Introduction

Due to problems of technique and apparatus, demonstrations of electrostatic phenomenon have traditionally been limited to the simplest experiments using the most elementary equipment. Moreover, the traditional demonstrations usually gave qualitative rather than quantitative results. PASCO has attempted to remedy this by designing the complete ES-9079 Basic Electrostatics system. This guide will give the instructor enough of a step-by-step explanation to master demonstration techniques. The range of demonstrations in this guide more than covers the material usually presented in an undergraduate unit on electrostatics.

There are several essential principles of electrostatic demonstrations that should be remembered.

- Read the first section of this manual regarding theory and use of the electrostatic accessories.
- Equipment orientations - Arrange the apparatus to be used so that it is sufficiently separated and neatly arranged to insure that the students can clearly see the set-up. Each demonstration includes a diagram of suggested equipment set-up. A preferred set-up would also use a computer with a Science Workshop interface to display the readings from the Electrometer (ES-9078) in a computer screen that all can easily see. (You can use an analog display, for example, to show the deflections of the needle; or a digits display to show the voltage.) If a computer is not available, set the demonstration electrometer upright to allow the meter to be seen more easily. Always consider how the equipment arrangement may affect charge distributions. For example, a misplaced power supply can easily change the charge distribution on a nearby sphere. Finally, always stand behind the demonstration table to avoid obstructing anyone's view.
- Earth grounds - Although it is not always strictly necessary, the demonstrator should be connected to an earth ground. Stray charges on the demonstrator can cripple an experiment. Also keep the electrometer grounded unless specific instructions are given to the contrary.
- Avoid unnecessary movement - If the demonstrator walks around or waves his/her arms excessively, charge can build up in clothing and affect the results.
- Humidity - The PASCO demonstration electrometer has been designed to minimize the effects of humidity. However, a particularly humid day can cause charges to leak off various apparatus, radically changing the charge distribution. To help minimize leakage, keep all equipment free of dust and oil (e.g. from fingerprints). On the other hand, a particularly dry day can cause charge to easily build up in any moving object, including people. Minimize all movement when demonstrating on a very dry day.
- Practice - Nothing can ruin the instructive value of a demonstration more than failure due to a demonstrator unfamiliar with the equipment and procedure.

Before presenting a series of electrostatic demonstrations, the student (and of course, the instructor) should be made aware of the following:

- The theory and use of the Faraday Ice Pail. (This is adequately covered in the product description of this section and in Demonstration 1.)
- The possible distortion of charge density due to improper use of the proof plane. (See the product description section.)
- Residual charge may build up in the plastic insulator between the handle and disk of the proof plane and charge producers. Make sure to ground these parts before any experiment.
- The capacitance of the electrometer must be considered when calculating the magnitude of a charge from the voltage reading of the electrometer. (See Demonstration 3 for the procedure necessary to determine the electrometer's capacitance.)

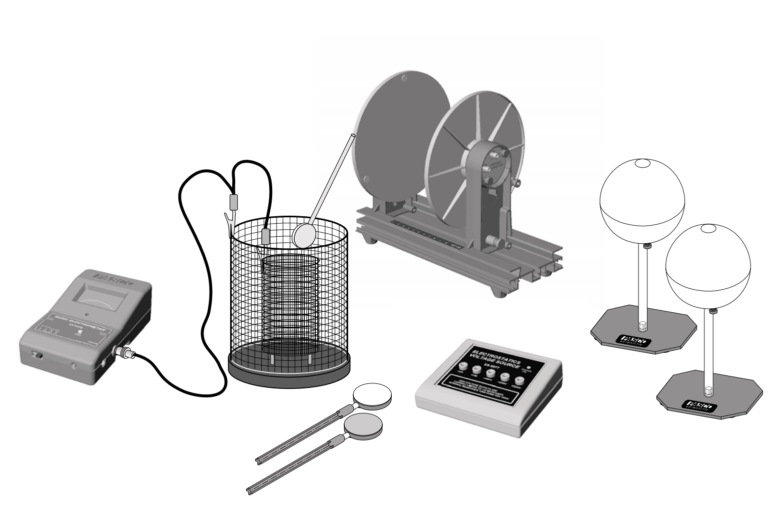
By following the above principles and by practicing, the demonstrator should have a high degree of success with the demonstrations and find their educational effect of great value

Equipment

Included:

- ES-9078* Basic Electrometer
- ES-9077* Electrostatics Voltage Source
- ES-9079* Basic Variable Capacitor
- ES-9057B Charge Producers and Proof Plane
- ES-9042A Faraday Ice Pail and Shield
- ES-9059B Conductive Spheres

*Some cables not shown



Optional:

- *ScienceWorkshop*® Computer Interface, Series 500 or 700.
- DataStudio™ or ScienceWorkshop® software

Theory

ES-9042A Faraday Ice Pail

The PASCO Faraday Ice Pail (ES-9042A) is shown in Figure 1. Originally designed by Michael Faraday, it works on the principle that any charge placed inside a conducting surface will induce an equal charge on the outside of the surface. It is an excellent product for sampling charges and charge distributions. The PASCO version illustrated above consists of two wire mesh cylinders, one inside the other, mounted on a molded plastic bottom.

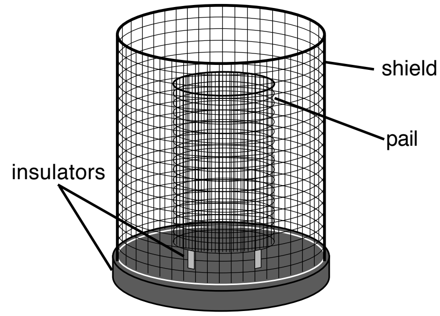


Figure 1. Faraday Ice Pail

The outer cylinder is called the shield. It provides complete visibility to the inside of the pail and, when grounded, helps eliminate stray charges and AC fields. The inner cylinder is the actual pail. Notice how the pail is mounted on insulated rods. The pail is 10 cm in diameter and 15 cm high. When a charged object is placed inside the pail, but without touching it, a charge of the same magnitude is induced on the outside of the pail. (See Figure 2). An electrometer connected between the pail and the shield will detect a potential difference. The greater the charge, the greater the potential difference. So even though the electrometer will give readings of voltage, it is possible to use those values as relative charge measurements.

To prevent stray charges from producing erroneous results, it is extremely important that the Ice Pail be momentarily grounded prior to starting any experiment. The demonstrator must also be continually grounded while performing an experiment.

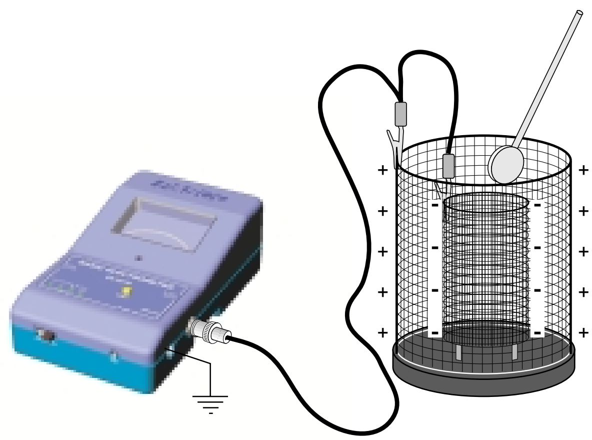


Figure 2. Charge induction

Other accessories included with this system are the Charge Producers and the Proof Planes (PASCO ES-9057B). The Charge Producers are used as charged objects to lower into the Ice Pail. The Proof Planes are used to sample surface charge densities.

ES-9059B 13-cm Spheres

The conductive spheres are used to store electrical charge. The PASCO Model ES-9059B spheres are composed of plastic resin mold plated with a copper base, outer plating of non-sulphur brite nickel, with final plating of chrome. The spheres are mounted on insulting polycarbonate rods, attached to a support base. Each sphere has a thumb-nut on the lower half that can be used for attaching a ground cable or a lead from a power supply. The

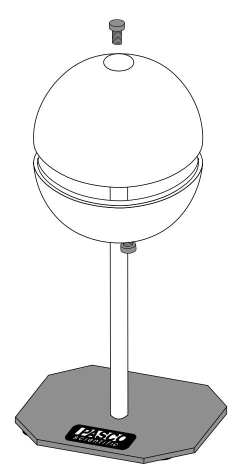


Figure 3. Conductive Sphere

sphere and insulating rods should be kept free of dirt, grease, and fingerprints to minimize leakage of charge from the sphere.

ES-9077 Electrostatics Voltage Source

The ES-9077 is a high voltage, low current power supply designed exclusively for experiments in electrostatics. It has outputs at 30 volts DC for capacitor plate experiments, and 1 kV, 2 kV, and 3 kV for Faraday ice pail and conducting spheres experiments. With the exception of the 30 volt output, all of the voltage outputs have a series resistance associated with them which limit the available short-circuit output current to about 8.3 microamps. The 30 volt output is regulated, but is capable of delivering only about 1 milliamp before falling out of regulation.

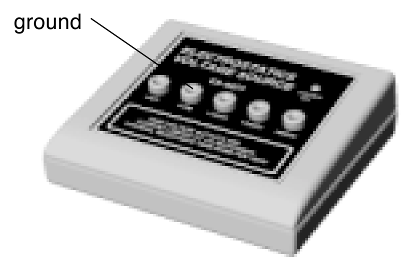


Figure 4. Electrostatics Voltage Source

ES-9053A Resistor-Capacitor Network

Three resistors (50 MΩ, 100 MΩ, and 200 MΩ) and two capacitors (0.47 µF and .94 µF) are wired into a switching network which permits the components to be connected in various configurations. The RC Network is designed for the study of RC time constants and for investigating capacitors connected in series and parallel (the RC time constants range from 25 to 200 seconds). A third capacitor (0.22 µF) can be selected in series or parallel with the other two capacitors.

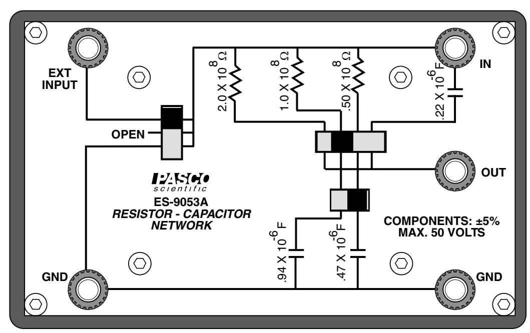


Figure 5. RC Network

On the front of the RC Network, a diagram shows the connection of the components. The positions of the three slide switches indicate the exact components being used. Figure 5 shows the front panel of the RC Network with the slide switches in various positions. The three-position slide switch on the left has a very useful “Open” position. It is often convenient to stop the charging process when making a measurement, and the “Open” position permits the circuit to be disconnected from the power supply.

Five binding posts allow the voltage source and/or the electrometer to be connected to components.

IMPORTANT: Never place more than 50 VDC across any component in the RC Network.

ES-9078 Electrometer

The Model ES-9078 is a voltmeter used for direct measurements of voltage and indirect measurements of current and charge. Because of its high (“infinite”) impedance of 10^{14} Ω, it is especially suited for measuring charge in electrostatic experiments. It has a sensitivity nearly 1000 times that of a standard gold-leaf electroscope, a center-zero meter that directly indicates charge polarity, and measures charges as low as 10^{-11} coulombs.

With these features, you’ll find that your electrostatics demonstrations and labs are easier to perform and, with quantitative data, are more informative.

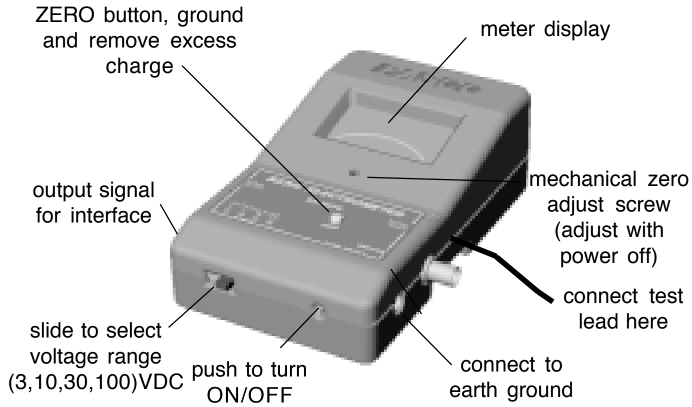


Figure 6. Front Panel Controls of the Electrometer.

The electrometer is powered by four AA-alkaline batteries, easily replaced by opening the back casing of the electrometer. One of the front panel range-indicator LEDs will blink slowly when the batteries need to be replaced. When replacing batteries, take care not to touch any of the components or wires in the integrated circuit panel, since they are all static sensitive.

Operation

The controls on the front panel of the electrometer are explained in Figure 6. Whether you are using the electrometer to measure voltage, current or charge, the setup procedure should be followed each time you turn on the electrometer.

Warning:

1. Never use the electrometer for measuring potentials more than 100 volts.

2. Never connect the electrometer to an electrostatic generator such as a Van de Graff generator of a Wimshurst machine.

3. Never touch the input leads until you have grounded yourself to an earth ground. A person walking across a rug on a cool dry day can easily acquire a potential of several thousand volts.

More information on making accurate measurements is provided in the demonstrations that follow.

Setup

1. Before turning on the electrometer, check that the meter reads zero. If not, turn the Mechanical Zero Adjust screw, located just below the meter face, until it does.
2. Connect the test lead to the input connector of the electrometer.
3. Connect the ground post of the electrometer to an earth ground.
4. Push the power button ON. One of the range switch LEDs will blink twice in quick succession.
5. To zero the meter, press the ZERO button. You're now ready to use the electrometer to measure charge, current or voltage.
6. Set the range switch to the desired voltage range. The range setting refers to the voltage input required to produce a full-scale meter deflection (e.g., a setting of 30 means that a full-scale meter deflection indicates a voltage of 30 volts).

Important Points for General Operations:

1. Between measurements, always press the Zero button to discharge all current from the electrometer.
2. Shorting the test leads together is insufficient. There may still be stray charges within the electrometer circuitry.
3. For good results, it is essential that the electrometer be connected to an earth ground (a water pipe or the ground wire from a 120 VAC socket). Only an earth ground provides a sufficient drain for excess charges that may build up during an experiment. It is also helpful if the experimenter is grounded. Just touch one hand to a good earth ground just before, or during measurements.

ES-9057A Charge Producers and Proof Planes

The Charge Producers and the Proof Planes are electrostatic components for use with the PASCO Electrostatic System. The charge producers are used to generate charges by contact. The proof planes are used to measure charge density on a charged surface.

The Charge Producers

The charge producers consist of two wands, one with blue and one with white material attached to a conductive disk, as shown in Figure 7. If the blue and white surfaces are briskly rubbed together, the white surface acquires a positive charge, and the blue surface acquires a negative charge.

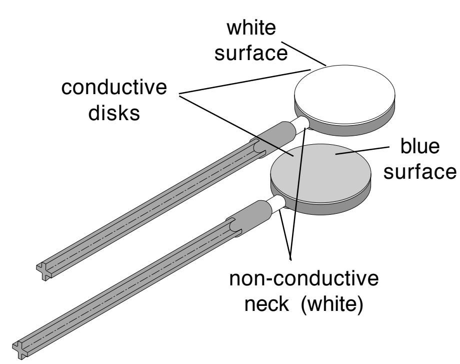


Figure 7. Charge producers.

Here are some guidelines in the proper use and care of the charge producers that are important to remember:

- If a zero charge is desirable, discharge the charge producers by touching the conductive disk to ground. To be sure the disk is fully discharged, gently breathe on the non conductive neck. The moisture from your breath will help remove any stray charge.
- Avoid touching the neck during normal use. The oils from your hands will provide a path for charges to leak off. If you experience a lot of leakage, wash the white insulator shafts with soap and water rinsing generously, the leakage should disappear. Occasionally clean the disk surfaces with alcohol.
- When you first use the charge producers, or just after cleaning, they may not produce charges readily. Rub the white surface vigorously on the conductive proof plane disk.
- The charge producers are designed to be used with the electrometer ES-9078. They do not produce sufficient charge for use with a standard electroscope.

The Proof Plane

As shown in Figure 8, the proof plane is an aluminum-covered conductive disk attached to an insulated handle. The conductive disk material is carbon-filled black polycarbonate (about $10^3\ \Omega$) with an aluminum disk. The nonconductive neck is white polycarbonate (about $10^{14}\ \Omega$).

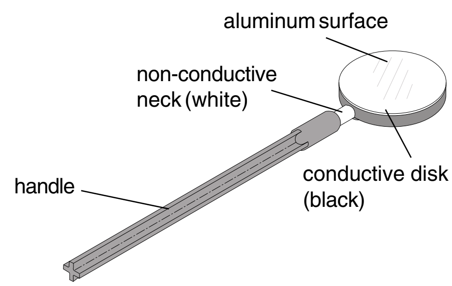


Figure 8. Proof Plane

The Proof plane is used to sample the charge density on charged conductive surfaces. A Faraday Ice Pail can then be used to measure the charge density on the proof plane.

By touching the proof plane to a surface, the proof plane will acquire the same charge distribution as the section of the surface it touched (see Figure 9). By measuring the charge on the proof plane, the charge density on that part of the surface can be determined. The greater the charge on the proof plane, the greater the charge density on the surface where the proof plane made contact.

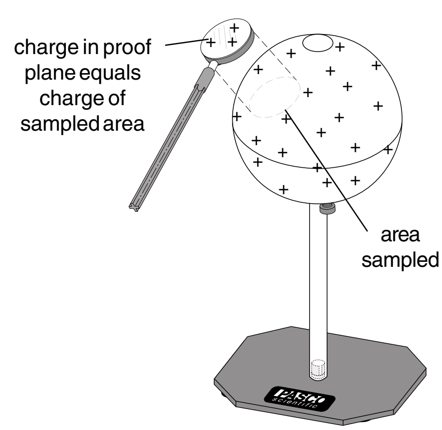


Figure 9. Proof Planes removing charge

When a proof plane is touched to a conductive surface, the proof plane becomes part of the conductive surface. If the effect on the shape of the surface is significant, the sampling of the charge density will not be accurate. Therefore, always touch the proof plane to the conductor in such a way as to minimize the distortion of the shape of the surface. Figure 10 shows the recommended method for using the proof plane to sample the charge on a conductive sphere.

> **NOTE:** The proof planes can be used to test for charge polarity on conductors of any shape. However, if you want accurate readings of charge density, the conductor surface sampled has to be considerably larger than the disk of the proof plane and have a relatively large radius of curvature at the point of contact.

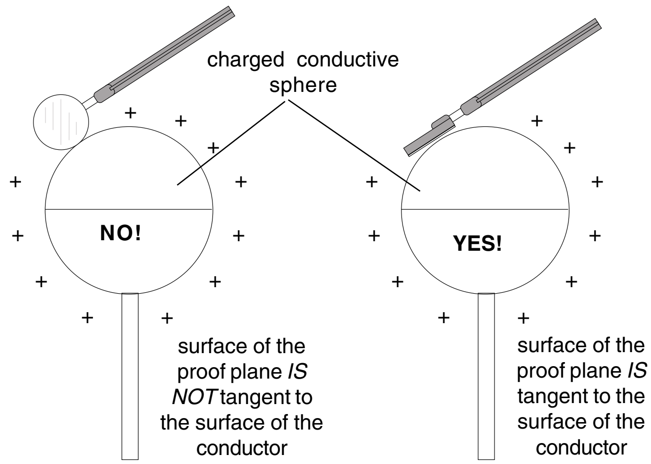


Figure 10. Proper use of a Proof Plane to Sample Charge.

Variable Capacitor (ES-9079)

The PASCO experimental variable capacitor consists of two metal plates, 20 cm in diameter, which can be adjusted to various separations. The movable plate is mounted on a calibrated slide which gives the plate separation directly in centimeters. Binding posts are provided for electrical connection to each plate. Three plastic spacers are attached to the fixed plate so that when the movable plate is made to touch these spacers, the plate separation is 1 mm.

Use a low-capacitance cable to connect the plates to the electrometer. Keep the leads of the cables separated as much as possible to minimize capacitance.

It is extremely important that the plates of the capacitor remain parallel. It is possible that through mishandling, they will cease to be parallel and adjustment must be made. On the back side of the fixed plate is a second, smaller plate with three set screws. By adjusting these three screws, the two plates may be made parallel.

Keep the clear acrylic plate supports clean to prevent charge leakage from the plates.

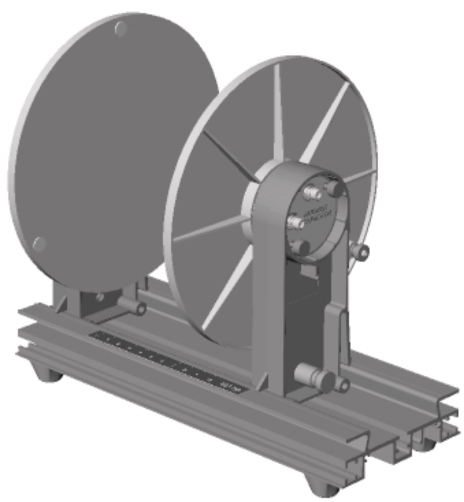


Figure 11. Basic Variable Capacitor.

Demonstration 1: Faraday Ice Pail and Charge Production

EQUIPMENT NEEDED:

—Electrometer
—Faraday Ice Pail
—Charge Producers
—Test Leads
—Earth Ground Connection
—Proof Plane (optional)

Suggestions for Introducing the Experiment

Start by showing that the electrometer is directly measuring potential difference by connecting a battery to it and measuring its voltage. You can explain that when using the ice pail, you will be only indirectly measuring charge, knowing that the amount of charge is proportional to the voltage. The readings will be in volts, not in coulombs. Change the polarity of the leads to show how the meter needle deflects in the opposite direction. Explain how this can tell us the type of charge in the ice pail.

Equipment Set Up

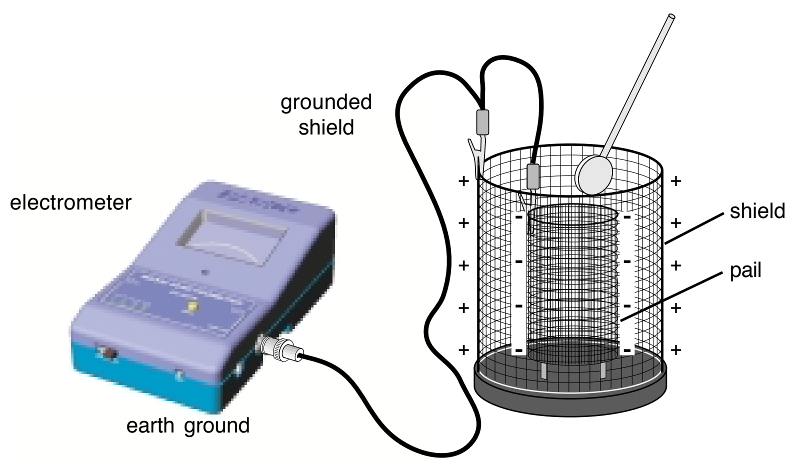


Figure 1.1 Demonstration Setup

Introduction

The purpose of this demonstration is to investigate the relation between the charge induced on the ice pail by a charged object placed in the pail, and the charge of the object. This demonstration is also useful for investigating the nature of charging an object by contact as compared to charging it by induction, and to demonstrate the conservation of charge.

Before beginning any experiment using the ice pail, the pail must be momentarily grounded. When the ice pail is connected to the electrometer, and the electrometer is connected to an earth-ground, simply press the ZERO button whenever you need to discharge both the pail and the electrometer. While conducting an experiment, it is convenient to keep yourself grounded, by continuously resting one hand on the upper edge of the shield, or by direct contact with the earth-ground connector.

NOTE: Make sure the electrometer is connected to an earth-ground, or the pail will not be properly grounded.

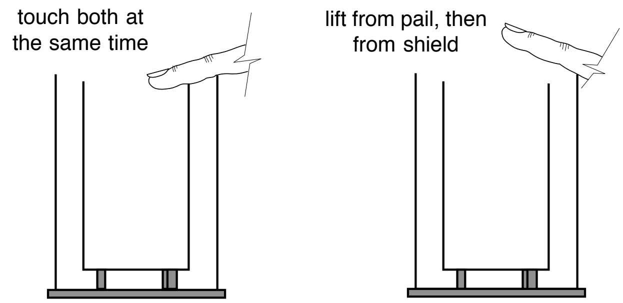


Figure 1.2 Grounding the Ice Pail.

Procedure 1A: Charging by Induction vs. Charging by Contact

1. Connect the electrometer to the Faraday Ice Pail as shown in Figure 1.1. Make sure to ground the electrometer and the ice pail. The electrometer should read zero when grounded, indicating there is no charge in the ice pail. Press the zero button to completely remove all charge from the electrometer and the ice pail.

2. Always start with the voltage range in the higher setting (100 V) and adjust down if needed. Analog meters are typically most accurate in the range of 1/3 to 2/3 of full scale.

3. The charge producers will be used as charged objects. Here is a general procedure to follow when charging the producers:

   - Always remove any stray charge on the necks and handles of the charge producers by touching the necks and handles to the grounded shield. You must also be grounded while doing this. It also helps if you breathe on the neck of the charge producer, so that the moisture in your breath removes any residual charge on the neck.

   - Rub the white and blue surfaces together to separate charges.

   - Keep in your hand only the producer you are going to use. Put the other charge producer away, far from contact with any of the ice pail surfaces.

   - Before inserting the charged disk in the ice pail, make sure you're touching the grounded shield.

4. Carefully insert the charged object into the ice pail, all the way to the lower half of the pail, but without letting it touch the pail. Note the electrometer reading.

5. Remove the object and again note the electrometer reading. If the handle never touched the pail, the reading must be zero.

   Question to think about: Why was there a potential difference between the pail and the shield only while the charged object was inside?

6. Push the zero button to remove any residual charge. Now insert the object again, but let it touch the ice pail. Make sure your students know and see that you are touching the ice pail with the charged disk this time.

7. Remove the object and note the electrometer reading.

   Questions: Why is there now a permanent potential difference between the ice pail and the shield? Where did the charge on the ice pail come from?

8. To show that the charge gained by the ice pail was lost by the disk, ground the ice pail to remove all charge. Press the ZERO button to remove residual charges from the electrometer. Insert the wand again into the ice pail. Does any charge remain on it?

Procedure 1B: Conservation of Charge

1. Starting with initially uncharged charge producers, rub the blue and white materials together. Follow the general procedure for charging listed in part A, except that in this case you must keep both producers from touching anything else after charging. (Keep them in your hands, without letting them touch each other or the ice pail.)

2. Use the Faraday Ice Pail to measure the magnitude and polarity of each of the charged wands by inserting them one at a time into the ice pail and noting the reading on the electrometer.

   Questions: What is the relation between the magnitude of the charges?
   What is the relation between the polarity of the charges?
   Was charge conserved in the demonstration?

3. Completely remove all charge from the charge producers by grounding them. Do not forget to also remove any stray charge from the necks and handles.

4. Insert both charge producers into the ice pail and rub them together inside the pail. Note the electrometer reading. Do not let the charge producers touch the pail.

5. Remove one charge producer and note the electrometer reading. Replace the charge producer and remove the other. Note the electrometer readings. Using the magnitude and polarity of the measurements, comment on conservation of charge.

Extra Things to Try

1. Try repeating Procedure A with the opposite charged wand.

2. Try rubbing the white charge producer with a proof plane, then measure the magnitude and polarity of the charges produced.

3. Try rubbing the blue material with a proof plane. Measure the magnitude and polarity of the charges produced.

4. Construct a list of materials such that if a material lower in the list is rubbed with a material higher in the list, the higher material is always positive.

Demonstration 2: Charge Distribution

EQUIPMENT NEEDED:

—Electrometer
—Faraday Ice Pail
—Electrostatic Voltage Source (ES-9077)
—Proof Planes
—13 cm Conductive Spheres (2)
—Test Leads
—Earth Ground Connection - Patch cord

Equipment Set Up

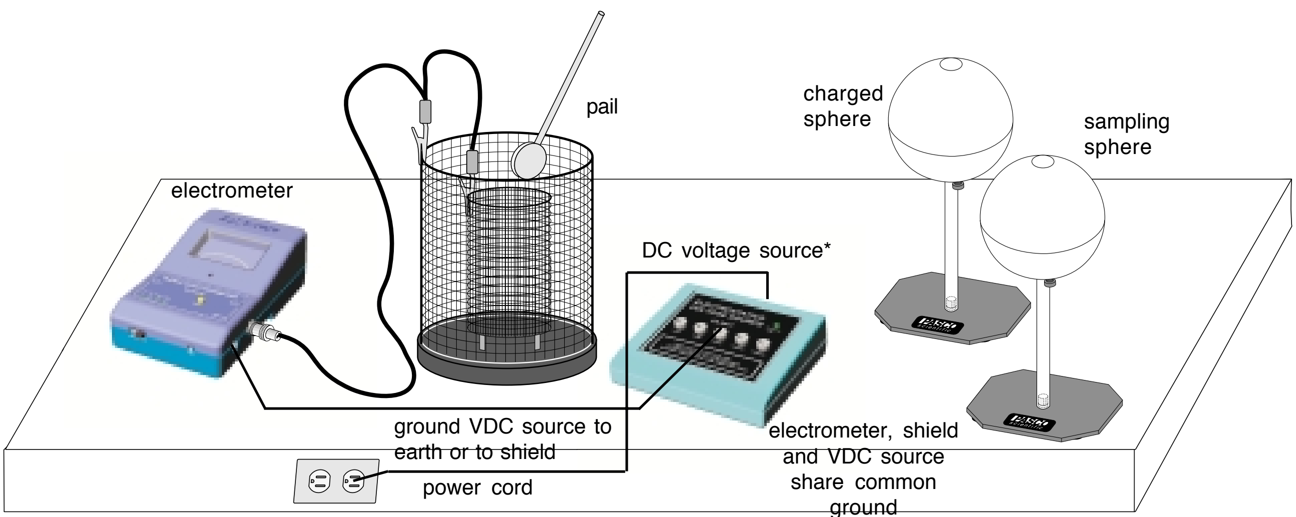


Figure 2.1 Demonstration Setup

* An earth ground for the system is obtained through the DC voltage source wall-mount power supply.

Introduction

The purpose of this demonstration is to investigate the way charge is distributed over a surface, by measuring variations of charge density. A charged surface will be sampled with a proof plane. The proof plane will then be inserted in the Faraday Ice Pail to measure the charge. By sampling different sections of the surface, the relative charge density can be observed. For example, you may find that the amount of charge on two equal sized regions on the surface of a conductor may differ in magnitude or even in sign. This occurs for non-uniform charge distribution. Or you may observe that everywhere on the surface the charge has the same magnitude and sign. This occurs for uniform charge distribution.

An important aspect of measuring charge distributions is charge conservation. The proof plane removes some charge from the surface it samples. If the proof plane is grounded after each measurement, the surface will be depleted of charge with consecutive measurements. However, by not grounding the proof plane (and by not letting it touch the ice pail), the charge on the surface is not depleted. That charge which the proof plane removed for one measurement is always returned to the surface when the next sampling is made.

> ***NOTE: When the disk of the proof plane touches the surface being sampled, it essentially becomes part of the surface. To minimize distortion of the surface shape when sampling, hold the proof plane flat against the surface, as indicated in the accessory instructions. Please refer to the accessory instructions for the details on how to use the proof planes.***

Procedure:

1. Before starting, make sure the Faraday Ice Pail is properly grounded, with the shield connected to earth ground. The electrometer, connected to the pail, must also be grounded.

2. Place the two aluminum spheres at least 50 cm apart. Connect one of the spheres to the Electrostatic Voltage Source (ES-9077) providing 1000 VDC. The voltage source is to be grounded to the same earth ground as the shield and the electrometer. The connected sphere will be used as a charging body.

3. Momentarily ground the other sphere to remove any residual charge from it.

4. Start the demonstration by sampling and recording the charge at several different points on the sampling sphere. (The sphere that was grounded in step 2.) Choose points on all sides to represent an overall sample of the surface.

5. Now bring the 1000 VDC sphere close to the grounded sphere, until their surfaces are about 1 cm apart. Turn the voltage source ON, then sample and record the charge at the same points sampled before.

6. Momentarily ground the sampling sphere again, by touching one hand to the grounded ice pail shield and the other hand to the sphere. (Make sure the ice pail is grounded before doing this.) Again, sample and record the charge at the same points sampled before.

7. Remove the 1000 VDC sphere until it is at least 50 cm away from the sampling sphere. Again, sample and record the charge at the same points sampled before.

Analysis

1. What produced the charge distributions at each step of the experiment?

2. Why did any charge remain on the second sphere even after it was grounded?

Extra Things to Try

1. To show that the charge on a conductor always resides on the outside surface, bend a flexible sheet of metal into a cylinder. Charge the cylinder and measure the charge density in the inner and outer surfaces. Notice that charge is always on the outside.

2. To show how the surface shape affects charge density, try touching two charged proof planes together so that they are symmetrical around their point of contact. Measure the charge on each. Next touch them in an asymmetrical manner and measure the charge in each. Does any have more charge than the other? Which one? (Care should be taken to eliminate stray charges from necks and handles, to prevent erroneous readings.)

Figure 2.2 Test of Different Sampling Configurations