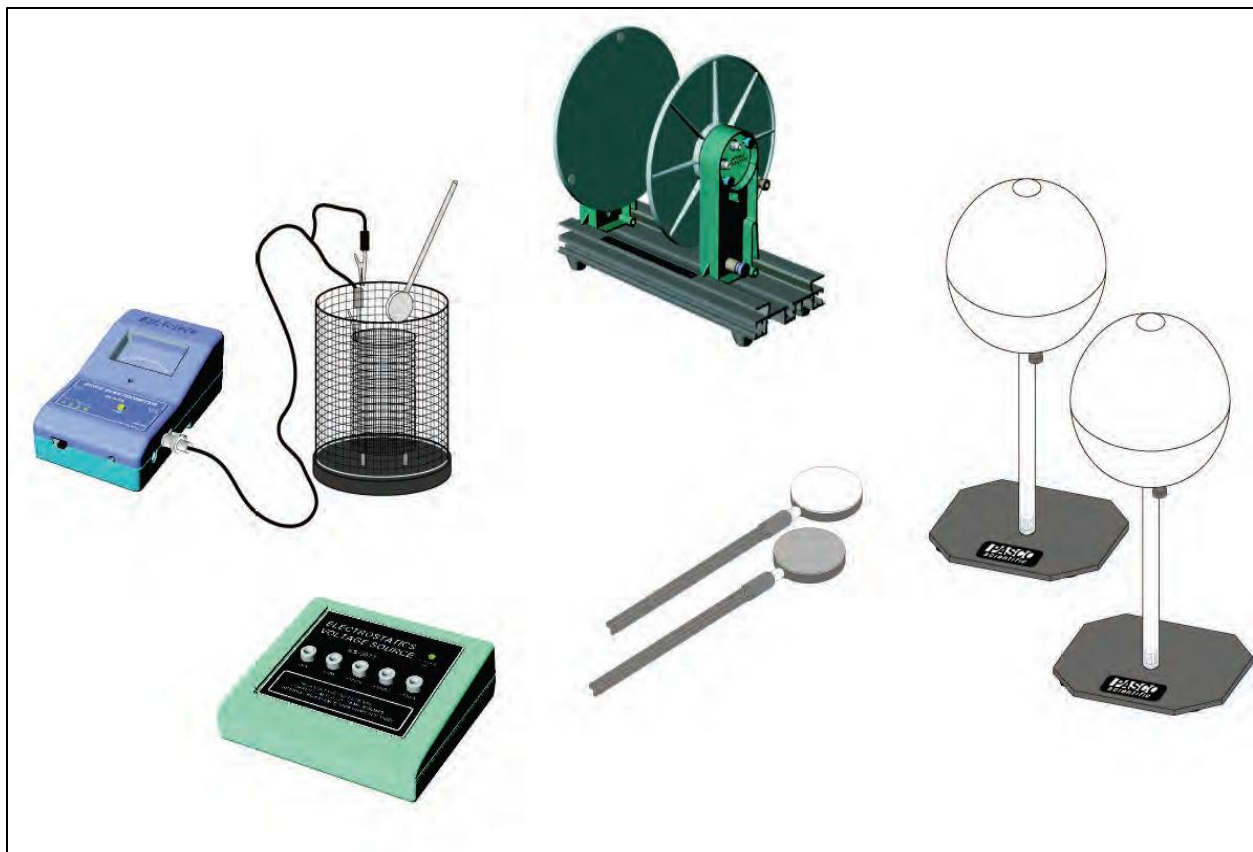


[Basic Electrostatics System]



Name:-----

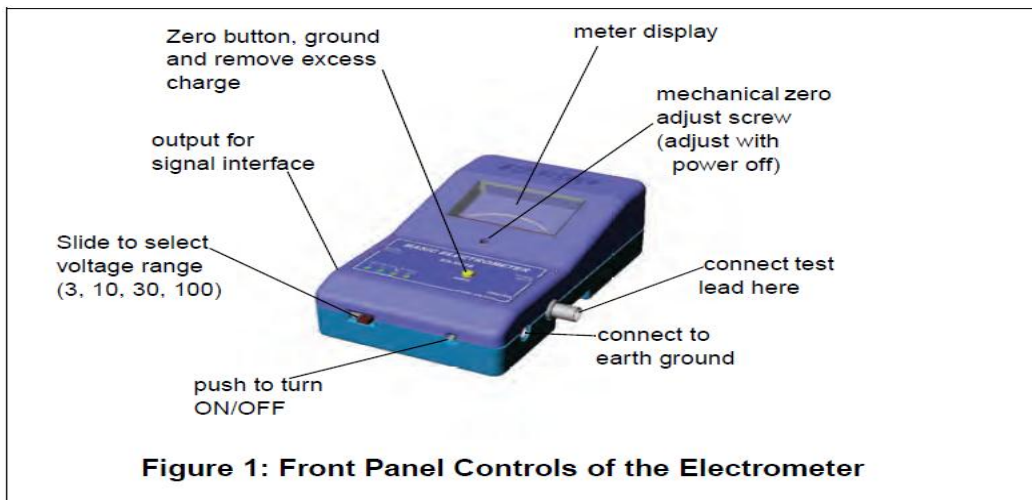
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Equipment Description

Electrometer

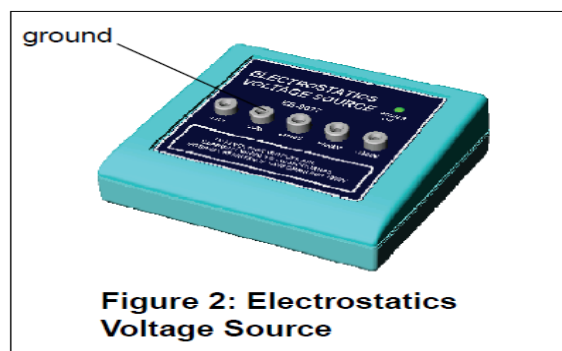
The Electrometer is a voltmeter used for direct measurements of voltage and indirect measurements of current and charge.

It is especially suited for measuring charge in electrostatic experiments. A center-zero meter that directly indicates charge polarity.



Electrostatics Voltage Source

The Electrostatics Voltage Source 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 1000 V, 2000 V, and 3000 V outputs for the Faraday ice pail and conducting sphere experiments.



Variable Capacitor

The variable capacitor consists of two metal plates, 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.



Figure 3: Variable Capacitor

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 very important that the plates of the capacitor remain parallel. It is possible that through mishandling, they will cease to be parallel, and adjustments 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 kept parallel. Keep the clear acrylic plate supports clean to prevent charge leakage from the plates.

Charge Producers and Proof Plane

The charge producers are used to generate charges by contact. The proof plane is used to measure charge density on a charged surface. The charge producers consist of two wands, one with blue and one with white material attached to a conductive disk, as shown in Figure 4. 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.

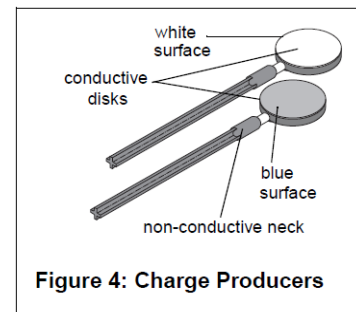


Figure 4: Charge Producers

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

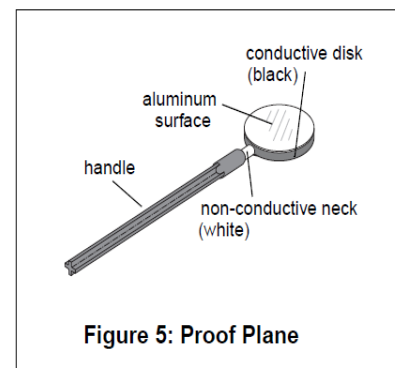
- If a zero charge is desirable, discharge the charge producers by touching the conductive disk to ground. To be sure the disk is fully discharged; gently breathe on the non-conductive neck. The moisture from your breath will help remove any stray charge.

- 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.

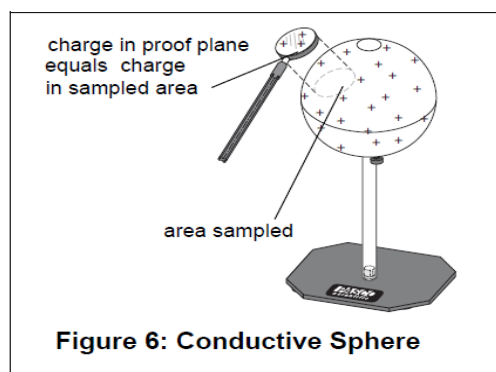
- When you first use the charge producers, or just after cleaning, they may not produce charges readily. Rub the white surface vigorously on the conductive proof plane disk.

The Proof Plane

As shown in Figure 5, the proof plane is an aluminum-covered conductive disk attached to an insulated handle. The conductive disk material is carbon-filled black polycarbonate with an aluminum disk. The nonconductive neck is white polycarbonate. 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.

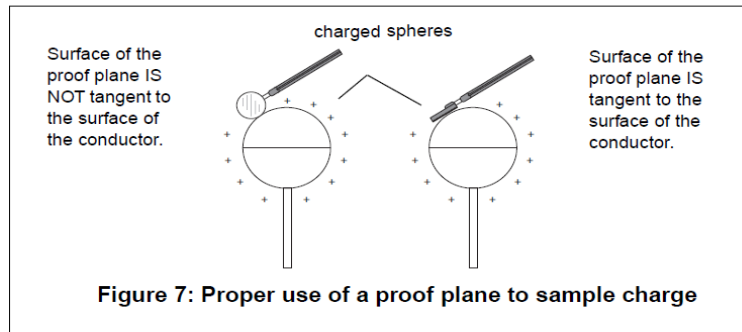


By touching the proof plane to a surface, the proof plane will acquire the same charge distribution as the section of the surface it touched (See Figure 6).



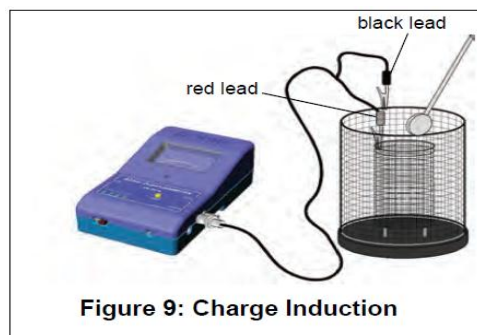
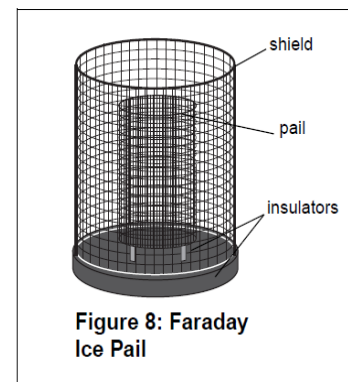
By measuring the charge on the proof plane, the charge density on that part of the surface can be determined. The greater the charge on the proof plane, the greater the charge density on the surface where the proof plane made contact. When a proof plane is touched to a conductive surface, the proof plane 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 7 shows the recommended method for using the proof plane to sample charge on a conductive sphere.



Faraday Ice Pail

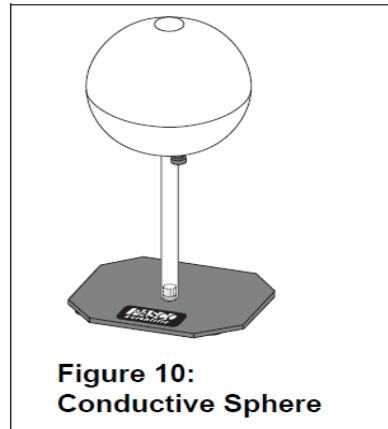
The Faraday Ice Pail is shown in Figure 8. Originally designed by Michael Faraday, it works on the principle that any charge placed inside a conducting surface will induce an equal charge on the outside of the surface. It is an excellent product for sampling charges and charge distributions. The PASCO version illustrated above consists of two wire mesh cylinders, one inside the other, mounted on a molded plastic bottom. 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. 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 9).



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 Faraday Ice Pail be momentarily grounded prior to starting any experiment.

Conductive Spheres

The conductive spheres are used to store electrical charge. The PASCO Model 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 insulating 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 sphere and insulating rods should be kept free of dirt, grease, and fingerprints to minimize charge leakage from the sphere.

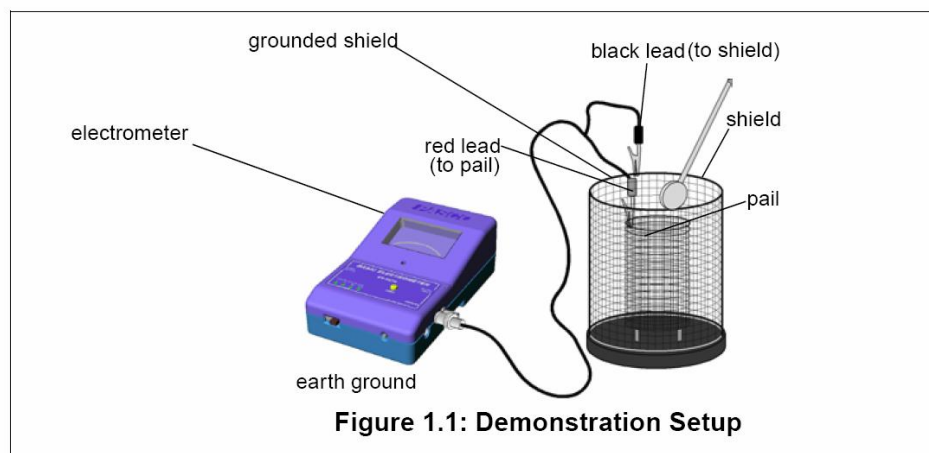


Demonstration 1: Faraday Ice Pail and Charge Production

Equipment required

Electrometer	Charge Producers
Faraday Ice Pail	Proof plane
Earth ground connection	Test Leads

Equipment Setup

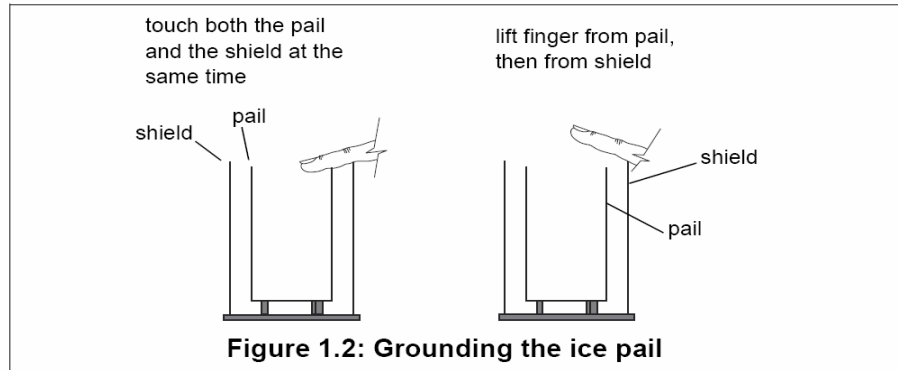


Purpose:

-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.

-Investigating the nature of charging an object by contact as compared to charging it by induction, and to demonstrate the conservation of charge.

WARNING: Make sure the electrometer is connected to an earth ground, or the pail will not be properly grounded. Performing tests or experiments with an ungrounded pail could cause possible electrical shock or injury.



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.
- 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.

Charge producer	Electrometer reading
Blue	
White	

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

Charge producer	Electrometer reading
Blue	
White	

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

6. Try again to 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.

Charge producer	Electrometer reading
Blue	
White	

7. Push the **Zero** button to remove any residual charge. Now insert the object again, but let it touch the ice pail.

Charge producer	Electrometer reading
Blue	
White	

8. Remove the object and note the electrometer reading.

Charge producer	Electrometer reading
Blue	
White	

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?

9. 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?

Charge producer	Electrometer reading
Blue	
White	

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 1A, 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.

Charge producer	Electrometer reading
Blue	
White	

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.

Electrometer reading	
----------------------	--

5. Remove one charge producer and note the electrometer reading. Replace the charge producer and remove the other. Note the electrometer readings.

Charge producer	Electrometer reading
Blue	
White	

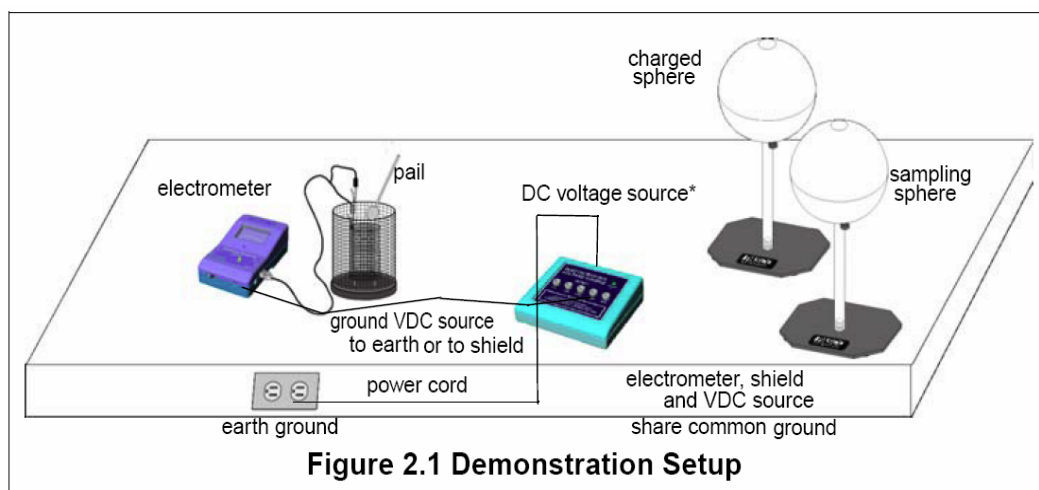
Questions: What is the relation between the magnitude of the charges? What is the relation between the polarity of the charges? Was charge conserved in the demonstration?

Demonstration 2: Charge Distribution

Equipment Required:

Electrometer	Earth ground connection
Electrostatic Voltage Source	Faraday Ice Pail
Conductive Spheres	Proof Planes

Equipment Setup



Introduction

Purpose:

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**. Alternately, 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 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. Follow the setup in Figure 2.1, with the black lead connected over the edge of the shield and the red lead connected over the edge of the ice pail.

2. Place the two aluminum spheres at least **50 cm** apart. Connect one of the spheres to the Electrostatic Voltage Source, providing **2000 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.

	Front	Right	Left	Up	Down	Back
EM reading						

5. Now bring the 2000 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.

	Front	Right	Left	Up	Down	Back
EM reading						

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.

	Front	Right	Left	Up	Down	Back
EM reading						

7. Remove the 2000 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.

	Front	Right	Left	Up	Down	Back
EM reading						

Demonstration 3: Capacitance and Dielectrics

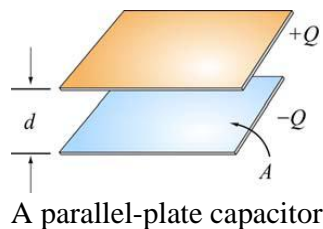
Equipment Required:

Electrometer	Test leads
Faraday Ice Pail	13 cm Conductive Spheres(2)
Charge Producers	Variable Capacitor (Parallel Plates)
Proof Planes	Capacitor (about 30 pF)
Electrostatic Voltage Source	Sheet of dielectric material

Introduction

A capacitor is a device which stores electric charge. Capacitors vary in shape and size, but the basic configuration is two conductors carrying equal but opposite charges. Capacitors have many important applications in electronics as storing electric potential energy.

The simplest example of a capacitor consists of two conducting plates of area A , which are parallel to each other, and separated by a distance d , as shown in Figure



Experiments show that the amount of charge Q stored in a capacitor is linearly proportional to ΔV , the electric potential difference between the plates. Thus, we may write

$$Q = C|\Delta V|$$

The purpose of this series of demonstrations is to investigate the relationship between charge, voltage and capacitance for a parallel plate capacitor. Each one of the variables will be held constant in turn, varying one of the others while measuring the third. The capacitance of a parallel plate capacitor is given by

$$C = \frac{\epsilon A}{d}$$

where

ϵ : the dielectric coefficient,

A : the plate area, and

d : the plate separation.

Various materials can be inserted between the plates to measure the dielectric coefficient of the materials.

3A: Measuring C, V and Q for a Parallel Plate Capacitor

3A.1: V Measured, Q Variable, C Constant

Theory:

In this experiment the plate separation is fixed to about 2 mm in this way C is kept constant, the proof plane transfers the charge from the charged sphere to one of the plates of the capacitor causing a potential difference between the two plates, this potential difference can be read from the electrometer as follows:

The capacitance of the capacitor is calculated using:

$$C = \frac{\epsilon_o A}{d}$$

Where:

$\epsilon_o = 8.85 \times 10^{-12} \text{ F/m}$ (the dielectric coefficient)

$A = \pi r^2$ (area of the plate)

d (separation between the two plates)

Procedure:

1. Figure 3.1 below shows the equipment set up. The Parallel Plate capacitor is connected to the electrometer. The electrometer is grounded to earth. One of the spheres is connected to the voltage source, set at **2000 VDC**. Take care to place the capacitor sufficiently far away from the sphere and the voltage source, to prevent it from being charged by induction.

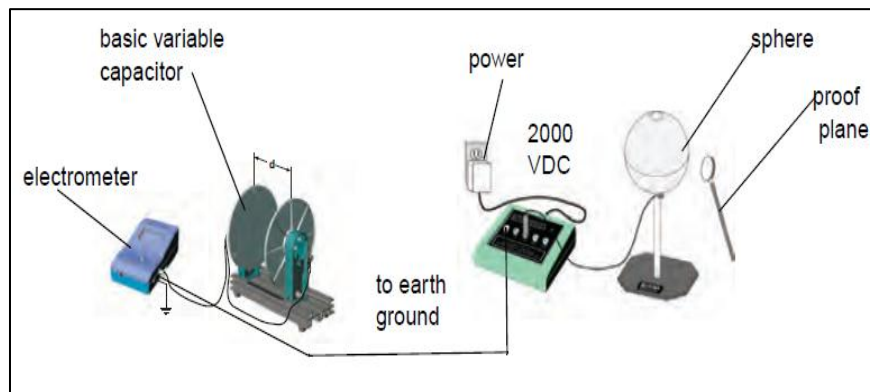


Fig 3.1 : Demonstration Setup

2. Press the **ZERO** button to remove any residual charge from the electrometer and the plates of the capacitor.

3. Set the plate separation to about **2 mm**. Use a proof plane to transfer charge from the charged sphere to the capacitor plates. The charge is transferred merely by touching the proof plane to the sphere and then to one capacitor plate. If you always touch the sphere and the capacitor plate at the same place, equal amounts of charge will be transferred each time.

4. Observe how the potential difference reading from the electrometer varies as more charge is put in the capacitor.

Results:

$d =$ -----

$r =$ -----

$A =$ -----

	$C = \frac{\epsilon_0 A}{d}$ (Farad)	V (volts)	$Q = CV$ (coulomb)
1			
2			
3			
4			
5			

3A. 2: Q Measured, V Variable, C Constant

Introduction:

For all experiments, the electrometer can be thought of as an infinite impedance voltmeter in parallel with a capacitor. The capacitor C_E represents the internal capacitance of the electrometer, plus the capacitance of the leads.

Whenever you want quantitative measurements of charge, voltage or capacitance, you need to consider the effect of the internal capacitance of the electrometer; unless you are certain that the capacitor you are using has a high enough capacitance to disregard C_E .

$C_E = 25 \text{ PF}$ is the capacitance of the electrometer.

Procedure:

1. Figure 3.2 shows the equipment set up. The Parallel Plate capacitor has an initial plate separation of 6 cm and is connected to the voltage source, set initially at **3000 VDC**. The Faraday Ice Pail is connected to the electrometer and the electrometer is grounded to earth.

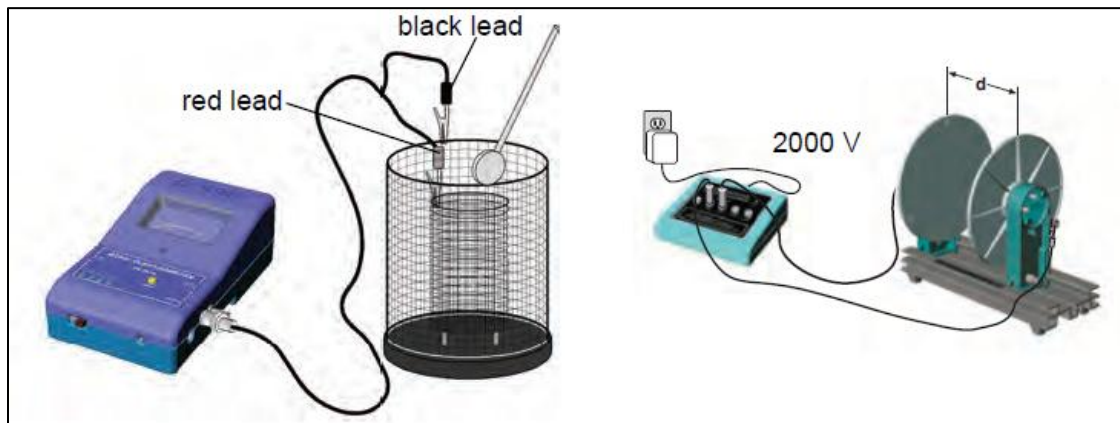


Fig 3.2: Demonstration Setup

2. Keep the plate separation constant and change the potential across the plates by changing the setting of the voltage source. You have to move the connecting cable from the 3000 V to the 2000 V to the 1000 V slot.

Results: $d = \text{-----}$ $r = \text{-----}$ $A = \text{-----}$

V (volts)	$C = \frac{\epsilon_0 A}{d}$ (Farad)	$Q = CV$ (coulomb)	V_E (volts)	$q = C_E V_E$ (coulomb)	$\frac{q}{Q}$
3000					
2000					
1000					

3A. 3: V Measured, C Variable, Q Constant

Procedure:

1. Figure 3.3 shows the equipment set up. The Parallel Plate capacitor is connected to the electrometer and the electrometer is grounded to earth. The voltage source will be used to only momentarily charge the capacitor.

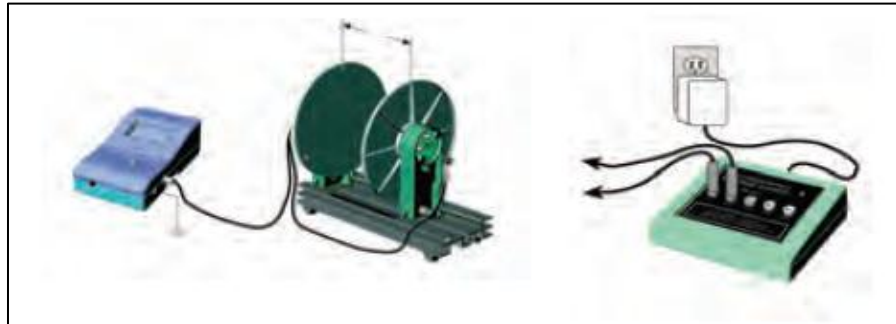


Fig 3.3: Demonstration Setup

2. With the plate separation at **2 mm**, charge the plates by momentarily connecting them across the voltage source, set at **30 V**. Adjust the scale sensitivity of the electrometer so that the initially charged plates represent a meter reading of about 1/5 scale.

3. Increase the plate separation and note the electrometer's readings at various separations, tabulate your results as follows:

Results:

$r = \text{-----}$

$A = \text{-----}$

$d(mm)$	$C_p(farad)$	$C = C_p + C_E$ (farad)	$V(volts)$	$Q(coloumb)$
2				
6				
10				
14				

3B: Dielectric Coefficients

Introduction:

The dielectric coefficient is κ the dimensionless factor by which the capacitance increases (relative to the value of capacitance before the dielectric) when a dielectric is inserted between the plates. It is a fundamental property of the dielectric material and is independent of the size or shape of the capacitor. Table 3.1 lists the dielectric coefficients of some common materials. The ideal procedure to measure would be to simply slip a piece of dielectric material between a set of charged capacitor plates and then note the changes in potential. Then calculate the dielectric coefficient using this formula:

$$\kappa = \frac{C_E(V_i - V_f) + C_p V_i}{C_p V_f}$$

Where:

C_E is the electrometer capacitance = 25 pF

C_p is the capacitance of the parallel plate capacitor $C_p = \frac{\epsilon_0 A}{d}$

V_i is the initial reading of the electrometer before inserting the dielectric

V_f is the final reading of the electrometer after inserting the dielectric

However, sliding a dielectric between the plates of the capacitor when they are too close together can generate a significant static charge that will alter the measurements. Hence, it is best to proceed as follows:

Procedure:

1. Connect the electrometer across the plates of the capacitor and set the separation between the plates to about **3 mm**.

NOTE: Since your model allows both plates to be moved, choose one to keep fixed and the other to be the movable one.

2. Raise the side of the set up nearest the movable plate by setting a block about **3 cm** high below it, as shown in Figure 3.4.

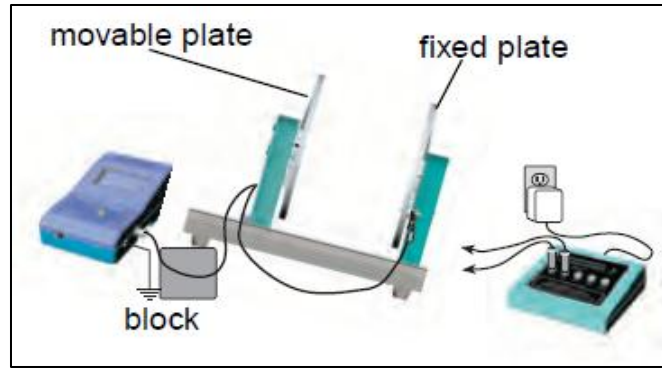


Fig 3.4: Demonstration Setup

3. Use the voltage source to momentarily touch the plates and charge them to about 4/5 full scale. Record the voltage reading of the electrometer V_i .

4. Carefully increase the separation of the plates until it is enough to insert the dielectric without forcing it. It should be enough so that you can simply lean the dielectric sheet against the stationary plate. Make sure the dielectric you are using is free of residual charge before inserting it.

5. After inserting the dielectric, return the plates to the original **3 mm** separation and record the new electrometer reading V_f .

6. Pull the plates apart again, and lift and carefully remove the dielectric sheet.

7. Return the plates to the original **3 mm** separation and check that the electrometer reading agrees with the original V_i reading.

Table 3.1: Some Dielectric Coefficients

Material	κ
Vacuum	1
Air	1.00059
Polystyrene	2.6
Paper	3.7
Pyrex	4.7
Mica	5.4
Porcelain	6.5

Results:

Material	V_i(volts)	V_f(volts)	κ
Air			
Plastic			
Paper			