SECTION THREE
BUILDING AND WORKING WITH ELECTROSTATIC EQUIPMENT

LABORATORY ACTIVITY 1: Separating Charges & Forces between Charged Objects

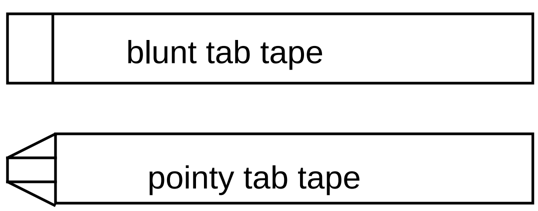
Materials: plastic straw, styrene foam picnic plate, styrene foam cups, acrylic sheet, thread, fur, wool, masking tape.

When two materials with different affinities for positive and negative charges are rubbed together or separated, one may end up with an excess of negative charge and the other with an excess of positive charge, giving the materials net negative and positive charges. This will occur to some extent with any two materials, but the results may not be obvious unless the materials are good insulators. This process is called *triboelectric charging,*. The actual mechanisms of frictional or contact charging are complex and not fully understood, depending on the nature of the materials, surface impurities, moisture, etc. and may involve both motion of electrons and ions. The contact between dissimilar surfaces seems to be the important feature, with rubbing acting to increase the number of contact points.(See Cross, 1987, and Loeb, 1953, Horn and Smith, Science, **256**(5055),362, Apr 17, 1992).

Charged Tapes.

materials: Scotch™ Magic™ tape or similar tape, foam plastic cup, plastic straw, small piece of paper.

1 Making tabs. To make it easier to handle the tapes and to distinguish different pieces of tape, you can make a BLUNT tab by folding about 0.5 cenimeters of tape back on itself, with the two sticky sides in contact. You can make a POINTY tab by folding the two corners of the end of the tape back on themselves, as in the illustration.



2. Make a base tape. Make a blunt tab on the end of a piece of tape, roll about 20 cm of tape off the roll and make a blunt tab on the other end. Stick the tape to a tabletop as a working surface. Take about a 10 cm (4 inch) piece of the tape and make a pointy tab.. Stick the tape to the base tape and press it down with your finger. Now peel the short tape briskly from the base tape.

3. Bring the non-sticky side of the tape near the small piece of paper. What happens?

Does distance have an effect? How do you know?

Does the tape seem to be charged?

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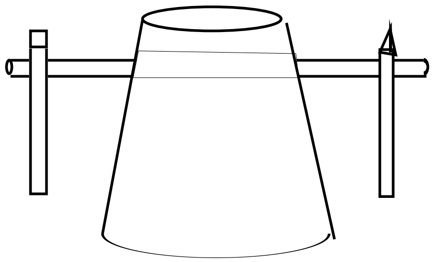
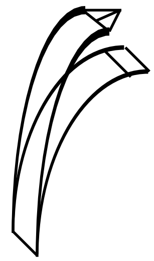
4. Make a second pointy tab tape strip. Press both down on the base tape separately, then peel them off. Bring the tapes near each other and see what happens. Does it matter which sides of the tape face each other?

5. Make a test stand. Poke holes with a pencil in the sides of the foam cup, then insert a plastic straw as shown in the illustration. Simply stick a tape on the straw to hold it. Alternatively, use the edge of the table as a test stand.



Test stand with blunt and pointy tapes



Tape 'sandwich'

4. Leave one pointy tab strip hanging from the test stand. Make a blunt tab strip the same length as the pointy tab strip. Make a tape 'sandwich' by sticking the sticky side of the pointy tab tape to the non-stick side of the blunt tab tape. Press the two tapes together, and run both sides of the tape combination gently between your fingers. Test the combination tape against your pointy test tape and against the piece of paper. What do you observe?

Does the combination tape seem to be charged? If so, is it strongly charged?

5. Carefully but briskly peel apart the two tapes. Hold one in each hand and bring their non-sticky sides slowly towards each other. What do you observe?

Bring first the pointy tab tape and then the blunt tab tape towards the pointy tab test tape. What do you observe?

6. Hang your blunt and pointy tapes on the test stand. Make another set of blunt tab and pointy tab tapes in the same fashion. After separating them, bring them near the test stand tapes.
How do two pointy tapes interact?

How do two blunt tapes interact?

What do you conclude about the charges on pointy and blunt tapes?

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Further activities

The Electrostatics Activities section (Appendix A) is a teaching unit starting with tape charging. Another treatment is given by Sherwood (1992 Electrical Interactions and the Structure of Matter, CDEC, Carnegie Mellon University) See also Arons (1990, A Guide to Introductory Physics Teaching, Wiley & Sons, p 146ff) The charge difference in the tapes lies in the asymmetry of pulling apart a sticky surface from a non-sticky surface. It is not surprising that electrostatic charging occurs with adhesives, as electrical forces are the underlying forces responsible for sticking the surfaces together, although the complete mechanism of tape sticking is more complex. . Formica™ tabletops without a base tape also give good results. Students can peel tapes from different surfaces to see if they get the same sign of charge. You may wish to clean the surface first with rubbing alcohol to remove grease and dirt.

Charging by Friction

The traditional way to charge non-conducting materials is to rub different materials together. Experimenters have established lists of materials and their relative affinities for negative and positive charge when rubbed together. Such a list is called a *triboelectric series*. The example here is from Graf (1964, p 37.) Once students know how to determine the sign of a charge (see Laboratory Activity Five) construction of such a series using materials found in the classroom and the home can be an interesting independent investigation.

More positive

- Rabbit's fur
- Glass
- Mica
- Nylon
- Wool
- Cat's fur
- Silk
- Paper
- Cotton
- Wood
- Lucite
- Sealing Wax
- Amber
- Polystyrene
- Polyethylene
- Rubber balloon
- Sulfur
- Celluloid
- Hard Rubber
- Vinylite
- Saran Wrap

More negative

As you can see from the series above, many common plastics will acquire a negative charge when rubbed with rabbit fur, wool, or clean dry hair.

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Charging by Friction

1. Tear some paper into small bits or take some paper punchings, and scatter them on the table. Rub a plastic straw on hair, wool or rabbit fur, and bring it near the paper bits. Also try this with the foam plastic cup. What happens?

Does distance have an effect? How do you know?

2. Tape a long piece of thread to the bottom of a foam plastic cup and tape the other end of the thread to the ceiling so that the cup hangs about a meter above the floor. Rub the hanging cup with wool, fur, or hair. Rub another cup and bring it near the first. What happens? Does distance have an effect?

3. Take the foam picnic plate and rub its bottom against the acrylic plastic sheet. Bring the plate near the suspended cup, then bring the acrylic sheet near the suspended cup. What happens in each case?

4. The suspended cup is acted on by three forces: gravitational force pulling down, the string tension pulling along the string, and the electrical force. Can you keep the cup in a stable position with a single charged cup or foam plate? With a single acrylic plate? With two charged foam or acrylic plates?

5. You may wish to hang two or more cups from the same point on the ceiling and see what happens when they are all charged. You could also try suspending charged plastic straws from a thread, either by the ends or by the middle. Charged balloons also work well.

6. Arrange the suspended foam cup so it can swing and just clear the top of a lab table. Tape several charged cups to the table top and see how the hanging cup interacts with them when it is pulled to the side and released from different distances. This experiment is analogous to atomic scattering experiments You can vary the mass of the swinging cup by adding a few pennies to it.

7. Rub half of a foam picnic plate with fur or wool. Bring it near the hairs on the back of your hand or arm. Can you detect which part of the plate was charged?

8. Charge two foam plates and try floating one plate above the other by the electrostatic repulsion. Can you distribute the charge on the pad to stably support the foam plate?

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9. Recharge your pointy and blunt tapes, and hang them back on the test stand. Try bringing charged straws, foam cups or plates and acrylic sheets near the tapes. Describe what happens in each case.

If we name charges by pointy and blunt, which kind of charge does rubbed foam have? rubbed acrylic? a rubbed straw?

10. Take a vinyl plant dish and rub it against the acrylic plate. Use the tapes to determine the charge of the dish and the acrylic. Record your results.

Take a foam plate and a vinyl plant dish and rub them together. Use the tapes to determine the charge of each and record your results. Rub another foam plate against the acryilic sheet and determine the charge of each. Record your results.

Compare the charges. Did any of the three objects always get the same charge in all the pairs? Did any of the three objects have one charge in one case and one charge in another?

Ranking the three objects from most pointy charged to most blunt charged, what would be the order of the triboelectric series formed by these objects?

How could you explain your results using the atomic model of matter?

Many different materials can be charged by rubbing. Some materials may need to be held by an insulator to be charged. Other materials you may find useful include the acetate and vinylite strips sold by scientific supply houses, PVC water pipe, plastic shower curtain rod covers, plastic golf club tubes, packing foam, and different kinds of plastic bags.

LABORATORY ACTIVITY 2: Electroscopes

The electric pendulum or “pith ball” electroscope.

Materials: straight and flexible plastic straws, aluminum foil, polyester sewing thread, plastic coffee cup, glue stick and tape.

Any device to indicate the presence of electrical forces has traditionally been called an electroscope. The simplest version of this was often made from a small piece of pith from the inside of a plant stem such as elder. (D. Olmsted, A Compendium of Natural Philosophy, S. Babcock, New Haven, 1847, pp33-34) A substitute for the traditional pith ball on a string is a “foil bit” made from small pieces of foil covered plastic drinking straws. (A plain piece of foil may be used, but is too easy to crush, and hard to keep smooth.) Use a glue stick to apply glue to a strip of smoothed aluminum foil and roll a single layer of foil plus a small overlap around a plastic drinking straw. Before the glue is dry, use scissors to cut the foil covered straw into pieces about a centimeter long. Partially unroll the foil on each bit of straw and lay one end of a 10 cm (or longer) length of polyester sewing thread under the foil, pressing the foil down against the glue to secure it.

A foil bit may also be made using tape. Take a pencil and wrap a piece of tape sticky side out one and half times around the pencil so it overlaps and sticks to itself. Cut if from the roll. Take a piece of thread and stick one end to the tape. Take a smoothed strip of aluminum foil the same width as the tape and wrap it around the tape, so it goes once around the pencil. Cut off the excess foil. You now have a foil-covered piece of tape that can be slid off the pencil. Cut the thread to an appropriate length.

Make a stand to hold the foil bit by taping a flexible drinking straw to an upside down foam coffee cup with masking or duct tape. Bend the top of the straw horizontally and cut a short vertical slit in the end of the straw. Slip the suspension string of one or more "foil bits" into the slit and adjust the string lengths to suit.

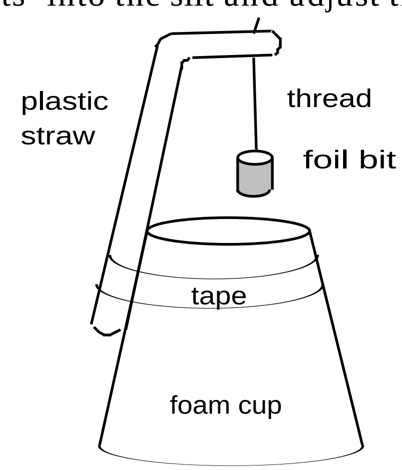

Figure III.2.1 “pith-ball” or foil bit electroscope

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Things to investigate:

1. Rub a plastic straw, a comb or a plastic ruler with hair, wool or fur and bring it near a single or double foil bit. What happens if it does not touch the foil bit? If it does touch the foil bit?

2. Rub a piece of acrylic plastic vigorously against a styrofoam picnic plate. Bring each in turn near the foil bit. What happens? What happens if you bring charged tapes near the foil bit?

3.Hang several foil bits from the same support and try charging them by induction.

4. Make a pair of foil bits with conducting threads by using Christmas tree tinsel instead of thread. Hang them over a horizontal straw that has been covered with foil or a piece of wire, and support the straw on the rim of a jar to make an electroscope. Hold the straw in place with a bit of tape. (Figure III.2.2)

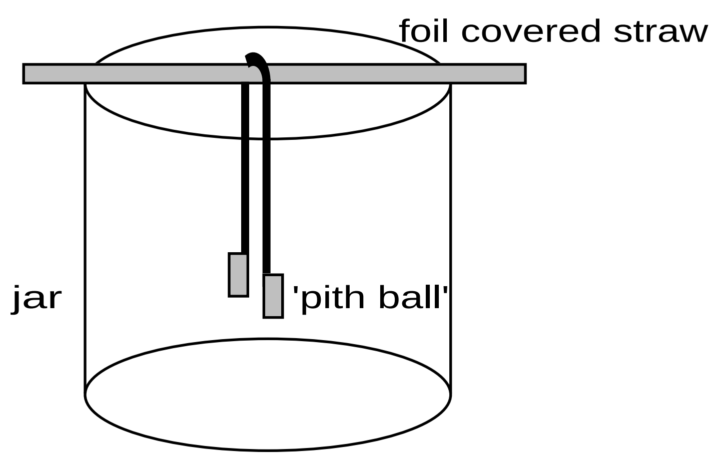

Figure III.2.2 Jar Electroscope

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Soda can electroscopes.

A variety of other electroscopes can be constructed from simple materials. A simple one uses an empty aluminum soda can, a styrofoam cup, aluminum foil and tape. Bend the pull-ring on the soda can so that it sticks straight out from the end of the can. Tape the soda can horizontally on top of an inverted foam cup so that the plane of the pull ring is horizontal. Cut a strip of aluminum foil about 5 cm long and a half cm wide. Form a loop in the middle of the strip (rolling it around a drinking straw works well) and hang the loop over the end of the pull-ring on the soda can. You may wish to close the gap between the ends of the foil strip with a bit of tape to keep the foil from flying off the pull-ring when bringing strongly charged objects near it. (See Figure III.2.3.) Bring a charged object near the soda can and the foil leaf will be repelled by the can. (Note that the two ends of the foil will not separate from each other.)

A variation on this electroscope uses christmas tinsel instead of the aluminum foil. Take a strip of tinsel, double it, and double it again so that you have four strands. Tape the end with the double loop to the pull tab with a small piece of tape. Cut the strands to a length of about five centimeters.

This electroscope works particularly well for demonstrating the effect of induction of charge.Place two of them end to end, then bring a charged foam cup near one end of the arrangement. Keeping the charged foam cup in position, move the other electroscope away from the first using the insulating stand. Now remove the charged foam cup. The two electroscopes will be oppositely charged. A similar electroscope was also described by H. Kruglak ("A Simpler Soft-Drink-Can Electroscope" .The Physics Teacher 28(9), 620, Dec 1990, 620) .

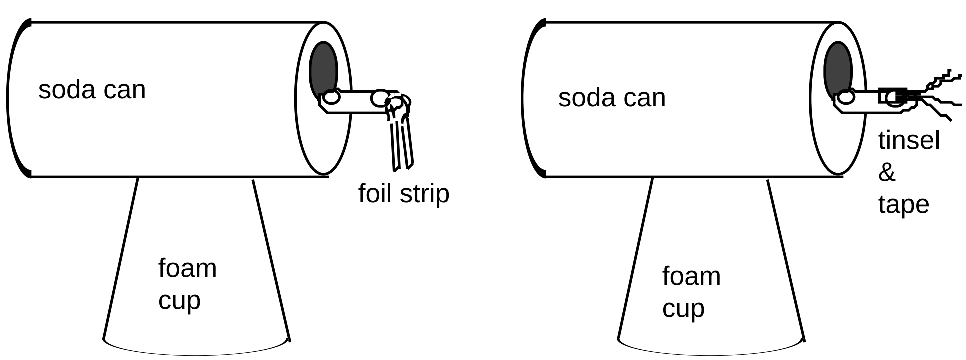

Figure III.2.3 Soda-can Electroscope

A nice experiment with the tinsel electroscope is to charge it using tape separation. Make a blunt tab tape and stick it down along the top surface of the soda can. Make a pointy tab tape and stick it on top of the blunt tab tape. Make sure

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the electroscope is discharged, then peel the pointy tape up, holding the electroscope only by the foam cup. Observe the tinsel. Now try the effect of bringing the charged pointy tape near the electroscope, or bringing charged foam or acrylic plates near the electroscope.

Any device that can show electrostatic effects is an electroscope. Standard electroscopes are designed to shield the indicating parts from outside electrical effects and from air currents. Experimenters developed on the order of a hundred designs for electroscopes during the 18th and 19th centuries. With a small amount of work students can construct sensitive shielded electroscopes suitable for more precise work than the simple open designs given here. Christmas tree tinsel is a good substitute for gold leaf for sensitive electroscopes.

More Electroscope designs

The diagrams below show some other electroscope designs.The second and third designs shown could be calibrated for use as electrometers (a calibrated electroscope) to give quantitative comparisons of the amount of charge. Another simple design for an electrometer is described by R. D. Edge (“Electrostatics with soft-drink cans”, The Physics Teacher. 22(6), 396, Sep 1984).

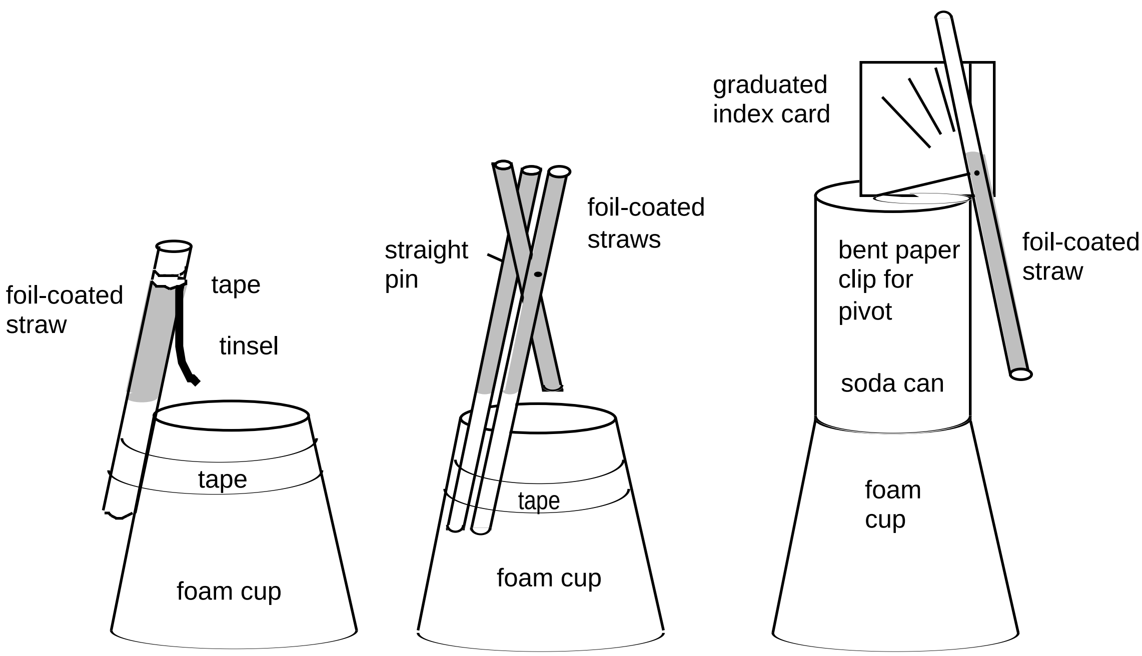

Figure III.2.4.: More Electroscopes

LABORATORY ACTIVITY 3: The electrophorus and charging by induction

The electrophorus is often used to produce charges for other demonstrations, but this is an interesting device in itself, and when equipped with a built in foil bit electroscope can be used to discuss the induction of charge.

Materials: Styrofoam™ insulation or foam picnic plates, disposable aluminum pie plate, foam coffee cup, plastic drinking straw, aluminum foil, glue stick, wool or fur, and tape.

Blue Styrofoam™ insulation is sometimes sold in two foot by four foot sheets, 3/4 inches thick, four sheets to a package by hardware, lumber or building supply stores. Blue and pink polystyrene foam insulation is also sold in other thicknesses in 2 foot by 8 foot and 4 foot by 8 foot sheets. This material, when rubbed with fur, wool or various kinds of synthetic cloth, readily acquires a large surface charge. Other polystyrene foam objects will work also, but are not as durable as the blue foam, although foam picnic plates have the advantages of low cost and ready availability. To make an electrophorus, cut a 30 cm (one foot) square of foam for the base or set a styrofoam picnic plate upside down. Fasten two eight inch aluminum pie tins together at their rims with a few strips of masking tape, and attach an insulating handle by taping a styrofoam cup in the center of the top pie plate. (Figure III.3.1.)

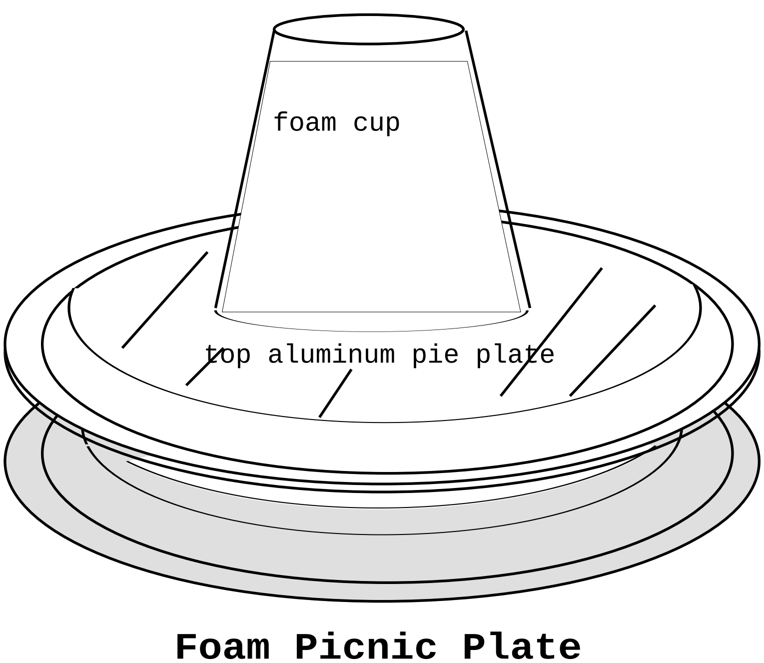

Figure III.3.1A Simple electrophorus

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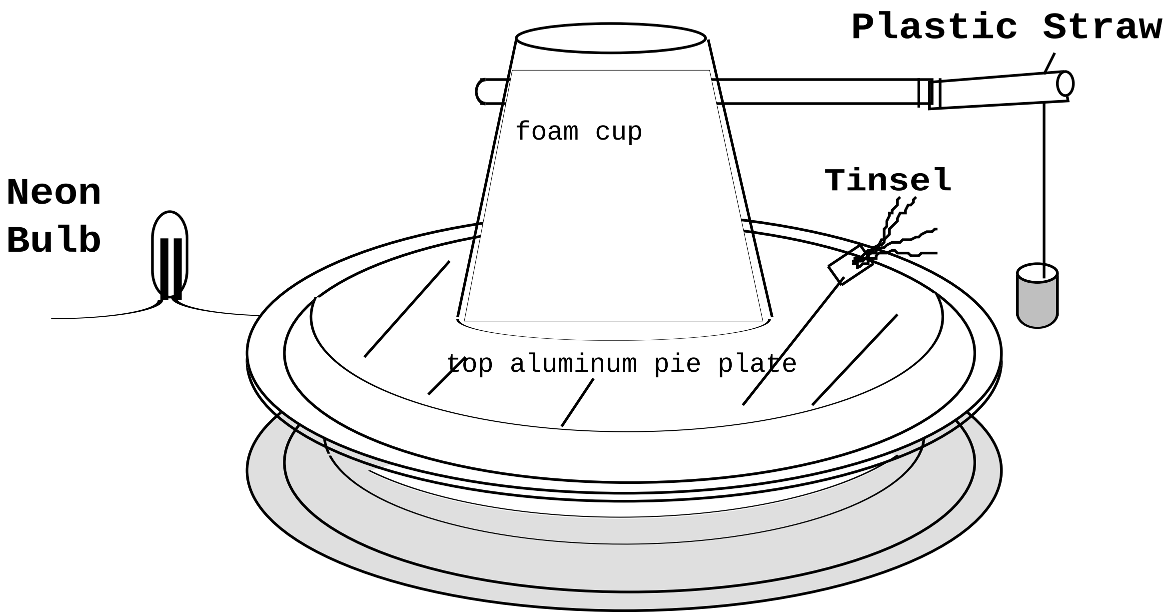

Figure III.1.B Indicating electrophorus

To use the electrophorus, rub the top surface of the foam with fur, cloth or acrylic plastic to charge it. Holding the electrophorus by the foam cup, set it on top of the foam, touch the rim of the electrophorus with your finger (feel the spark!), remove your finger and then lift the plate by the handle. Bring it near an electroscope or a foil bit, or discharge it by touching it. Now take the plastic straw and tape it horizontally to the top of the cup (or slide it through holes poked in the cup) so that it extends over the edge of the pie plate. (If you use a flexible straw, have the bendy end out so that you can adjust the location of the foil bit easily.) Cut slits in the end of the straw and suspend a foil bit so that it is just touching the edge of the plate. You may now investigate induction of charge by the following procedure. Charge the foam with cloth, and slowly lower the pie plate holding it by the cup handle. Observe the foil bit as the pie plate gets close to the foam. With the pie plate sitting on the foam, bring your finger near the foil bit, which will now move rapidly back and forth between your finger and the pie plate.

The foil bit initially has the same kind of charge as the pie plate, and is repelled from the plate, and attracted to the finger. When it touches the finger, it gives up the excess charge and is attracted back to the plate, where it picks up more charge, is repelled again by the plate, and the cycle repeats. If you keep your finger the same distance from the plate, the rate of oscillation gives a qualitative idea of the current. As the plate is discharged by this process, you find you must move your finger closer to maintain the motion. The distance of your finger from the plate to just maintain the motion gives a qualitative measure of the electric potential

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difference between the plate and your finger. When the foil bit finally stops, raise the pie plate and observe the position of the foil bit as you move the plate up and down near the foam. The angle of deflection of the foil bit gives a rough indication of the electric potential of the pie plate. You may now discharge the pie plate through the foil bit and again observe the discharge current. You may compare the sign of the charge on the pie plate with that on the foam by bringing the foam slab near the foil bit before you discharge the pie plate. You may make another indicator for the electric potential by taping a few strands of tinsel so that they lie along the surface of the top pie plate, slightly overhanging the edge. The repulsion of the plate for the tinsel will change as the electrophorus is moved up and down near the charged foam.

You should also find that you can feel the force required to separate the pie plate from the foam. Indeed, with a foam picnic plate, the electric force is often sufficient to lift the foam. It is instructive to have your students feel the force between plate and foam while carefully observing the foil bit to see the relation between work and potential difference.

You can also charge the electrophorus using the charged acrylic plate. If you do this, put the acrylic plate on top of an inverted foam cup to keep it away from the table surface. This will prevent partial cancellation of the charge by induced charge in the table top. (The bottom of the foam plate is far enough from the table surface so that the problem does not occur.)

Things to investigate:

1. Can you feel forces between the plate and the foam?

2. Is the sign of the charge on the plate the same as or different from the sign of the charge on the foam? How do you know?

Tape some tinsel to the edge of the plate. What happens to the tinsel as you charge the plate? What happens to the tinsel as you bring the charged plate near the foam again?

3. You can recharge the plate many times without having to rub the foam again. Why? Is the charge as strong each time? Why or why not?

4. Charge one of the foil bit electroscopes from Activity 2 from the electrophorus by contact with the pie plate. Is the foil bit attracted or repelled by the pie plate? by the foam?

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5. Charge the foil bit electroscope by induction from the pie plate of the electrophorus by bringing the plate near the foil bit, but being careful not to let the foil bit touch the plate. Now touch the foil bit briefly with your finger, then move the plate away. Look for attraction and repulsion. Repeat this with the soda can electroscope. Explain your observations in terms of the motion of charges in the materials.

6. Instead of touching the plate with your finger, use a second plate with a handle to charge the first. Try holding the surfaces of the two plates parallel and carefully bringing them close together. Do you feel any force? Is it attractive or repulsive?

7.Repeat this and use the foil bit electroscope to investigate the sign of the charge on the plates.(If you have done Activity Six, you may wish to use the neon bulb to investigate the sign of the charge on the plates and the foam) What is happening here?

8. Have you noticed the electrostatic charge acquired by your television screen? Try charging the electrophorus from the TV screen instead of the foam.

(I have recently found an electrophorus of similar design, but without the indicating foil bit, described by Albert Kuhfeld in a handout sheet from the Bakken Library of Electricity in Life, 3537 Zenith Avenue South, Minneapolis, MN 55416)

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LABORATORY ACTIVITY 4:The versorium, electric dipoles and the electrostatic compass(adapted, with permission, from the CASTLE© project,Pasco Scientific, 1991)

Permanent Electric Dipoles

Consider the forces that would act on a piece of material that had BOTH kinds of charge. First imagine a short rod with a particle of positive charge attached to one end and a particle of negative charge attached to the other end, an arrangement called an electric dipole. (Figure III.4.1) For each of the dipoles shown, draw arrows to show the force on each end of the dipole due to the positively charged plate. At each dot draw a dipole in the orientation it would have if it could pivot freely in the field due to the charged plate.

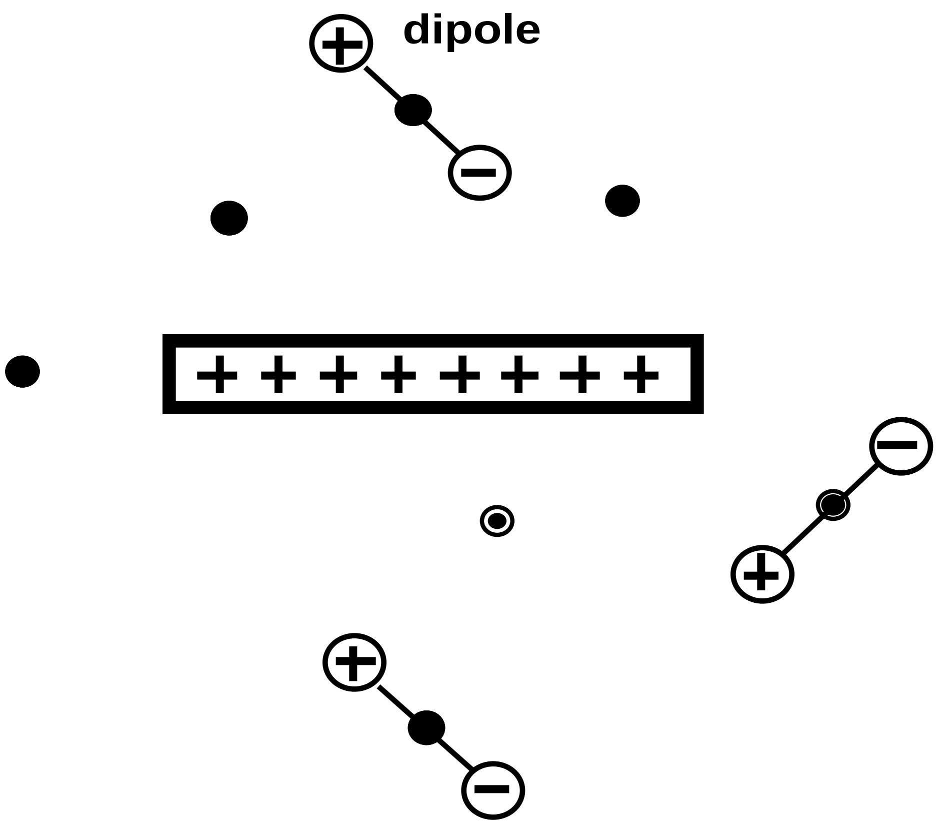

Figure III.4.1 Dipoles near a charged plate

You can test these predictions for dipole behavior by making a device that approximates an electric dipole. This can be done by charging two strips of tape with opposite charges and sticking them together so they overlap (Figure III.4.2) with a piece of thread as a suspension.(This device is due to Bruce Sherwood, 1991 Electrical Interactions and the Structure of Matter, CDEC, Carnegie Mellon University) A fancier version can be made by taking a piece of paper about 2 cm by 8 cm and folding it into a tent shape by creasing it along both axes. Now stick the tab ends of two charged tapes about 5 cm long on the ends of the tent and balance it on the sharpened end of a pencil stuck through the bottom of a foam cup. Be careful in making any of these not to touch the charged parts of the tapes. This can be a little tricky. Charge two more pieces of tape and bring them near the dipole. You may also bring a charged foam plate or acrylic sheet near the dipole. Were your predictions for dipole behavior correct?

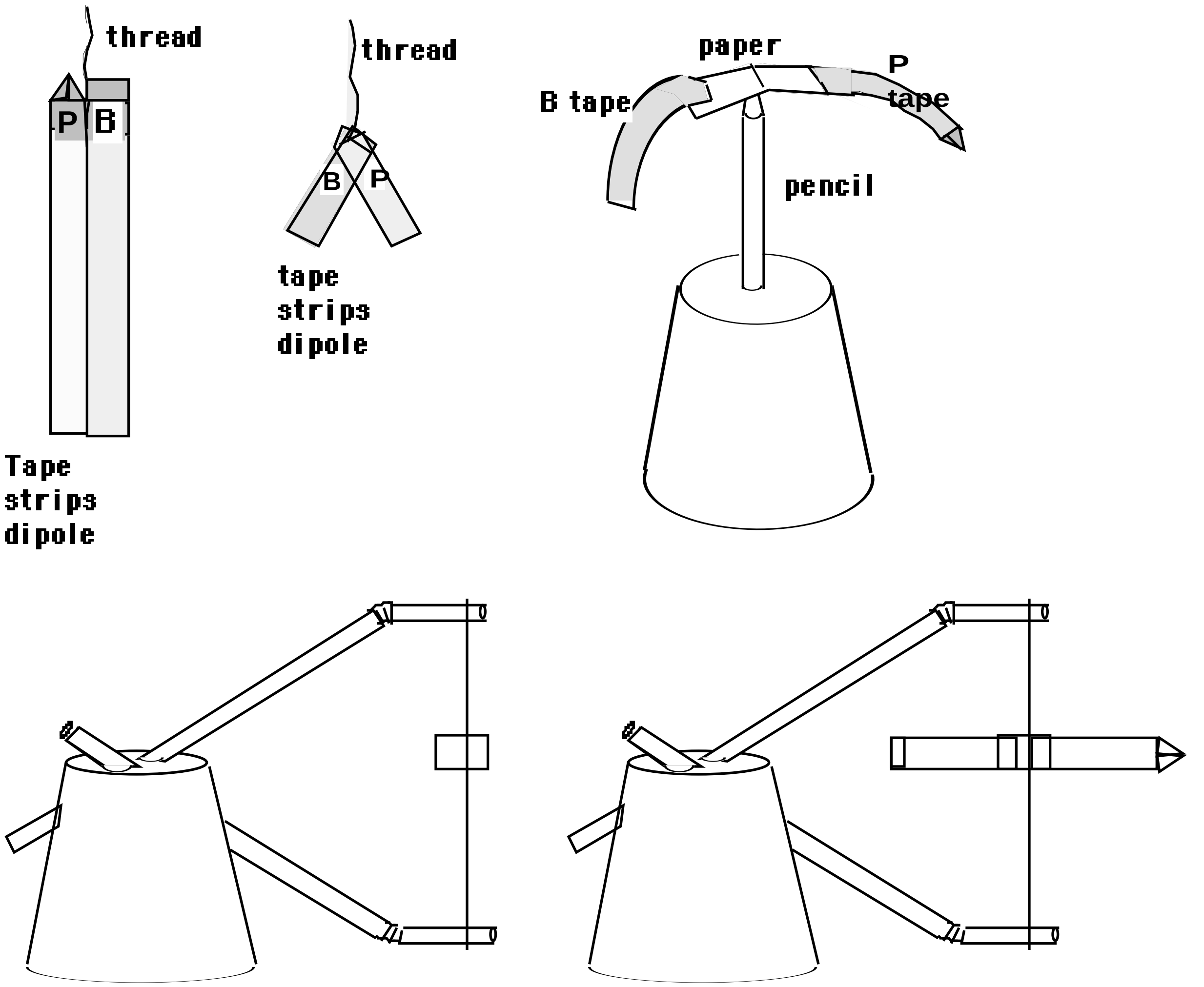

Figure III.4.2 three approximations to electric dipoles, and the electrostatic compass

The electrostatic compass

A more robust arrangement of a tape strip dipole can serve as an electrostatic compass. Take a foam cup, two plastic straws, thread and tape. Poke holes in the cup with a pencil to mount the straws as shown in the diagram above. Cut slits in the end of each straw.Iinsert the end of the thread in the slit in the top straw, wrap it several times around the straw and down again through the slit. Run the thread through the slit in the bottom straw, leaving it almost taught, wrap it several times around the straw and back through the slit. Cut off the excess thread. Take a two centimeter piece of tape, and fold it in half on itself around the thread about halfway up, as shown in the diagram on the left, forming a tab on the thread. Make a pointy and blunt tape, stick them together with pointy on top of blunt, separate them and tape the pointy tape to the tab so that it sticks out in one direction. Tape the blunt tape to the tab so it sticks out the other direction. You now have an electrostatic compass that can be held by the foam cup and moved around in the vicinity of charged objects.

Induced Electric dipoles in conductors

The dipoles you have just made are permanent dipoles, at least for a few minutes. In practice there are relatively few large size permanent electric dipolar objects. It is possible to manufacture permanent dipolar devices called electrets, the analog of a permanent magnet, and some forms of these are used in electret microphones. (See Jefimenko and Walker, "Electrets", The Physics Teacher 18(9), 651,Dec 1980 and Section 9 for references on electret microphones.) More commonly, we find situations where a neutral conductor or insulator is placed in an electric field and a dipolar arrangement of charge is induced in the neutral material.

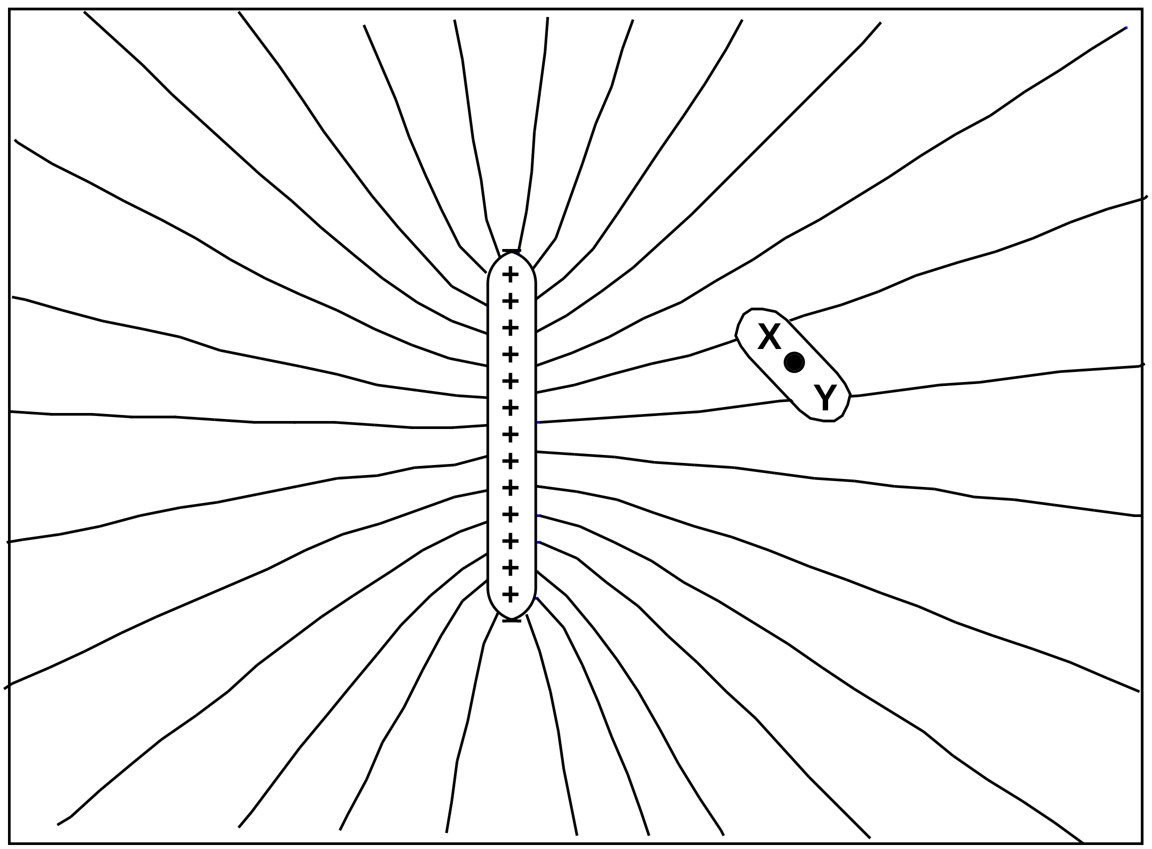

Figure III.4.3 A Conductor in an Electric Field

Consider an elongated conductor placed in the electric field of a positively charged insulator as in Figure III.4.3. What effect would the electric field have on the distribution of negative electrons in the conductor?

As a result of the motion of negatively charged electrons, what is the sign of the charge on the X end of the piece of conductor? On the Y end of the piece of conductor?

Draw arrows to show the direction of the electric force on each end of the piece of conductor.
What do you predict would happen to a conductor that was free to pivot in an electric field?

To test your prediction, cut a rectangular piece of aluminum foil 2 cm by 8 cm. Smooth it on the table, and crease it by folding it in half along its long axis, unfolding it and then folding it in half along its short axis, and then opening it into a "tent" shape. Take a foam cup, remove the straw and stick a sharp pencil up through the hole with its point up. Balance the creased foil tent on the end of the pencil. (Figure III.4.4) Rub the acrylic plastic with the foam plate, and bring first the acrylic plastic, and then the foam plate near the foil. Was your prediction correct?

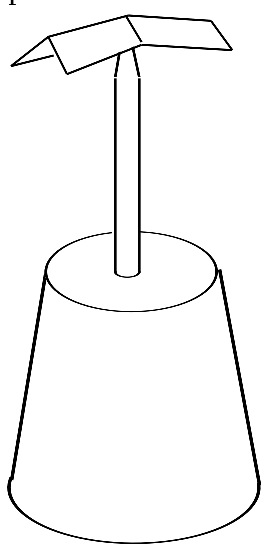

Figure III.4.4 The Versorium or Induced Dipole, described by W. Gilbert in 1600

Induced dipoles in insulators

We consider that the difference between conductors and insulators is that both positive and negative charge are present in both types of material, but that it is very hard to separate the two kinds of charge in insulators. You have seen that you can separate charge in insulators by rubbing as with the foam and the acrylic plate, and by pulling apart materials that are in close contact as with the tape strips. To see if there is more evidence for insulators containing both kinds of charge, cut a piece of paper

2 cm by 8 cm and crease and fold it as you did with the foil. Balance the paper strip on your pencil point instead of the foil (Figure III.4.4) and bring first the charged acrylic and then the charged foam plate near the paper strip. Discuss your observations and explain how they contribute to or detract from the evidence that insulators are composed of both positive and negative charge.

The device you have just built was described by W. Gilbert in 1600 in his book De Magnete, the first modern treatise on electric and magnetic phenomena. An interesting way to map the electric field around a conductor is to make a large number of versoriums and place them in different locations in the vicinity of a charged plate or foam cup. Any small insulator will become an induced dipole in an electric field. An elongated insulator thus can be used to map the field lines.

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LABORATORY ACTIVITY 5: The Electrostatic Hydra.

Materials: paper clips, nylon, polyester or cotton thread with a smooth surface, Christmas tree tinsel.

This is an entertaining way to demonstrate electrostatic repulsion, similar to making your hair stand on end, and it works quite nicely with the electrophorus. Wind six turns of thread around your hand or an index card, cut the thread from the spool and cut the turns so you have a bundle of six strands of thread about 10 to 15 centimeters long. Double the threads over and knot or tape the bend in the bunch of threads to the paper clip so that the ends of the threads hang freely. (Figure III.5.1) Now slip the paper clip on the edge of the electrophorus pie plate and charge the electrophorus. As you lift it into the air the charged threads will spread out.

Things to investigate:

1. What happens to the threads during the entire charging sequence of the electrophorus?

2. What happens when you bring your finger near the charged threads?

3. What happens when you make hydras from different kinds of thread?

4. Compare what happens with a Christmas tree tinsel hydra and a thread hydra.

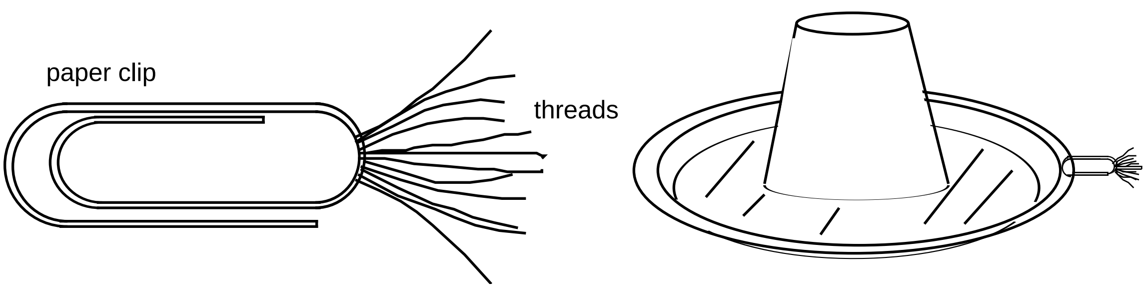

Figure III.5.1 The electrostatic hydra & hydra attached to electrophorus

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LABORATORY ACTIVITY 6: Neon bulbs and motion of charge

Materials: small neon bulbs, electrophorus, plastic straw

Small neon bulbs are available for about a dollar at Radio Shack or other sources, or for much less from various electronic suppliers in quantity (See Section 1 for sources and Section 2 for a background discussion). When a neon bulb flashes, it tells us that a current flows through it. The electrode at which the flash occurs indicates the DIRECTION of current flow. We can determine the sign of electric charges by noting that the flash occurs at the electrode that is LOSING negative charge or GAINING positive charge. In the neon glow lamp, the electrodes are designed to emit electrons. When a potential difference is established between the electrodes, the electric field accelerates electrons away from the negative electrode, where they crash into neon atoms and ionize them or kick them into an excited state. The neon atoms then emit the energy as photons creating the characteristic reddish-orange glow, which surrounds the negative electrode. You can show which electrode glows by lighting a neon bulb in series with a 100 kilohm current limiting resistor from a stack of 8 nine-volt transistor batteries snapped together in series.(Figure III.6.1) (**CAUTION Do not plug the neon bulb into a wall socket**. It may explode. If you use the bulb with the batteries without the resistor, you may get an arc in the bulb.)

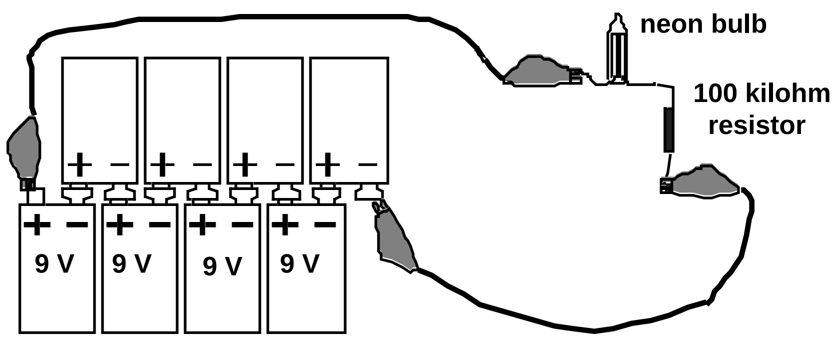

Figure III.6.1 Neon bulb and 9V batteries

(adapted with permission from the CASTLE© project, Pasco Scientific, 1991)

This definition is in agreement with Benjamin Franklin's arbitrary decision to call the charge on a glass rod rubbed with silk "positive" charge. We can now use the neon bulb to determine whether objects are positively or negatively charged, as long as we have a sufficient potential difference (about 70 V) to excite the neon in the bulb. A more detailed discussion of neon bulbs was given by Layman and Rutledge (" Neon Lamps and Static Electricity," The Physics Teacher,10(1), 49, Jan 1972). It is sometimes difficult to see the flash at the electrode, and a shield made of black or white paper may help provide the contrast needed to readily observe the flash.

A light shield for the neon bulb

Cut about a four centimeter length of straw, cut away half of it for about one centimeter. Cut slits about a half centimeter up the straw. Bend the leads of the neon bulb out at right angles and slide the neon bulb into the cut away part of the straw, leads first, so that you can see both electrodes of the bulb and the leads stick out from the slits on the sides of the straw. The white backing may make it easier to see what is happening inside the bulb.(Figure III.6.2)

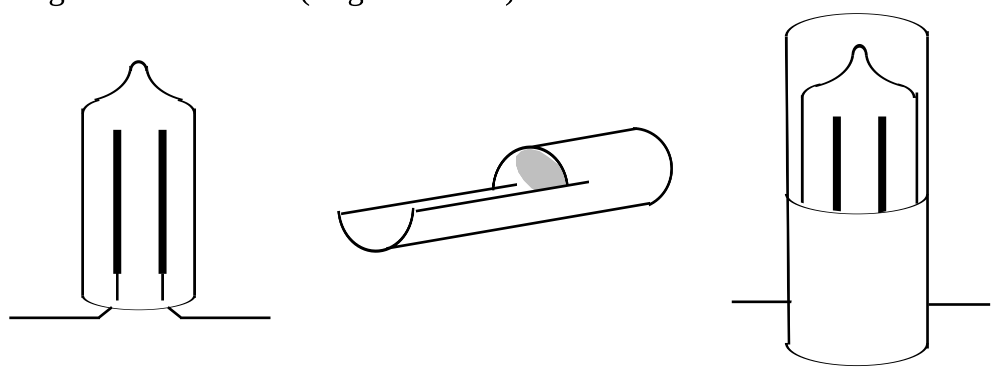

Figure III.6.2 Neon bulb and light shield

Investigating electrophorus charging with the neon bulb.

1.To use the neon bulb, hold one lead in your hand and touch the other lead to a charged object while watching the electrodes. Try the following sequence. Charge the foam pad or plate. Hold the electrophorus plate by its handle and discharge it. Lower it onto the foam pad and touch the electrophorus plate with one lead of the neon bulb while holding the other lead. Do you see a flash?

2. Did it flash around the electrode connected to the plate or to your hand?

Repeat the experiment until you are sure.

3. Now turn the bulb around and repeat the experiment holding the bulb by the other lead. Does the flash occur around the electrode connected to the plate or to your hand? Is this the same as before?

4. The flash occurs around the electrode which is losing electrons to the neon gas in the bulb. If the electrode connected to the plate lights, then electrons are moving from the plate to your hand and vice-versa. Which direction are electrons moving in this experiment?

5. Since the plate was neutral to start, did it lose or gain electrons?

Does the plate end up with an excess of positive or negative charge?

6. Now try the following sequence. Refresh the charge on the foam pad. Discharge the electrophorus plate. Lower the plate onto the foam and touch the plate with one

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lead of the neon bulb while holding the other lead. Watch for the flash. Remove the bulb, and then lift the electrophorus plate from the pad. Now touch the electrophorus plate again with the lead from the neon bulb. Did it flash around the same electrode as before?

Repeat the experiment until you are sure of your results. Can you explain both the charge and discharge process in terms of the motion of electrons in the electrophorus plate and the neon bulb?

Things to investigate:

1. Try bringing one lead of the bulb near the freshly charged foam plate or the charged acrylic plate. What happens?

2. Investigate the potential differences obtained from the electrophorus by using a number of neon bulbs connected in series, and taped to a straw or a black paper backing.

3. Have you noticed the electrostatic charge acquired by your television screen? Try charging the electrophorus from the TV screen instead of the foam. Use the neon bulb to determine the sign of the charge.

4. On a dry day, walk across a carpet while holding one lead of a neon bulb in your hand. Does the bulb light? Are you gaining or losing electrons to the air via the bulb? What must be happening at your feet?

The neon bulb demonstrates a connection between static and current electricity by showing that the bulb can be lit by either the electrophorus or a Leyden jar (see Activity 8) or by connecting eight to ten 9V transistor batteries in series with a resistor and using them to light the bulb.

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LABORATORY ACTIVITY 7: Two Plate Induction

(Adapted with permission from material written for the CASTLE© project, PASCO Scientific, 1991)

Materials: foam cups, foam picnic plate, acrylic sheet, aluminum pie plates, neon bulb, tape.

In conducting matter, at least one kind of charge can move when there is an electric potential difference, but in insulating matter charge does not seem to move with the potential differences available from ordinary batteries. Our investigations with charging by rubbing show that we can separate charge at the surfaces of insulators. In this investigation you will use foam picnic plates, acrylic plastic, metal pie plates and neon bulbs to look for separated charge on insulators and electric potential effects in conductors. We will use the common convention that describes the motion of charge in terms of the motion of positive charge. (See the discussion in section two on the electric field and the electric potential field.)

Activity

We suggest that an object with an excess of positive charge establishes an electric potential field in the space around it, with the potential values getting less and less with greater distance from the plate. IF this is the case, THEN metal conductors placed at DIFFERENT distances from a CHARGED object should be at DIFFERENT potentials. Similarly an object with an excess of negative charge would establish an electric potential field with the lowest value of potential near the charged charged object, and the potential values increasing with increasing distance from the object.

1. If they are at different potentials, what do you expect might happen if two conducting objects are connected through a neon bulb?

To test your prediction, assemble the equipment shown in Figure III.7.1. Take an aluminum pie plate and place it on the table. Tape a foam plastic cup upside down on the plate. Take another aluminum pie plate and another foam cup and tape this cup right side up on the plate. Nest the second cup and plate onto the top of the first cup as shown. Bend the leads of a neon bulb as shown in Figure III.7.2, and insert them into slits in a plastic soda straw. These will be your tools to look for electric potential effects.

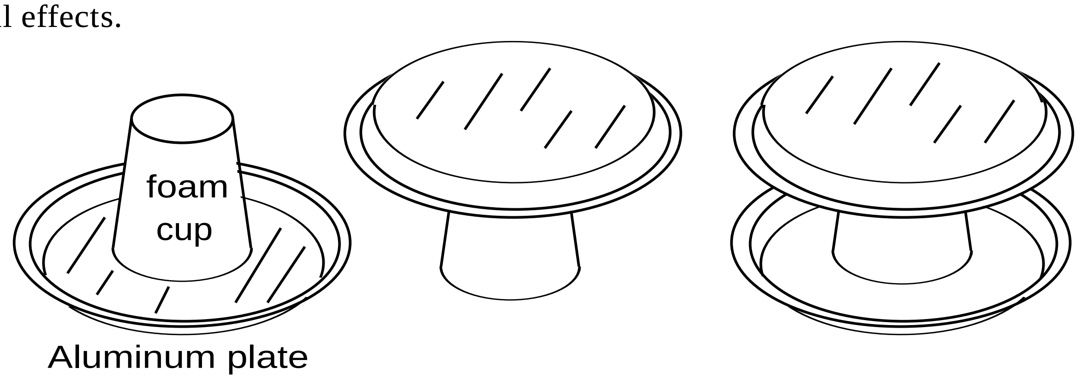

Figure III.7.1 Two Plate Induction Device

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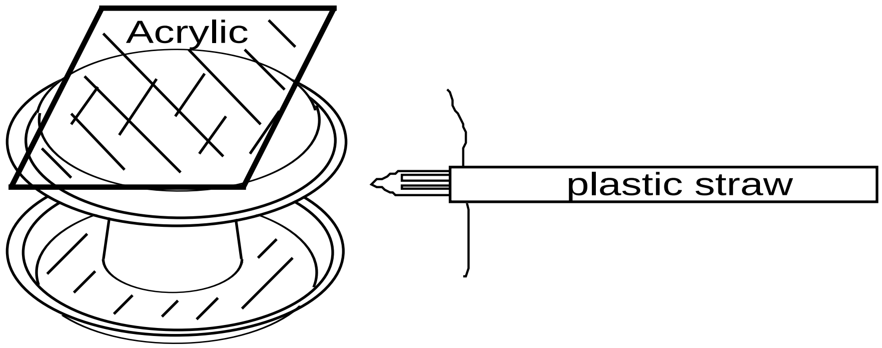

PIECE OF ACRYLIC NEAR TOP PLATE NEON BULB HELD IN PLASTIC STRAW

Figure III.7.2 Experimenting with Induction

Now take the foam picnic plate and rub the bottom of the foam with great vigor against the top of the piece of acrylic plastic. IF this rubbing has managed to separate negative and positive charges, THEN the foam might have an excess of one kind of charge and the acrylic would have an excess of the other kind of charge. You could test for this by using the electric potential effect as follows:
IF the presence of the charge on either the acrylic or the foam creates an electric potential field in the space around it, THEN placing the charged plastic just above the upper pie plate should cause the upper pie plate to have a different potential than the lower pie plate.

2. IF we then bring the neon bulb so that it connects the two pie plates, what do you expect to happen in the bulb if there is a potential difference?

3. Set the acrylic on top of the upper pie plate, then connect the two pie plates with the neon bulb. What do you see? (You may have to repeat this procedure several times to be sure you are not missing anything. When you repeat it, start by touching both pie plates with your finger, then bring the acrylic near the top pie plate, then touch the neon bulb leads to the two pie plates.)

4. When the pie plates were connected by the neon bulb, did anything happen to charge in the pie plates? What is your evidence?

5. As you have seen previously, the neon bulb (Lab Activity 6) not only lights when there is a potential difference, but it also indicates the DIRECTION of motion of charge. Which electrode in the bulb lights, that connected to the more negative potential or that connected to the more positive potential?

6. Repeat the activity above several times, and watch the neon bulb carefully until you are sure you can tell which electrode lights. (Be careful to discharge the pie plates before moving the acrylic near them by touching them briefly with your fingers.) Which electrode lights, that connected to the upper pie plate or the lower pie plate?

7. From your observation of the bulb lighting, which pie plate was at the lower potential after the acrylic was brought near?

9. Comparing the potentials of the two pie plates as determined by your observation, and using the idea of the electric potential field, was the charged acrylic negatively or positively charged?

10. Can you determine if the foam has an excess of one kind of charge? If so, find out which kind of charge the foam has. Describe what you did, including any electric potential effects observed, which plates have increased or decreased electric potential and your evidence for your conclusion.

11. You have just seen that the presence of a charged plastic piece does seem to cause conductors to change their electrical potential and consequently causes charge to move through a neon bulb. Now you will consider further consequences of these observations.

Repeat the process of charging the acrylic by rubbing, moving it close to the pie plate, and connecting the pie plates with the neon bulb. This time keep the acrylic near the pie plate, and keep the neon bulb connected to the two pie plates.

When you touched the neon bulb to the pie plates, the bulb lit, showing that charge moved from one pie plate to another. Thus one pie plate must now have an excess of positive charge and the other a deficit of positive charge. From the evidence of which electrode lit, which pie plate has an excess of positive charge?

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12. If you keep the acrylic near the top pie plate, does the bulb continue to light?

13. What does this suggest about the potential difference between the pie plates now?

14. Since the bulb does not light, there is little or no potential difference across the bulb, but the lower pie plate has an excess of positive charge and the top pie plate has a deficit of positive charge. The only thing that can compensate for what would otherwise be a higher potential in the bottom pie plate caused by the excess charge is the presence of the positively charged acrylic. According to the theory of the electric potential field the pie plate nearest the acrylic has its electric potential increased by the positive potential field.

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LABORATORY ACTIVITY 8: Storing charge–the electric bottle or Leyden jar.

Materials: clear plastic drink cups, aluminum foil or thin foil cup cake liners, large paper clip and glue or glue stick.

Early electrical experimenters envisioned “electricity” as a fluid, and naturally attempted to store the fluid in bottles. These are the fore-runners of modern capacitors. Franklin did much to develop understanding of the behavior of the electrical bottle or Leyden jar, and Appendix B has several experiments which follow Franklin’s study.

Plastic cup Leyden jar.

Small Leyden jars can be made by each student very simply from plastic cups or plastic film cans. The plastic cups which are made of the stiffer, more brittle clear plastic have a higher breakdown voltage than the softer clear plastic cups. If you intend to use these Leyden jars with a Van de Graaff generator you will need to use the brittle cups such as the 10 oz cup made by SWEETHEART™. You may have to purchase these in a party supply store if your grocery store does not stock the brittle kind. For use with the lower voltages of the electrophorus the soft plastic cups such as the SOLO™ 9 oz cups work well. Carefully glue foil cup cake liners to the inside and outside of the plastic cup with rubber cement or a glue stick. Use a second cup to help press the foil baking cup flat against the inside and outside of the cup, being careful not to crack the cup. Bend the outer leg of the paper clip straight (Figure III.8.1) and slide it over the edge of the cup so that the extended leg contacts the inner foil.

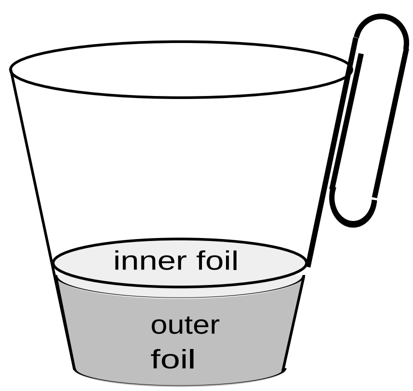

Figure III.8.1 Plastic cup Leyden jar

Film can Leyden jar

To make a film can Leyden jar, the simplest procedure is to glue a strip of aluminum foil to the outside of the film can, fill the can about 2/3 full with water, poke a hole through the top of the film can and push the straightened end of a paper clip through to contact the water. With a little more care, you can glue a strip of alumi-

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num foil to the inside surface of the can, with a tab of foil coming out of the top as a contact. (Figure III.8.2 shows several versions)

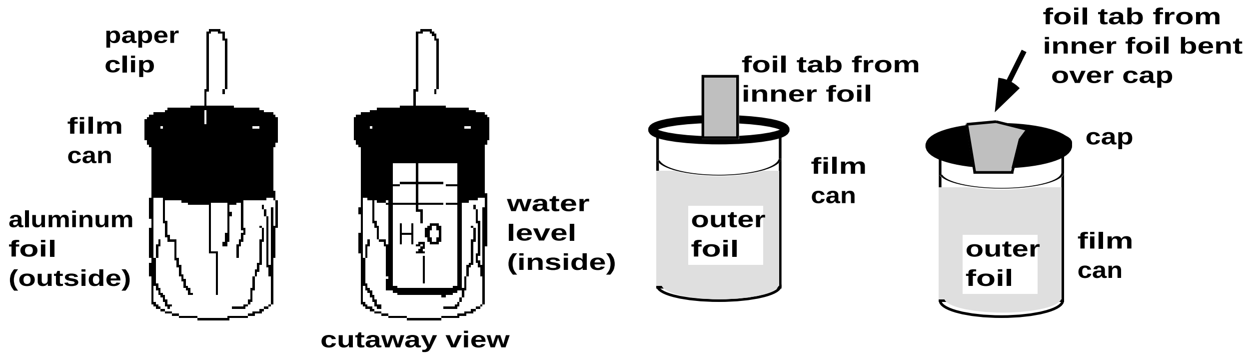

Figure III.8.2 film can Leyden jars

1. These Leyden jar can be charged from the electrophorus, and discharged safely through the fingers. The spark is noticeable, but not dangerous. To charge the jar, first charge the electrophorus. Holding the jar by its foil covering, touch the paper clip with the charged electrophorus plate. Try charging the Leyden jar once, set it on the table and discharge it by touching your thumb to the outside foil while moving your forefinger to touch the paper clip. Repeat, charging the jar several times before discharging it and notice the difference. Two jars can be connected in parallel by setting them on a sheet of aluminum foil with their paper clips touching (bend them if needed), and the spark from discharging the pair can be compared with the spark from discharging a single jar. More jars can be connected in parallel by setting them on a sheet of aluminum foil and and laying another sheet on top of them so that it touches all the paper clips. Several of the plastic cup jars can also be arranged in series by stacking them together, and the discharge compared with that of a single jar. First charge the individual jars, then carefully connect them in series or parallel, finally discharge the combination. Try to compare how fat or bright the sparks are and the distance that they can jump in the different arrangements. You may also charge the combination, then separate the jars and discharge them individually .Use the neon bulb to investigate both charging and discharging. Compare the brightness of the flash on discharge with different numbers of chargings from the electrophorus.

2. Investigate the effect of discharging Leyden jars by bringing the lead of a neon bulb near the outer electrode or the inner electrode, holding the other lead in your hand. Try putting the Leyden jar on an insulating stand by setting it on an upturned foam coffee cup, and investigate the various combinations of charging and discharging with different connections. See the experiments in Appendix B for suggestions.

3. A dissectible Leyden jar can be made by using two cups, each with foil only on the outside. These are slipped inside each other. In this case do not use a paper clip for the electrode, but glue a one or two cm strip of aluminum foil up the outside of the

inner cup, extending it above the rim to serve as the inner electrode. The Leyden jar may be charged and the two parts separated by holding on to the plastic. (See Greenslade,"The Dissectible Condenser"The Physics Teacher, 16(8), 557,Nov 1978, Huff "The Dissectible Leyden Jar", The Physics Teacher,24(5), 292, May 1986, Iona, “Dissectible Capacitor Discussed”, The Physics Teacher, 26(9), 9, Jan 1988.)

Larger Leyden Jars

Larger and more powerful Leyden jars for demonstrations can be made from a variety of glass or plastic jars. I have found that plastic cough syrup bottles, some shampoo bottles, (L'Oreal™ for example), and plastic peanut butter jars. (Skippy™ 12 oz for example) also work well. Glue aluminum foil to the outside. Drill or poke two 1/8 inch holes in the cap of the cough syrup bottle (the shampoo bottles have a hole in the cap already) and bend a large paper clip or a short length of copper wire into a U shape and insert the legs of the U through the hole. Alternatively you can use a foil covered straw inserted through a hole. Fill the bottle about 3/4 full of water and screw the cap on. You may seal the wire or foiled straw in place with a small dab of silicone bathtub caulk if you wish. The plastic peanut butter jar has a wide mouth and a strip of foil or a foil covered straw can be glued to the inside instead of filling it with water. These Leyden jar can acquire enough charge from repeated charging with the electrophorus to make a person jump after touching it. BE CAREFUL! Students may get the idea that bigger is better and try to make a really large Leyden jar. This is NOT a good idea for students to pursue at home. If you feel it is appropriate, you may choose to have students build a large Leyden jar under careful supervision with clear attention to safety.

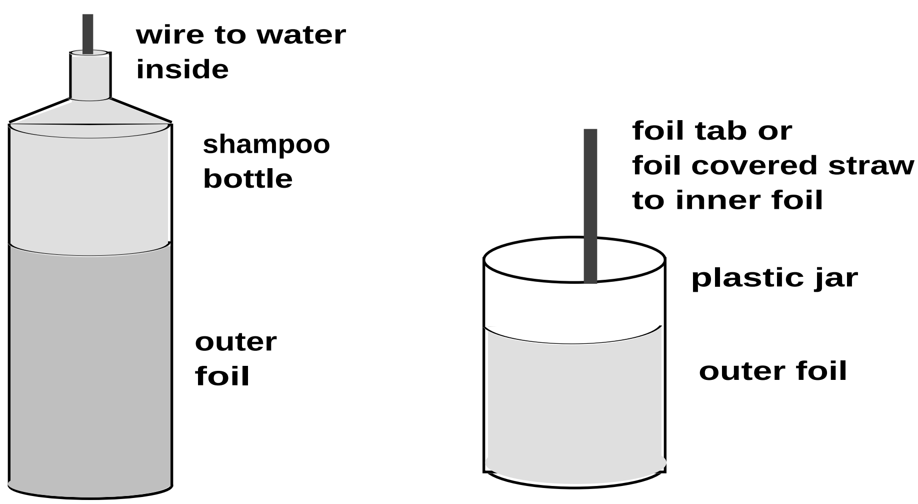

Figure III.8.3 Shampoo bottle and Peanut butter jar Leyden Jars

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Safety considerations in using Leyden Jars and electrostatic generators
(References are in Bibliography in Section One)

There seems to be little accessible information on the safety of discharging Leyden jars through people. Moore (Electrostatics, 1968) notes that a discharge with an energy of 10 J is dangerous and that a discharge of 250 mJ or 0.25 J gives a heavy shock. Cross (Electrostatics: Principles, Problems and Applications, p 353) notes that people experience different degrees of discomfort with shocks of above 10 mJ. Winburn (Practical Electrical Safety, Marcel Dekker, New York, p 15) cites possible ventricular fibrillation from impulse shocks and surge discharges with energies between 13.5 and 27 Joules. To determine some safety limits, we need to calculate the capacitance and the energy stored in Leyden jars of various sizes.

Is the Van de Graaff generator dangerous?

The capacitance of an isolated sphere of radius R is given by

$$C = 4\pi \varepsilon_0 R.$$

For a quick calculation this is equivalent to $C = (55.6\ \text{pF/m})\ D$, where D is the diameter of the sphere in meters. Treating the Van de Graaff generator as an isolated sphere will give an approximation of its capacitance. The sphere of a typical demonstration Van de Graaff generator has a diameter of about 0.25 m, giving a capacitance of about 14 pF. The energy stored in a charged capacitor is given by

$$U = 0.5\ C\ V^2 .$$

Assuming that the Van de Graaff reaches a voltage of 250 000 Volts, this gives it an energy of 0.44 J, about twice what Moore describes as giving a heavy shock. At 100 000 Volts, the energy would be 0.07 J, significantly less than the amount to give a heavy shock, and way below the energy required to cause possible harm. Cross (p 351) gives the capacitance of an isolated human body as between 100 pF and 300 pF, so a person connected to a Van de Graaff generator at 100 000 V might have an energy of 1.5 J. In practice, the voltage of a person connected to a school Van de Graaff seems to be much less, based on the length of spark in a discharge. The voltage is limited by corona discharge and leakage current. Using a Van de Graaff generator with a 25 cm diameter sphere, I got 9 cm long sparks to a grounded sphere of the same size. Using the sphere gap data in Cross (Table 3.1) this would give a generator voltage of about 225 000 Volts, assuming smoothly polished spheres. To estimate the voltage relative to ground of a person connected to Van de Graaff generator, I stood on a good insulating stand with my hand on the generator sphere, and had an assistant move a second large sphere in on the other side of the generator sphere. I was able to get only 2 cm long sparks, corresponding to about 60 000 Volts or less (with the somewhat rough surfaces of a well used Van de Graaff generator, breakdown may be triggered at lower voltages by corona discharges). With a capacitance of 300 pF, this would be a stored energy of 0.54 Joules. We conclude that there is no safety problem with shocks to a person from a school Van de Graaff generator. Nonetheless, many people find such shocks painful, and you should NEVER require students to experience such discharges. In addition, a large unexpected shock may make a student jump and cause injury.

Is the Leyden jar dangerous?

The answer to this depends on the size of the Leyden jar. There are several ways to estimate the capacitance of a Leyden jar. One way is to compare it to a commercially available Leyden jar. The Sargeant-Welch 1992-93 catalog (p614) lists a dissectible Leyden jar with a capacitance of 100 pF (#1989), and a glass pint Leyden jar with a capacitance of 350 pF (#1983). The quick conclusion is that these jars would be as safe as the discharges described in the previous section.

Simple ways to calculate the approximate capacitance of a Leyden jar are to treat it as a cylindrical capacitor and ignore the capacitance due to the bottom of the jar (it is easier to make one with no conductor on the bottom.), or to treat it as a flat parallel plate capacitor. For a cylindrical capacitor with inner radius a, outer radius b, and length L, the capacitance is given by

$$C = (\kappa\, 2\, \pi\, \varepsilon_0\, L) \,/\, \ln (b / a).$$

(Halliday and Resnick, Fundamentals of Physics, 3rd ed., John Wiley & Sons, New York, 1988, pp 632-633.) In practice for the small wall thickness of the Leyden jar relative to the radius of the jar, the formula for the capacitance of a parallel plate capacitor

$$C = \kappa\, \varepsilon_0\, A / d$$

could be used where A is the plate area and d is the thickness of the dielectric.

A film can Leyden jar has inner radius of 1.5 cm, a wall thickness of about 0.05 cm, and a length of about 4.0 cm. The plastic has a dielectric constant of about 3 (polyethylene has a dielectric constant of 2.4 Handbook of Chemistry and Physics, 53^{rd} Ed., p E-48) so the capacitance is about 65 pF. A rough measurement comparing RC decay curves with an oscilloscope confirms the magnitude of this calculation. The typical voltage reached by this Leyden jar seems to be less than 10 000 V, giving a maximum energy of 0.003 J, way below that of a heavy shock.

A peanut butter jar Leyden jar made from a 12 oz plastic jar has a wall thickness between 0.05 and 0.10 cm, an outer radius of about 3.8 cm and a length of about 8 cm. With a dielectric constant of 3 this would have a capacitance of about 1000 pF. The 1000pF value would store an energy of 1J at 45 000 Volts, enough to give a heavy shock, but much less than the 10 J needed for a dangerous shock. In practice the capacitance is likely to be less as it is difficult to get the foil surfaces totally smooth. A rough measurement comparing RC decay curves with an oscilloscope gave a capacitance of about 700 pF. A more realistic voltage is about 20 000 V, as measured by a sphere gap (Moore, 1968, p 203), which would give an energy of 0.14 J, about half of the heavy shock value described by Moore.

As an example of charging the peanut butter Leyden jar, I connected one to the friction electrostatic generator on a moderately dry day and gave 50 turns on the generator. I estimated the sparkover voltage using a sphere gap at 10 000 Volts. This would give an energy of 0.05 J.

Based on the size of the peanut butter jar, a good rule of thumb would be to limit the size of Leyden jars for casual use to no more than about a half liter or a pint. This is equivalent to about a 200 sq cm area in a flat plate capacitor.

Shocking students

A traditional “shocking” experience has been to line up a class of students holding hands and discharge a pint size Leyden jar through the group. This practice seems safe from the calculations above, and from the experience of many teachers. Nevertheless, the current path does cross the chest of the students. IF you decide to do this demonstration, I would suggest instead that students who volunteer to try it put out their RIGHT hands, each student grasping the RIGHT thumb of the student to his / her RIGHT in the fist, with his / her thumb grasped in turn by the student to the left.(Figure III.8.4) In this manner the discharge will only pass through the hands of the students. Only students who volunteer should participate. In addition, as an extreme precaution ANY student with any HEART PROBLEM or with a pacemaker (yes, there are some students with pacemakers) should not participate.

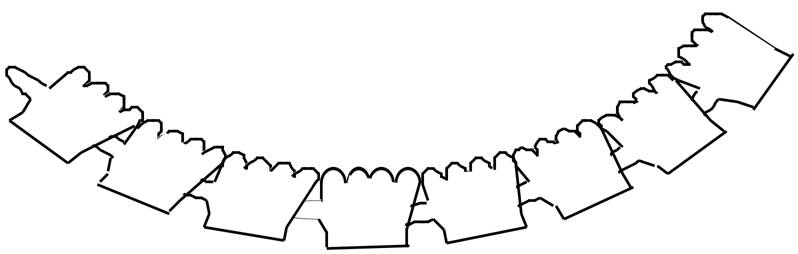

Figure III.8.4 Chain of hands

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LABORATORY ACTIVITY 9: Frictional Electrostatic generators

The generators in the next two activities are not as simple to build as the projects so far, but they are relatively easy to assemble, work fairly well and provide an inexpensive alternative to the commercial Van de Graaff, Wimshurst or Dirod machines. They will NOT achieve the very high voltages of the commercial machines. Measurements using a spark gap (Moore, Electrostatics, 1968,p 64) gave results between 10 kV and 25 kV in dry conditions.

MATERIALS and TOOLS: { those in brackets are for advanced version}
Two empty soda cans,
fur or wool
aluminum foil
rubber bands
four 15 cm by 30 cm (6" by 12") pieces of blue styrofoam
{ or one 15cm length of 2"x6" lumber and two 15cm x 30 cm pieces of plywood}
four new unsharpened pencils {or four 8" pieces of 1/2" PVC pipe}
four 2" nails { or four 1.5" wood screws}
8" length of three inch diameter PVC pipe (or two 9 ounce styrofoam cups for quick and dirty version)
piece of stiff wire or wire coat hanger
{ or two 15 cm lengths 1/2" PVC pipe and a 1/2" PVC elbow fitting
drafting compass
1/4" drill bit
hacksaw blade or coping saw
{ electric drill, 5/8" wood bit, electric saber saw, screw driver}

CONSTRUCTION:

1. Tape or clamp two of the styrofoam pieces together, and mark them as in figure III.9.1. Using a 1/4 inch drill bit make four holes through both pieces of foam at the points marked. Use a utility knife to make an initial cut on the circle and cut out the circle from both pieces using a hacksaw blade or a coping saw.

2.Using the third styrofoam piece as a base, and the fourth as an end plate fasten the two cut out pieces to it by pressing the nails through the foam side pieces into the base. (You may use the pencils through the 1/4" holes to help align the styrofoam sides.) Once steps 3 and 4 are done, you may hook rubber bands on the outer ends of the pencils or PVC pipe pieces and pass them around the end plate to secure the structure.

3. Loop three rubber bands over two of the pencils and insert the pencils in the lower holes so they connect the two sides. Arrange the rubber bands so that a soda can may lie on its side across the machine and be supported by the rubber bands. Cut a piece of fur or thick wool that will cover half the circumference of the can and tape it, fur side out, to the can with duct tape. Place this can fur side up on the rubber bands joining the lower pencils.

4. Loop two rubber bands over the other two pencils and insert them in the upper holes so that they connect the two sides. Take a 10 cm by 6 cm piece of aluminum

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foil and tape one long edge of this piece to the collector can. Suspend the collector can between the rubber bands on the top pencils so that the other edge of the foil points at the surface of the rotor with a clearance of a few millimeters. You can adjust this by rotating the can within the rubber bands, and bending the foil. Alternatively you may use a utility knife to cut a flap in the side of the can and bend the flap out. BE CAREFUL not to cut yourself on the sharp edge. (Figure III.9.3)

5.Bend the coat-hanger wire into an L-shaped crank handle and mount it on the end of the 3 inch PVC pipe rotor using duct tape. Alternatively, you may make a crank handle from two 15 cm pieces of 1/2 inch PVC pipe fastened together with a PVC pipe elbow. (Figure III.9.3) To mount the crank drill two 5/8" holes through the walls of the PVC rotor at opposite ends of a diameter using an electric drill and a 5/8" spade bit. Use a few small nails or screws to wedge the 1/2" PVC pipe in place.

6. Slide the rotor into the holes so that the fur covered side of the lower can presses against the rotor surface. (Figure III.9.3) By turning the crank, the fur rubbing against the rotor charges the surface of the rotor, and these charges are collected by the foil on the top can. Some adjustment of the foil tab may be necessary to get the best performance. It may be necessary to have the foil rub against the surface of the rotor to effectively collect the charge. In operation, opposite charges now appear on the top and bottom cans. Connections may be made to the cans using foil covered straws. This generator has been successfully used to power the electrostatic motor described above. It can also be used to charge Leyden jars. It works quite well in dry weather, but may not function effectively in humid conditions.

7.A slightly more durable model of this generator uses a base made of 2"x6" lumber, sides cut from plywood, with the holes for the rotor cut out with a coping saw or an electric saber saw after drilling a pilot hole. The sides can then be screwed to the base. Instead of pencils, short lengths of 1/2 inch PVC water pipe may be used to support the cans. Measurements for this model are included in the diagram below.

Quick and Dirty version

A less expensive model can be constructed with a rotor made of two large styrofoam cups taped mouth to mouth. You will have to adjust the size of the holes for the rotor according to the diameter of the cups where they pass through the side walls. Keep the centers of the holes for the pencils about 4.5 cm above or below where the top or bottom of the rotor will be. Since the rotor will be larger in diameter in the middle, you will need to indent the middle of the lower fur covered can to match the profile of the rotor, and similarly trim the edge of the foil charge collector on the upper can to match the rotor profile. You may simply punch holes in the styrofoam to mount a stiff wire handle on the rotor.

Connections:

Connections to the machine can be made using foil covered straws. If the tabs on the end of each can are bent out, a foil covered straw can be hooked through the loop on the tab. A connection to the lower can can be made by slipping a strip of aluminum foil between the can and the rubber bands supporting it and letting the foil rest on the base plate of the machine. A Leyden jar can now rest on the foil with its other conductor connected to the top can by means of a foil covered straw.

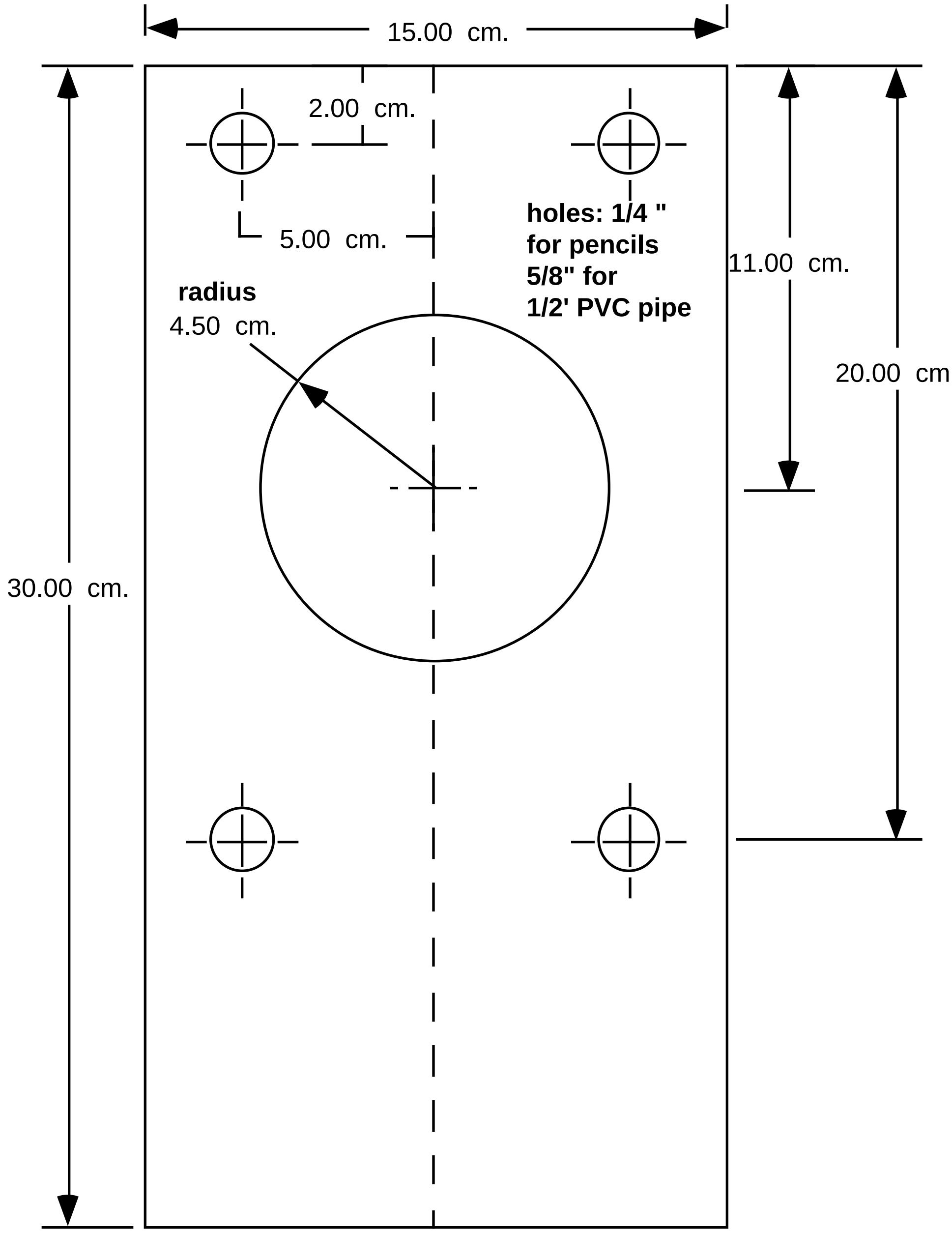

Figure III.9.1 Side panel for generator

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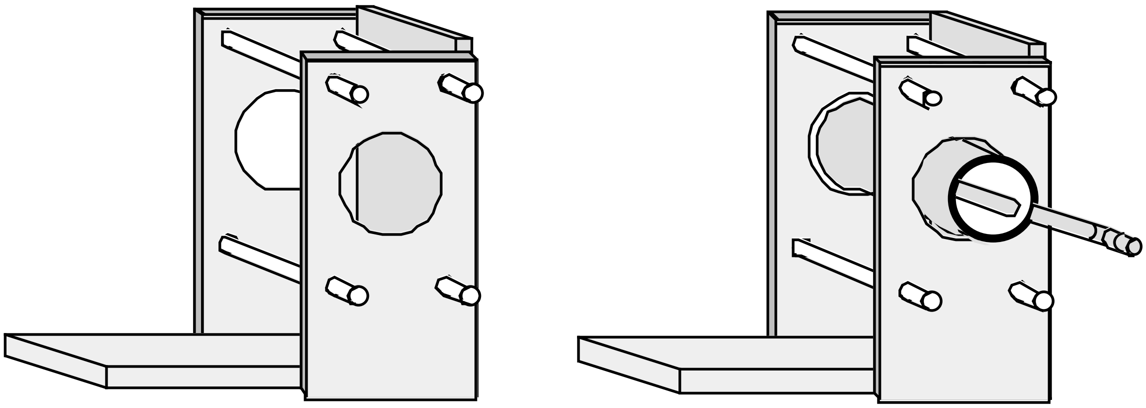

Figure III.9.2 Generator frame and frame with rotor inserted

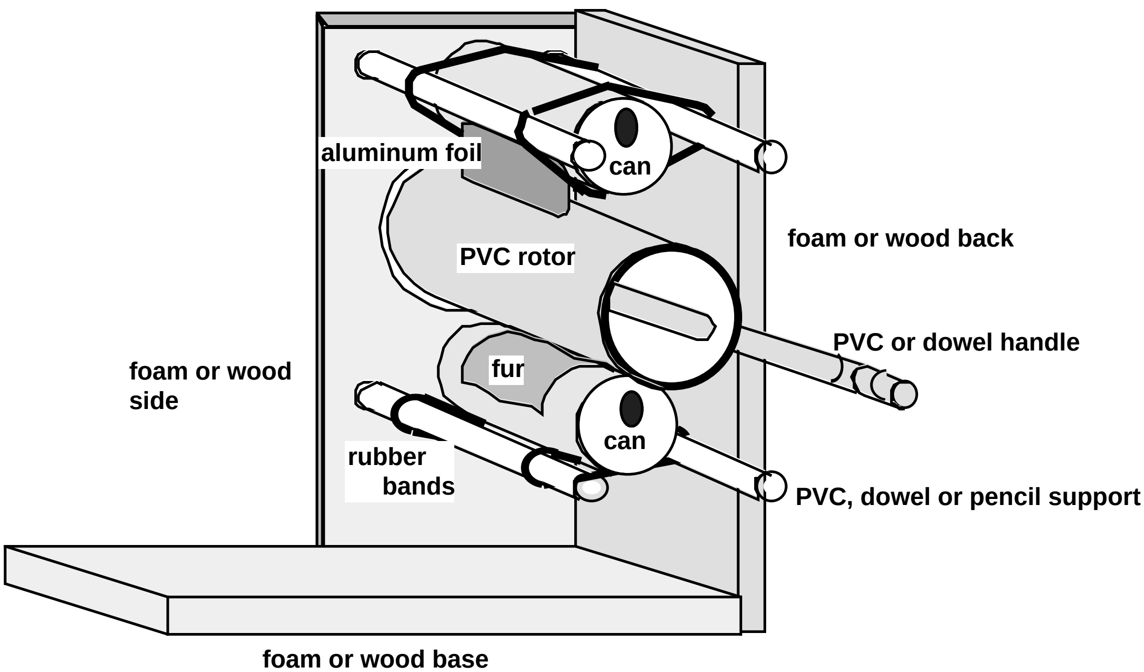

Figure III.9.3 Cutaway view of assembled generator

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LABORATORY ACTIVITY 10: THE AUTOMATIC ELECTROPHORUS: An Induction Electrostatic Generator:

This machine automates the operation of the electrophorus using a record player turntable. It is an inexpensive and relatively unsophisticated version of electrostatic generators that operate by induction. The Wimshurst machine and the Dirod generators are other examples. This generator has the advantage that its geometry is very simple and students who have understood the operation of the electrophorus can readily understand how this machine operates.

MATERIALS and TOOLS:
Phonograph turntable--yard sale special
Old LP record
Six aluminum soft drink cans
8" by 12" piece of fine grained styrofoam, 1/2" to 1" thick
4 plastic soda straws with flexible ends
aluminum foil
glue stick, tape, fur or wool
8" length of 2"x6" lumber
screws or nails

CONSTRUCTION

Take four of the soda cans and tape them onto the LP record so that they stand upright at opposite ends of diameters, with their outer edges tangent to the edge of the LP. Set the LP record on the phonograph turntable. The base of the turntable should be small enough so that the edge of the record overhangs the edge of the base, or at least comes within a centimeter or so of the edge. (Figure III.10.1). Take the piece of styrofoam and mount it to the side of the piece of lumber using nails or screws so that it forms the upright leg of an "L" with the piece of lumber as the base of the "L" (Figure III.10.2). (You could just tape it securely to the wood block using masking or duct tape.)

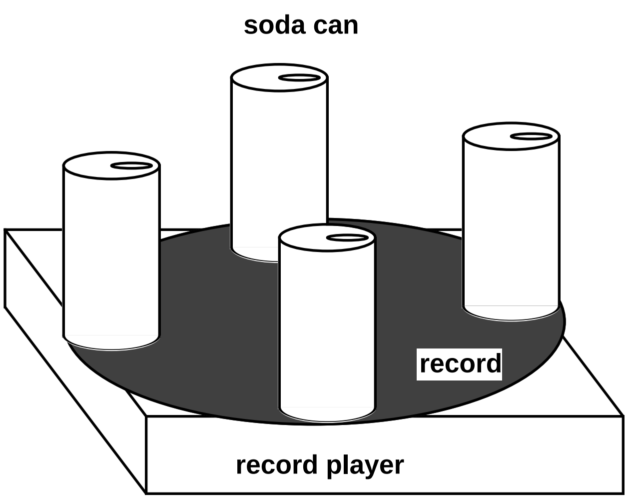

Figure III.10.1

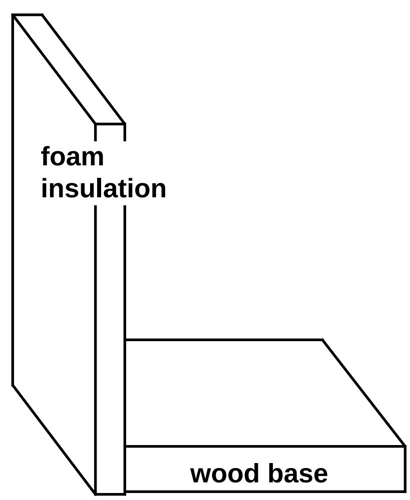

Figure III.10.2

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Set the "L" next to the turntable so that the edge of the record passes very close to the foam, and mark the height of the top of the soda cans against the foam. Poke two holes in the foam with a pencil at a height of 3 or 4 cm above the level of the tops of the soda cans, and separated by about 10 cm (Figure III.10.3). Take two plastic flex type soda straws, crimp the long end of one slightly and slide it into the long end of the other, making a long "straw" with two flexible ends. The total length of the combined straws should be about 30 cm. Repeat this with two more straws, and use a glue stick and aluminum foil to cover the straws with aluminum foil, leaving a flag of foil about 5 cm by 5 cm on one of the flexible ends of each combined straw. Slide the straws through the holes in the foam (Figure III.10.3). Adjust the position of the straws so that the flag on one straw brushes the top of a can as it passes close to the surface of the foam, and the flag on the other straw brushes the top of a can as it is about a quarter turn away from its closest approach to the foam. Take two more soda cans and bend their tabs upright. Hang these cans from their tabs on the ends of the straw projecting through the other face of the foam (Figure III.10.3).

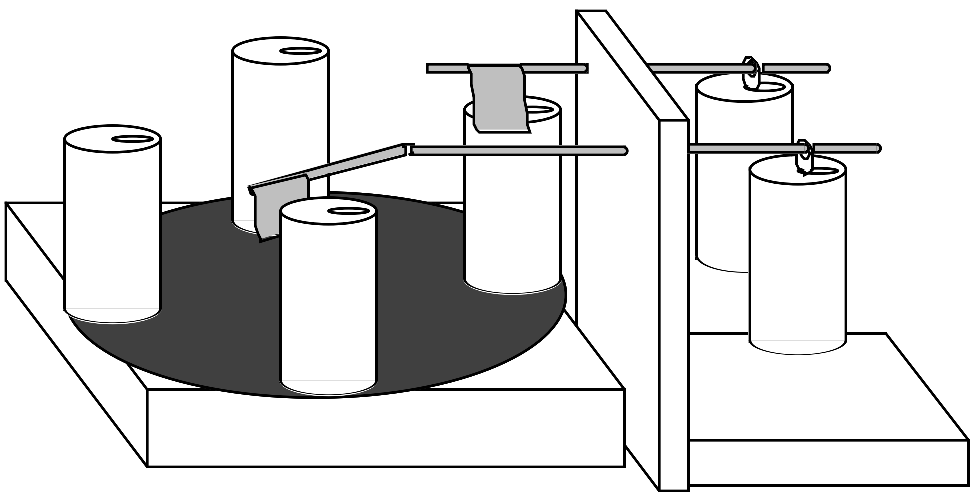

Figure III.10.3 Assembled Automatic Electrophorus

OPERATION:

To operate the generator, slide the foam away from the turntable and charge the foam with a piece of wool or fur. Slide the foam back into position so that the moving cans pass close to the charged surface of the foam. The negatively charged foam induces negative charges to flow out of the can through the foil covered straw to the collector can, giving it an excess of negative charge. As the connection is broken by the rotation of the record, the positively charged can moves on to the second brush. Since it is now some distance from the charged foam, negative charges from the second brush run back onto the can partially neutralizing the excess positive charge, and leaving the collector can with an excess positive charge. The moving cans take the place of the electrophorus plate in the process of charging by induction. The machine will work with only one can, but the rate of charging is obviously improved with more. The collector cans can be connected to each other through a series of neon bulbs to see the charging cycle in action, or the charge can be collected with a Leyden jar. This generator can also be hooked up to the electrostatic motor of the previous section. The flexible ends of the combined straws allow the flags and the other ends to be bent to adjust the positions of flags and collectors.

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LABORATORY ACTIVITY 11: Building an electrostatic corona discharge motor

This is a more ambitious project, but it is fun to make and get working. For a detailed discussion of its operation, see Jefimenko and Walker ("Electrostatic Motors", The Physics Teacher, 9(3), 121, Mar 1971).

MATERIALS:

Four empty thin aluminum soda cans.
(Having two of one brand and two of another makes explanation of the motor easier to follow.)
A one liter plastic soda bottle with its top.
A number of styrofoam coffee cups.
A thumb tack.
Aluminum foil, tape and scissors. Plastic drinking straws. Glue stick. Electrostatic generator or electrophorus and Leyden jar

CONSTRUCTION:

1. Remove the plastic base from the soda bottle, pulling it off the bottle. This may be easier if you use warm water to soften the glue. Make the rotor by gluing a well-smoothed strip of aluminum foil around the inside of the base. Push a thumbtack through the center of the bottom of the base (Figure III.11.1). Measure the combined height of a soda can sitting on an upside-down styrofoam cup. Cut off enough of the bottom of the soda bottle so that the top portion of the soda bottle is about three centimeters less than the height of the can and styrofoam cup. Set the bottle on the table with its cap on, and balance the rotor with the tip of the thumbtack resting on the cap of the bottle. You may wish to make a slight dimple in top of the bottle cap to assure a stable position for the rotor. You can balance the rotor by adding small bits of tape to the top until it sits evenly.

2. Take the four soda cans and some styrofoam cups. Set two soda cans on stacks of inverted cups so that the bottoms of the cans are about even with the lower edge of the rotor, and stand them on opposite sides of the rotor. You may wish to partly fill the cans with water or sand to make them more stable. Set the other two cans up similarly, but with the level of the top of the cans two centimeters or so above the top edge of the rotor. Arrange the cans in a square centered on the rotor, with the high-set cans at the ends of one diagonal and the low-set cans at the end of the other diagonal (Figure III.11.2).

3.Make the corona vanes from well-smoothed aluminum foil. Heavy duty foil may be easier to work for this purpose. For each vane, cut a piece of foil about 6 centimeters wide and as high as the vertical height of the rotor. Trim this to a trapezoid so that the angled edge will be parallel to the outer surface of the rotor. Trim the corners to a rounded shape to avoid excess discharge there. Tape the vertical edge to one of the cans, bend the foil out and adjust the can so that the vane points at the outside surface of the rotor and sits about a half centimeter from the surface of the rotor. You may have to do some fine trimming of the foil vane to achieve this (Figure

III.11.3). Repeat this procedure for each can, then adjust the angles of the vanes and cans until they point at the surface of the rotor, but offset slightly to one side of center of the rotor (Figure III.11.2). An alternative procedure is to form the vanes from the can itself, by cutting a flap into the side of the can and bending it out. A utility knife works well to make the cuts in the can, and the flap can then be trimmed using scissors. This works well, but the tools and sharp edges of the can must be dealt with carefully and students need to be very cautious to avoid cutting themselves.

4.The cans must now be cross-connected. Take two long plastic straws, some aluminum foil and a glue stick, and glue a wrapping of smoothed foil to each straw. Lay one straw across the tops of the lower cans and the other across the tops of the higher cans. The straws should clear each other by several centimeters where they cross in the center, and the lower straw should also clear the top of the rotor. To keep the straws in place, tape a ring of aluminum foil to the top of each can, with the straw passing through it, or pass the straws through the holes in the pull tabs on the tops of the cans. You wish to keep the straws from falling off, while still being able to adjust the locations of the cans.

OPERATION:

To operate the motor, connect one pair of cans to each electrode of your electrostatic generator. You may tape a strip of aluminum foil to one of each pair of cans and fasten clip leads to the strips of foil. Turn on the electrostatic machine. The rotor should start to spin. You may have to adjust the spacing and angles of the vanes in order to get the most efficient operation. The foam cups will allow you to do this without getting a shock if you are careful. You may have to give the rotor a gentle push to get it started. Fine tuning of the arrangement should allow you to reach a fairly high speed.

If you do not wish to use the electrostatic generator, you may run the motor from the large Leyden jar and the electrophorus. Tape a strip of aluminum foil to one of the lower cans and run it onto the table top. Set the bottom of the Leyden jar on the foil strip. Make another foil covered straw, and tape it from one of the high-set cans to the top electrode of the Leyden jar. Use the electrophorus to repeatedly charge the Leyden jar. After five to twenty charges, the rotor should begin to spin. Follow the adjustment hints above to get the best performance from your motor.

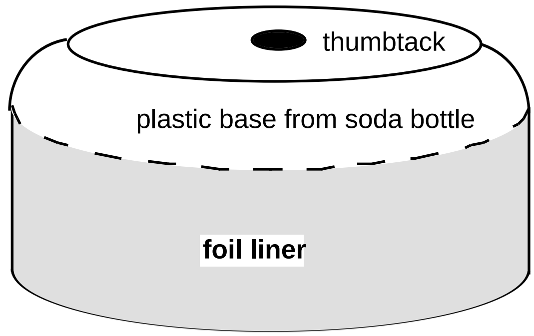

Figure III.11.1 Electrostatic Motor Rotor

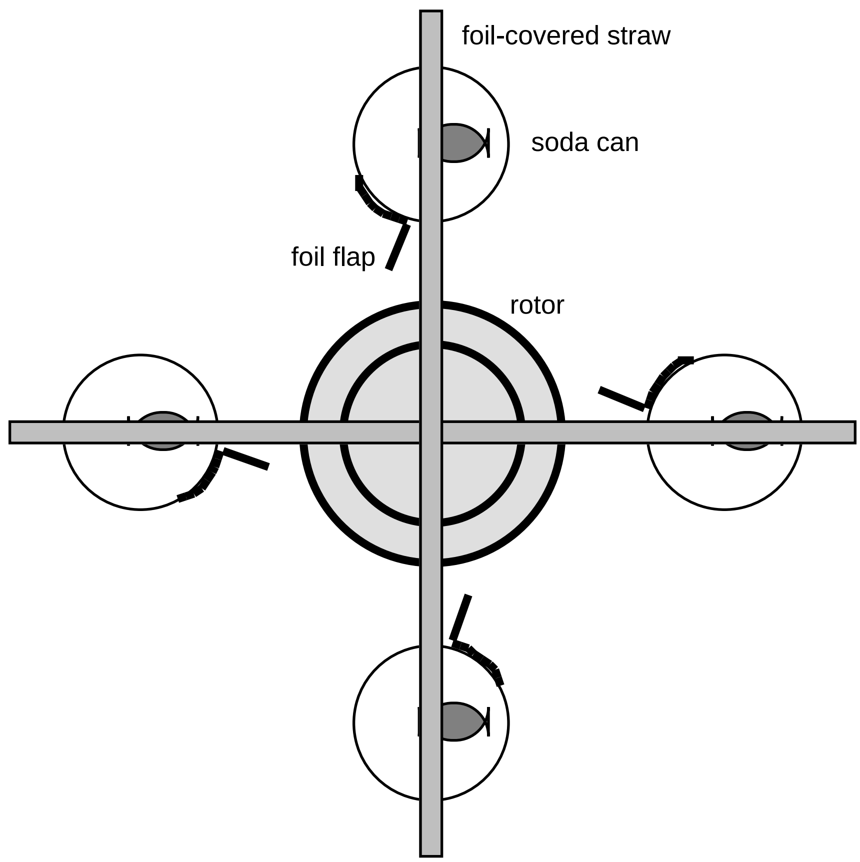

Figure III.11.2 Electrostatic motor -top view

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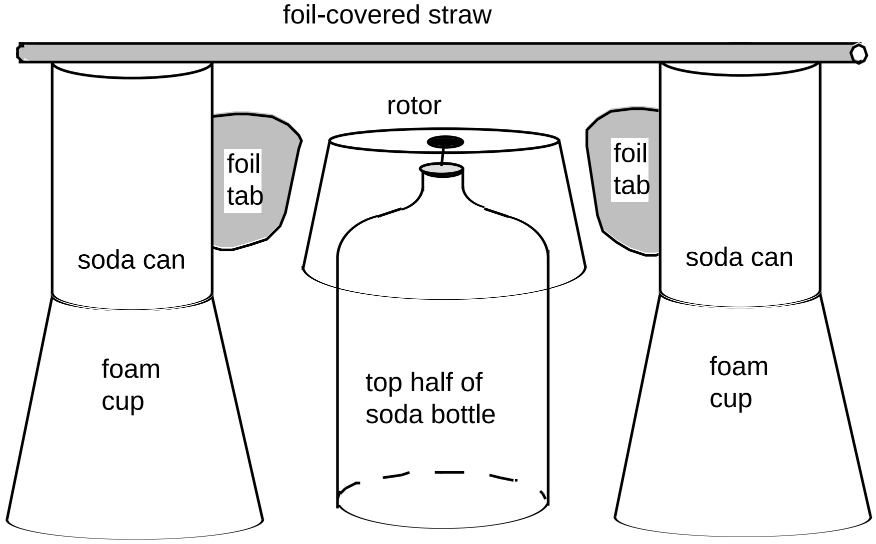

Figure III.11.3 Electrostatic motor-side view

Things to investigate:

How fast does the motor turn?

Will it spin faster with two Leyden jars in series?

How close should the corona vanes be to the rotor?

Can you bend the corona vanes to form a better shape?

Can you connect more than one motor to a Van de Graaff?

Try building a Kelvin water drop generator and see if you can use it to power the motor.

Hold an electrostatic motor contest to see who can make the fastest motor.

Can you design a motor with more vanes? Try different vane designs. You might cut the edge of the vane with pinking shears to give a series of sharp points. Try making a vane from a foil covered straw with many sewing pins stuck through it. Read the article on Electrostatic motors mentioned previously for more ideas. Try other rotors and bearing arrangements.

Can you make a smaller one from a 35 mm plastic film can? A bigger one using a rotor such as an empty yogurt or cottage cheese container, a plastic drinking cup lined with foil, an entire one or two liter soda bottle, etc.?

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