Electrostatics Demonstration and Lab Equipment Workshop

By Robert A. Morse and Charles Toth

Revised Version 6 June 10, 1988

 The authors would greatly appreciate comments on your experience with this material and suggestions to improve the material. Address comments to :

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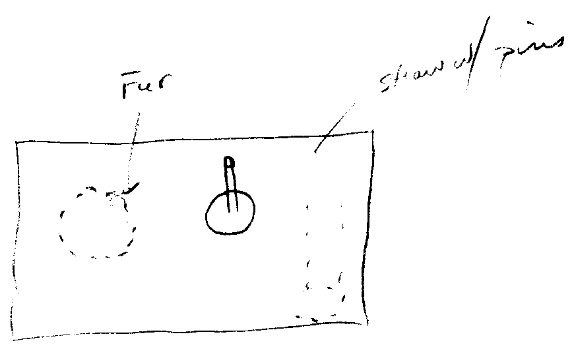
The extensive use of plastics in disposable containers makes it inexpensive and easy to construct a variety of electrostatics equipment so that every student can experiment with static charges and the fields they create. Constructing and experimenting with these simple devices makes a good workshop activity for teachers from elementary through high school. The materials required are low in cost and can be readily obtained at grocery and hardware stores.

Throughout the development of this workshop we have followed the philosophy that students should have as much experience as possible with phenomena, and that the equipment that students use should work as well as possible to illustrate the phemomena clearly. Nonetheless, electrostatic events happen suddenly, and humidity and dirt can provide conducting paths which are unseen. There is no substitute for careful and repeated observations, and clean and dry equipment.



RUNNING THE WORKSHOP

THE PRINTED MATERIALS:

The workshop package is still being revised. (Ideas and suggestions are solicited!) The current package is divided into several pieces.

WORKSHOP: This contains instructions for building the laboratory and demonstration equipment and suggestions for investigations.

BIBLIOGRAPY: An extensive, albeit incomplete list of relevant articles from THE PHYSICS TEACHER.

ELECTROSTATICS ACTIVITIES by R. Morse: A carefully structured sequence of instructions and questions for students, which leads them to develop a model for the behavior of electrical charges, and a sign convention for charge.

ELECTROSTATIC INVESTIGATIONS by R. LaBrecque: A further sequence of investigations recreating some of Benjamin Franklin's work with excerpts from his letters on the subject.

HIGH VOLTAGE HIGH JINX by C. Toth: Pre-Visit, On Site, and Post-Visit activities for lower grades who are shown some of this material in visits to the Prince George's County Owens Science Center in Maryland, and could be used with a traveling demonstration visit to elementary schools.

TIME:

There is more than enough material in this package to run a workshop which lasts all day. A reasonably complete exploration of the topics in the workshop and the two student activity modules might take two days. However, a one day or half day workshop is sufficient to establish the principles so that the participants can try the student modules out themselves.

Half Day Workshop: Sufficient to introduce the material to a group, although not long enough for a thorough experience with all the activities. Paricipants should be lead through activities I, II, III, IV, V and VIII. The other devices can be demonstrated, and built if there is time remaining.

Full Day Workshop: Participants can build and try all the devices themselves, including the electrostatic motor. Use the morning to work together through the material suggested for the half day workshop, and the afternoon to more freely investigate the remaining topics in the workshop or the student activity modules.

MATERIALS LIST:

You will need an ample supply of the following to allow for mistakes and experiments:
{optional materials}

straight and flexible plastic straws
aluminum foil
polyester or nylon sewing thread with a smooth surface
foam plastic coffee cups
glue sticks and/or rubber cement
Scotch Magic tape
Masking tape
Duct tape
paper clips, large and small
wool
fur
christmas tree tinsel.
thin foil cup cake liners
straight pins
thumb tacks
scissors
utility knives are not required, but are very handy.
{a dead cassette of audio recording tape}

For each participant you will need:

1 or more clear plastic drink cups # (allow for breakage)
{1 35 mm plastic film can with top}
2 one-liter or two-liter plastic soft-drink bottles with tops
1 small neon bulbs (NE-2 or similar)
5 empty thin aluminum soda cans.
1 nine inch to one foot square of Dow blue styrofoam insulation *
2 foam picnic plates
1 disposable aluminum pie plate
{1 plastic cough syrup or medicine bottle}

For a moderate size group you will need:

1 Electrostatic generator: Van de Graaf or Wimshurst to easily demonstrate the Cottrell precipitator, the ion wind, and the corona motor.
1 source of smoke such as a cigarette or incense

You should also have samples of the devices already prepared as examples for people to look at.

The plastic cups which are made of the stiffer, more brittle clear plastic seem to work better for this purpose than the softer clear plastic cups. You may have to purchase these in a party supply store if your grocery store does not stock the brittle kind (I used a 10 oz cup made by SWEETHEART).

* Blue styrofoam insulation (Dow's Fight Back Insulation Pack) is sold in two foot by four foot sheets, 3/4 inches thick, four sheets to a package by hardware, lumber or building supply stores. It is available in other thicknesses in four by eight foot sheets.

I. Suspended "pith balls" and pith ball electroscope. Materials: straight and flexible plastic straws, aluminum foil, polyester sewing thread, plastic coffee cup, glue stick and tape.

A good substitute for the traditional pith ball on a string may be made from small pieces of foil covered plastic drinking straws. Apply glue (I used a glue stick) to a strip of aluminum foil and roll a single layer of foil around a plastic drinking straw. Before the glue is dry, cut the foil covered straw into pieces about a centimeter long with scissors. 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 it down against the glue to secure it.

Make a stand to hold the pith ball 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 slit in the end of the straw. Slip the suspension string of one or more "pith balls" into the slit and adjust the string lengths to suit.

Things to investigate:

Rub a drinking straw with cloth or fur and bring it near a single or double pith ball.

Charge the pith ball from the electrophorus (see below) by contact with the pie plate. Is the pith ball attracted or repelled by the pie plate and the foam base.

Charge the pith ball by induction from the pie plate of the electrophorus by bringing the plate near the pith ball, but being careful not to let the pith ball touch the plate. Now touch the pith ball briefly with your finger, then move the plate away. Look for attraction and repulsion.

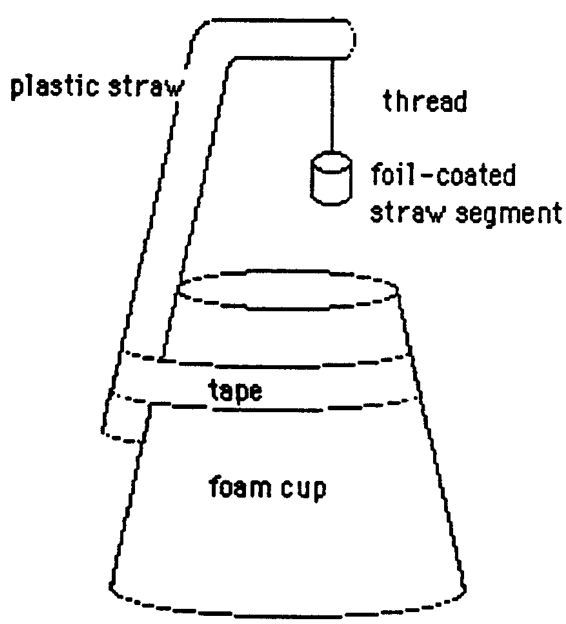


Figure 1

II. Foil leaf electroscope.

Materials: plastic coffee cup, flexible plastic straw, paper clip, aluminum foil and tape.

This is an inexpensive version of the gold leaf electroscope. Fasten the shorter end of the straw to the cup with tape and bend the straw so the long end is vertical. Bend the paper clip so the two U-shaped sections lie in perpendicular planes. Tape the paper clip to the top of the straw so that the longer U-shaped leg is vertical and extends a little above the top of the straw. The other U-shaped leg is now sticking out horizontally from the straw. Cut two strips of aluminum foil about a centimeter wide by five centimeters long and smooth them with your fingernail. Bend the top of each strip around one of the horizontal bars of the paper clip, so that they swing freely from the bars. Bring a charged object near the top of the paper clip and the leaves will repel each other. Use this device anywhere you would want to use an electroscope, but remember that it is sensitive to breezes. A more durable electrometer was described in a previous "String and Sticky Tape" column. (1)

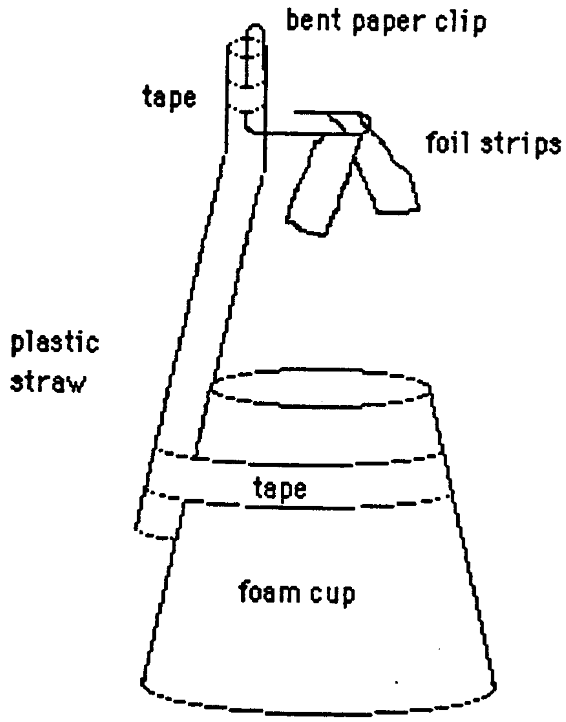


Figure 2

A variety of other electroscopes and electrometers can be constructed from simple materials. The simplest of these requires an empty aluminum drink can, a styrofoam cup, aluminum foil and tape. Carefully bend the pull-ring on the drink can so that it sticks straight out from the end of the can. Set the styrofoam cup upside down and tape the drink can horizontally on top of the cup so that the plane of the pull ring is horizontal. Cut a strip of aluminum foil about 3 centimeters long and a half centimeter wide. Form a hook on one end of the strip (rolling it around a drinking straw works well) and hang the hook over the end of the pull-ring on the drink can. You may wish to close the loop in the end 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 the diagram.) Bring a charged object near the drink can and the foil leaf will be repelled by the can. This electroscope works particularly well for demonstrating the effect of induction of charge, and two of them may be charged oppositely by induction quite easily. {See the appendix for diagrams of several other electroscopes.}

1. R.D. Edge, Phys. Teach., 22, Sept 1984, 396-398.

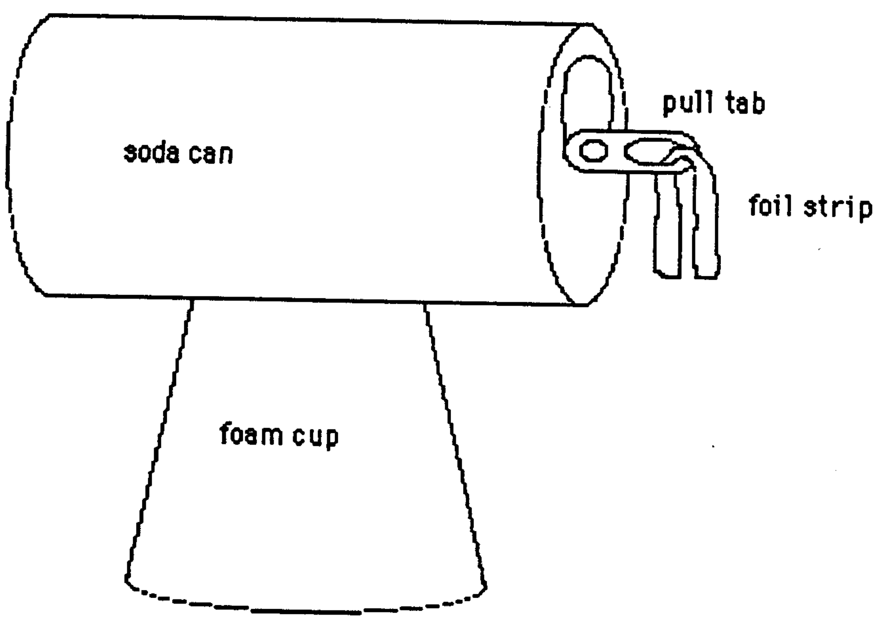


Figure 3

III. Electrophorus: often used to produce charges for other demonstrations, this is an interesting device in itself, and equipped with a built in pith ball electroscope can be used to discuss the induction of charge.

Materials: Dow blue styrofoam insulation or other styrofoam such as foam picnic plates, disposable aluminum pie plate, foam coffee cup, plastic drinking straw, pith ball from I., wool, fur or other cloth, and tape.

Blue styrofoam insulation is sold in two foot by four foot sheets, 3/4 inches thick, four sheets to a package by hardware, lumber or building supply stores. This material, when rubbed with fur, wool or various kinds of synthetic cloth, readily acquires a large surface charge. Other styrofoam objects will work also, but are not as durable as the blue foam, although styrofoam picnic plates have the advantages of low cost and ready availability. To make an electrophorous, cut a 30 cm (one foot) square of foam for the base or set a styrofoam picnic plate upside down. Take a disposable aluminum pie plate (an eight or nine inch foil pan) and fasten an insulating handle to it by taping a styrofoam cup in the center of the pie plate. (See figure 3.) To use the electrophorus, rub the top surface of the foam with fur or cloth to charge it. Then set the pie plate on top of the foam, touch the plate with your finger (feel the spark!), remove your finger and then lift the plate by the handle. Bring it near the electroscope or a pith ball, or discharge it by touching it. Now take the plastic straw and tape it horizontally to the top of the cup so that it extends over the edge of the pie plate. Cut slits in the end of the straw and suspend a pith ball 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 pith ball as the pie plate gets close to the foam. With the pie plate sitting on the foam, bring your finger near the pith ball, which will now move rapidly back and forth between your finger and the pie plate.

The pith ball 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 difference between the plate and your finger. When the pith ball finally stops, raise the pie plate and observe the position of the pith ball as you move the plate up and down near the foam. The angle of deflection of the pith ball gives a rough indication of the electric potential of the pie plate. You may now discharge the pie plate through the pith ball 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 pith ball before you discharge the pie plate.

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

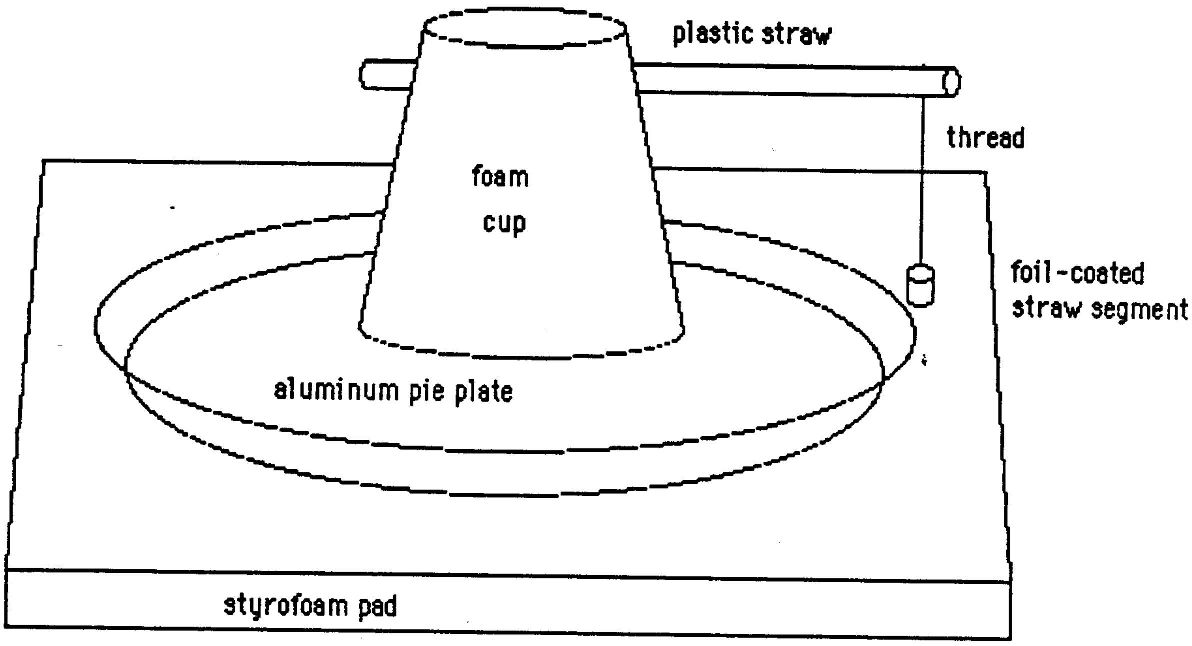

plastic straw
thread
foam
cup
foil-coated
straw segment
aluminum pie plate
styrofoam pad

Figure 4

Things to investigate:

Can you feel forces between the plate and the foam?

Take the back of your hand and move it around in the space above the charged foam to feel the effect of the field on the fine hairs on the back of your hand.

Try rubbing only part of the foam with the fur, and "feel" the field. This can be done with an entire sheet of the foam.

Charge the blue foam pad and a styrofoam picnic plate and try floating the picnic plate above the pad by the electrostatic repulsion. Can you distribute the charge on the pad to stably support the foam plate?

What is the sign of the charge on the foam? on the plate? See the instructions for using the neon bulb to detect the sign of the charge (Section VIII) .

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?

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? Repeat this and use the pith ball electroscope and the neon bulb to investigate the sign of the charge on the plates. What is happening here?

Have you noticed the electrostatic charge acquired by your television screen? Try charging the electrophorous from the TV screen instead of the foam. Use the neon bulb (see section VIII) to determine the sign of the charge.

IV. 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 a cup or beaker, 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. 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:

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

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

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

Compare what happens with a christmas tree tinsel hydra and a thread hydra.

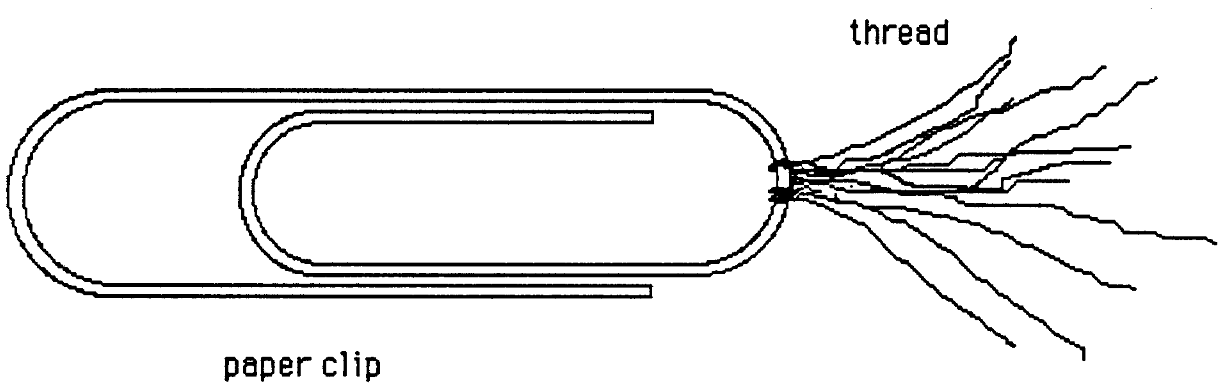


Figure 5

V. Leyden jars: the original capacitor, for storing charge.

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

A small Leyden jar can be made for each student. The plastic cups which are made of the stiffer, more brittle clear plastic seem to work better for this purpose than the softer clear plastic cups. You may have to purchase these in a party supply store if your grocery store does not stock the brittle kind (I used a 10 oz cup made by SWEETHEART). Carefully glue a foil cup cake liner 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 (see figure 6) and slide it over the edge of the cup so that the extended leg contacts the inner foil. This Leyden jar can be charged from the electrophorous, and discharged safely through the fingers. The spark is noticeable, but not dangerous. Try charging the Leyden jar once and discharging it between thumb and forefinger. Repeat, charging the jar several times before discharging it and notice the difference. Two or three jars can be connected in parallel by setting them on a sheet of aluminum foil with their paper clips touching, and the spark from discharging the assembly can be compared with the spark from discharging a single jar. Several jars can also be arranged in series by stacking them together, and the discharge compared with that of a single jar. Try to compare how fat or bright the sparks are and the distance that they can jump in the different arrangements.

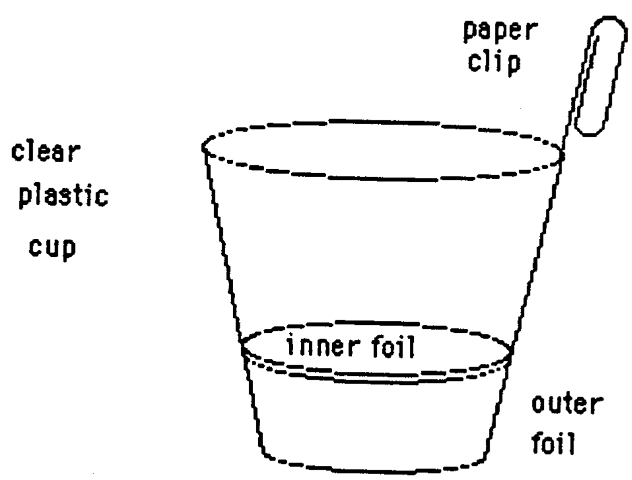


Figure 6

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 the articles "The Dissectible Condenser" by Greenslade(2) and "The Dissectible Leyden Jar" by Huff(3).)

A larger and more powerful Leyden jar for demonstrations can be made from a white plastic cough syrup or medicine bottle. Glue a foil baking cup to the outside, and cut and glue or tape additional aluminum foil on the outside of the jar up to the shoulder. Drill two 1/8 inch holes in the cap of the bottle 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 as shown in figure 7. Fill the bottle about 3/4 full of water and screw the cap on. You may seal the wire in place with a small dab of silicone bathtub caulk if you wish. This 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.

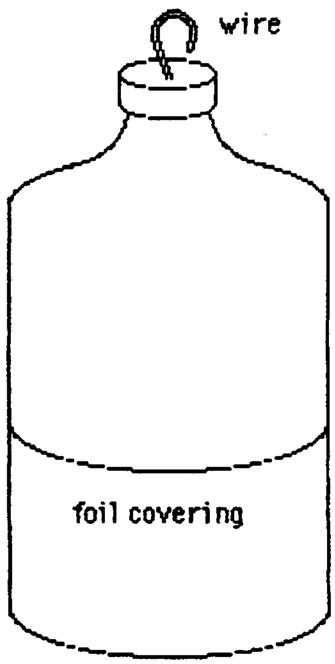


figure 7

2. T.B.Greenslade,Jr., Phys. Teach., 16, 557.

VI. Cottrell smoke precipitator.

Materials: one-liter clear plastic soft-drink bottle, aluminum foil, glue or tape, straight pins, paper clips.

A simple version of this important industrial device is a good model showing how to remove particulate matter from the air. Cut off the bottom of the bottle, fasten a strip of aluminum foil around the base and another strip of foil around the bottle just below the shoulder of the bottle. These may be glued or taped on. Take several straight pins and insert them through each foil strip piercing the bottle so that they point straight in. A paper clip slipped over each foil strip and bent outward serves as a connection to clip leads coming from a Van de Graaf or Wimshurst generator. Place a smoking object such as a cone of incense on a suitable surface, and place the bottle over it like a chimney. When the electrostatic generator is turned on, the smoke particles will become ionized and stick to the walls of the bottle. If the smoke does not clear immediately, try reversing the polarity of the charging device.

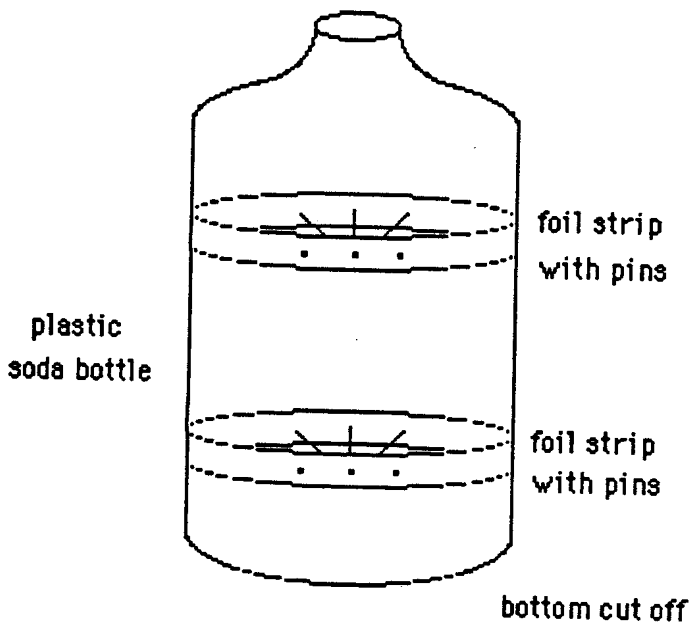


figure 8

3. G.B. Huff, Phys. Teach., 24, 292.

VII. Ion Wind Generator.

Materials: One liter plastic soda bottle, aluminum foil, plastic straws, straight pins, glue or tape.

Take the soda bottle, remove the label and cut off both ends of the bottle leaving a cylinder. Wrap a plastic soda straw in a strip of aluminum foil and cut off two lengths just a little longer than the diameter of the bottle. Insert one length across a diameter of the bottle about one third of the way from one end and secure it in place by sticking two straight pins through the outside of the plastic bottle into the straw. Have one of the pins stick through the straw so that it contacts the aluminum foil wrapping, and leave this pin sticking part way out of the bottle to use as a contact point for the ground connection from a Van de Graaf or Wimshurst machine.

Stick four straight pins through the other straw, equally spaced and parallel to form the corona discharge points (see figure 8), and insert the assembly in one end of the cylinder so that it spans the diameter, parallel to the other straw, with the points towards the other end of the cylinder. Secure this in place with duct tape or by sticking pins through the cylinder walls to the inside of the straw. Connect the other lead of the Van de Graff or Wimshurst machine to this straw. With the electrostatic generator running, a wind can be felt coming from the end of the blower opposite the corona points. The breeze is strong enough to blow a match flame or candle flame sideways. If the wind is not clearly apparent, reverse the polarity of the connections to the charging device.

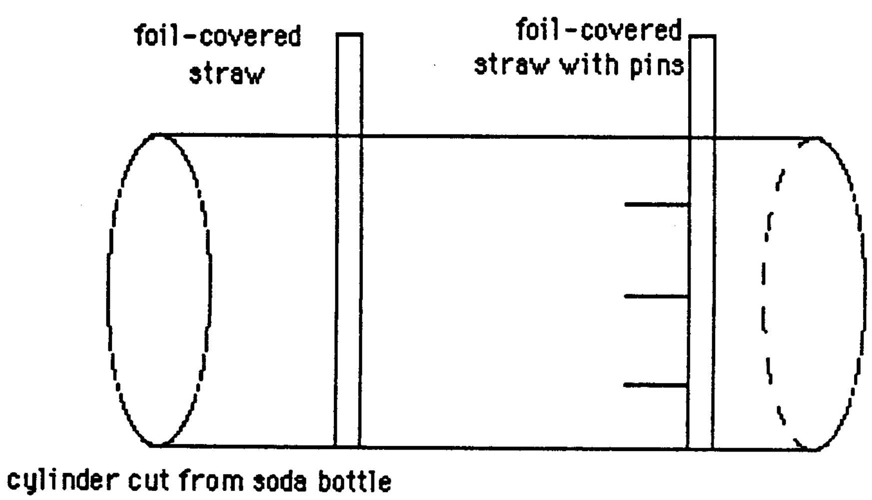


Figure 9

VIII. Neon Bulb.
Materials: small neon bulbs.

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. When a neon bulb flashes, it tells us that a current flows through it. The electrode at which the flash occurs indicates the relative DIRECTION of current flow. We can define the sign of electric charges by the convention that the flash occurs at the electrode that is LOSING negative charge or GAINING positive charge. This definition turns out to be in complete 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 bulb. A more detailed discussion of neon bulbs was given by John Layman(4). 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 more readily observe the flash.

Things to investigate:

Try bringing the one lead of the bulb near the electrophorus or the freshly charged foam pad. Try both using the bare end of the wire lead, or fastening a bit of straw covered with aluminum foil on the end of the wire.

Investigate the effect of discharging Leyden jars, bringing the lead near the outer electrode or the inner electrode. Consider putting the Leyden jar on an insulating stand first by setting it on an upturned foam coffee cup.

Use the neon bulb to investigate both the charging and discharging of the electrophorus. 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.

The neon bulb can be used to demonstrate a connection between static and current electricity by showing that the bulb can be lit by either the electrophorus or Leyden jar or by connecting nine or ten 9V transistor batteries in series and using them to light the bulb, taking care not to get shocked by the batteries yourself.

4. J. Layman, Phys. Teach, 10, 49.

IX. Electrostatic corona motor. This is a more ambitious project, but it is fun to make and get working. For a detailed understanding of its function, see the article by Jefimenko and Walker in the March 1971 Physics Teacher, p 121.

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:

First remove the plastic base from the soda bottle, pulling it off. This may be easier if you use warm water to soften the glue. Use the base to make the rotor by gluing a well-smoothed strip of aluminum foil around the inside of the base. Take a thumbtack and push it through the bottom of the base, centered on the bottom as in figure 10. 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.

Next 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, as in figure 11.

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. See figure 12. 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, as in figure 11. (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.)

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.

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.

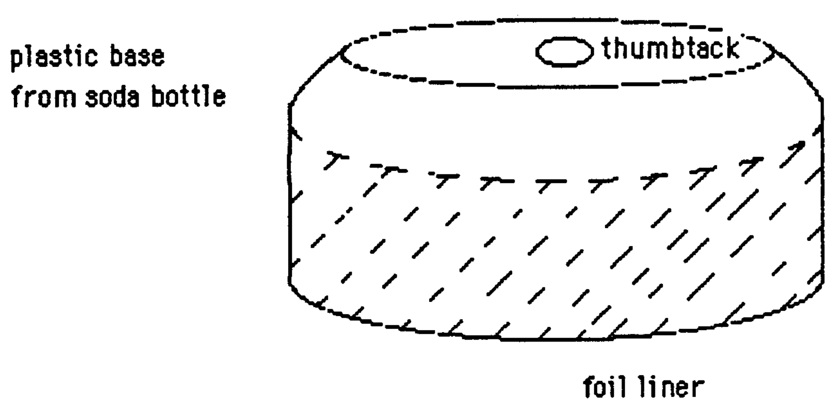
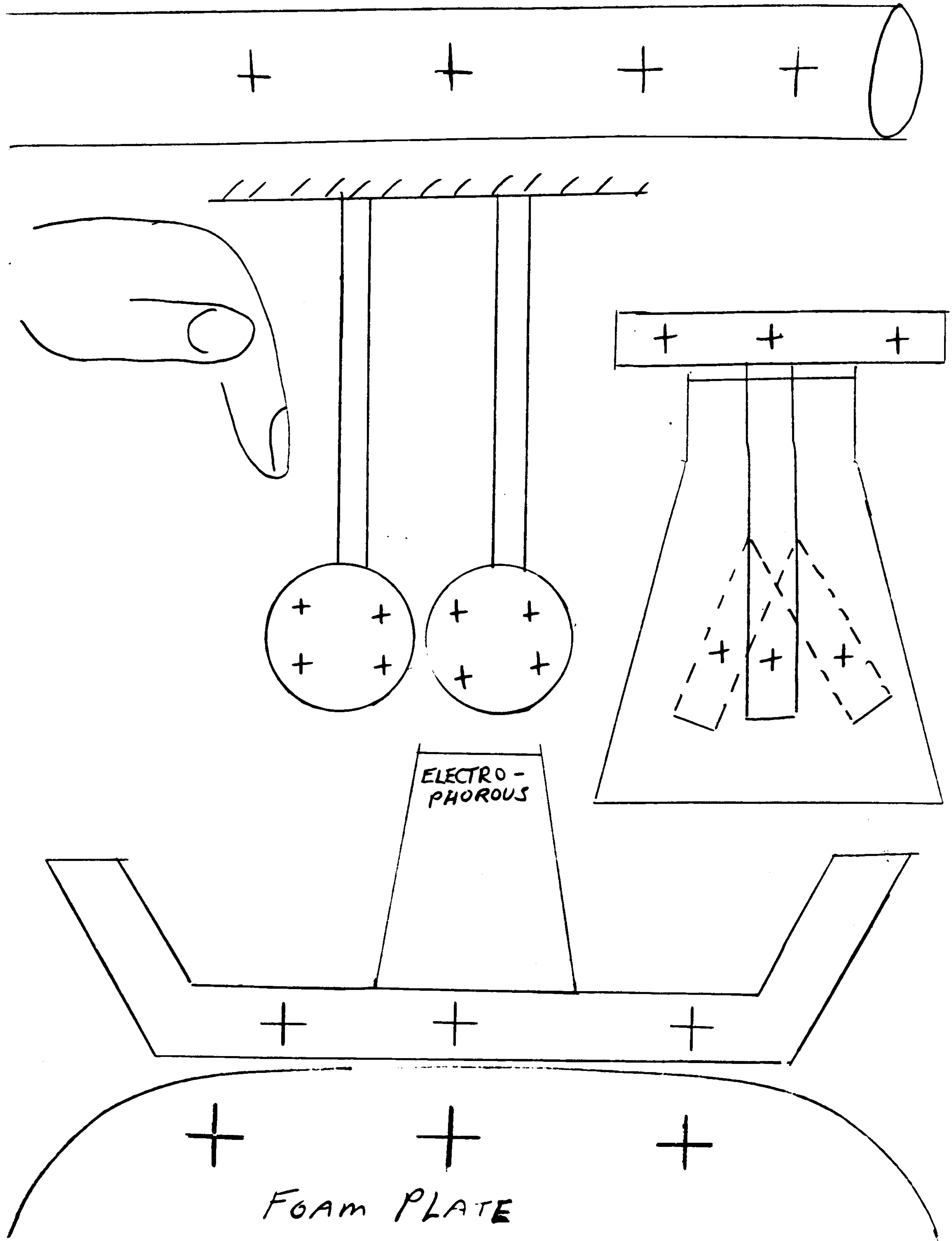
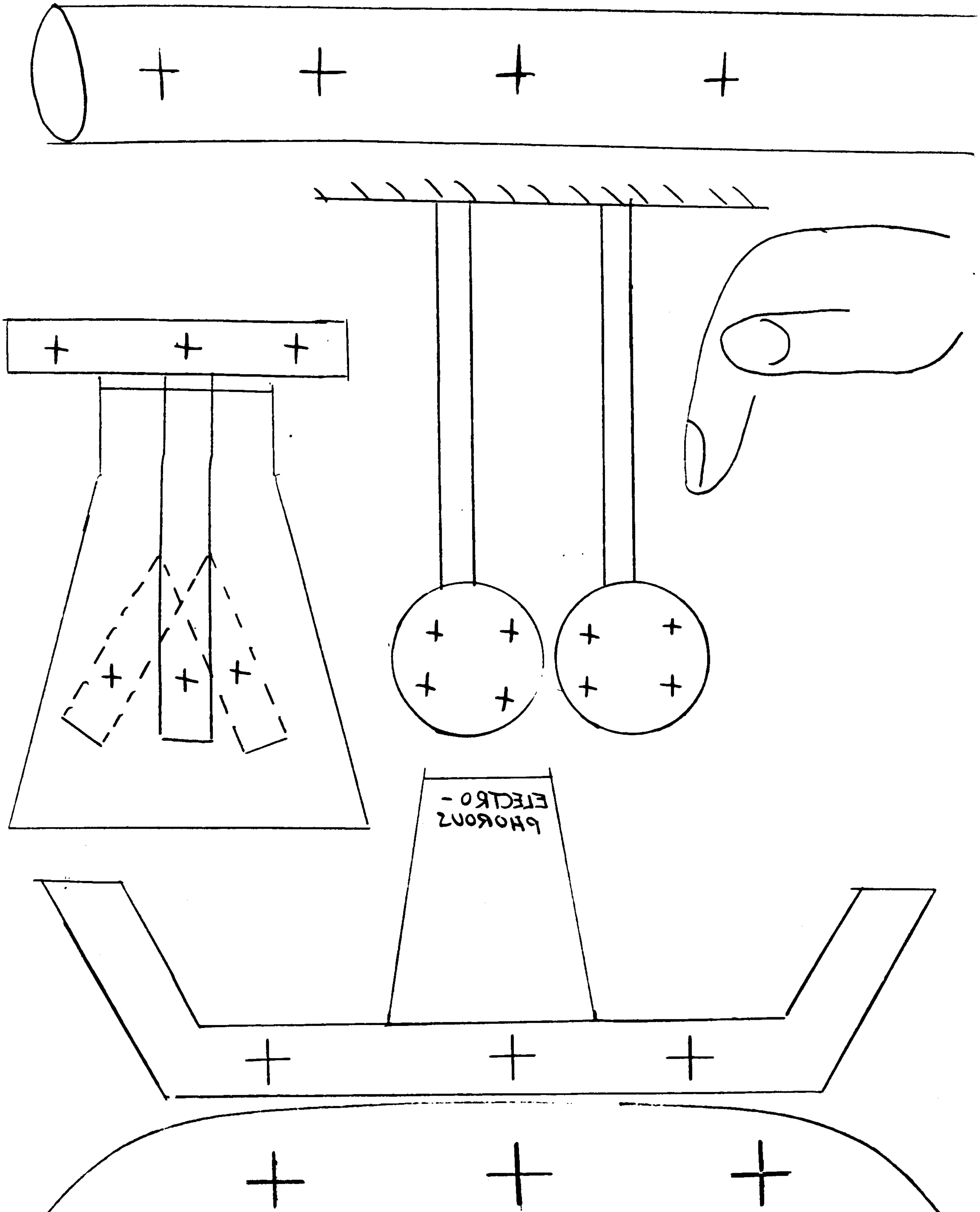


Figure 10


ELECTRO-
PHOROUS
FOAM PLATE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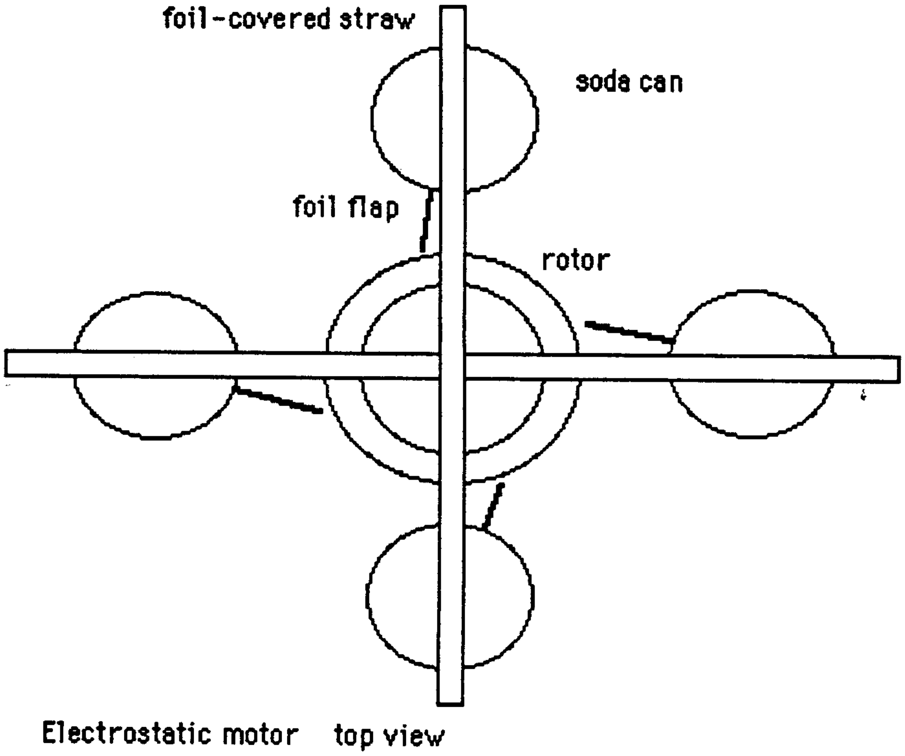

Figure 11

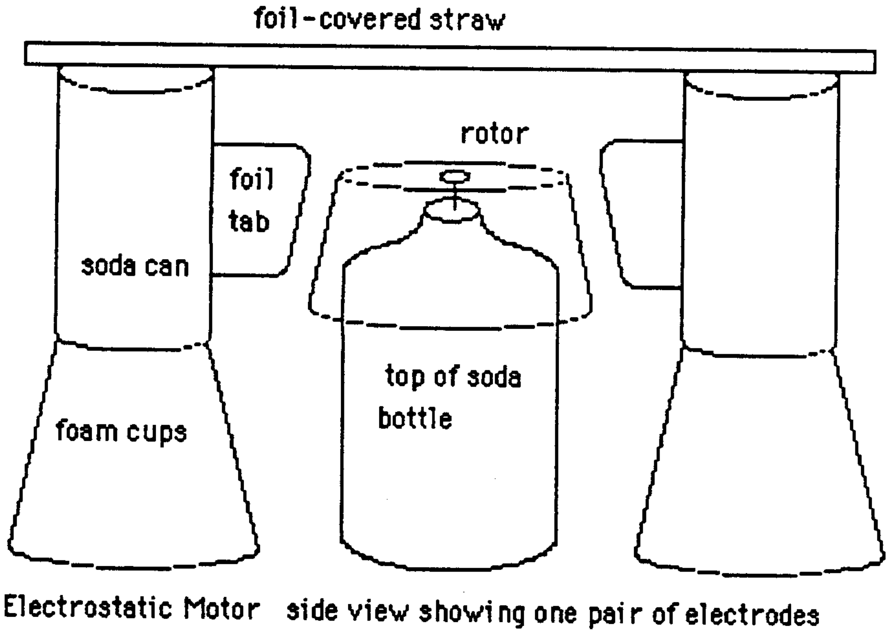

Figure 12

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 Graaf?

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, etc. If you come up with new designs, please let us know.

APPENDIX ONE:
Electrostatics article citations from THE PHYSICS TEACHER 1963-1986

An incomplete list idiosyncratically arranged.
A more complete collection planned for the next revision.

J. E. Girard
Negative Charges from an Electrophorous Vol 16,#6, Sept 78, 402

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M. Fast
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M. A. Rothman
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R. N. Jones
-And more on the same subject Vol. 11, #11, Oct. 73, 388

Z. Prezeniczny
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C. Pounder
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M. Ohriner
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Can an electrophorus lose its charge and then recharge itself? Vol 20, #4, Apr. 82, 254

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O. Jefimenko and D. Walker Electrets Vol 18, #9, Dec 80, 651

B. N. Turman
Is a swimmer safe in a lightning storm? Vol18, #5, May 80, 388

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R. D. Edge
Electrostatics with soft-drink cans Vol 22, #6, Sept 84, 396

R. Orville
The Lightning Discharge Vol 14, #1, Jan 76, 7

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Attraction and repulsion of metallic particles over water Vol 14, #9, Dec 76, 575

O. Jefimenko and D. Walker
Electrostatic Motors Vol 9, #3, March 71, 121

B. Huff
Dissectable Leyden Jar Vol 24, #5, May 86, 292

E. Waldroup
Electric Field in the Vicinity of Charged Spheres Vol 24, #4, April 86, 232

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Neon Lamps and Static Electricity Vol 10, #1, Jan 72, 49

R. Orville
Lightning Photography Vol 19, #6, Sept 71, 333

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Three Nice Demos Vol 24, #6, Sept 86, 353

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The Kelvin Water Dropper: An elementary experience Vol 22, #8, Nov 84, 516

F. Sears
A substitute for pith balls and balloons in the demonstration of electrical forces
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H. N. Pienaar
An Electrostatic Friction Machine Vol 3, # , 65 , 227

R. Lanni
Electrostatics Demonstrations Vol 7, # , 69 , 513

M. Ohriner and S. Machtinger
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P. Highsmith
Static Electricity Demonstration Vol 6, #8, Nov 68, 427

T. Miner
Lenz's Law Demonstration Vol 6, #8, Nov 68, 427

W. Hilton
An electroscope for the overhead projector Vol 6, #1, Jan 68, 40

W. Muha
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S. Marantz
Extinguishing a Fluorescent Lamp in a Magnetic Field Vol 5, #2, Feb 67, 86

N. Borowsky
The Dirod: A New Electrostatic Generator Vol 8, #1, Jan 70, 43

J. Mahoney
Coulomb's Law on the Overhead Projector Vol 9, # , 71 , 282

Z. Gubanski
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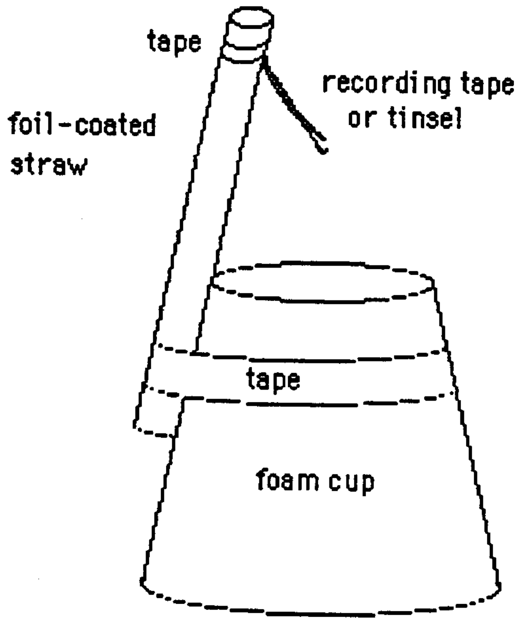
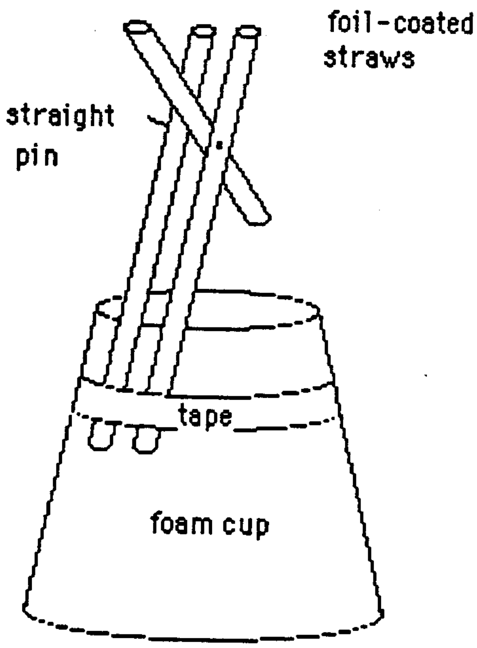
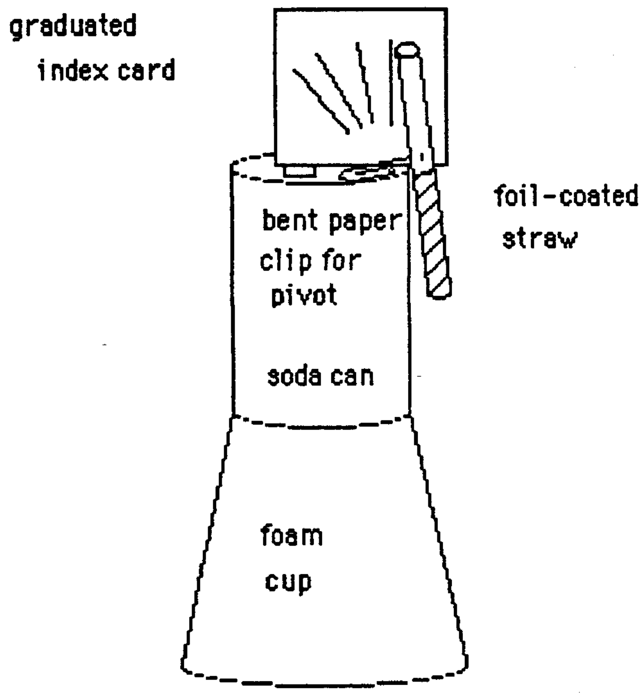
APPENDIX TWO: A VARIETY OF ELECTROSCOPE DESIGNS






graduated
index card
foil-coated
straw
bent paper
clip for
pivot
soda can
foam
cup