NSTA Physics Day Baltimore, MD, Friday 6 Oct 2017, Hilton Key 9

Handout: Investigating Electrostatics with an Inexpensive Electrophorus

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NSTA Baltimore, 6 Oct 2017

Abstract: An "instrumented" version of Volta's Electrophorus is a versatile tool to explore electrostatic charging by both induction and conduction, and highlights the difference between insulators and conductors. By adding some inexpensive indicators of charge state and charge transfer, it is a useful experimental context for students to use a qualitative atomic model to account for the observed phenomena. A classroom set is readily assembled from common household/grocery store materials at very low cost, and can be used in classes from middle school through introductory college. Participants will carry out a set of activities to get familiar with the construction and use of this historically important device. Participants - up to 40.

Introduction:
There are several ways to electrostatically charge objects. Many students have experience with charging by contact - by rubbing things - and have a simple model in which one object takes charge from another. Many students also have experience with induced charge effects such as sticking a rubbed balloon to a wall. Very few are likely to have observed or thought about the electrostatic charging of a conductor by the process of induction.

In this workshop you will have an opportunity to see how a simple atomic model and inexpensive equipment can be used to guide students to an understanding of the process of electrostatic induction, using the concept of electrical action at a distance.

I - What do you already know - a basic atomic model

1. Atomic theory - what are the parts of an atom?

2. where in the atom are the parts located - i.e. what is the structure of an atom?

3. What are the signs of electrical charges of the parts of an atom?

4. Which parts of an atom are heavy and hard to move? which parts are light and easy to move?

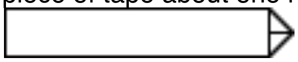
5. What parts of atoms are involved in chemical interactions between atoms?

6. What parts of atoms behave differently in a conductor and in an insulator?

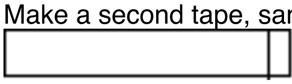
Give questions to students, use discussion to reach agreement on answers. have students write paragraph summarizing their knowledge.

III.

II Charging Scotch™Magic™ Tape.

Tear off a piece of tape about one hand’s breadth long. Fold corners on one end under to make a “pointy tab” tape. 

Make a second tape, same length but fold the end under to make a “square tab” tape.



Carefully stick the sticky side of the pointy tape to the non-sticky side of the square tape. Press them together, then draw them lightly between finger and thumb. Finally hold the tapes by their tabs and pull them briskly apart.

Holding the tapes by their tabs, bring the non-sticky sides of the two tapes near each other. What happens?

Bring the non-sticky side of two pointy tapes near - what happens?

Bring the non-sticky side of two square tapes near - what happens?

How do two tapes prepared the same way interact?

How do two tapes prepared differently interact?

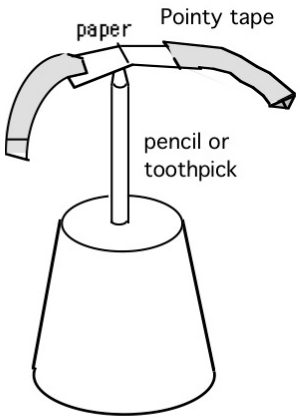
Discussion: For now, assume that pointy tape is positive.

1) In terms of the atomic model, how can you account for a difference between the pointy and square tab tapes when they have been separated?

2) What questions might you have to use with students to help them apply the atomic model to the question above?

III.

IV. **Building an electrostatic “compass” or dipole**



Make a set up like the one shown at the left - you may use a paper cup and a toothpick, or a foam drink cup and a sharp pencil. Fold the strip of paper in half long way , crease, unfold and fold it the short way, crease and unfold - pinch the paper to make a tent shape.

Make two new short pointy tab and square tab tapes, stick them on either end of the paper ‘tent’ and balance the set up on the toothpick. This now forms an “electrostatic compass” or electrostatic dipole.

Make another pair of tapes or refresh your previous tapes and try bringing each near the compass.

Which tape does the pointy end of the compass point towards?

Which tape does the pointy end of the compass point away from?

IV. Electrostatic Charging - Contact, Conduction, induction

Contact:

We often think of charging by rubbing - formally known as triboelectric charging, but as you have seen with the tape charging the process depends on the separation of chemically different surfaces. Rubbing simply serves to make lots of contacts and separations between the surfaces at the atomic scale. Pressure rather than speed gives better charging.

Good materials:
Acrylic window glazing and polystyrene picnic plates give reliable charging and predictable charge signs under most conditions as long as they are reasonably clean.
PVC pipe rubbed with cloth, clean dry hair or fur charges well.
Reference: Triboelectric series at http://www.trifield.com/content/tribo-electric-series/

Conduction:
Charging by conduction occurs in several situations.

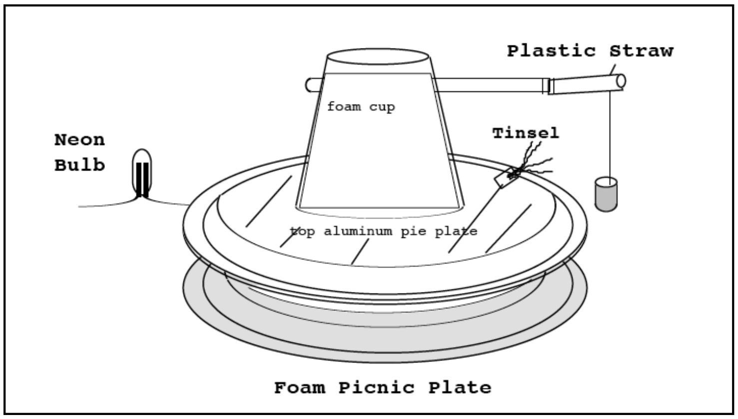
A charged insulator touches a conducting object and transfers charge from a small area of the insulator to the object. Piece of aluminum foil or a pith ball hanging on a thread touches a charged plastic rod and is then repelled.

An insulated charged conductor touches another conductor. Person walking across carpet touches a door knob or metal surface, possibly generating a spark so that air is locally turned into a conductor. If the second conductor is insulated they share the charge and both end with the same charge.

Induction:

In some ways the most interesting and fruitful way to understand electrostatics. Originally understood and clearly explained by Franklin (1740's), and later employed in several electric instruments by Alessandro Volta (late 1700's). Investigations with an "instrumented" version of Volta's electrophorus can be an effective way to build a useful conceptual understanding of electrostatic phenomena explained by the atomic model.

Volta's Electrophorus - instrumented version



Two Al pie tins held together with 3 small binder clips .

Foam or plastic cup attached to top plate with masking tape.
Masking tape with spray of aluminized Mylar™ tree tinsel.

Hanging foil bit (tube of Scotch™ tape sticky side out, with thread and layer of Al foil.)

Thread runs through slit in end of straw stuck through foam cup. Foil bit hangs so center just touches pie tin rims.

Using the electrophorus:

1. Charge the foam plate by rubbing it with acrylic plate or other material.
2. With hanging foil bit and tinsel in place, hold electrophorus by foam cup, taking care not to touch the pie tins, and lower it onto the charged foam plate.
3. Bring your finger near the hanging foil bit - watch what happens to foil bit and tinsel. When activity ceases, touch the pie tin with your finger.
4. Holding electrophorus by foam cup, and without touching pie tins lift the electrophorus off the foam and raise it in the air, watching the tinsel.
5. With electrophorus in the air bring your finger near the hanging foil bit and watch the action of foil bit and tinsel.

6. Repeat the process, but at steps 1, 4, and 5 use the electrostatic compass to determine the charge sign (pointy or square) on the foam plate, and the pie tins.

7. Does the electrophorus get charged? Does it have the same sign of charge as the foam?

Give your evidence for each of your observations.

Discussion: Based on the atomic model and the properties of insulators and conductors, how can you account for the observed behavior of the electrophorus?

Physics Electricity Activity: Volta's Electrophorus

1. Terms: **Foam** - foam picnic plate **Acrylic**- sheet of clear acrylic plastic
Top and bottom **pans**- aluminum pie tins **foil bit**- hanging tube of tape covered with foil
tinsel- bunch of tree tinsel taped to top plate of electrophorus
Assumption: only atoms/ions shown are those that participate in charge transfer.

Charge Diagram Standards

See "Simple Pencil-and-Paper Notation for Representing Electrical Charge States", The Physics Teacher, Nov 2017, pp 470-471

= neutral atom

= polarized atom

= atom that has lost an electron

= atom that has gained an electron

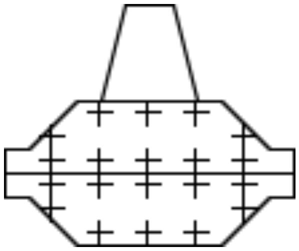
top +

top –

bottom +

bottom –

foam +
foam -



2. The diagram to the left shows an electrophorus. `Positive charges have been drawn in place.
Draw the distribution of negative charges when the electrophorus is in its initial neutral condition.
Record the number of + and - charges in each pan.

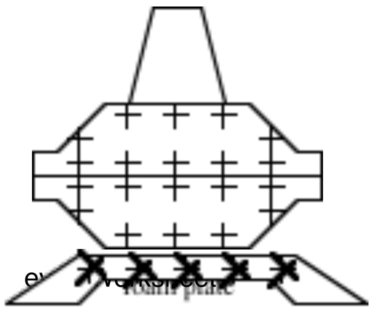
top +

top –

bottom +

bottom –

foam –



3. Draw the distribution of negative charges when the electrophorus has been brought close to the negatively charged foam plate. The charges on the foam are already shown.

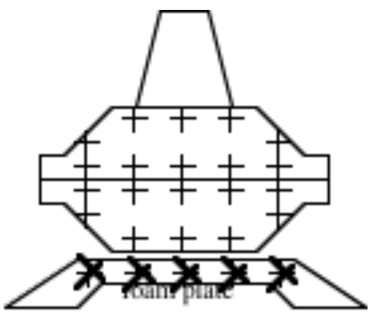
top +

top –

bottom +

bottom –

foam –



4. Show distribution of negative charges after the top pan has been touched with your finger, but before the electrophorus has been lifted from the foam.

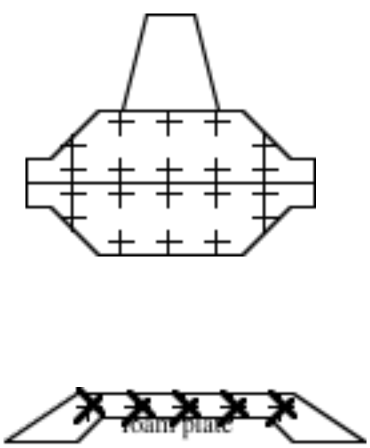
top +

top –

bottom +

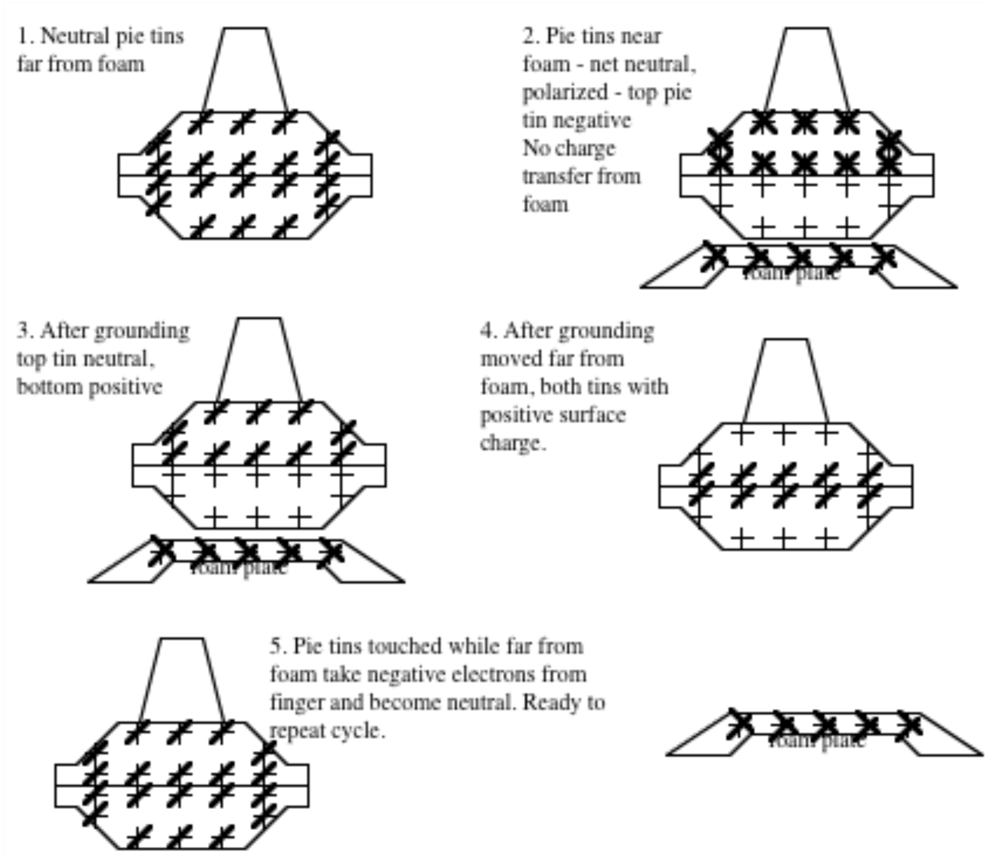
bottom –

foam –



5. Show distribution of negative charges after the electrophorus has been lifted well above the foam plate.

Key to worksheet



Distinguishing positive and negative charge states:

A neon bulb can be used to determine which sign of charge is which. When negative charges flow through the neon bulb, the electrons at the negative electrode are absorbed by positive neon ions in the bulb and the neon glow appears at the negative electrode. If you hold one of the wires and touch the other to the electrophorus, you can determine which way electrons are traveling. If the glow is at the electrode you are holding, then you are losing electrons to the electrophorus. If the glow is at the electrode connected to the electrophorus, then it is losing electrons to you.

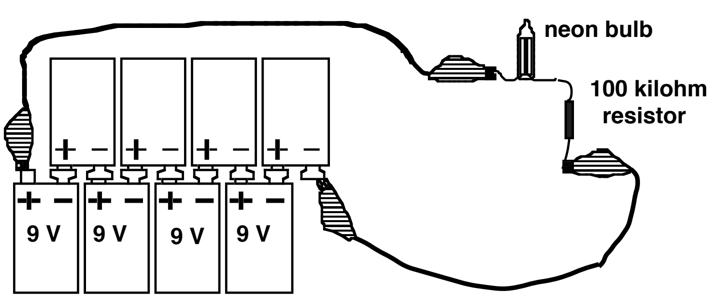


Figure III.6.1 Neon bulb and 9V batteries
(adapted with permission from the CASTLE© project, Pasco Scientific, 1991)

Demonstrator to show glow is at negative electrode using batteries.

NE-2 or 606-A9A neon bulb in series with high resistance (10 kohm to 100 kohm)

Use clip leads to connect to snapped together battery made of 8 to 10 nine-volt batteries.
Positive and negative terminals of battery stack marked.
Look at bulb - which sign is associated with glow around electrode in bulb?

Resources:

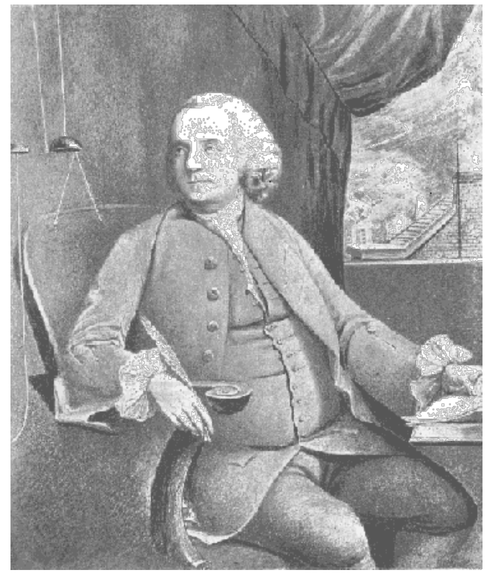
PhET Simulations: https://phet.colorado.edu/en/simulations/category/physics

Balloons and Static Electricity : charging by rubbing and effect of electrostatic induction in a wall.

John Travoltage: Charging by rubbing and transfer of charge by spark

"**Electrostatics with Computer-Interfaced Charge Sensors**" - **Robert Morse** The Physics Teacher, vol 44, Nov 2006, pages 498-502. download pdf from http://www.vernier.com/innovate/electrostatics-with-charge-sensors/

Low cost electrostatic generators made from FunFlyStick™ toy
(description of entry in 2009 Apparatus competiion)
https://aapt.org/Programs/contests/upload/morse.pdf



B. Franklin observing his lightning alarm.
Described in Section VII.
Engraving after the painting by Mason Chamberlin, R. A.
Reproduced from Bigelow, 1904 Vol. VII

Books

Moore, A.D., Crowley, Joseph M., Electrostatics: Exploring, Controlling and Using Static Electricity, 2nd ed., Laplacian Press, 1997

Morse, Robert A. Teaching About Electrostatics, AAPT 1992 (somewhat out of date - new version planned)

Web Resource: Benjamin Franklin's experiments: 1747
"Ben Franklin as my Lab Partner" and
"Collected Electrical Writings of Franklin"
at **http://www.compadre.org/psrc/Franklin/**

Ben Franklin as my Lab Partner has directions for other electrostatic equipment that is inexpensive to construct and allows students to repeat some of Franklin's experiments - see review below.

Review excerpt from Anderson,Robert. "Ben's 300th." Natural History Magazine, June 2006

"My favorite Franklin site, however, was created by one Robert A. Morse while a fellow at the Wright Center for Science Education at Tufts University (**http://www.compadre.org/psrc/Franklin/**) . In nine lessons titled "Ben Franklin As My Lab Partner," Morse explains how to reproduce Franklin's electrostatic experiments. The lessons are accompanied by thirteen video clips that show how to build the apparatus with ordinary items such as aluminum foil, Christmas tinsel, pencils, and Styrofoam cups. If all the grade school science teachers across the country exposed their students to the fun of these lessons, Franklin's scientific contributions might gain the broad appreciation they deserve. I can't think of a better way to celebrate Ben's 300th birthday than generating a few sparks."

ROBERT ANDERSON is a freelance science writer living in Los Angeles.

Neon Bulb - Mouser Electronics www.mouser.com part 606-A9A about $0.30 each - less in bulk

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Home: 5530 Nevada Ave, NW, Washington, DC 20015 ramorse@rcn.com

A number of compasses can be arranged in the vicinity of charged objects to investigate the direction and pattern of the electric field created by a charged object in the space around it. A charged piece of 2 inch or so PVC pipe can be stood on end, and compasses placed around it.
A sheet of styrofoam insulation board rubbed with cloth or dry hair can be used to show the field near a charged flat plate.

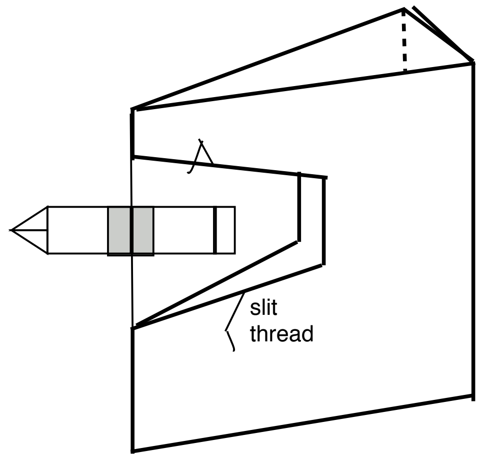
A more durable electrostatic compass.

Electrostatic Compass - Tape dipole

Based on idea from Sherwood & Chabay - *Electromagnetic Interactions*

Tape dipole on thread supported by frame cut from manila folder.

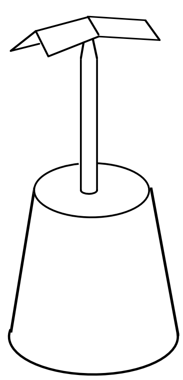
Cut two from one folder.
height 14.7 cm, unfolded base 17.6cm
cutout 9 cm deep, 2 cm down from top
3.5 cm up from bottom, height of cut at inside about 3 cm.
Fold side panels for 5 cm overlap, fasten with paperclip. unfold flat to store.



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

Foam or paper cup supports sharp pencil or toothpick.
Folded paper balanced on point.Variation : use Al foil strip.

Shows alignment of electric field but does not distinguish which charge is which. Also shows induction of charge polarization in an insulator.



NSTA Baltimore October 2017

Investigating Electrostatics with an Inexpensive Electrophorus

Robert A. Morse

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How do things get charged?
Three processes to investigate
Contact Conduction Induction

I – What do you already know - a basic atomic model

1. What are the parts of an atom?
2. Where in the atom are the parts located - i.e. what is the structure of an atom?
3. What are the signs of electrical charges of the parts of an atom?
4. Which parts of an atom are heavy and hard to move? Which parts are light and easy to move?
5. What parts of atoms are involved in chemical interactions between atoms?
6. What parts of atoms behave differently in a conductor and in an insulator?

Briefly answer - Check with neighbor

II Charging Scotch™Magic™ Tape.

Make a “pointy tab” tape.

Make a “square tab” tape

Stick sticky side of pointy tape to slick side of square tape.
Press together, draw lightly between finger and thumb.

Grab tapes by tabs – pull briskly apart.

Holding tapes by tabs, bring slick sides of tapes near each other. What happens?

Try two pointy tapes and two square tapes - what happens?

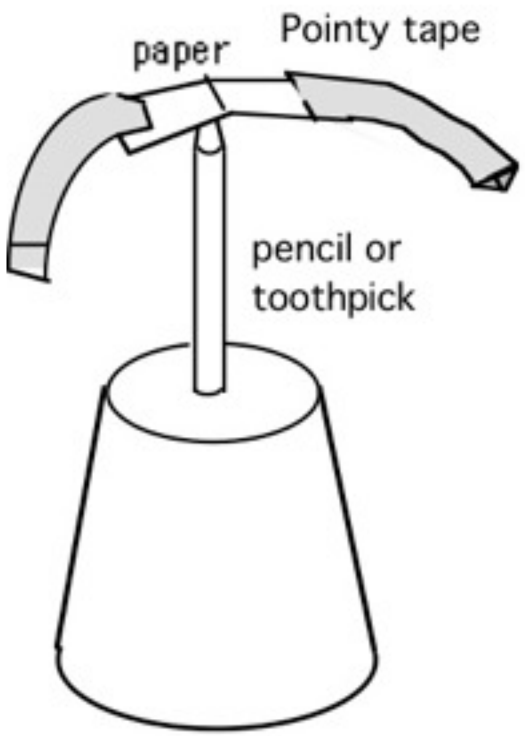
How do tapes prepared the same and those prepared differently interact?

Discussion: (Alliteratively assume pointy tape is positive.)

1) Using atomic model account for difference between pointy & square tab tapes when separated? Check with neighbor.

2) What questions might you use to help students generate explanation?

III. **Building an electrostatic “compass” or dipole**



Make set up shown at the left - use paper cup & toothpick.

Fold strip of paper in half long way, crease, unfold & fold short way, crease & unfold - pinch to make tent shape.

Make two short pointy & square tapes, stick them on ends of paper ‘tent.’ Balance on toothpick. This is an “electrostatic compass” or electrostatic dipole.

Make another pair of tapes, bring each near the compass.

Which tape does the pointy end of the compass point towards?

Which tape does the pointy end of the compass point away from?

IV. Electrostatic Charging - Contact, Conduction, Induction

Contact:

Students familiar with charging by rubbing - triboelectric charging.
But tapes only needed separation of chemically different surfaces.
Rubbing makes lots of contacts & separations between atoms & molecules in surfaces.
Pressure rather than speed gives better charging.

Good materials:

Reasonably clean acrylic window glazing & polystyrene picnic plates give reliable & predictable charging under most conditions.
PVC pipe rubbed with cloth, clean dry hair or fur charges well.
Reference: Triboelectric series at http://www.trifield.com/content/tribo-electric-series/

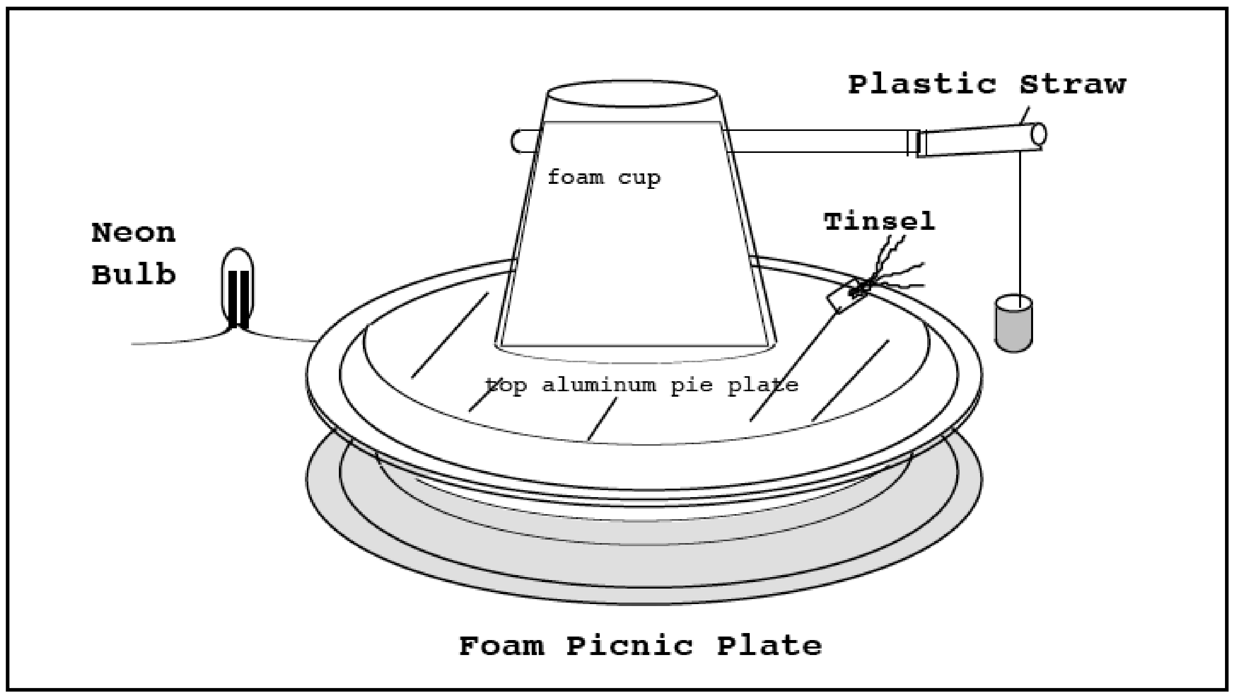
Conduction:

Charged insulator touched by conducting object transfers charge from small area of insulator to object. Example: bit of aluminum foil or pith ball hanging on thread touches charged plastic rod and is then repelled.

Insulated charged conductor touches another conductor. Walk across carpet & touch door knob or metal surface – feel a shock and possibly generate a spark when air locally turns into conductor. If second conductor is insulated they share charge and end with same charge sign.

Induction: Volta's electrophorus - an "instrumented" version

Interesting & fruitful tool to understand electrostatics using distant effect of charge.
Principle understood & clearly explained by Franklin (1740's and '50s).
Later employed in electrical instruments by Alessandro Volta (late 1700's).
Investigations with "instrumented" version of Volta's 1775 electrophorus – effective in building conceptual understanding of phenomena explained by atomic model and using the effect of the electric field – emphasized in NGSS



2 pie tins clipped together with binder clips

Foam cup handle taped to top pie tin - with straw poked through cup

Thread through slit in end of straw with foil bit hanging to just touch rims of pie tins - shows transfer of charge

Spray of tinsel taped to top pie tin - indicates amount of charge on top

Neon bulb held in hand can be touched to rim to show transfer of charge.

Using the instrumented electrophorus:

1. Charge foam plate by rubbing with acrylic plate.

2. Hold electrophorus by cup, without touching pie tins – lower onto charged foam plate – watching tinsel.

3. Bring finger near foil bit – watch action of foil bit & tinsel. When activity ends, touch pie tin with finger.

4. Hold by cup, lift off foam and raise it in the air, watching tinsel.

5. Bring finger near foil bit – watch action of foil bit and tinsel.

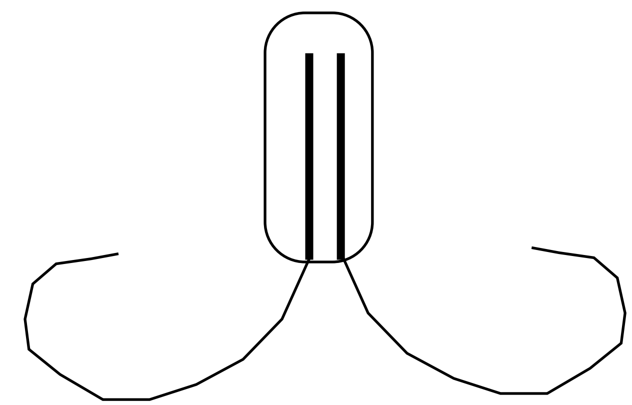
6. Repeat process – at steps 1, 4, 5 use electrostatic compass to determine charge sign on foam plate, and pie tins.

7. Does electrophorus get charged? Does it have same charge sign as foam?

   What is your evidence?

Bend neon bulb wires into shape shown

Hold bulb by one wire. Repeat charge and discharge cycle of electrophorus, but instead of touching foil bit, touch wire of neon bulb to pie tins. Watch to see which electrode flashes. Practice.



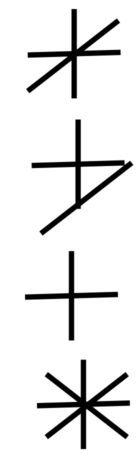
Assume that electrode that flashes is the one that is transferring negative charge to other electrode. Record which flashes when electrophorus is on the foam and when it is lifted in the air.

Discussion: Based on atomic model and properties of insulators and conductors, how do you account for observed behavior of electrophorus?
Use assumptions that pointy tape is positive and the flashing neon electrode is negative. Refer to page 5 of handout.

11. Physics Electricity Activity Volta's Electrophorus

1. Terms: **Foam** - foam picnic plate **Acrylic**- sheet of clear acrylic plastic
Top pan- top aluminum pie tin of electrophorus **Bottom pan**- the bottom aluminum pie tin
foil bit- hanging piece of straw covered with aluminum foil **tinsel**- bunch of tree tinsel taped to top plate of electrophorus

Assumption: the only atoms/ions shown are those that participate in charge transfer.



= neutral atom

= polarized atom

= atom that has lost an electron

= atom that has gained an electron

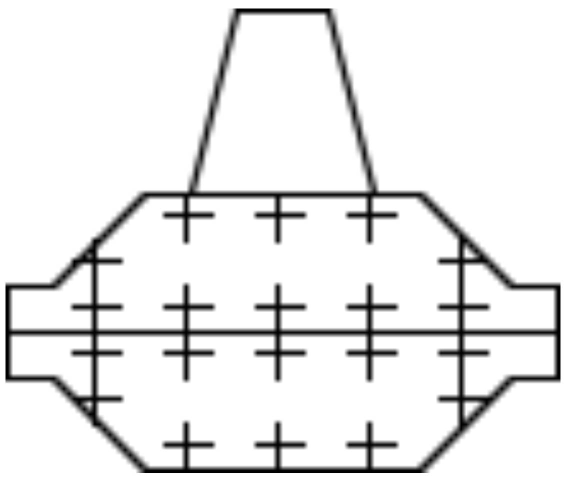
top +

top –

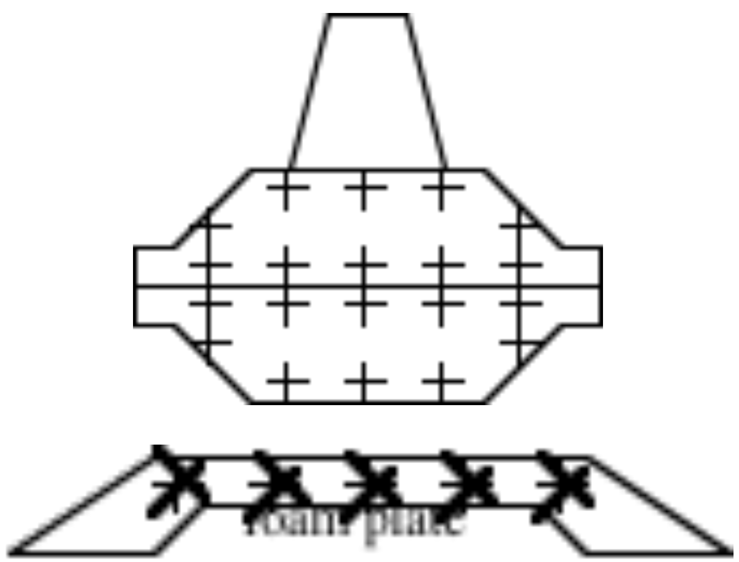
bottom +

bottom –

foam +
foam -



2. The diagram to the left shows an electrophorus. Positive charges have been drawn in place.
Draw the distribution of negative charges when the electrophorus is in its initial neutral condition.
Record the number of + and - charges in each pan.



3. Draw the distribution of negative charges when the electrophorus has been brought close to the negatively charged foam plate. The charges on the foam are already shown.

Charge Diagram Standards See "Simple Pencil-and-Paper Notation for Representing Electrical Charge States", The Physics Teacher, Nov 2017, pp 470-471

Determining the sign of charge and direction of charge transfer with batteries and neon bulbs.

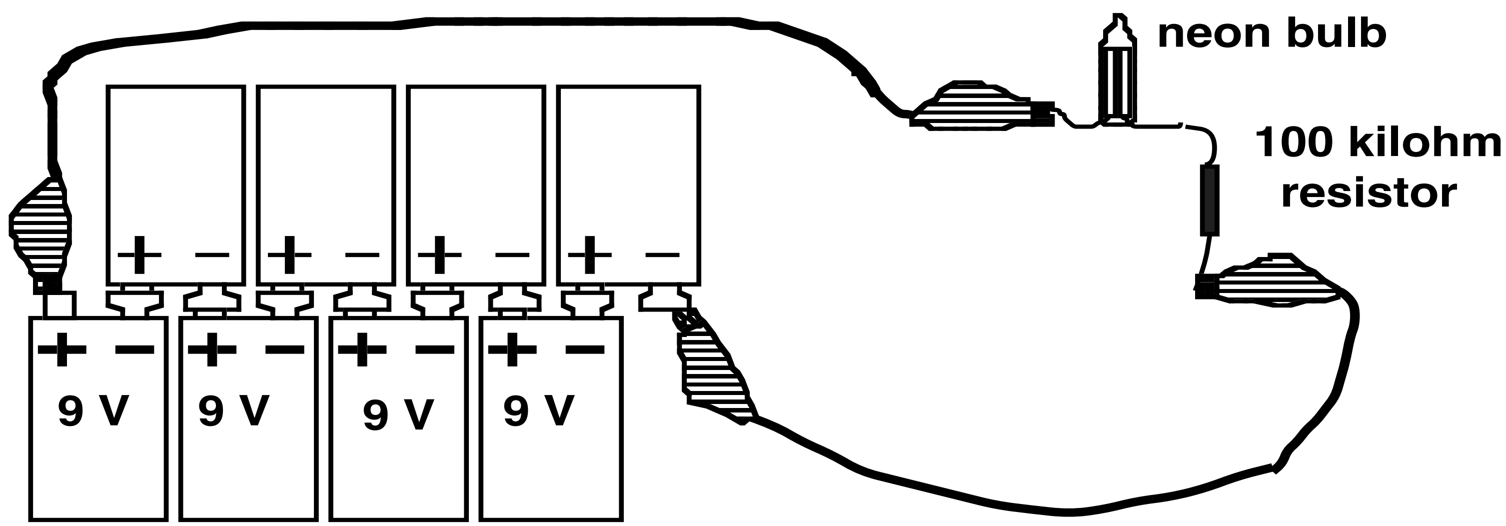


Figure III.6.1 Neon bulb and 9V batteries (adapted with permission from the CASTLE© project, Pasco Scientific, 1991)

NE-2 neon bulb in series with high resistance (10 kohm to 100 kohm)

use clip leads to connect to snapped together battery made of 8 to 10 nine-volt batteries. Positive and negative terminals of battery stack marked as + and −

Look at bulb - which sign is associated with glow around electrode in bulb?

Contact information and various resources on handout

ramorse@rcn.com