UNIVERSITY PHYSICS

EXPERIMENT 1

www.ccccd.edu/physics

COLLIN COUNTY COMMUNITY COLLEGE

Transferring Electric Charge

Produced by the Physics Staff at
Collin County Community College

Purpose

In this experiment, you will investigate electric charges.

Equipment

- Electrometer
- Faraday cage
- Variable capacitor
- 2 Proof planes - black
- Plastic stool
- Six long clip leads
- Power Supply
- Black spheres
- Charge producers - blue & white
- 1-meter ruler
- Wrist strap w/ alligator clip

Introduction

In the first semester you learned of two types of forces: *contact* forces that objects exert when they touch each other and *field* forces that they exert at a distance. The only field force you studied then was the force of gravity, caused by the mass of an object. In effect, according to Newton, the space surrounding every mass (e.g., mass *A*) has a special property such that any other mass (say, mass *B*) in that space feels a force of attraction toward mass *A*.

Gravity is a very weak field force; it takes an enormous mass to cause a measurable gravitational force. But there is a much stronger field force between certain objects that has nothing to do with their masses. Philosophers have known since the time of the Greek *Thales* in 600 BC that under certain conditions, certain objects exert measurable forces of attraction or repulsion on each other.

Until the early nineteenth century, physicists believed there were two separate forces, called magnetic and electric, that acted at a distance between certain objects. The magnetic force was unique to one family of substances—iron, cobalt, nickel, and some of their alloys. It did not occur between any other substances. The electric force, however, occurred between many substances but only after they had been rubbed with a different substance.

It wasn’t until 1819 that Hans Christian Oersted, in Copenhagen, discovered that electricity was a fundamental phenomenon and that magnetism was one of the results of electricity. In the 2600 years since *Thales*, physicists have developed a model of the relationships between electrical properties to describe how they act. Our modern understanding of electricity can be described by six statements:

1. All matter exhibits an inherent property, independent of its mass and density, called electric charge.
2. There are two kinds of electric charge, called positive and negative.
3. This charge property resides in the smallest discrete constituents of matter. Positive charge is a basic property of protons, and negative charge is a basic property of electrons.
4. If any object (of either microscopic or macroscopic size) contains more protons than electrons, the object exhibits the overall properties of positive charge. If it has a surplus of electrons, it exhibits the properties of negative charge. If the object contains equal

numbers of protons and electrons uniformly distributed throughout, it exhibits no electric properties—it is said to be electrically neutral.

5. If two objects have the same type of electric charge (both positive or both negative), they exert a repulsive force on each other. If they have opposite types of charge, they exert an attractive force.
6. Electric charge can be transferred from one region of a substance to another, or from one object to another. In solid matter, charge is transferred by movement of electrons. In fluid matter, both electrons and protons move to transfer charge.

You can "charge" a neutral object (endow it with an excess charge of one type) by transferring some electrons to it or from it. It will then exert a force on a nearby charged object. You can also redistribute the charge on a neutral object so that even though it remains neutral overall, it will exert a force on a nearby charged object.

In this experiment, you will charge neutral objects by rubbing them together or by connecting them to an electric power supply; you will use a special instrument to measure the excess charge on an object; you will charge several conducting objects and observe how the excess charge distributes itself over their surfaces; and you will observe the effects of charging your body with excess electrons.

Electrical Conductors

All substances can be categorized by how easily electric charge moves in them. Solids or fluids in which charge easily flows from point to point are called *good electrical conductors*. Substances in which charge flows very little from point to point are called poor electrical conductors or *good insulators*. A third category of substances in which charge moves only under special conditions is called *semiconductors*.

All solid substances can be ranked according to their electrical conductivity, from the best conductor (silver) to the best insulator (fused quartz). A small amount of charge can be made to move even in poor conductors but, given the same conditions, the higher the conductivity, the more charge can be moved.

A neutral object has equal numbers of protons and electrons (equal amounts of positive and negative charge) throughout its volume, but the charge is not necessarily distributed uniformly. Local regions having an excess of positive charge will locally display the characteristics of a positively-charged object, but you be sure that some other region of the object is locally displaying the opposite characteristics. You can change the distribution of charge on any object *A* (conductor or insulator, neutral or charged) by bringing another charged object *B* near to it. Object *B* will exert a force on the electrons in object *A*, causing some of them to move and thus redistribute the overall charge on *A*.

Charged Objects

Any excess charge on an *insulator*, with no other charge nearby, will distribute itself uniformly throughout its volume. Any excess charge on a *conductor* will reside entirely on its surface. Any object having an excess charge of one kind, or any neutral object whose charge is distributed unequally so that local regions have excess charge, is said to be *charged*. You can charge an object, leaving it with an excess of one kind of charge, in either of two ways.

Charging by Contact

Some charge will almost always flow between two solid objects (either conductors or insulators) that are brought into physical contact. If the objects have different amounts of excess charge before they touch, electrons will be pushed from the object having more electrons to the object having fewer electrons. In Figure 1.1, a negatively-charged rod made of amber touches a neutral ball made of pith hanging from a string. Some electrons flow from the rod to the ball, leaving both negatively charged. The repulsive force between the two negatively-charged objects pushes the ball away from the rod. But how was the amber rod negatively charged in the first place? If two neutral objects have different physical properties (i.e., if they are different elements or compounds) electrons will flow from one to the other when they touch. The atoms of amber, for example, attract electrons with a stronger force than the atoms of cat fur do. When you put amber and cat fur into contact, some electrons leave the fur and move to the amber, leaving the two objects with equal but opposite excess charges. The more intimate the contact, the more charge flows over, so rubbing two objects together transfers more charge than simply touching them.

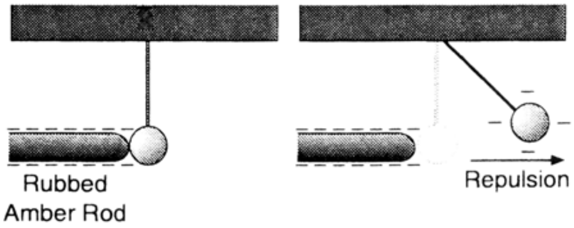

Figure 1.1

Charging by Induction

If you bring a charged object near to but not touching) a neutral object, the electrons in the neutral object will redistribute themselves. In Figure 1.2, a negatively charged rod brought near to a neutral ball will redistribute the charge on the ball. If you then remove some of the electrons on the back side of the ball by grounding it, the ball will be left with excess positive charge.

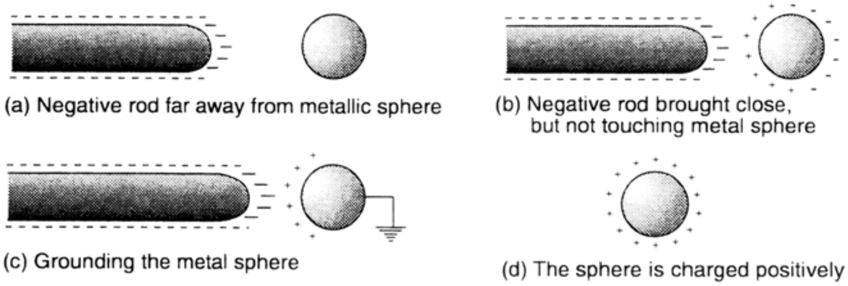

Figure 1.2

<u>Electric Force</u>

Charles Augustin de Coulomb was the first to actually measure the force between two charged objects. Imagine his surprise and delight when he discovered that the relationship between force, charge, and distance had the same mathematical form as Newton's famous gravitational relationship between force, mass, and distance. Coulomb wrote the relationship as

$$F = \frac{kQ_1Q_2}{d^2}$$ ***Equation 1.1***

where F is the force between two small objects with charges Q_1 and Q_2, d is the distance between them, and k is a constant of proportionality whose value depends on the units of measure being used.

Electrostatics

The field of study concerned with the characteristics of electric charges at rest (as opposed to charges continuously flowing through a conductor) is called *electrostatics*. Many modern devices, e.g., the photocopier, are designed using electrostatic principles. An image of the page to be copied creates a similar pattern of positive charge (wherever the image is dark) on a non-conducting sheet. Small particles of negatively charged toner (carbon soot) are spread evenly across the sheet but they stick only where the pattern is positively charged. This pattern of toner is transferred to a blank sheet of positively charged paper and then fused into place by heat. The residual charge is removed from the paper as it is ejected with the pattern permanently printed on it.

To experimentally investigate the characteristics of charges at rest, you will need some kind of charge measuring instrument. The electrometer is such an instrument. Not only will it will detect small amounts of excess charge, it is quantitative (it has a calibrated scale which indicates the amount of excess charge), and it shows the polarity of the excess charge (positive or negative). In this experiment, you will use the electrometer in Figure 1.3 to measure the excess charge and charge distributions that you produce.

Note. *The electrometer is a sophisticated and delicate instrument. You need to understand the information in this section before you perform the experiment.*

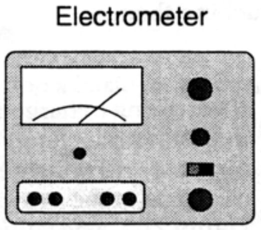

Figure 1.3

The electrometer measures the potential difference of any conductor it is attached to. Potential difference is measured in units of volts and is proportional to the amount of excess electric charge on the conductor. The electrometer scale is calibrated to display the voltage between the meter's input probe and ground clip, but you can convert the scale reading to coulombs of charge with the conversion factor $1\text{ V} = 1.7 \times 10^{-6}\text{ C}$.

The electrometer has two inputs, red and black. The black input is connected inside the instrument to the earth (i.e., it is put in electrical contact with the earth via a conductor that goes into the ground, such as the ground terminal of the building's power outlets). Any conductor, such as the black input, that is electrically connected to the earth is said to be *grounded*. Therefore, we call the black input the "ground". We will call the red input of the electrometer the "probe", and we will connect clip leads to both the probe and ground inputs on the electrometer.

Charging the Electrometer

If you set the electrometer to the 10-volt range and connect the probe and ground clips to the positive and negative terminals, respectively, of a 6-volt battery, the meter will read + 6 volts. If you then remove the battery, leave the electrometer probe lying on an insulating surface, and bring a charged piece of plastic (charged by rubbing it with cloth) near it, you can again make the meter read + 6 volts. In both cases, the meter tells you that the electric potential of the probe is 6 volts greater than the electric potential of the ground clip.

What is actually happening? When the battery is connected to the electrometer, the positive terminal attracts electrons from the probe and deposits them on the ground clip. This leaves the probe with an excess positive charge, and the ground clip with the same amount of excess negative charge. The meter indicates the potential difference between the probe and the ground clip (proportional to the excess charge on the terminals). You have charged the probe by direct contact with the battery.

Then when you bring the positively-charged plastic near the unconnected probe, the plastic attracts electrons in the conducting probe cable to its outer end, leaving a net positive charge at its inner end (inside the electrometer). The charged plastic has induced a like charge on the inner end of the cable. The meter indicates the charge on the inner end. You will use both methods of charging (contact and induction) in this experiment.

Grounding

The most important requirement for making accurate measurements in electrostatics is that instruments, connecting wires, experimental devices, and your body all be well grounded (i.e., they all must have a good conduction path to earth). Many stray charges are produced on all these objects (by contact between dissimilar substances), and some way is needed to drain these stray charges away. Also, a well-grounded conducting shell around the apparatus will shield it from 60-Hz electromagnetic radiation (which is emitted by the ceiling lights). Furthermore, a grounded conductor acts as a reference potential from which you can make all potential difference measurements. Only an earth ground satisfactorily meets all these requirements.

The Faraday Cage

This is a device to help you investigate charging by induction. It operates on the principle that a charge placed inside a hollow neutral conducting surface will induce an equal but opposite excess charge on the inside of that surface and an equal charge of the same sign on the outside, as in Figure 1.4. For example, if you hung a positively-charged object inside a metal coffee can, an equal positive charge would be induced, and could be measured, on the outside of the can. The Faraday cage you will use in this experiment is a wire mesh cylinder 8 cm in diameter by 12 cm tall. The bottom end of the cylinder is also covered with wire mesh, but the top end is left open. The cylinder is mounted on an insulating base. A larger wire mesh shield is mounted around the cage but insulated from it. When it is properly grounded, this outer shield protects the cage from stray charges and electromagnetic radiation, but the shield is not part of the Faraday cage. When you connect the electrometer probe to the inner cage and lower a charged object into it, the meter indicates the amount of charge induced on the cage by measuring the potential difference between the cage and ground. The greater the induced charge, the greater the potential difference. Thus, you can easily measure the magnitude of a charge by placing it deep inside the cage (without touching the mesh) and reading the meter.

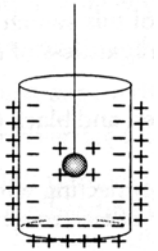

Figure 1.4

Charge Producers

You will use these to separate charge by contact. They are two wands with dissimilar materials mounted on insulating disks. By rubbing the blue and white disks together, you can produce excess positive charge on one disk and an equal amount of excess negative charge on the other.

It is usually desirable to begin an experiment with zero excess charge on the disks. You can easily accomplish this (if your body is grounded) by gently squeezing the flat surface of each disk between your thumb and finger. You can then remove any stray charge on the insulating wand handle near the disk by breathing on it (water is a good conductor; and the moisture in your breath will transport the excess charge away from the disks).

Warning. Do not touch the plastic insulators between the disks and the handles. The oils and perspiration from your hands will coat the insulator surface and allow charge to leak across the insulator.

Proof Planes

These are the two other wands—the ones with black conducting disks on their ends. When you touch a proof plane to a charged object, the proof plane will acquire the same distribution of charge (charge per unit area) as the object. By using the Faraday cage and electrometer to measure the charge acquired by the proof plane from different locations on the object, you can determine the object's charge distribution.

Caution: When you touch a charged object with a proof plane, it becomes an extension of that object (the disk of the proof plane is a conductor). Since the charge distribution on any object depends on the object's shape, distorting the shape of the object will distort its charge distribution.

For example, if you touch a large sphere with the flat surface of a proof plane, the disk of the proof plane adds a minor distortion to the spherical surface. But if you touch the edge of the disk to the sphere, the overall conducting surface is then severely distorted from a spherical shape, and the proof plane will not sample the original charge distribution on the spherical surface.

To achieve the most intimate contact, gently rub the flat disk surface of the proof plane on the charged surface. To get an accurate measure of the charge distribution at a specific point, minimize the area where you rub.

Power Supply

The source of charge you will use in this experiment has two ranges, 0–30 volts and 0–1000 volts (Figure 1.5). In each range, you can continuously adjust the output potential difference with the VARIABLE control knob. You switch the power supply on by turning the VARIABLE control knob clockwise.

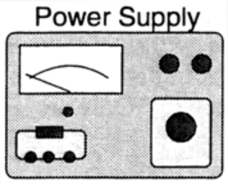

Figure 1.5

You select the range you want to use with the OUTPUT SWITCH. The center position of this switch is labeled Standby. In this position, there is zero potential difference between the terminals, regardless of the setting of the VARIABLE knob.

When you are using the 0–30-volt range, connect the device to be charged to the red and black terminals. For the 0–1000-volt range, use the green and black terminals.

There is no shock hazard in this power supply. You can safely touch the terminals, connecting wires, or devices even at potential differences up to 1000 volts. The electric current (the rate of flow of electrons) that causes electrical shocks is internally limited to less than 1 milliampere (you won't feel it).

Rules for Good Performance

You will achieve good results in this experiment if you carefully observe the following three rules:

1. Always keep your body grounded by wearing a grounding wrist strap.
2. Always keep the electrometer grounded unless you are specifically instructed to the contrary.
3. Always consider how the placement of equipment and of your body can affect the results. Having the power supply or your arm in the wrong position can change, by induction, the charge distribution you are trying to measure. In essence, any nearby conducting object will affect charge distributions.

Procedure

INCLUDE IN YOUR LAB REPORT diagrams of the charging circuit (power supply, cage, and wires connecting them) and the measuring circuit (wands, electrometer, and wires connecting them) for parts A, B, and C of this experiment.

A. Measuring Charge with the Faraday Cage

1. Connect the electrometer to the Faraday cage by connecting the probe to the inner cage and the ground clip to the outer shield. With another wire, connect the ground input to an electrical outlet box located on your lab table. Switch on the electrometer.
2. Momentarily ground the cage by gently pushing the PUSH TO ZERO knob on the electrometer. The meter should read zero while the cage is grounded (i.e., while you hold the knob in). If it does not, turn the ZERO ADJUST knob to make it read zero while you are pushing the PUSH TO ZERO knob in.
3. Ground the two charge producer wands.
4. Holding the two wands by their handles, briskly rub the blue and white surfaces of the disks together for a few seconds. This will transfer charge between the two disks, leaving opposite excess charges on each.
5. While holding wand #2 (blue) away from the cage, insert the charged disk of wand #1 (white) into the cage without letting it touch anything. Record the electrometer reading (polarity and value) when you hold the disk only slightly below the open top of the cage, and when you hold it near the bottom of the cage. Adjust the FUNCTION switch

as needed so the needle stays on the scale. Remove wand #1 and again record the meter reading. These readings should be recorded in Data Table 1.1.

6. Repeat step 5 using wand #2.
7. Repeat steps 3, 4, and 5, except this time touch the inserted charged disk to the cage wall near the bottom. Record the meter reading while the disk is touching the cage and after you remove it. Continue to hold both wands by their handles.
8. Repeat steps 3 and 4, except this time rub the disks together inside the cage (without touching the cage). While holding the disks a few centimeters apart inside the cage, note the meter reading. Remove wand #2 from the cage and note the meter reading. Replace wand #2, remove wand # 1, and note the meter reading. Record all readings in Data Table 1.1.

B. Charge Distribution on a Spherical Surface

The distribution of charge on a large conducting surface is described in terms of the charge density (charge per unit area). A charge distribution is said to be uniform when the charge density has the same value everywhere; a non-uniform distribution has a charge density which varies with location.

The surface of some charged objects (such as parallel conducting plates whose surface area is much greater than their separation) has a uniform charge distribution, but the charge density on most surfaces (such as a sphere) is variable.

You can examine charge distributions by (1) sampling the charge density at specific points on a surface by touching a proof plane at those points, (2) measuring the charge on the proof plane by inserting it into the Faraday cage and measuring the charge induced on the cage.

When using this technique to measure charge distributions, it is vital that you conserve the charge on the spherical surface. The proof plane removes a small amount of charge from the sphere every time you take a sample. If you ground the proof plane each time you remove it from the cage, the charge on the spherical surface will be slowly depleted with consecutive samplings.

However, by not grounding the proof plane (or not touching it to the cage), you will not deplete the charge on the spherical surface. The charge you remove with the proof plane during one sample is always returned to the sphere when you take the next sample. Even though you take your next sample at a point where the charge density is different, the excess charge on the sphere redistributes itself to the original density.

Caution: To minimize distortion of the charge distribution on the spherical surface, always touch the flat side of the proof plane to the sphere.

1. Place the two black spheres so that their centers are about 50 cm apart. Accurately measure and record the separation in Data Table 1.2. With the power supply switched off, connect the green terminal to one sphere (it will be charged positively) and the black terminal to the other sphere (it will be negative).
2. With the power supply OUTPUT switch set to the center position (Standby), switch the power on by turning the VARIABLE knob clockwise. Now put the OUTPUT switch to the 1000 VDC position and rotate the VARIABLE knob clockwise until the meter reads 1000 volts.

The sphere connected to the green terminal now has an excess positive charge distribution on its surface, and the sphere connected to the black terminal has a similar negative charge distribution. Both distributions are non-uniform over the spherical surfaces. In fact, they are mirror images of each other, i.e., the charge distributions on the spheres are symmetric about the imaginary perpendicular plane that bisects their center-to-center line. The charge densities have the greatest value at the points where the spheres are closest, decreasing with distance from the other sphere and reaching the minimum value at the most distant points on the opposite side.

Note. The charge density on each sphere is circularly symmetric about the closest point on the surface. You can measure this non-uniform surface charge distribution by sampling along any great-circle arc passing through the closest point. The most convenient arc for this is the joint between the two hemispheres.

3. Switch on the electrometer. Using a proof plane, Faraday cage, and electrometer, sample the negative charge distribution along the joint on the negative sphere. Sample at four equally-spaced positions along the joint from 0° to 90° (from the closest point to a quarter of the way around). Record all measurements in Data Table 1.2.
4. Ground the negative sphere by having one group member place a finger on it while touching the shield around the Faraday cage. Repeat step 3.
5. Put the OUTPUT switch to the center position (Standby), move the spheres about 2 cm apart (as close as you can get them and still have room to get the proof plane between them), then return the OUTPUT switch to 1000 VDC. Accurately measure and record the new separation in Data Table 1.2.
6. Switch the electrometer to a higher voltage scale and repeat step 3.
7. Ground the negative sphere by having one group member place a finger on it while touching the shield around the Faraday cage. Repeat step 3.

C. Transferring Charge in Small Steps

1. Leaving the spheres connected to the power supply 50 cm apart, connect the parallel plate device to the electrometer with the probe connected to the stationary plate and the ground clip to the movable plate.

Caution: Take care to place the plates and electrometer sufficiently far from the spheres and power supply so that the charge distribution on the plates is not effected by the proximity of the other devices.

2. Switch the electrometer on. Separate the plates by 2 mm and charge the spheres to a potential difference of 1000 V.
3. Press the PUSH TO ZERO button on the electrometer to momentarily ground the plates and remove any excess charge from them.
4. Use the proof plane to transfer some charge from the highest-density region of the positive sphere to the stationary plate. Adjust the electrometer's sensitivity (FUNCTION knob) so that you can measure the effect of each charge transfer. Make five charge transfers and record the plate's charge each time in Data Table 1.3.

Note. The charge is transferred merely by touching the flat side of the proof plane to the sphere and then to the plate. Transfer equal amounts of charge each time by touching the proof plane to the sphere and to the plate in the same manner each time.

5. Repeat steps 3 and 4 with the plates separated by 5 mm and again by 8 mm (measure to be sure).
6. Disassemble your equipment, return all equipment to the lab cart, and clean up your lab table area.