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BASIC ELECTRICITY. SCIENCE IN ACTION SERIES, NUMBER 14.

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DESCRIPTORS- *ELECTRICITY, *ELEMENTARY SCHOOL SCIENCE, *INSTRUCTION, *SCIENCE ACTIVITIES, *TEACHING GUIDES, INVESTIGATIONS, *SECONDARY SCHOOL SCIENCE,

THIS TEACHING GUIDE, INVOLVING ACTIVITIES FOR DEVELOPING AN UNDERSTANDING OF BASIC ELECTRICITY, EMPHASIZES STUDENT INVESTIGATIONS RATHER THAN FACTS, AND IS BASED ON THE PREMISE THAT THE MAJOR GOAL IN SCIENCE TEACHING IS THE DEVELOPMENT OF THE INVESTIGATIVE ATTITUDE IN THE STUDENT. ACTIVITIES SUGGESTED INVOLVE SIMPLE DEMONSTRATIONS AND EXPERIMENTS WHICH THE STUDENT MAY DO. ACTIVITIES INVOLVING STATIC ELECTRICITY SERVE TO INTRODUCE THE ELECTRICAL NATURE OF THE ATOM AND INCLUDE EXPERIENCES INVOLVING (1) CONDUCTORS, RESISTORS, AND INSULATORS, (2) THE ELECTROSCOPE, (3) INDUCED CHARGE, AND (4) ELECTRICAL FIELDS. ELEMENTARY EXPERIMENTS INVOLVING CURRENT ELECTRICITY INVOLVE (1) A SIMPLE VOLTAIC CELL, (2) ELECTROLYSIS, (3) RESISTANCE CIRCUITS, (4) OHM'S LAW, AND (5) SERIES AND PARALLEL CIRCUITS. ACTIVITIES SUGGESTED ARE SUITABLE FOR JUNIOR HIGH SCHOOL PUPILS. (DH)

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SCIENCE *electricity* in ACTION

1967

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BASIC ELECTRICITY

Prepared by Bureau of General and Academic Education

Text material written by Mr. Richard Cassel

Commonwealth of Pennsylvania

DEPARTMENT OF PUBLIC INSTRUCTION

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1967

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INTRODUCTION

This booklet has been written on the premise that the major goal in teaching science is the development of the investigative attitude in the student. It is most important, therefore, that the science teacher trigger the students' curiosity which leads to investigation, and because of this the teacher's approach and methods become even more important than the scientific facts with which he works. By encouraging his students to draw *their own* conclusions from *their own* observations made during controlled experiments, the teacher can stimulate his students and at the same time develop the correct scientific approach.

The material in this booklet is arranged so that the teacher's demonstrations, student experiments, drawings, and information allow the student to make logical step by step deductions and in this way provide the student with the "trial and error" atmosphere so necessary for making him feel personally involved in scientific investigation. Most of the experiments and demonstrations, which were chosen to stimulate interest and to develop the reasoning process, can be performed safely by the students themselves and require inexpensive or easily constructed equipment.

Finally, it should be re-emphasized that the purpose of this booklet is not so much to provide facts *per se* but to help the teacher direct his students in an investigation of electricity. In this way the students will, primarily ask questions and seek answers, not memorize facts.

STATIC ELECTRICITY

A thorough understanding of the behavior of the electron is necessary to understand electricity because the electron *is* electricity. It is easiest to study the electron when it is in a static condition.

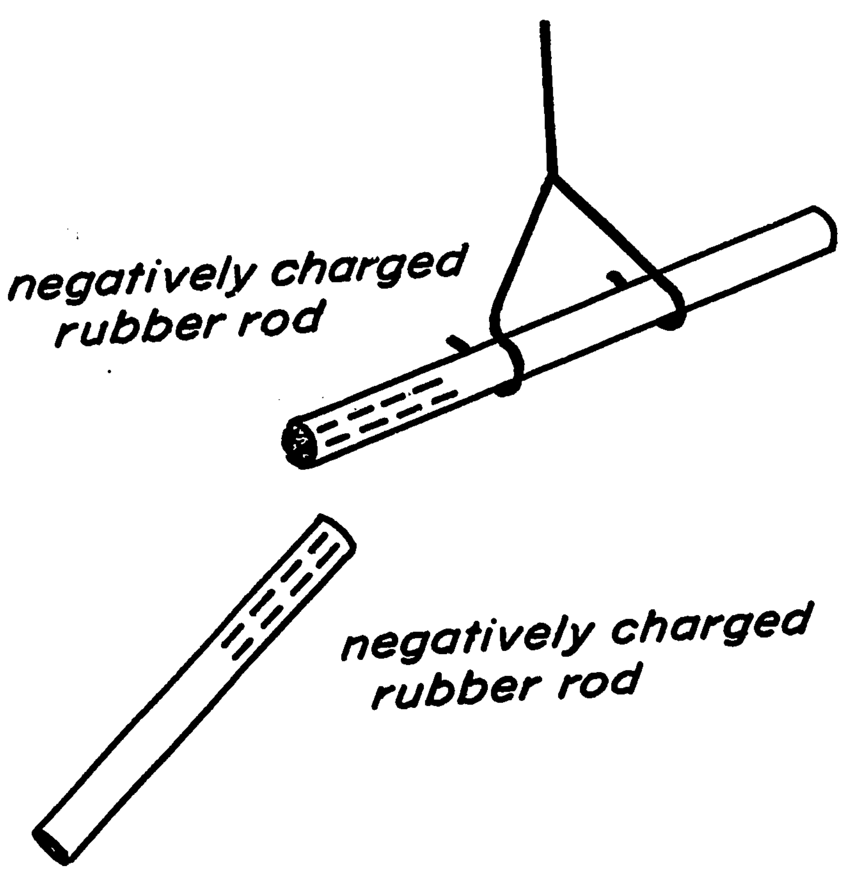
Electrified Objects: Experiment 1

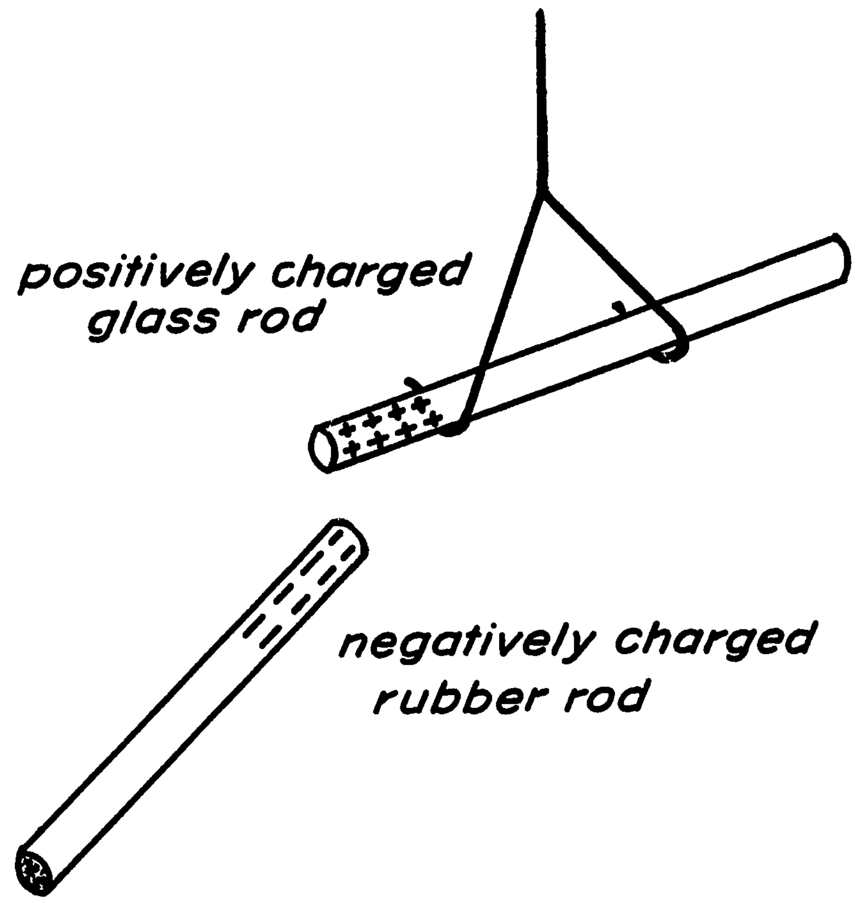
Have students run their combs through their hair. (A plastic pen or pencil against a sweater will also work.) Then have them try to pick up bits of paper with the comb. Ask them why there is an attraction. (It should also be pointed out to the students that they may have done this many times, but probably never really knew why the paper was attached to the comb.) Point out to the students that they have produced electrified objects and that more investigation of such objects may answer the question, "Why is there an attraction?".

There are many ways to detect electrified objects, but the method of detecting them depends upon the forces between these objects.

Electrified Objects: Experiment 2

Have students place a hard rubber rod in a stirrup made from a large paper clip (as shown below) and suspend with thread from a ring stand. This will allow the rod to rotate freely.





Rub the suspended rod with a piece of cat's fur or wool cloth. Next rub another rubber rod with cat's fur. Bring this rod near the suspended one and point out that some invisible force seems to cause them to repel each other.

Now suspend a glass rod (or large test tube) and rub it with a piece of sheet rubber or silk. Rub another glass rod with sheet rubber or silk and bring it near the suspended one. *Observe* that these rods also seem to have an invisible force between them that causes repulsion. Now rub the rubber rod with cat's fur again and bring it near the suspended glass rod. Now note that this time an invisible force causes the two rods to attract each other. Try other objects such as fountain pens, or combs, using for all objects the suspended rod as a reference to determine whether they are attracted to or repelled from it.

At this point encourage students to discuss possible explanations for these reactions. Lead them to conclude that objects of the same material which have been "electrified" by the same procedure always repel, while different "electrified" objects may either attract or repel.

Electrified Objects: Experiment 3

To investigate this phenomenon further, have groups of students suspend pith balls from ring stands. (Puffed rice kernels will substitute for pith balls.)

Ask the students to predict what will happen if they rub a rubber rod with cat's fur or wool and bring it near the pith ball. Then ask the students why the ball is first attracted to and then leaps away from the rubber rod. (The students may conclude that something must have flowed from the rubber rod into the pith ball and that whatever it was, it must have opposed itself.)

Repeat this prediction and experiment, this time bringing a glass rod rubbed with rubber or silk near the pith ball. Again it is attracted to the rod and then is repelled. (Thinking back to the experiment with the suspended rods, the students could conclude that something different has flowed from the glass rod to the pith ball, than has flowed from the rubber rod to the pith ball.) Give the students plenty of time to think about this, but help them to note that whatever it is that flows, it always repels itself.

Now while the pith ball is still being repelled by the glass rod, bring the rubber rod near it. The pith ball is attracted to the rubber rod and away from the glass rod.

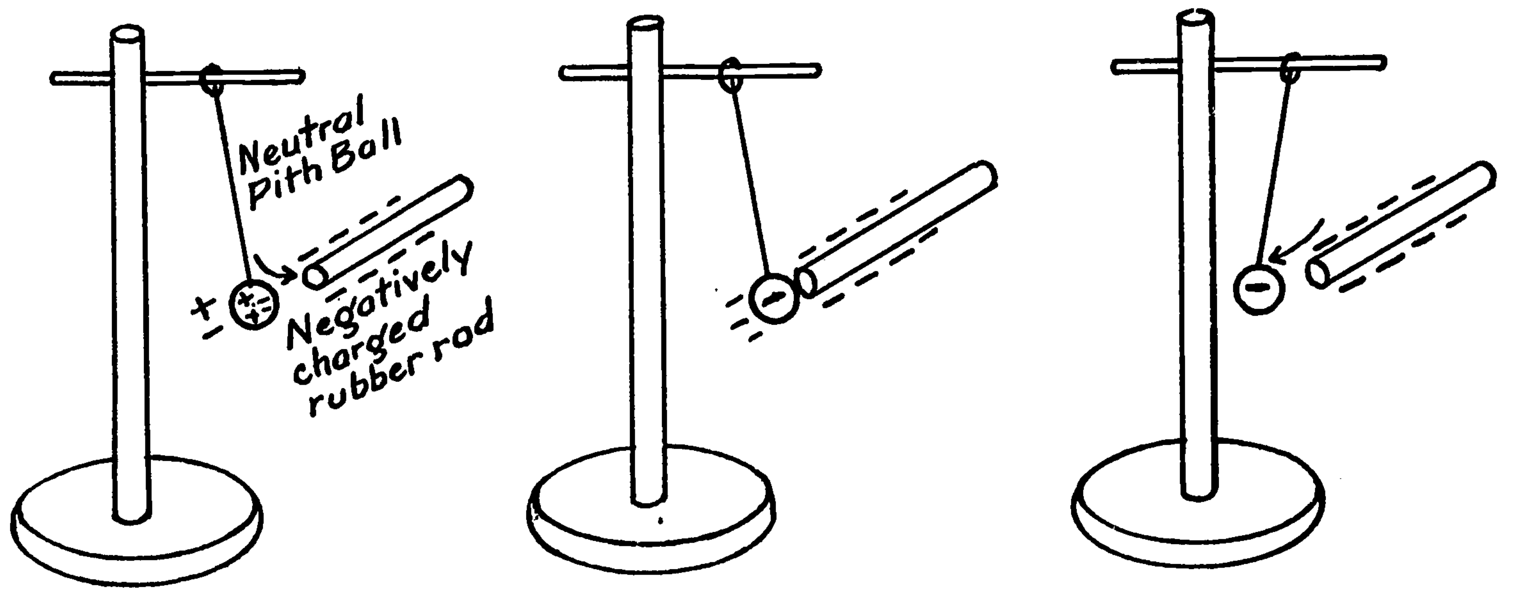
This should lead us to conclude that the *two different* things that flowed must have attracted each other! (This conclusion will be modified by the study of the atom which follows.)

Now attach some labels to the previous observations so that they can be conveniently discussed.

The term *charged* can be used to designate the process of electrifying an object.

The terms ***positive*** and ***negative*** can be used to designate the type of charges. When the phenomenon exhibited by a rubber rod which has been rubbed by cat's fur or wool is referred to, it is said to be "negatively charged." This use of terms dates back to Benjamin Franklin and is a simple way of saying that the rubber rod when rubbed with wool behaves oppositely to the glass rod when it is rubbed with silk. The glass rod, then is said to be "positively charged."

The conclusions so far can be listed in the following order:



(a) *Pith ball attracted* (b) *Pith ball touches rod* (c) *Pith ball repelled by rod*

1. All charged bodies fall into two electric states, one similar to that of the rubber rod called negative, and one similar to that of the glass rod called positive.
2. Like charges repel each other. (E.g., a positively charged glass rod repels a positively charged glass rod.)
3. Unlike charges attract each other. (E.g., a positively charged glass rod attracts a negatively charged rubber rod.)

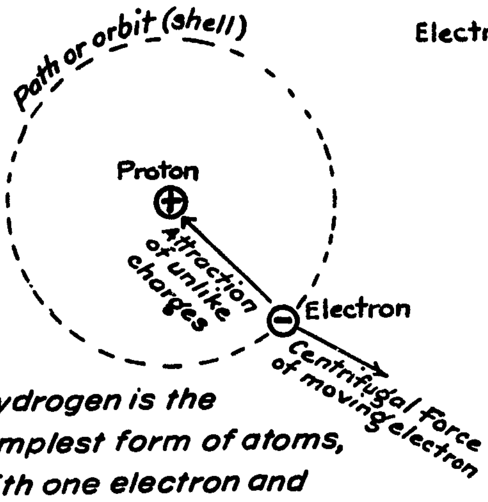
THE ATOM

But the students will probably ask, "What are these charges and where do they come from?"

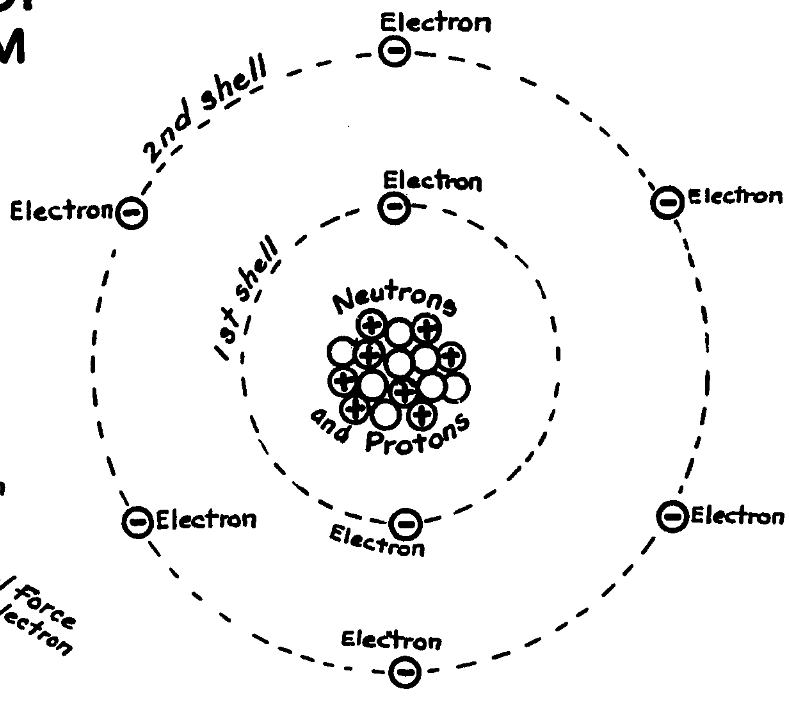
To answer this question the students must examine the scientist's concept of the atom in its natural state.

By diagramming on the blackboard simple atoms, such as the hydrogen and oxygen atoms (see below), the teacher can show the various forces affecting the atom. (These diagrams are oversimplified and are only a model to be used for our special purpose.)

DIAGRAM OF THE ATOM



Hydrogen is the simplest form of atoms, with one electron and one proton



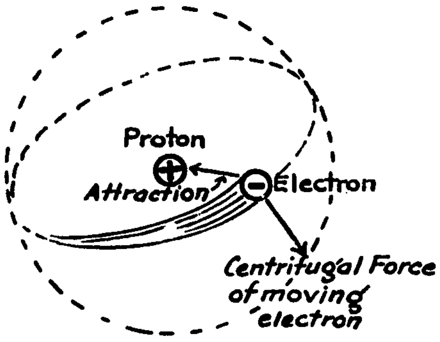
Oxygen is more complex with 8 neutrons and 8 protons in the nucleus and 8 electrons in two different shells

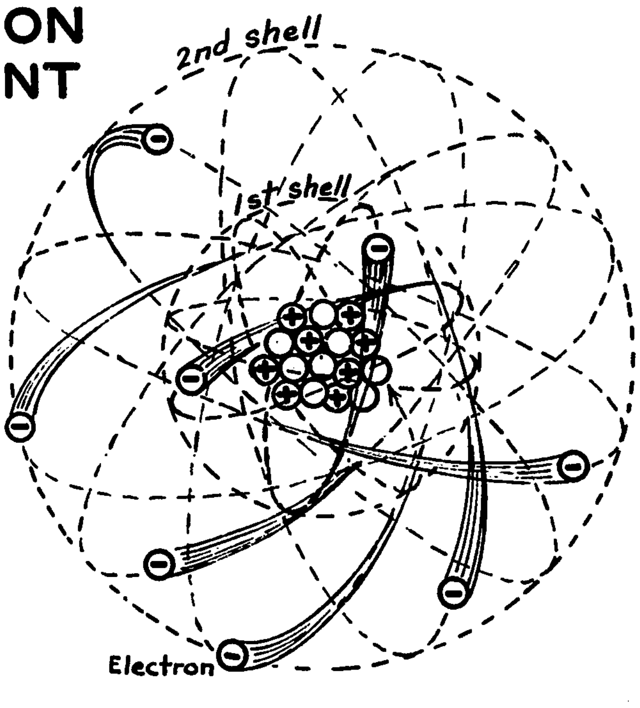
Point out the following details in discussing the diagram of the atom:

1. The atom is made up of three main particles, the *neutron* with no electrical charge, the positively charged *proton,* and the negatively charged *electron.*
2. The protons and neutrons weigh almost 2000 times as much as the electron and make up the center or nucleus of the atom.
3. The lightweight electrons orbit around the nucleus in layers or shells.
4. Because the electron and proton have an attraction for each other and are equal in the quantity of their charge, the effect of their forces is neutralized when there is an equal number of electrons and protons together.
5. An atom is normally found with an equal number of protons and electrons, and thus is said to be electrically neutral. When electrons are "lost", or extra electrons are accepted, the atom develops a charge and then is called an ion.

Many of our previous observations about electrified objects can be explained if we assume that some of the electrons in the outer shell are rubbed loose from the rest of the atom when two objects are rubbed together, leaving an excess of protons on one object and an excess of electrons on the other object. The electrical force or "charge" will exist as long as the excess of charged particles remains on the two objects.

ELECTRON MOTION at a GIVEN MOMENT





Electrons move in all orbits within their area (shell) at some time or other

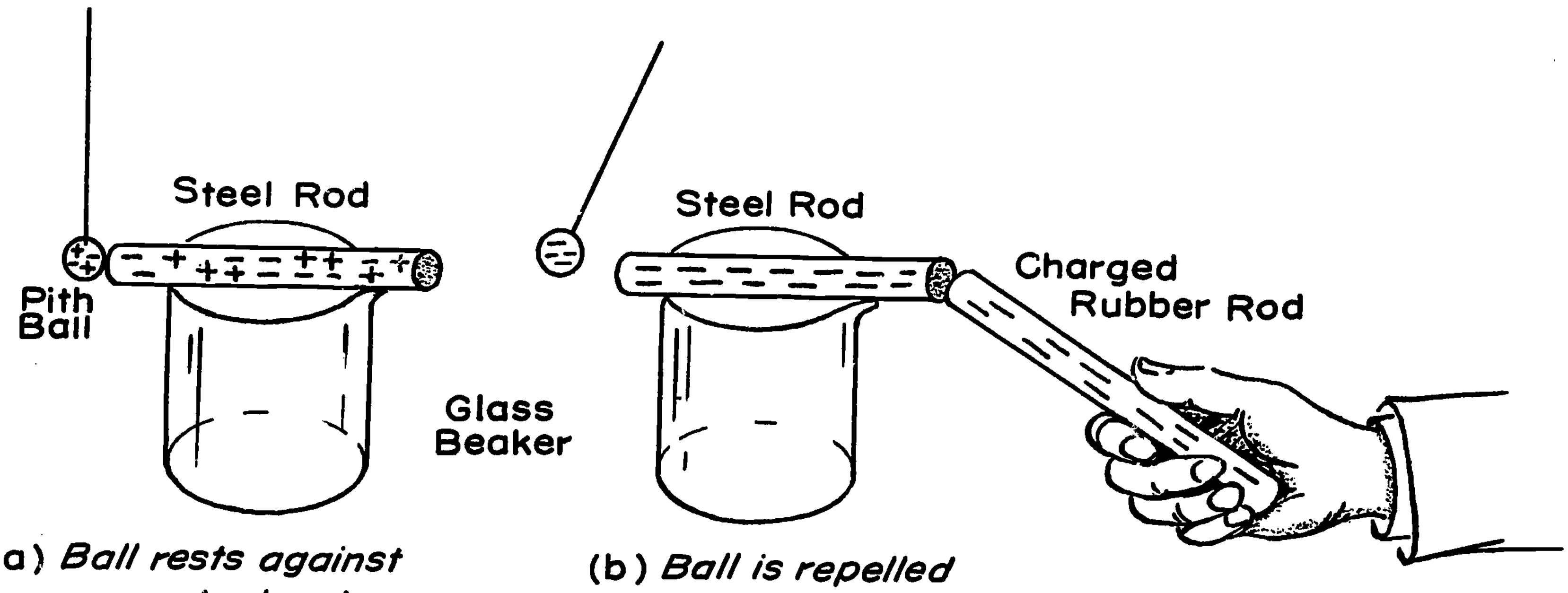
CONDUCTORS, RESISTORS, AND INSULATORS

Conductors, Resistors, and Insulators: Experiment 1

As in the following diagram, have the students suspend a pith ball from a ring stand or some other support, so that it just touches the end of a steel rod resting on a beaker.

Help students to conclude that the electrons must have flowed back out of the steel rod into the human body, leaving the rod positively charged and the pith ball negatively charged. Hence, the pith ball was attracted back to the steel rod.

Now replace the steel rod with other pieces of material, such as a rubber rod, glass rod, piece of wood, strip of copper, etc., and repeat the previous experiment with each item. Have the students predict the outcome before trying the demonstration.



(a) *Ball rests against steel rod*

(b) *Ball is repelled from rod*

If the students rub a hard rubber rod with a piece of cat's fur or wool cloth and then touch the rubber rod to the end of the steel rod, the pith ball will jump away from the far end of the steel rod and stay suspended away from the steel rod. (The rubber rod may have to be rubbed and discharged into the steel rod several times before it becomes saturated enough to repel the pith ball.)

Bring the rubber rod near the pith ball and the ball will be repelled. This shows that since like charges repel, the charge that is on the rubber rod is now on the pith ball.

Encourage the students to discuss the possible ways the charge got from the rubber rod to the pith ball. Ask students what will happen if they touch the steel rod.

Touch the end of the steel rod with a finger and the pith ball will return to its original position.

Have students discuss their observations and lead them to conclude that many materials allow the electrons to "flow" through them. These materials are called *conductors*. However, some materials resist the movement of electrons through them. These are called *resistors*. If a material has a resistance so high that electrons do not normally flow at all, it is called an *insulator*.

Now ask the students the purpose of the glass beaker under the various rods. Have them try the demonstrations with a tin cup in place of the glass beaker. Ask them what the results indicate.

From the previous experiments it can be seen that one of the commonest things we do is to charge bodies electrically. Every time we rub one kind of material across another, as when we comb our hair, or scuff our feet on the carpet, we remove electrons from one body and add them to another. But in some substances this charge is lasting enough and great enough that we notice it. These substances are nonconductors, like rubber and glass, which cannot readily give up the charge developed upon them.

THE ELECTROSCOPE

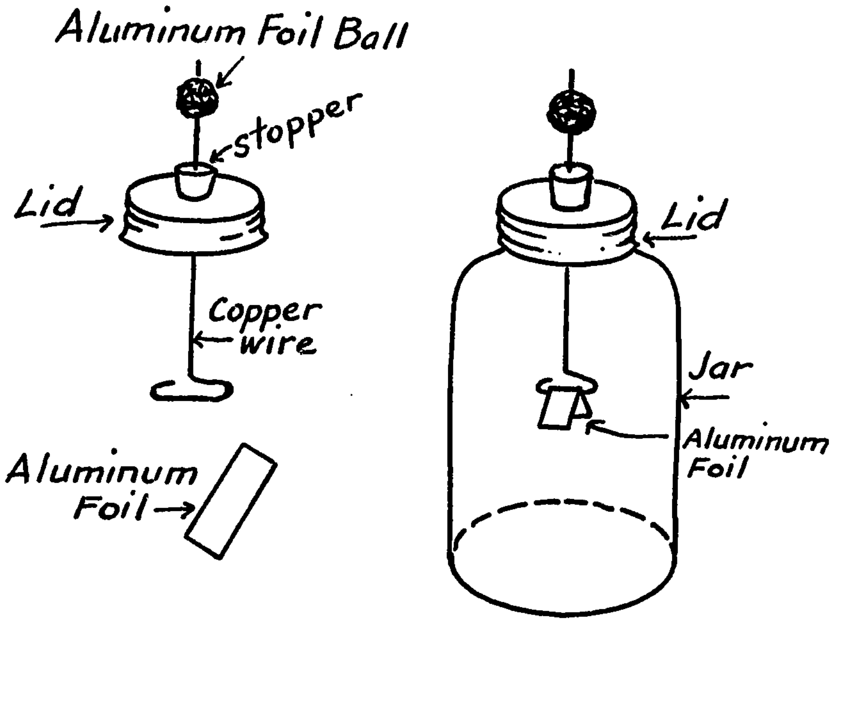
A simple device that is very useful in observing some of these fundamentals of electricity is the electroscope. Students can easily build this piece of apparatus which is more sensitive than the previous apparatus used.

The Electroscope: Experiment 1

To construct the aluminum leaf electroscope shown below, use a large jar with a metal lid and a piece of foil from a gum or cigarette pack. Drill a hole in the lid of the jar to receive the stopper. Pierce stopper to make a hole and push the copper wire through.

Bend the lower end of the wire into a "T" shape, as shown. Fasten the upper end of the wire to an aluminum foil ball by pushing it halfway into the ball. Use plastic cement to seal the juncture of the stopper and the lid.

Now remove a piece of aluminum foil from a cigarette pack or gum wrapper, using alcohol to separate the foil from its paper base. Cut two strips of foil, each about an inch long and one-half inch wide. Mount them through the "T"-shaped end of the copper wire and glue with plastic cement. For best results, the jar and lid should be warmed in an oven for a few minutes to drive out all moisture. Be sure to screw the lid on tightly before it cools off. This completes the electroscope.



A Gold Leaf Electroscope can be purchased from any science supply house. The operation of both the student-constructed electroscope and the purchased one is the same and quite simple.

INDUCED CHARGE

Because of the sensitivity of the electroscope, more precise investigations can now be made.

Ask students if they observed that charged objects had effects on each other, even though the objects didn't touch. Again have students run combs through their hair or rub plastic pens or pencils on their sweaters, and try to pick up bits of paper without touching them. They will notice that the bits of paper seem to jump to the comb. It should be impressed upon the students that according to our past conclusions only oppositely charged objects should attract each other. Yet, although the paper was not charged, it was attracted anyway.

Induced Charge: Experiment 1

Use the electroscope to observe this phenomenon more closely. Have the students charge a glass rod with silk. Bring the rod near the foil ball on top of the electroscope. Notice that the leaves spread apart. Now take the rod away and notice the leaves go back together. Repeat this procedure using a rubber rod rubbed with wool. Now *touch* the ball with a charged rod. Notice that the leaves still stand out after the rod is taken away. Now touch the electroscope ball with a finger, and notice that the leaves collapse.

Allow students to discuss these results. Help them to reason that electrons probably flowed into the electroscope ball when it was touched by the charged rod. Since the ball was connected to both leaves of our electroscope, they would each have the same charge and thus oppose each other. The electrostatic force, being much stronger than that of gravity, pushes the leaves apart. Yet there was no apparent way the electrons could move into the electroscope when the charged rod was brought near, but didn't touch the foil ball. There apparently must be some way for the electrons to move from the rod to the electroscope without the two touching. Encourage the students to give possible explanations.

The most logical explanation would be the rearrangement of loosely held electrons within the electroscope due to the force of the charge in a nearby object. Thus, if a positively charged rod was brought near the electroscope, the part of the electroscope nearest the rod (the foil knob) would have extra electrons attracted into it and in effect cause that part of the electroscope to have a negative charge. Of course, the other end of the electroscope (the leaves) would have to have an opposite positive charge on it, since electrons had been drawn away from it, leaving behind extra protons. This reaction is called an *induced* charge, since it was not caused by mechanical contact. The electrons return to their normal positions after the charged object is taken away, leaving the entire electroscope neutral again and allowing leaves to fall back together.

The fact that the leaves went together when the electroscope knob was touched by a finger can be explained if the students will think back to their investigations of conductors and insulators. Remembering that the human body is a pretty good conductor, the student should conclude that the excess electrons placed on the electroscope by the charged rod flow back off the electroscope through our body, making the leaves neutral.

Ask students how a charged balloon is attracted to a neutral wall. The students should be able to explain that the electrons on the balloon pushed some of the free electrons, making up the wall, back into the wall leaving extra protons, or a positive charge, on the surface of the wall which then attracts the negatively-charged balloon.

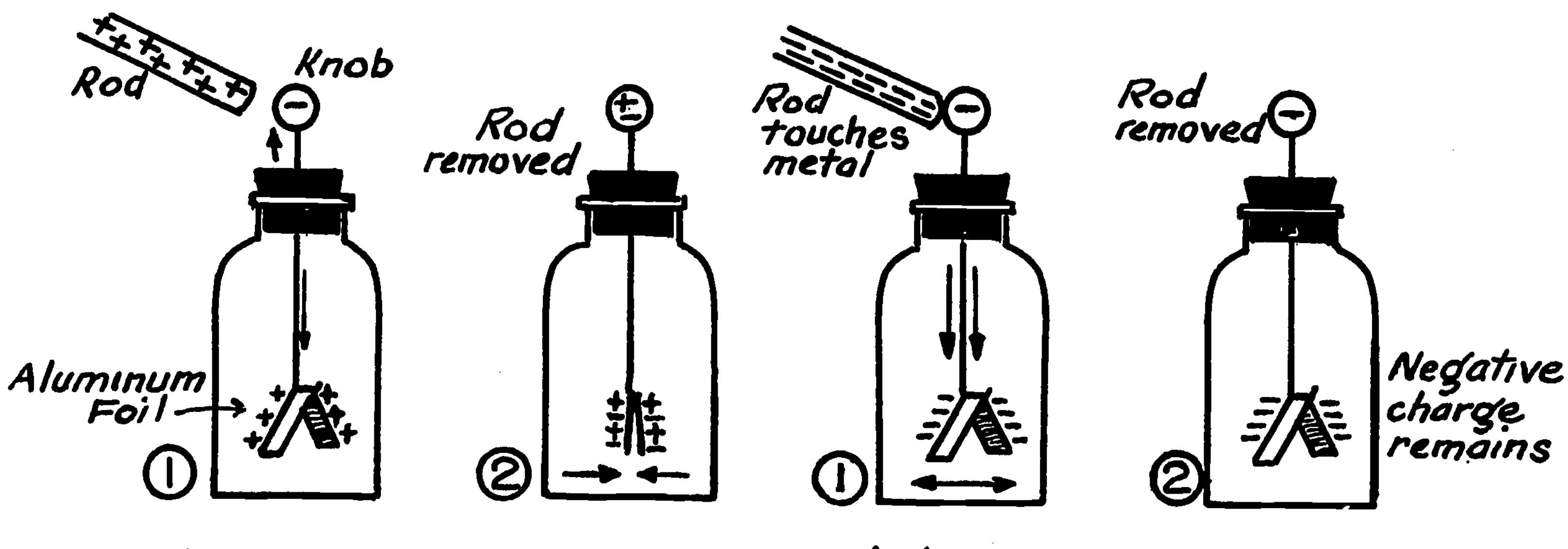
Perhaps the students will more clearly visualize the process that brings about an induced charge after one more demonstration.

Induced Charge: Experiment 3

Place two metal rods on glass beakers (used as insulating stands) so that the rods touch and make up one conductor as shown below. Bring a positively-charged glass rod (rubbed with silk) near one end of the steel rods. Now while the glass rod is still held near, separate the two metal rods by pushing their beakers apart.

Ask the students what the charges on each metal rod should be, and why.

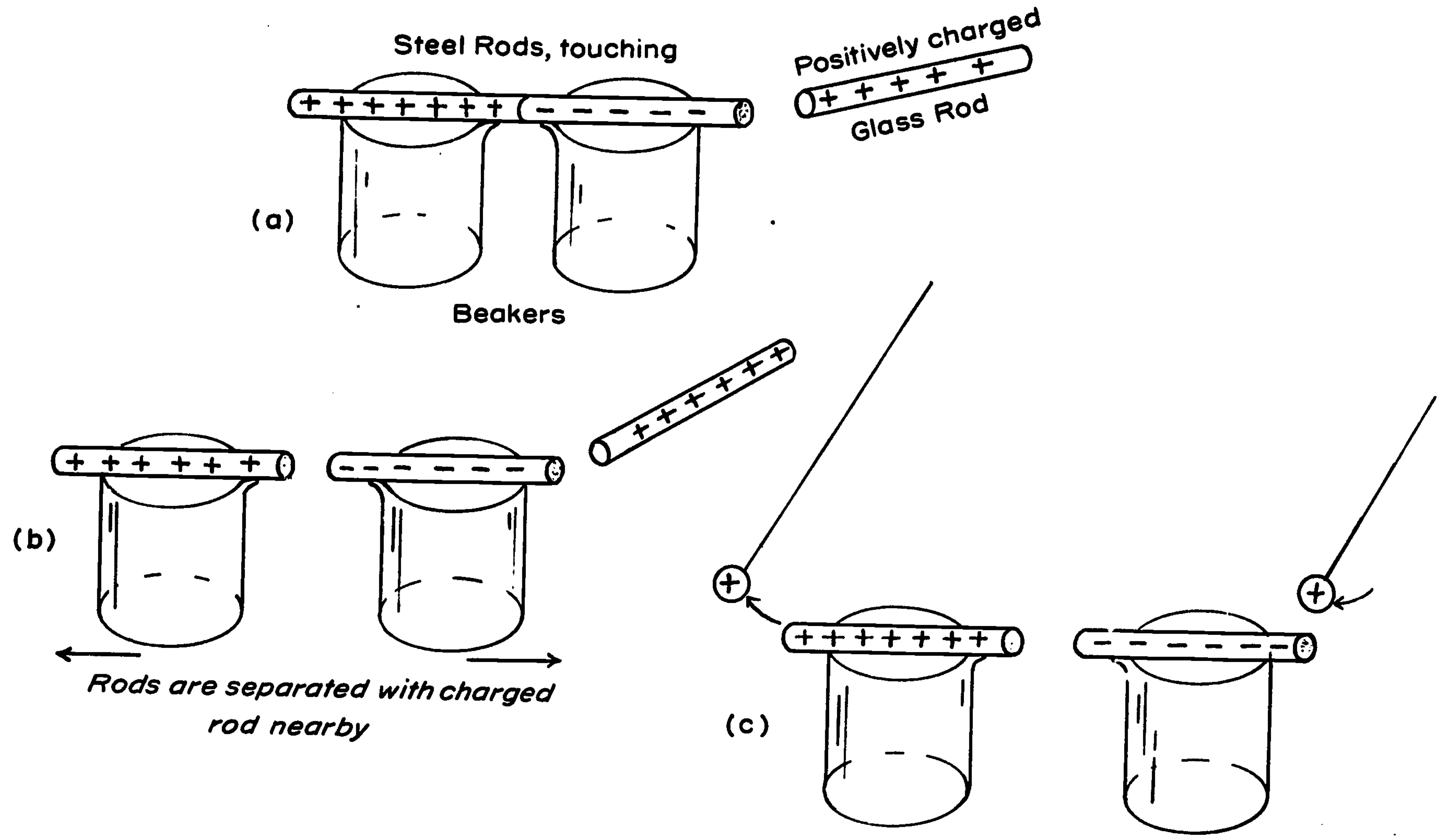
Now let the student check his conclusions by positively charging a pith ball (puffed rice kernel) on a string by touching it with the positive glass rod and bringing it near each of the metal rods. The metal rod nearest the positive-charged glass rod should attract the positive-charged pith ball, showing this metal rod is negative, due to the attraction of an excess amount of electrons into it. This leaves the steel rod farthest from the charged glass rod with an excess of protons and it should repel the pith ball.



(a) *Induced charge* (b) *Conducted charge*

Induced Charge: Experiment 2

Another example of an induced charge can be shown by rubbing an inflated balloon against a wool sweater and then placing the balloon against the wall, where it "sticks."



Rods are separated with charged rod nearby

Two pith balls, both charged positively, show the charges on the rods are opposite

Induced Charge: Experiment 4

There is finally another unusual example of *electrostatic induction* which will probably impress students. Turn open a water faucet till just a trickle of water flows. Bring a charged rubber rod or comb near the stream of water. Notice how sharply the stream of water is bent by the attraction of the charged rod to the water molecules that have an induced opposite charge.

Here again the electroscope can be used, not only for detecting a charge, but also for identifying the type of charge.

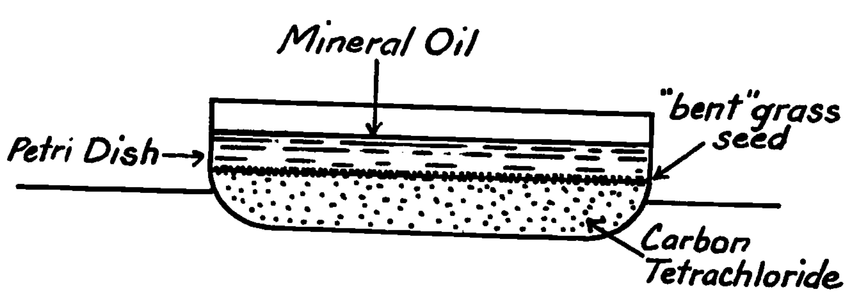
By putting a known type of charge on our electroscope and watching the action of the leaves when an unknown charge is brought near, we can discover from the reaction, the type of charge. For example, if we put a positive charge on the electroscope and then bring a negatively-charged rod near, electrons will be pushed, by induction, down into the leaves neutralizing the positive charge, causing the leaves to collapse; whereas a positively-charged rod would cause the leaves to spread still farther.

ELECTRIC FIELDS

With some slightly more elaborate equipment than used thus far, the students can be shown the actual pattern of the electrostatic fields of force that surround charges.

Electric Fields: Experiment 1

First pour carbon tretrachloride (CCL_4) into a glass Petri dish. (If the room cannot be well ventilated, film cleaner should be used instead, for it has no poisonous fumes.) Then carefully drop a layer of fine "creeping bent" grass seeds on the liquid. Next add a one-fourth inch layer of mineral oil. Now spread the seeds evenly with a clean dry glass rod. The seeds will remain in the boundary between the dense carbon tetrachloride and the less dense mineral oil as shown below.

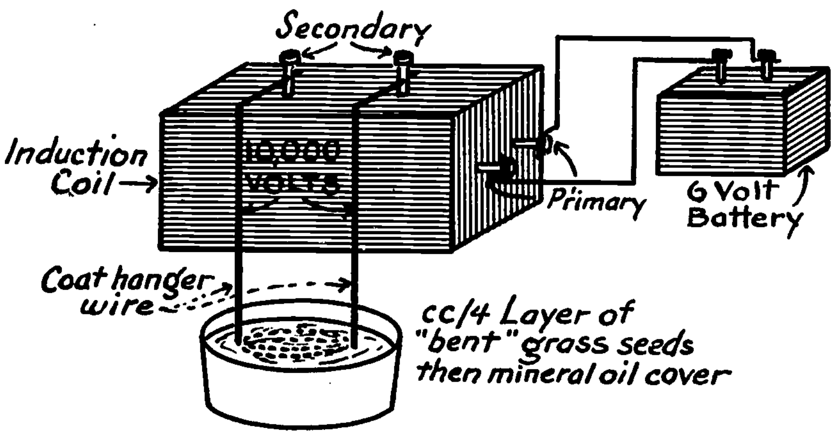


Now connect a six-volt cell (with a switch in the circuit) to an induction coil. (An induction coil can be purchased from almost any scientific supply house. A small neon sign transformer can be used in place of the induction coil, but its use can be dangerous due to the presence of much current at high voltage. To reduce the current flow, therefore, a 40-million ohm radio resistor must be used in each of the high voltage leads.)

After connecting the battery to the input or primary terminal of the induction coil, connect two right-angled coat hanger wires to the high voltage or out-put terminals of the induction coil.

Carefully place the two ends of the coat hanger wires into the Petri dish, so that the wires touch the bottom of the dish. (The induction coil will change the six volts of the battery into 10,000 volts at the high voltage or out-put terminals. Be careful not to get within four inches of these terminals as the current will jump several inches.)

Now close the switch.



Apparatus to see field patterns

One of the terminals will have a negative charge and the other will have a positive charge with a potential difference of from 5,000 to 10,000 volts. The carbon tetrachloride and mineral oil are good insulators so that no electrons can flow. However, the attraction forces between the charged wires and the grass seeds show up because charges are induced into the grass seeds causing one end of each seed to become positively charged and the other end negatively charged. (This is called a *dipole.*) Consequently, the negative end of each seed will point to the positively charged coat hanger wire. The seeds align themselves along the lines of force.

Have students notice that the seeds form a pattern like the spokes of a wheel around each coat hanger wire.

Now move the two wires closer together and see the elliptical pattern formed by the attractive forces between the two different charges on the wires. This is a *dipole electric field pattern.*

Shut off the current and replace one of the vertical wires with a flat plate. Now the lines of force run from the single pole and enter the flat plate at right angles. Again shut off the current and add a second flat plate in place of the other vertical wire. The lines of force run from plate to plate, and are uniform. (This is actually a condensor which we will discuss later.)

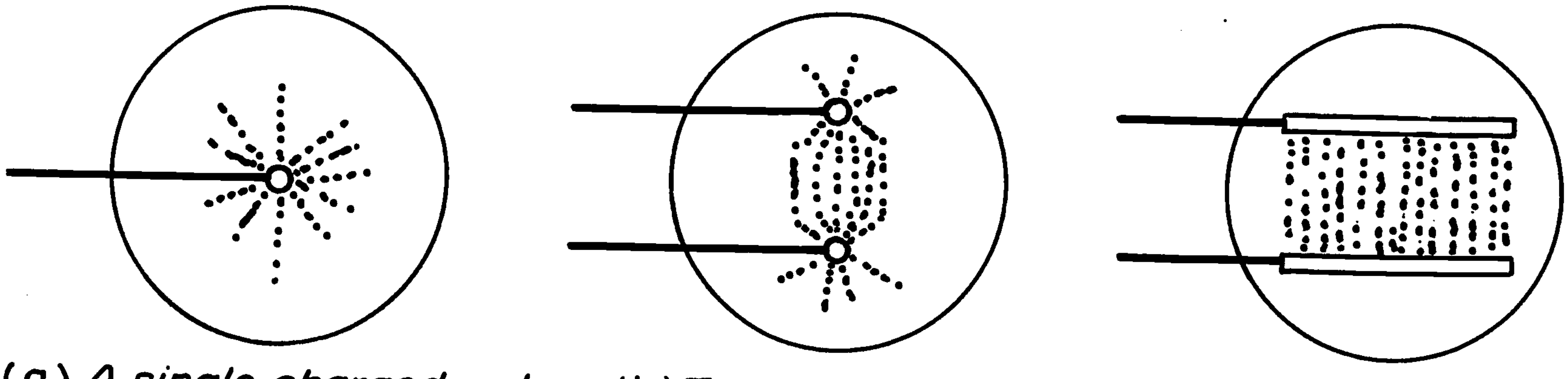
Turn off the current and connect two wires to the same terminal.

Ask the students what type of pattern they will expect to see. This time the lines of force show that the two charged wires oppose each other since they would be of the same charge.

If a ring is connected to one terminal the pattern shows there is no field inside the ring showing that charges always reside on the outside of an object.

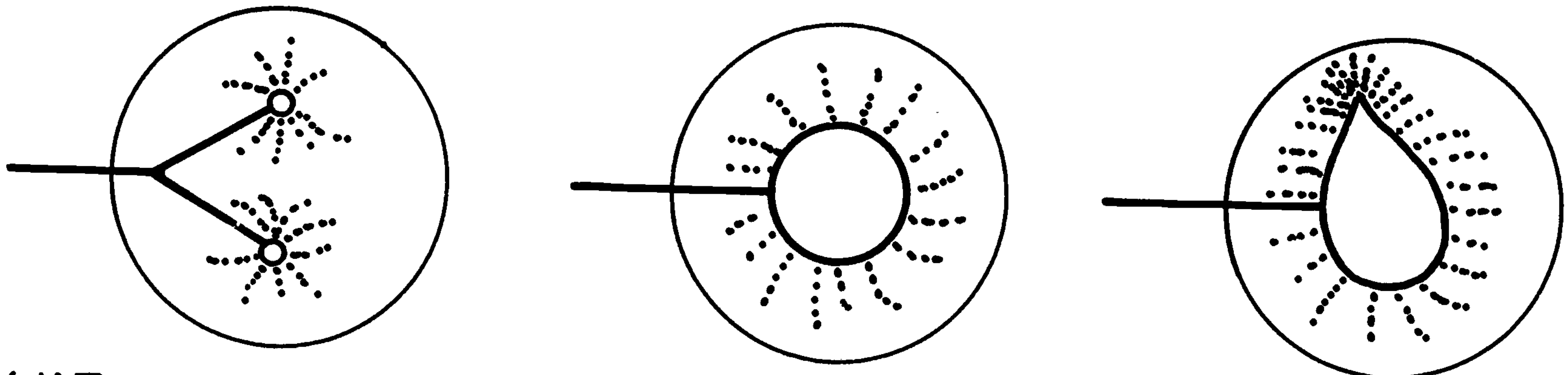
When a tear-shaped piece of wire is connected to one terminal, it can be seen that the electric field concentrates at the pointed end. (The reason for pointed lightning rods, which will be discussed later.)

FIELD PATTERNS



(a) *A single charged rod* (b) *Two rods with opposite charges* (c) *Two plates with opposite charges*

FIELD PATTERNS (continued)



(d) *Two rods with same charge*

(e) *A metal ring*

(f) *A wire in teardrop shape*

GROUNDING

Grounding: Experiment 1

Suggest to the students that they suspend a small metal ball (aluminum foil) from a silk string and touch the ball to the knob of a charged electroscope. Notice the leaves drop a little showing that the ball absorbed some of the charge. Try a larger ball (recharging the electroscope each time) and notice that the leaves drop even more. Try still larger balls, until finally a very big ball absorbs all of the charge on the electroscope, causing the leaves to collapse completely. The students should estimate and record the amount of "drop" of the leaves in each trial.

The teacher can now relate the foil ball to the huge ball—the earth, and point out that the earth can absorb and neutralize any charge produced. This process of passing charges into the earth is called *grounding*. Applications of this phenomenon will be explained later.

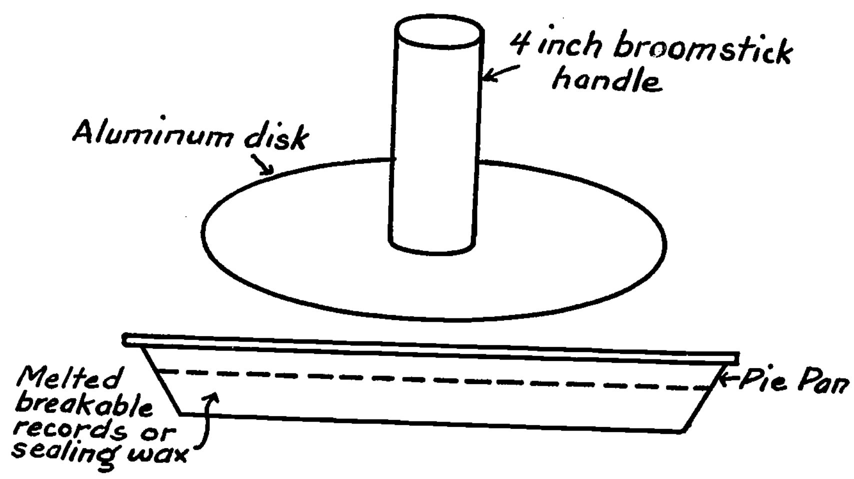
Up to this point the static charges created by friction have been very weak. To detect these charges the students have had to use fairly sensitive pieces of equipment, such as an electroscope or a pith ball. It is now time to investigate stronger charges. To create these stronger charges the teacher and students will use slightly more complex equipment than a rubber rod and a piece of cat's fur. The two pieces of equipment used to produce more powerful charges are the electrophorus and the Van de Graaff generator.

ELECTROPHORUS

The electrophorus can be made by filling a pie tin with a layer of melted phonograph records (breakable type), which can be melted over a low flame. (Sealing wax can also be used.)

Next attach a flat disk of aluminum to a 4-inch or 5-inch piece of broom stick. Now charge the wax surface by rubbing it with a piece of cat's fur.

Bring the disk down flat against the wax surface. Now touch the top of the metal disk with a finger, remove the finger and lift the disk from the wax surface. To test the charge bring the edge of the metal disk near the knuckle of your finger: a good-sized spark should jump from the disk to your finger.

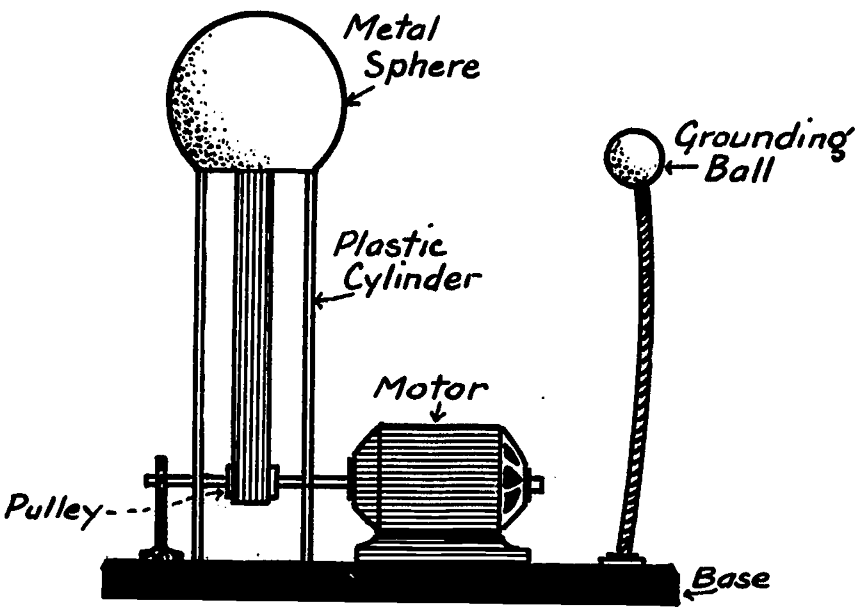


Electrophorus

THE VAN DE GRAAFF GENERATOR

The Van de Graaff generator can be built from plans found in several different source books, but it is probably more satisfactory to purchase one of these machines. The Van de Graaff uses a rubber belt driven by a motor at one end and has a conducting device at the other end to remove the charge from the rubber belt and pass it along to a metal sphere, where it is stored. This machine can develop up to 200,000 volts.

Although the voltage is high there is a relatively small current flow, making it a safe device to operate for anyone with a healthy heart. Nonetheless one should be careful in handling this machine and remember that although air is a good insulator, 200,000 volts will arc 3 or 4 inches through it.

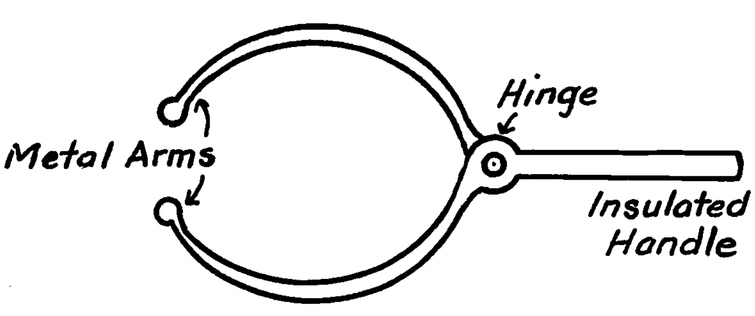


Van de Graaff Generator

The Van de Graaff Generator: Experiment 1

The Van de Graaff generator can be used in many different types of demonstrations. Using a discharger (a device that can be purchased or made and which consists of two conducting arms and an insulated handle), touch the end of one arm to the charged metal sphere and bring the other arm near the grounded base. This will produce a larger discharge, looking much like miniature lightning bolts. (A darkened room enhances the dramatic value.)

Ask the students why the electricity flows in short bursts or bolts, rather than continuously. This might indicate the insulating value of air.



Discharger

The Van de Graaff Generator: Experiment 2

Suspend strips of aluminum foil on the end of a silk string over the charged metal sphere, allow them to touch the sphere, and notice the intense repulsion as the strips stand "straight out."

A more dramatic demonstration of this can be done by having a girl, with long fine hair, place her hands on the discharged sphere of the Van de Graaff generator, while she is standing on a wood stool or some other insulating platform. Now start the machine and notice that the girl's hair is standing straight out from her head.

Ask the students why this has occurred. They should realize that each hair has the same charge and thus they repel each other.

The main use of the Van de Graaff generator is to provide a charge for charge-storing devices, such as Leyden Jars or condensors.

Ask students why the electrophorus or Van de Graaff generator is able to develop a more powerful charge than the previous equipment we used. The students may give many answers for this question, but it should be pointed out to them that the main difference between the equipment used to produce weak charges and the equipment used to produce powerful charges was the size of the apparatus on which the charge was stored. For instance, the rubber rod had very little surface on which to store electrons, compared to the surface area of the electrophorus metal disk or the Van de Graaff's metal sphere. So it would appear that on a larger surface area one can "build up" and store a stronger charge. One other major difference is that with our first apparatus the charge was produced and stored on a non-conducting material, such as rubber or glass; whereas the more powerful machines stored their charges on a conducting material. A stored charge can flow more quickly through the conducting material when it is discharged. Also since the charges are developed on conducting materials they must be kept insulated from an oppositely charged body or neutral body, which might develop an induced charge.

This is the reason for the wood handle on the electrophorus metal disk and the plastic cylinder separating the metal sphere and the grounded metal base on the Van de Graaff generator.

STORED CHARGES

Ask the students to design a device for storing large charges. From our previous study of the electrophorus and Van de Graaff generators, the students should realize that two plates will be needed and that they should be made of a conducting material, with something between them as an insulator. In this device, they could put a plus charge on one plate and a negative charge on the other. Their inductive attraction force would pass through the insulator, but the electrons could not. Thus, a store of electrons could be held on one plate by the attraction of the protons on the other.

An early device for storing charges, used by Ben Franklin, is called the Leyden Jar. This device is still used today and can be purchased or easily made. To make a Leyden Jar, the students can coat the inside of a milk bottle with aluminum paint, wiping the paint from inside the top inch of the bottle. Then paint the outside of the bottle with aluminum paint up to within one inch of the top. Fit a rubber stopper to the top of the bottle and insert a copper wire through the stopper so that one end (or a chain of paper clips hung on the end) touches the painted surface inside the jar, and the other end stands an inch above the stopper. The bottle should sit on a copper plate so that the aluminum coating on the outside of the bottle touches the plate. Now the Leyden Jar is ready to be charged.

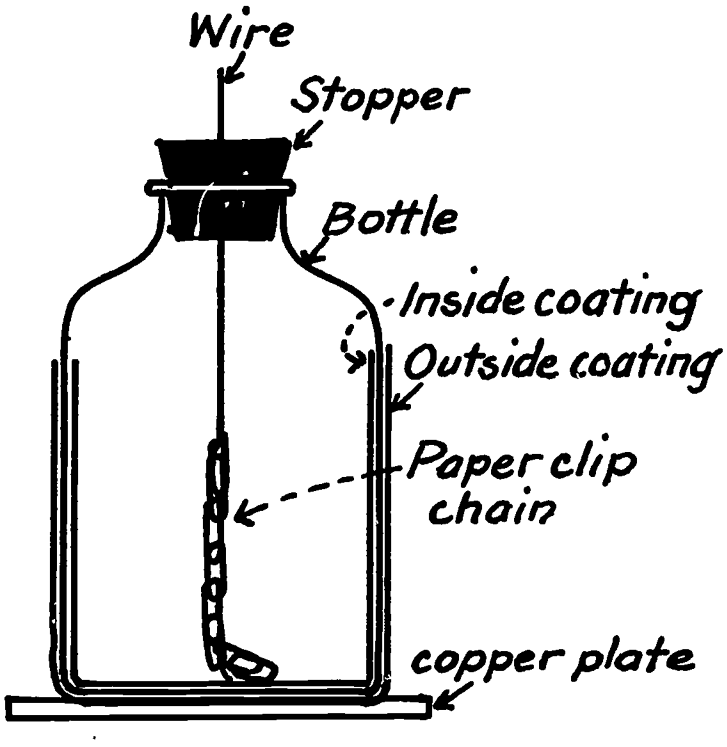
Stored Charges: Experiment 1

To charge the Leyden Jar attach a wire from the sphere of the Van de Graaff generator or electrophorus to the *internal* wire of the Leyden Jar and a wire from the ground or the base of the generator to the plate on which the jar is resting. Now carefully using insulated tongs (because the Leyden Jar contains a considerable charge), disconnect the wires. With the discharging device, touch one end to the external point on the jar and the other end to the internal wire.

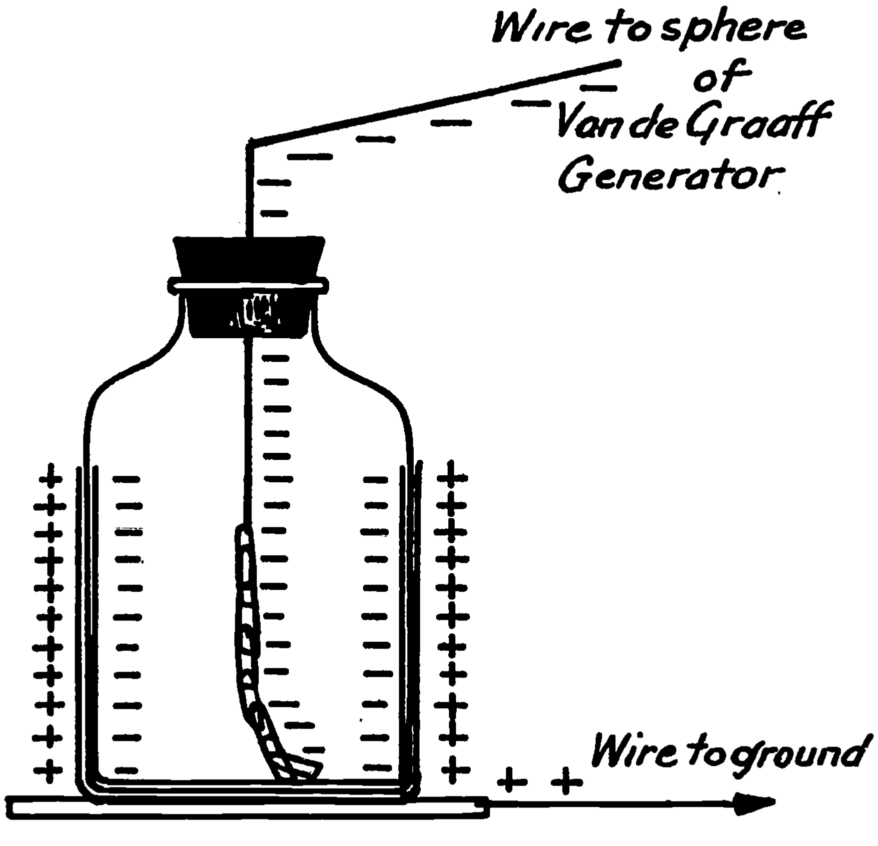
Notice the large spark just before the end touches. This shows the Leyden Jar had held a charge. More modern devices for storing charges are called condensors or capacitors, and are usually made up of metal plates separated by an insulator.

Stored Charges: Experiment 2

So far we have discussed the effect of the size of an object in relation to the amount of charge it can hold. Another way of saying this is that the amount of plate surface of a condensor is directly proportional to the amount of charge it can hold. Students can check this by making a small Leyden Jar and a large one; after charging each one, they can discharge them and measure the relative length of each



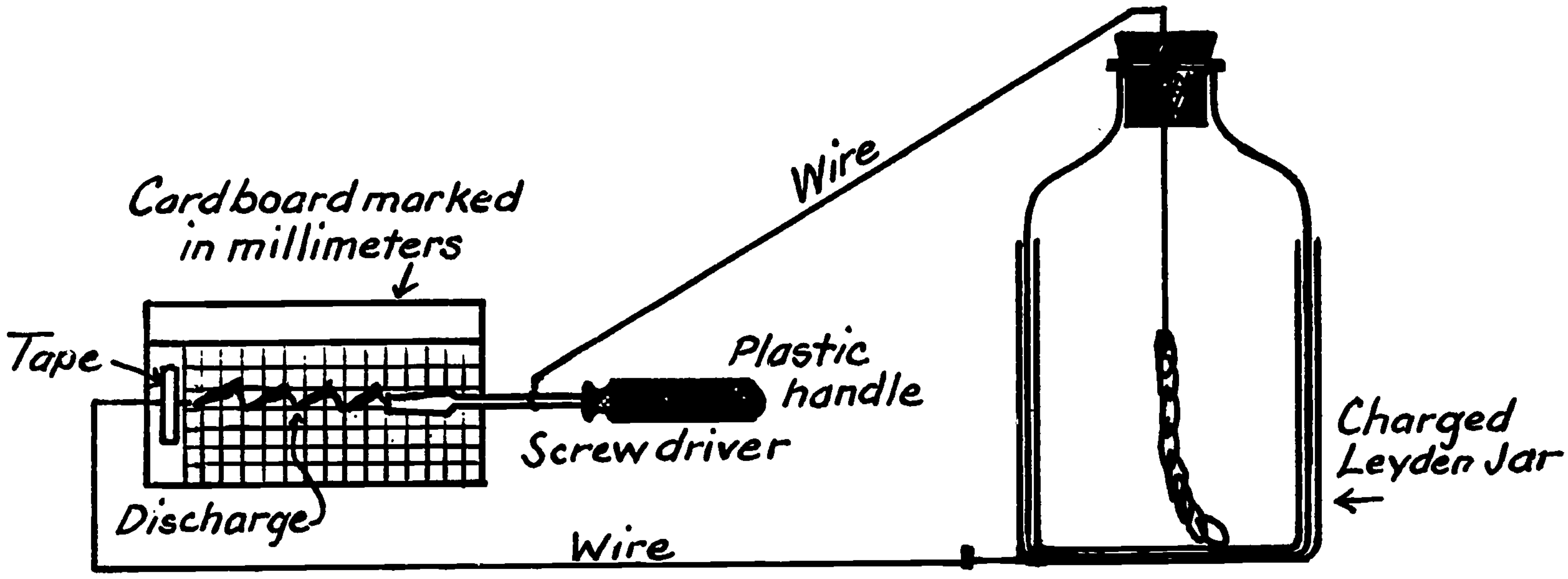
Homemade Leyden Jar



Charged Leyden Jar

spark. The spark can be measured by attaching one end of a wire to the interior wire of the Leyden Jar and the other end to the metal shank of a screw driver with a large plastic handle.

Next attach one end of the wire to the exterior of the Leyden Jar. Lay the other end of the wire on a paper marked off in millimeters. Grasp the plastic handle of the screw driver and move the metal end slowly towards the wire. When the spark takes place, measure the distance between the end of the wire and the end of the screw driver. Each millimeter may under some conditions represent 3,000 volts. Students can compute the surface area of each capacitor (the area of aluminum paint on the jar), and compare this with the relative size of the sparks.



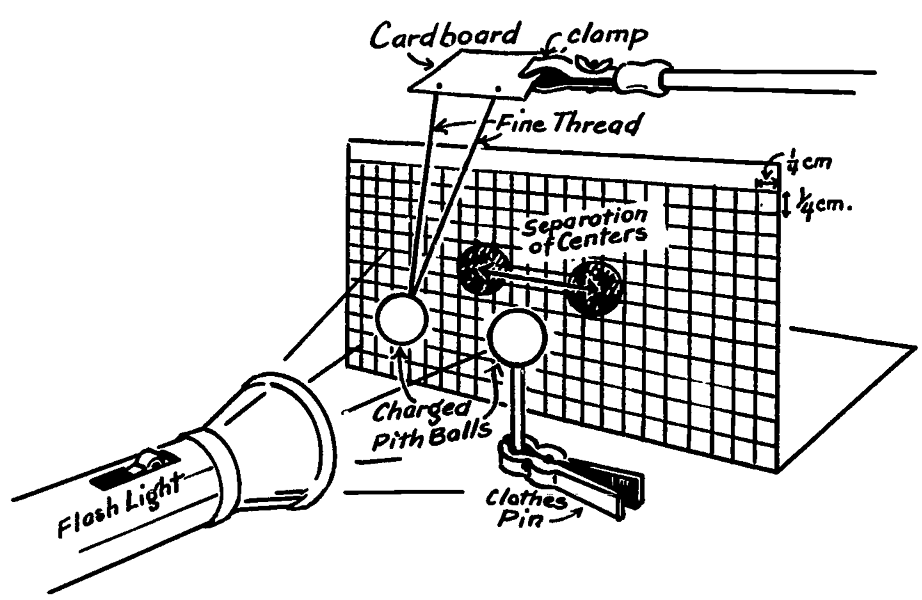
Device to measure length of spark

Stored Charges: Experiment 3

The other factor influencing capacitance, or the ability to store a charge, is the distance the plates are from each other.

To investigate this effect, glue a metal coated pith ball to the end of a rod clamp made of plastic or glass; put the other end of the clamp in a clothespin. Suspend a second pith ball with two silk threads so it moves in only one plane from a ringstand or other support.

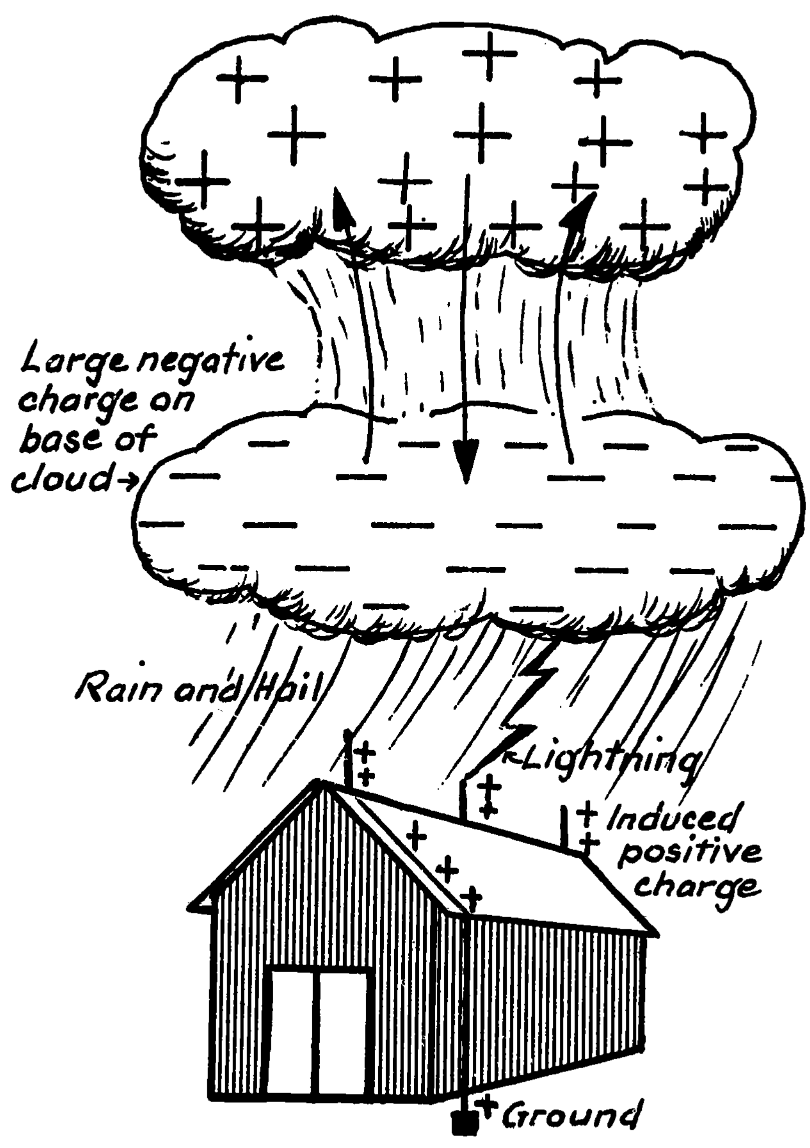
Now place a piece of cardboard with one-fourth centimeter squares behind the suspended ball. Negatively charge both balls from a rubber rod rubbed with cat's fur or wool. Place a light source in front of each pith ball so that its shadow falls on the cardboard. Move the pith ball on the clothespin toward the suspended one until it deflects another square. Again measure the distance between centers. Repeat, until there are at least five readings. Now plot the distance between centers as a function of deflection on a graph paper. Notice that the effects of the force are approximately inversely proportional (for practical purposes) to the distance the charges are apart. In fact, the forces of the charges obey the "inverse square law" of nature, just like gravity, magnetism, and the diffusion of light, that is, the effect *decreases* at the rate of the distance squared.



Device for measuring electrostatic forces in relation to the distance charges are apart

LIGHTNING

The biggest electrostatic generator of all is the thundercloud. It is a violent turbulence of moist air rising and being cooled often causing precipitation. The falling rain and hail may cause a negative charge to be produced at the bottom of the cloud and a positive charge at the top of the cloud. Since the top of the cloud may be 40,000 feet above the bottom of the cloud, the air between acts as a huge insulator between two huge charges. In effect, we have a giant capacitor. Since the base of the cloud is usually only a few thousand feet above the ground, it is easy for the electrons on the base of the cloud to induce a positive charge in objects on the ground and then flow to these objects (lightning), when sufficient voltage (many billions of volts) is developed. The tremendous energy of a bolt of lightning produces the brilliant, dazzling light; it also causes great heat. The heated air explodes, much like the hot gases in a shotgun shell, and causes the same type of noise.



Lightning rods conduct electrons safely to ground

With this background and with our study so far, ask the students how they would safeguard a house against being damaged by lightning. The first answer will probably be lightning rods. Ask the students to discuss how lightning rods function. Can they devise a way to demonstrate the operation of lightning rods?

Have the students consider other problems of protection from static electricity, such as static charges picked up on fuel trucks or the danger of static charges in an operating room. In the case of the operating room, cotton clothing is worn instead of silk or nylon; thus no charge is produced. (Why?)

REVIEW

Following are some review problems and questions:

1. Construct an experiment to show that like charges repel each other, and unlike charges attract each other.
2. (a) What is an electron? (b) What is a proton? (c) What is a neutron? (d) Compare an electron and a proton as to quantity of charge. (e) Compare an electron and a proton as to mass.
3. Using the electron theory, answer the following: (a) Why does a piece of glass become positively charged when rubbed with silk? (b) What charge does silk acquire? Why? (c) What is the functional difference between an insulator and a conductor of electricity?
4. (a) Explain how to charge an electroscope positively by contact. (b) How do the leaves of the electroscope indicate that the electroscope possesses an electric charge? (c) Has the electroscope lost or gained electrons?
5. (a) Explain how to charge an electroscope positively by induction. (b) By means of three diagrams show that the electroscope is made to lose electrons during this process.
6. (a) What happens when a positively charged body is brought near, but does not touch, the knob of an uncharged electroscope? (b) What happens when a positively charged body is brought near the knob of a positively charged electroscope? (c) Explain how you would use a negatively charged electroscope to determine whether a charged piece of wax has a positive or negative charge.
7. (a) What is a condensor used for? (b) How is a condensor charged? (c) How is a condensor discharged?

8. Explain how lightning resembles the discharge of a condensor.
9. Explain how the electrophorus is used.
10. State three ways in which electrons are liberated from the bodies to which they belong.

PRODUCING ELECTRIC CURRENTS

Currents of electricity can be produced in many different ways; thermoelectrically, photoelectrically, magnetically, with piezo crystals, and chemically. All the methods of producing electric currents use the same basic principles; that is, they put the outer electrons of an atom into motion by applying some type of energy to the atom. Probably the simplest method to investigate is the chemical production of electricity.

Using Electricity: Experiment 1

Have students place a strip of zinc (an electrode) and a strip of copper (an electrode) into a container of water to which a little sulfuric acid has been added. Connect a wire from each electrode to a one and one-half volt light bulb. Ask students what caused the bulb to light. This is a simple cell. Two or more cells constitute a battery.

To further explore the production of electricity chemically, attach a voltmeter (wrapping the wire around a magnetic compass will serve as a crude meter) in the circuit of our cell. Now substitute different metals for the zinc and copper electrodes such as lead, tin, aluminum, carbon, iron, etc.

Notice that many combinations of two different metals produce an electric current. What happens is that one metal (called the more active metal) gives up its electrons more easily than the other. The entire process in the case of zinc and copper is as follows:

Zinc, the more active metal, dissolves in the solution. Its atoms separate from the strip in the form of zinc ions. The zinc atoms become zinc ions by losing their electrons. The electrons lost by the zinc remain on the zinc strip and cause the strip to become negatively charged because it has a surplus of electrons. At the same time, hydrogen ions in the acid remove electrons from the copper strip in order to become molecules of hydrogen gas. Because the copper is losing its electrons to the hydrogen ions, the copper becomes positively charged, having developed a shortage of electrons. When the zinc and copper are connected by a wire (with a light bulb, voltmeter, etc.) the excess electrons on the zinc electrode flow to the positively charged copper electrode. As long as the chemical change continues to take place between the electrodes and the solution, the electrons will continue to flow through the wire.

Using Electricity: Experiment 2

Have students place the ends of two wires, connected to a fresh 6-volt battery, into a glass of water to which a small amount of sulfuric acid (H_2SO_4) has been added. (Use caution because sulfuric acid is very caustic to the skin.) Point out to them the bubbles that begin to climb up the wires. Also notice that one wire has about twice as many bubbles as the other.

Ask the students what the bubbles or gases are and what the experiment represents. Supply some reference material in which they can find the answer.

Call attention to the formula of water, H_2O, noting especially that there are twice the number of hydrogen atoms as oxygen atoms in a water molecule. While discussing the results thoroughly, impress upon the students that the molecule of water has actually been separated into hydrogen and oxygen, and that the atoms of these elements collected at a certain wire because the atoms had developed an electrical charge. This illustration should aid in explaining that all matter is electrical in nature.

Have the students dissolve copper sulfate in the water and add a small amount of sulfuric acid to the solution. Connect a strip of copper to one of the wires going to the positive terminal of the cell and a carbon rod to the negative terminal of the cell. (A carbon rod can be obtained from a worn-out dry cell. They are used for the center electrode.)

Immerse both strips in the solution. After a few minutes the students will notice the carbon rod is being coated with copper and that the copper strip is disappearing.

This is called electroplating, and shows that electricity can cause atoms to move through a liquid. This would also indicate that the atoms themselves must have charges. A possible explanation of this would be that the atoms have an extra electron or a deficiency of an electron. An atom which has developed a charge is referred to as an ion.

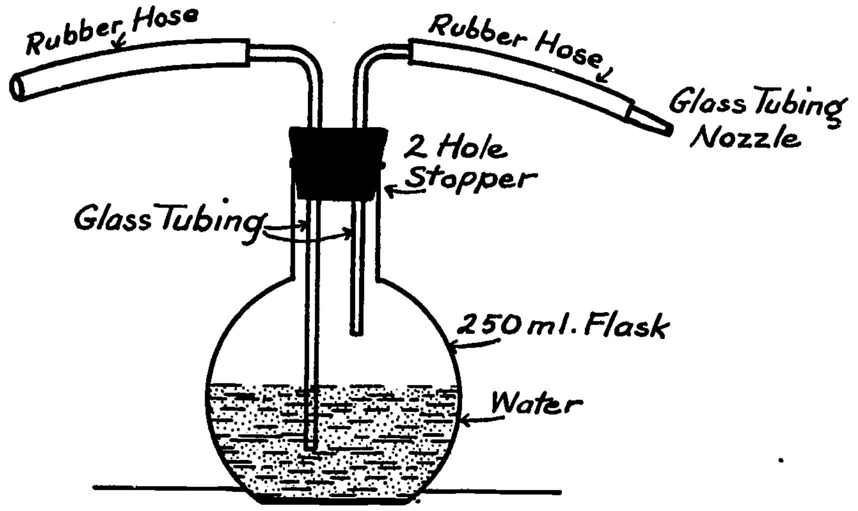
CURRENT ELECTRICITY

The problem in teaching this area of electricity is the difficulty students have in visualizing the flow of the invisible electron and in seeing that current electricity is electricity in motion. This problem can be overcome in two ways, however. First compare current electricity to something the student can visualize, such as water. Second, use the one sense that can detect electrons, the sense of touch. Also at this point, the student should be introduced to electrical terms and their meaning. It is helpful, therefore, to draw a chart on the board, such as the one below, and give the electrical term, its counterpart in a water analogy, the units, and symbols.

Electrical units of measurement:

Terms	*Units*	*Symbols*	*Water*	*Analogy Units*
Voltage	volt	V. (E)	Pressure	lbs./sq. in.
Amperage	ampere	A. (I)	Amount of flow	gal./hr.
Resistance	ohm	Ω (R)	Area of pipe	sq./in.

These characteristics can be demonstrated by use of a flask equipped as shown in the following diagram:



Current Electricity: Experiment 1

To illustrate voltage, have the student observe that when the flask is inverted the water just trickles out. Now blow into the other tube (for added attention direct the stream toward students) and ask the students why the water had more force when air was blown into the flask. The pressure would represent the voltage and is the push or difference of potential.

Did more water leave the flask in the same amount of time when the flask was blown into than when it was simply inverted? This flow of water represents the electrical characteristics of amperage. Amperage is the number of electrons that flow in a given unit of time.

To illustrate resistance pour 100 ml. of water into the above flask and 100 ml. into a 250 ml. beaker or wide mouth jar. Invert both over a sink. Ask students why the beaker emptied faster than the flask. This type of analogy for resistance can be carried further by doing a quantitative experiment using different diameters and lengths of glass tubing from the flask. Have the students measure the volume, flow, and time.

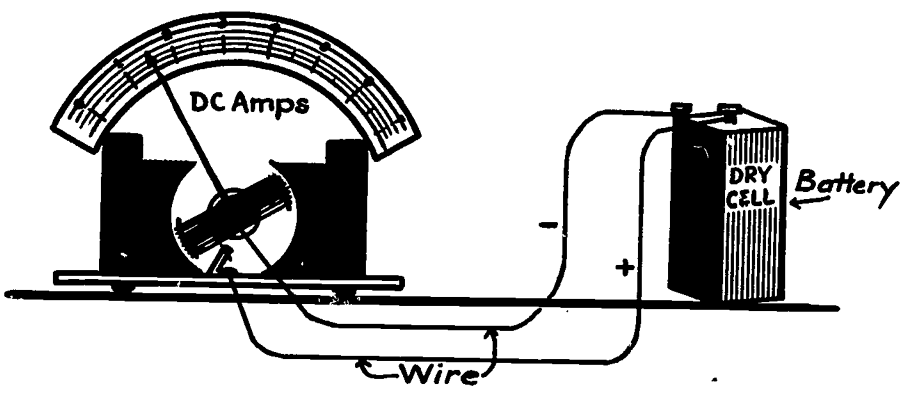
An analogy can be used to tie these relationships together. Ask the students to imagine that half the class is going to push the other half up the hall in baby carriages. If the halls were only one half as wide it would be much more difficult to get the same number of baby carriages through in the same time.

Now ask students what each group of students in the above analogy represents in electrical terms. They should see that the students in the baby carriages represent electrons and that their movement or flow represents amperage. The students pushing the baby carriages represent voltage, or the pressure that moves the electrons, and the students passing in the halls between classes represent resistance or the force that opposes the flow of electrons (or baby carriages).

Many variations of this analogy can be made. For example, what would happen if two people pushed one baby carriage, (in effect doubling voltage)?

Current Electricity: Experiment 2

Have the students connect different lengths, thicknesses, and kinds of wire to a dry cell and an ammeter as shown in the following diagram:



(Ready made boards with different lengths, thicknesses, and kinds of wire on mounted spools can be purchased.) Students should then make a comparison of resistance in relation to length, thickness, and type of wire. Have them run several trials and record their findings. They should conclude that the longer wire, and/or the thinner wire, allow less current to flow, indicating that there is more resistance. They should also discover that steel wire has more resistance than copper wire.

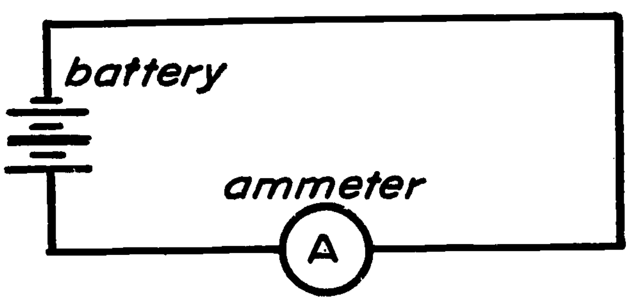
Now see if students can verbally relate voltage, resistance, and amperage in terms of quantity.

Have students connect carefully measured wires of a known diameter to a fresh dry cell with an ammeter and volt meter in the circuit as shown. (Remember that the diameter of a wire decreases as the number of the wire increases. For instance, #28 wire is smaller in diameter than #14 wire. Remember also that an amp meter is hooked in series and a voltmeter is hooked in parallel.) Each student should construct a chart as shown below:

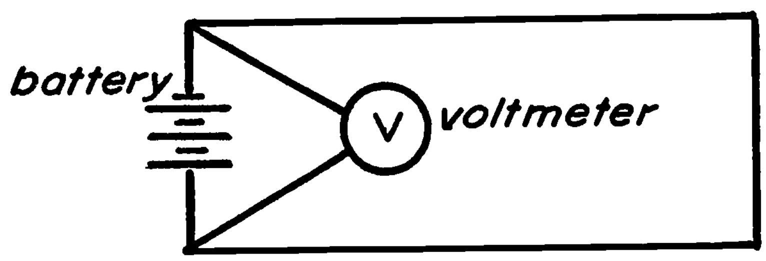
Now carefully read the voltmeter and enter the reading in the column under volts. Do the same thing with the ammeter.

Ask the students if they can see any numerical relationship between resistance, which is unknown, and amps and volts which they have measured. The students should be reminded that previous investigation showed that as resistance increased amperage decreased. Suggest that the students try multiplying the number of volts times the number of amps. (It will then be seen that this does not give a correct corresponding proportional resistance reading.) Then have the students divide the number of amps into the number of volts. This does give a correct corresponding proportional increase in resistance. An ohm meter can then be used to verify these calculations.

wire making up circuit



To measure amps connect ammeter so that all the current must flow through



To measure volts connect voltmeter in parall to the the rest of the circuit

TYPE OF MATERIAL OF WHICH WIRE IS MADE	WIRE SIZE #	LENGTH of WIRE	VOLTS	AMPERES	OHMS
German Silver	30	80 cm			
German Silver	30	160 cm			
German Silver	30	240 cm			
Copper	14	200 cm			
Copper	28	200 cm			
Copper	30	200 cm			
Copper	14	2000 cm.			

The preceding observations, calculations, and conclusions were made by George Ohm in 1827. He found that a current flowing in a circuit is directly proportional to the applied voltage and inversely proportional to the resistance of the circuit. This is known as Ohm's Law. In mathematical form it appears that:

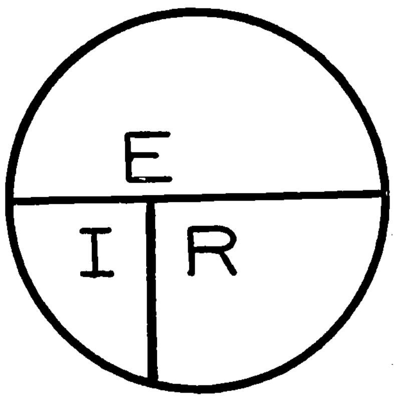
$$\text{Current (amps)} = \frac{\text{voltage}}{\text{resistance}}$$

or using symbols

$$I = \frac{E}{R}$$

Thus if any two factors of a circuit are known, the third can be found.

The following diagram will help the students find the relationships between these three factors:



If the unknown symbol is covered, the proper mathematical relationship of the two knowns can be seen and used to find the unknown. Thus we can find voltage (E) by multiplying amperage (I) times resistance (R). Or to find resistance, we divide voltage by amperage.

Here are some typical problems:

1. A circuit has a total resistance of 12 Ω. If a battery is wired to it, how much voltage would be required to push .5 amps through it?

(a) step 1 (b) step 2 (c) step 3

$I = \frac{E}{R}$ $E = .5A \times 12\,\Omega$ $E = 6V$ (answer)

$E = IR$

2. A television set is wired to a portable 110 volt power supply at a hunting camp. If the internal resistance of the television set is 12 Ω, how many amps would it draw at 110 V.?

(a) step 1 (b) step 2 (c) step 3

$I = \frac{R}{E}$ $I = \frac{110\text{ V.}}{12\,\Omega}$ $I = 9.2$ Amps (answer)

3. If 75 amps are flowing through a wire at 12 volts, what is the internal resistance of the wire?

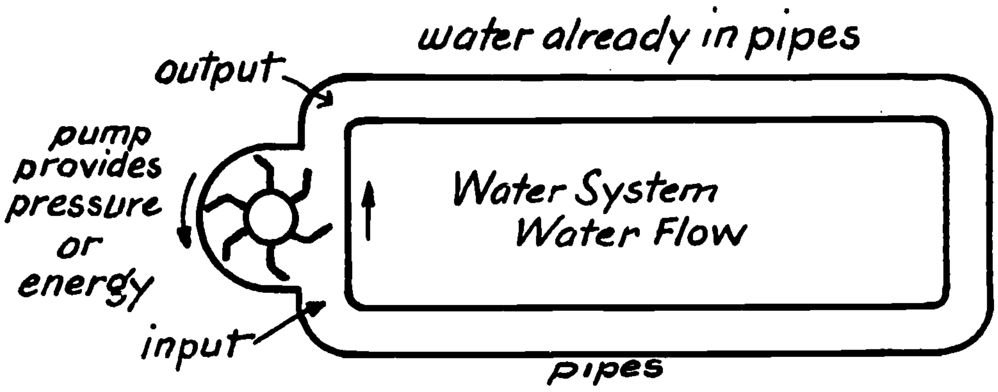
(a) step 1 (b) step 2 (c) step 3

$R = \frac{E}{I}$ $R = \frac{12\text{ V.}}{75\text{ Amps}}$ $R = .16\,\Omega$ (answer)

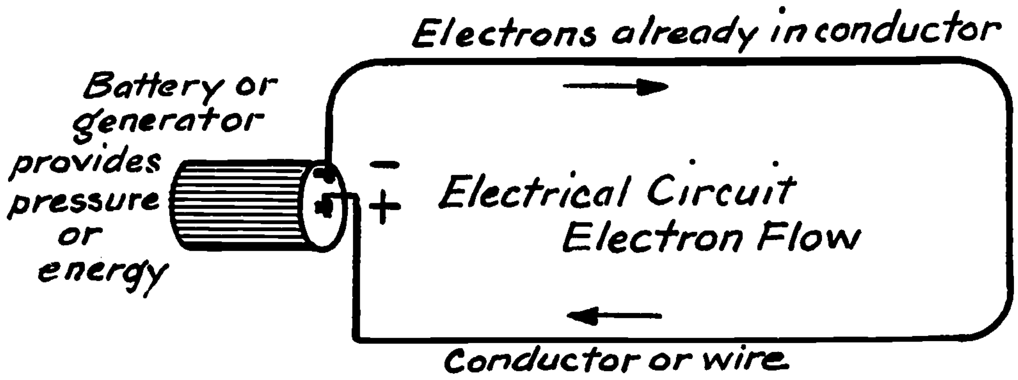
The students should work problems such as these until they are thoroughly familiar with the process.

The following diagrams placed on the blackboard may help students to understand the analogies on the following page:

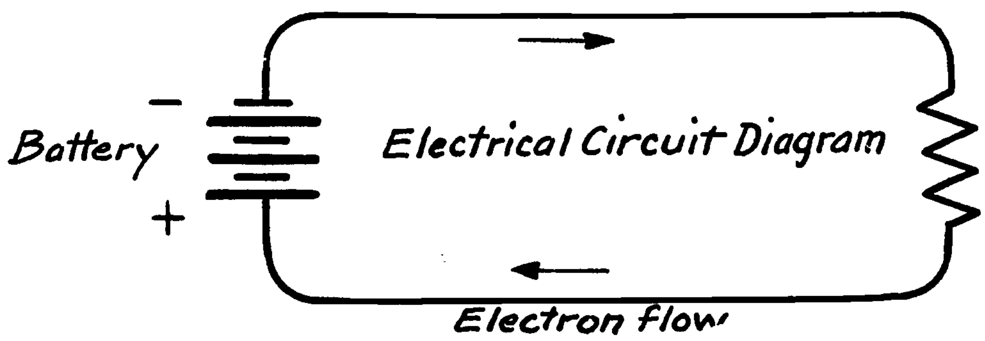
The diagram below if placed on the blackboard may help students to understand the analogies on the following pages



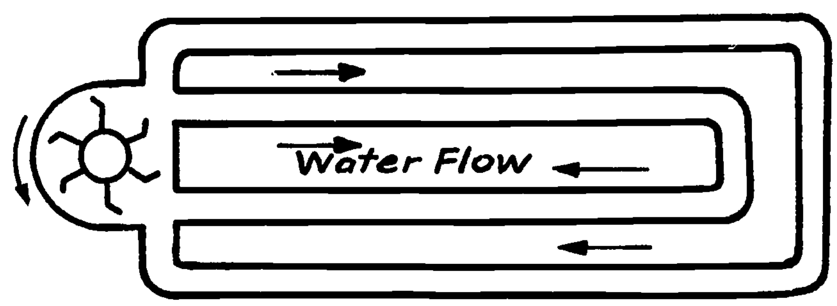
All the water must flow through the one pipe that makes up the system.



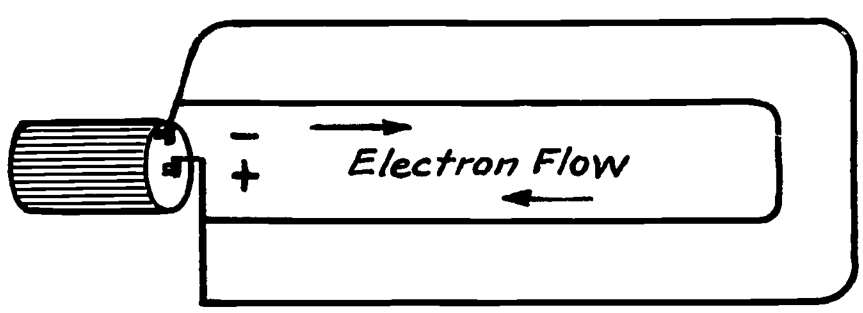
all the electrons must flow through the one wire that makes up the circuit. This is called a series circuit



Water pipes have friction. Electrical conductors have resistance



Now the water has two pipes to flow through. Some goes through each pipe.



The electrons have more than one path in which to flow. This is called a parallel circuit.

TYPES OF CIRCUITS

Both water and electricity are sent through different kinds of piping arrangements or circuits. There are two main types of electrical circuits called *series circuits* and *parallel circuits.* In the series circuit the current flows in an undivided, consecutive, and continuous path from its source through the circuit and back to its source. This is like connecting a water pipe from the output of a water pump and running it through the house and back to the intake of the water pump. All the water would have to flow through each part of the pipe.

In a parallel circuit the current divides into a number of separate, independent branches in going from its source, through the circuit, and back to its source. This is like connecting several pipes from a pump's output, then running them through the house, and back to the intake of the pump. In this arrangement the water would divide, some going through one pipe and some through another, and so on.

It follows then that all the resistances in a series circuit would simply be added to find the total resistance, since all the current would have to flow through each resistance. But in a parallel circuit, each resistance represents another avenue for the current to flow along, so that in effect each time we add resistances in parallel circuits the total resistance becomes less. This is sometimes difficult for students to understand.

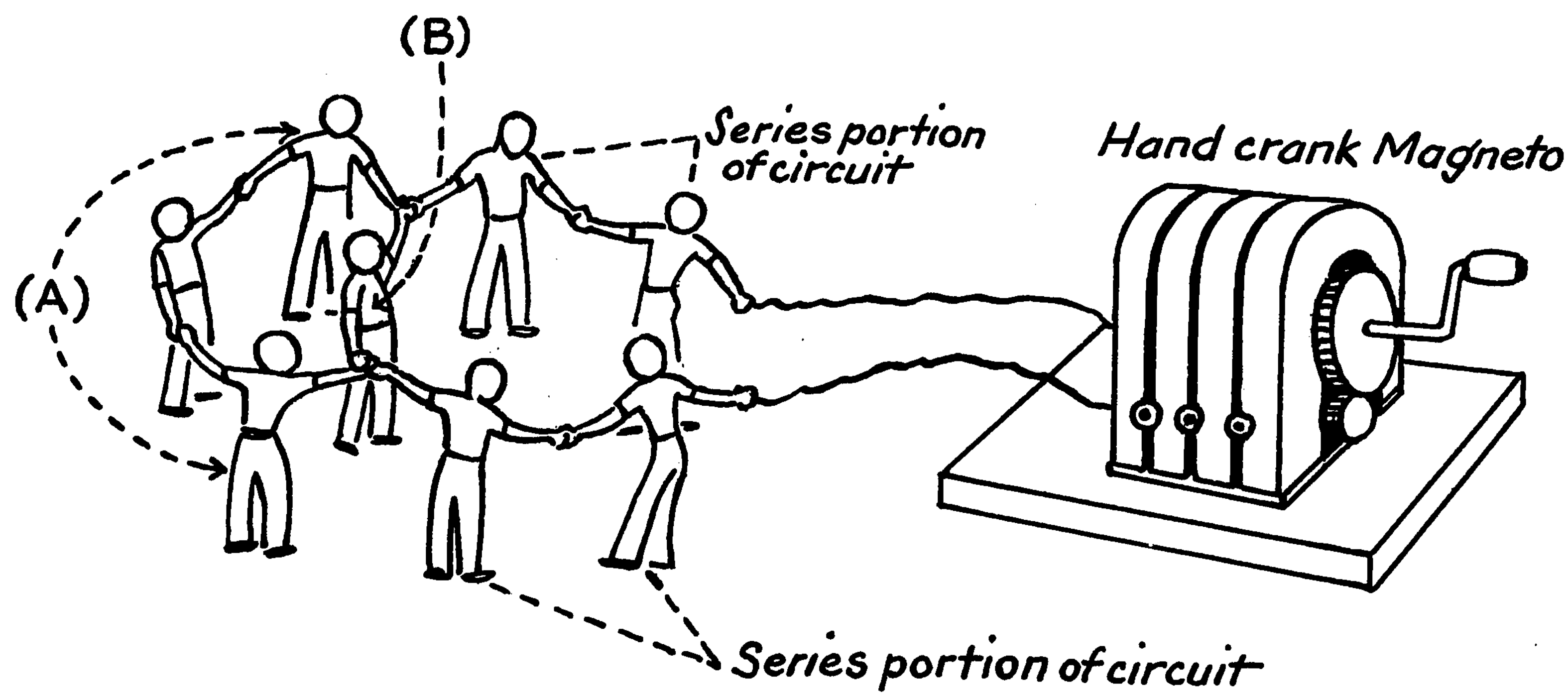
Other situations that are involved in series and parallel circuits are *open circuits, complete circuits,* and *short circuits.* The open circuit is that in which there is no complete path from the source of electricity back to the source. Whereas a complete circuit does have a path from the source back to the source. A short circuit is one in which a shorter, more direct path is provided from the source back to the source. This is usually undesirable since it leaves the rest of the circuit without current flowing through it.

Types of Circuits: Experiment 1

The different types of circuits can best be demonstrated by use of the students' sense of touch. Have the students volunteer to form "circuits" by linking hands around the room. A hand cranked magneto, like those found in the old hand cranked telephone, serves best to supply the current. Attach short leads (wires) to each pole of the magneto, and have the students on each end of the "chain" grasp these wires. (Assure the students they will feel only a tickle, but this tickle will also let them know when electrons are flowing through the circuit.)

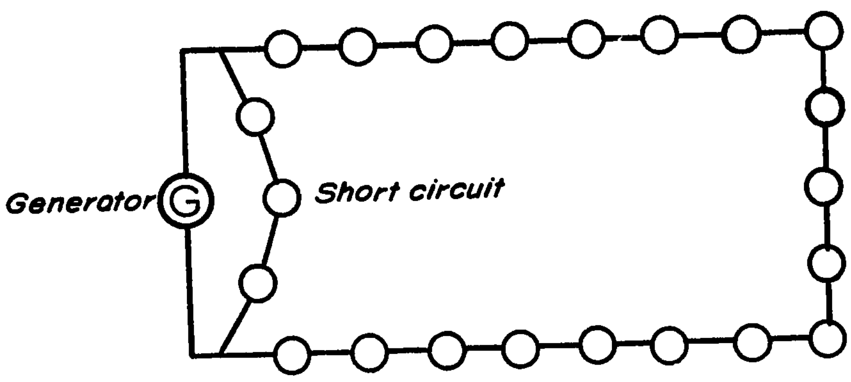
Call attention to the definition of a complete electrical circuit and give the magneto *crank about one half of a turn.* (Warning--uncomfortable amounts of electricity can be produced by excessive cranking.) Each student will feel a tickle. To illustrate an open circuit break the student chain at one point. Now there is no tickle felt by anyone. When hands are reclasped the students will immediately detect the flow of electrons if the magneto is being cranked. Point out that the complete circuit also fits our definition of a series circuit, since all students in the circuit felt current passing through them.

A parallel circuit can be demonstrated by arranging students according to the following pattern:



The students making up the parallel portion of the circuit will feel nothing when the crank is turned because current is divided between them, but students making up the series portion of the circuit will feel the normal tickle. To show the advantage of a parallel circuit, have the students in (A) circuit unclasp their hands; the students in series will still feel a tickle. This shows that the current still flows through the circuit even though part of parallel circuit is broken.

To demonstrate a short circuit arrange students according to the following diagram:



Let three of the more aggressive boys make up the "shorted" portion of the circuit. The rest of the students in the circuit will feel nothing because the three boys will make the easiest path for the current to follow.

These types of demonstrations can be carried further on a quantitative basis by placing volt, ohm, and ammeter in different portions of the student "circuit."

It should be remembered that at this point the student is trying to assemble a large number of fairly difficult concepts into one complete picture and it may be helpful to make other analogies in order to bring the picture into sharper focus.

CONCLUSION

If the student has taken part in the preceding experiments, followed the explanations, worked the problems and answered the review questions, he should begin to understand the basic facts about the nature of electricity. More important, however, he will have gained this information not through the memorization of facts but through small, controlled prototypic experiments. In this way he will have learned additionally the correct scientific approach. Finally, it is hoped that the investigation of electricity will have whetted the student's curiosity and will stimulate him to make investigations on his own.