done on a magnet if it were being forced closer to the other. The situation is similar when a charge is being forced through the electric field of another like charge. Both the moving magnet and the charge gain PE and if the driving force were removed, both would try to move away, changing some of their new PE into KE. The PE gained by the charge is related to the change in V in the areas of the electric field through which it is moved.

Q. What determines the PE gained by the magnet as it was moved closer to the other one?

The work done on the moving charge is found by $W = Vq$. W = work in joules, J, done on the charge, V = change in electric potential in volts, V, in the section of the electric field through which the charge moves, and the q = its charge, C.

The charge on an electron is just $1.60 * 10^{-19}$ C so the work to move one through a potential difference of 1 V is $W = Vq = 1 \text{ V} * 1.60 * 10^{-19} \text{ C} = 1.60 * 10^{-19}$ J. This particular amount of work is called an electronvolt, eV.

Electric Potential Energy The push or pull of adjacent charges creates PE in them just like squishing together or pulling apart the ends of a spring creates PE in it. A charge's electric PE is found by $U = K\, q1\, q2 / r$ where U = electric PE in J. A + answer equals repulsive PE and a -- answer means attractive PE.

Studying, Measuring and Controlling Charged Particles

Van de Graff Generator The behavior of intense charges is studied with this device. It consists of a hollow metal sphere sitting on the top of a non-conducting tube. Inside is a device that millions of electrons that are carried up to the sphere where they accumulate on its surface. The millions of like electric fields cause the electrons to push away from each other. Eventually, they leap to an area of lower electric potential, causing artificial lightning.

Millikan Oil Drop Experiment In the early 1920's, the American Millikan studied the charge on the electron. He sprayed charged oil droplets between horizontal charged plates. By adjusting the plates' potential difference, he was able to balance the downward tug of gravity and keep the drops suspended between them. Once the gravity force on the drops was calculated, their charge was determined to be $1.60 * 10^{-19}$ C.

Since the field intensity between charged parallel plates is uniform except at the plate margins, they are often used in charged particle measurement and control devices.

Proton Beams A modified cathode ray tube is used in which a stream of gas particles is sprayed through a shower of sparks, toward two oppositely charged metal washers. The spark shower is made by electrons jumping from a - to a + wire, and many gas particles collide with the electrons. Because some electrons from the gas particles' electron clouds are blasted free, the gas particles then become ions+. The electrons freed from the electron clouds stick to the + washer. The just created ions+ move through its aperture, attracted by the - washer. Most stick there but a few pass through its aperture and fly down the tube to strike the detector. By noting the particle travel time down the tube, the ion charge, and the washers' potential difference, the proton (ion+) mass has been calculated as $1.7 * 10^{-17}$ kg.

Electron Beams Inside a modified cathode ray tube, electrons spray from a heated filament and fly toward a pair of oppositely charged flat metal "washers". They pass through the aperture in the - washer, and are attracted to the + washer where most stick. Some fly through its aperture and down the tube to the detector. By noting the travel time, the electron mass has been calculated as $9.1 * 10^{-31}$ kg.

CRT The cathode ray tube in TV's and computer terminals shoots a beam of electrons at the flat front of the picture tube. Circuitry causes the charges on internal plates to change which, in turn, guides the vertical and horizontal motion of the beam – the beam to move side to side and up and down. Where ever the beam of electrons strikes the inside face of the picture tube, it "paints" a picture we see as some sort of image.

Current Electricity

Direct Current Chemical reactions inside batteries create what is called a potential difference. This is a type of pressure that pushes electrons out of the battery and through some electrical device, just like water pressure pushes water through the copper pipes in our house when we turn on a tap. As long as one end of the battery has a greater potential difference than the other, current can flow. Eventually, both ends of the battery are at the same potential difference and current flow stops; the battery is "dead." Potential difference is measured in volts, V. Note: A current that flows steadily in one direction is called a steady direct current, or DC.

Voltaic Cells The process of obtaining electrical current from chemical reactions was discovered accidentally in the 1800's by the Italian researcher Volta. A container of chemicals that react and create electricity is called a Voltaic cell; the common name is dry cell. A Voltaic cell contains two electrodes immersed in a conducting liquid or paste called the electrolyte. One electrode releases a stream of electrons and the other absorbs it. We get a Voltaic cell (dry cell) to so some work for us making the electrons go through some electrical device as they move from one electrode to the other. Note: the term battery means a group of dry cells connected together. A single AA "battery" is really a AA dry cell. A 9 V battery really is a battery: it has 6 tiny dry cells inside.

Q. a) Name four common sizes of dry cells and their voltages.
   b) Name two brands of rechargeable household batteries.