Van de Graaff

APPARATUS

- Heat lamp
- Electroscope
- Lucite rod and silk
- Van de Graaff generator
- Grounding sphere
- Ungrounded sphere
- Faraday cage
- Faraday pail
- Plastic box to stand on

INTRODUCTION

In this experiment, we will continue our study of electrostatics using a Van de Graaff electrostatic generator. If the electrostatics experiments were difficult because of humidity during the previous week, we will intersperse some of them with the experiments this week.
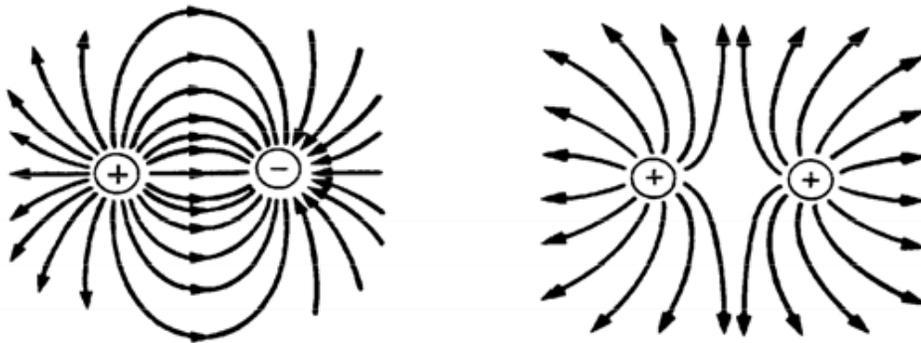
ELECTRIC FIELD

Consider an electric charge exerting forces on other charges which are separated in space from the first charge. How can one object exert a force on another object with which it is not in contact? How does the force move across empty space? Does it travel instantaneously at infinite speed or at some finite speed?

In the 19th century, physicists suggested the beginning of a solution to these questions. Instead of imagining that the charge produces forces on other charges directly, they imagined that the charge fills the surrounding space with an *electric field*. When other charges are inside the electric field, they experience electrical forces.

Electric fields can be visualized clearly by imagining that a small positive test charge is carried around, and the direction and strength of the force exerted on the charge are mapped. Think first about mapping the electric field of a single stationary positive charge. As we move the test charge around, the force is always directed radially outward from the stationary charge, and its strength decreases with distance from the stationary charge. If we draw arrows in the direction of the force, with lengths proportional to the strength of the force, we obtain a picture of the electric field similar to this:

and if we
connect the
arrows with
lines we get the
field line picture
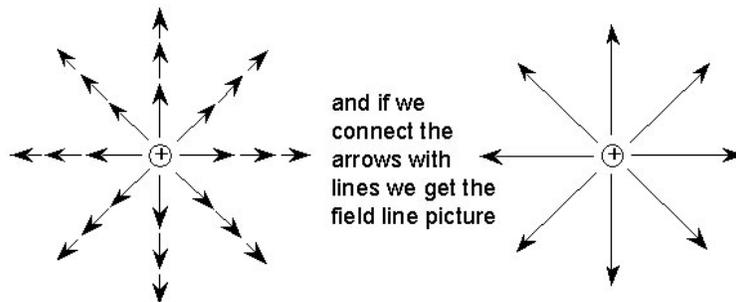
These lines provide a very convincing picture of electric fields. Look at the fields surrounding two unlike charges (which attract each other) and two like charges (which repel each other):

The electric field itself is defined as the force exerted on a test charge divided by the value of test charge. By dividing out the charge, we are left with only the properties of space around the charge:

$$\text{(electric field)} = \text{(force on a test charge q)}/\text{q} \tag{1}$$

or

$$E = F/q. \tag{2}$$

The field lines begin on positive charges and end on negative charges (or at infinity if the system is not overall neutral). Keep in mind that the lines do not necessarily represent the path a test charge would follow if released, but rather, the direction and strength of the force on a stationary test charge. That is, the direction of the force is along the field line passing through the test charge, and the strength of the force is proportional to the density of field lines near the charge. (Actually, the electric field is proportional to the number of field lines penetrating a unit area centered on the point of interest. Lots of field lines indicate a strong force.)

Imagine several positive and negative charges situated in space. The space around the charges is filled with field lines. These field lines start on the positive charges; the positive charges are the "sources" of the lines. The field lines end on negative charges; negative charges are the "sinks" of the lines. If there are more positive than negative charges in the region of space we are examining, then some of the field lines leave the area completely, moving to infinity. If negative charges predominate, then some of the field lines come in from infinity. This is the picture: field lines

filling space, starting on positive charges; or coming in from far away, ending on negative charges; or disappearing into the distance.

The introduction of the electric field concept seems to be an unnecessary complication at first, but physicists eventually discovered that the equations of electricity and magnetism are simpler when written in terms of fields than in terms of forces. The culmination of this process was reached around 1870 with the completion of Maxwell's equations.

ELECTRIC POTENTIAL

Since an electric field exerts forces on charges in it, there is potential energy associated with the position of a charged particle in the electric field, just as a massive object has potential energy in the gravitational field of the Earth. Imagine that we hold a positive charge fixed in position, and we bring in a small positive test charge (different from the fixed positive charge) from afar. As we move the positive test charge in, it is repelled by the fixed charge, and we must exert a force on the test charge to bring it closer. A force exerted though some distance performs work: we must do work on the test charge to move it closer. This work goes into increasing the electric potential energy of the test charge, just as the work done in lifting an object goes into increasing its gravitational potential energy. The electric potential energy can be converted into kinetic energy by releasing the test charge. The test charge flies away, gaining kinetic energy in the process.

We would like to introduce a quantity related to potential energy which depends only on the properties of the charge, so we divide out the test charge and write

$$\text{(potential)} = \text{(potential energy)}/\text{(charge)} \tag{3}$$

or

$$V = U/q. \tag{4}$$

This relationship defines a new quantity: the *electric potential V*. Potential is energy per charge and is measured in joules per coulomb (also known as *volts*, with unit symbol V). These are the same volts used in measuring the voltage of a battery. Understanding how the potential energy of an electric field is related to the voltage of a 6-V battery is one of the difficult conceptual leaps of electricity and magnetism. While you are trying to assimilate it, remember that as you learn new concepts in physics, it is important to keep the basic definitions in mind. If a battery is rated at 6 volts, then it is prepared to give 6 joules of energy to every coulomb of charge that is moved from one of its terminals to the other. For example, if we wire the filament of a small light bulb to the battery so that charge is moved through the filament, the energy goes into heating the filament "white hot".

GAUSS' LAW

Certain results in this lab can be understood most easily on the basis of Gauss' Law. Gauss' Law is an important reformulation of Coulomb's Law, which makes easier the derivation of some interesting consequences of electrostatics, such as the fact that all charge placed on a conductor

moves to its outside surface. Gauss' Law can be expressed as a surface integral of the electric field:

$$\int \mathbf{E} \cdot \mathrm{d}\mathbf{A} = q_{\mathrm{in}}/\epsilon_0. \tag{5}$$

The surface integral is called the *flux* of the electric field, and is evaluated over any closed surface. The charge q_{in} is the total charge enclosed <u>within</u> the surface, and ϵ_0 is the constant in Coulomb's Law:

$$F = kqQ/r^2 = qQ/4\pi\epsilon_0 r^2 \tag{6}$$

with $k = 1/4\pi\epsilon_0$.

We now derive Coulomb's Law from Gauss' Law. Let's start with an isolated charge q, and draw an imaginary sphere of radius r centered on the charge. This sphere is an example of a *Gaussian surface*.
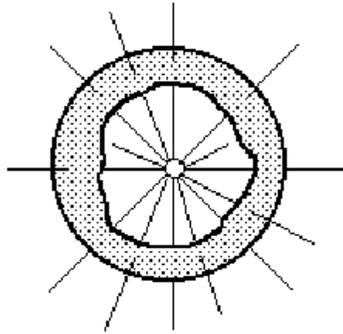
Here the electric field is always perpendicular to the imaginary sphere, and has the same constant value E at all points on the surface. Thus, the surface integral is simply the electric field E multiplied by the surface area $4\pi r^2$ of the sphere:

$$\int \mathbf{E} \cdot \mathrm{d}\mathbf{A} = \mathbf{E} \cdot \int \mathrm{d}\mathbf{A} = E(4\pi r^2) = q_{\mathrm{in}}/\epsilon_0 = q/\epsilon_0. \tag{7}$$

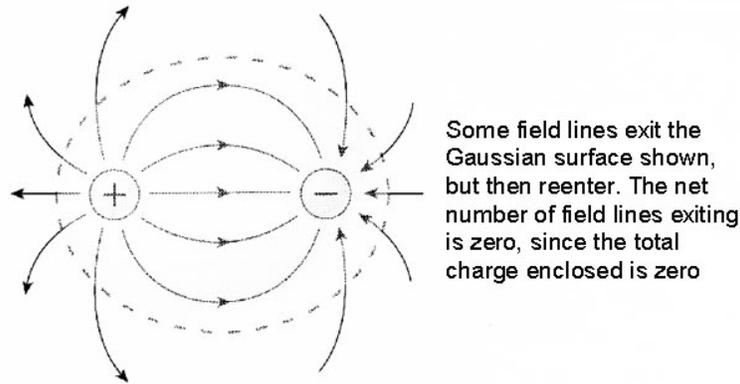This gives us the electric field of the charge q at a distance r:

$$E = q/4\pi\epsilon_0 r^2. \tag{8}$$

Since the force on a test charge Q due to this electric field is $F = QE$, we have $F = qQ/4\pi\epsilon_0 r^2$ — which is Coulomb's Law! In this sense, Gauss' Law is a reformulation of Coulomb's Law in terms of the electric field. It seems unnecessarily complicated, but you will see that we can immediately derive some interesting results with Gauss' ideas.

You can conceptualize Gauss' Law in terms of field lines by noting that the integral $\int \mathbf{E} \cdot \mathrm{d}\mathbf{A}$ over a surface is proportional to the number of field lines penetrating the surface (regardless of the angle between these lines and the surface). If field lines are entering and exiting the surface, then the flux integral is proportional to the number of lines exiting minus the number of field lines entering.

Here is an example. Imagine a closed surface of any shape (a Gaussian surface) enclosing a volume of space with possibly some charges inside. Let us find the net flux $\int \mathbf{E} \cdot \mathrm{d}\mathbf{A}$ through this surface.

If the surface encloses a positive charge and an equal negative charge, then some of the field lines from the positive charge may leave and then reenter the surface, heading for the negative charge. The contribution to the net flux from the field lines exiting and then reentering is zero.

Some field lines exit the Gaussian surface shown, but then reenter. The net number of field lines exiting is zero, since the total charge enclosed is zero

For this situation of equal positive and negative charges, the <u>net</u> flux is zero, because every field line that leaves later reenters. (Note that this is true no matter how the Gaussian surface is shaped or positioned, as long as it encloses both charges. If there are charges outside the surface, then their field lines will enter and later exit the surface, so the contribution from these charges is zero.)

$$\int \mathbf{E} \cdot \mathrm{d}\mathbf{A} = 0 \quad \text{for no \underline{net} enclosed charge.} \tag{9}$$

In fact, if the imaginary Gaussian surface encloses an unknown amount of charge, we can calculate the net flux $\int \mathbf{E} \cdot \mathrm{d}\mathbf{A}$ and multiply by ϵ_0 to obtain the charge inside: $q = \epsilon_0 \int \mathbf{E} \cdot \mathrm{d}\mathbf{A}$. (If there is a net entry of field lines, then $\int \mathbf{E} \cdot \mathrm{d}\mathbf{A}$ will be negative, and the equation above shows how much negative charge is enclosed by the surface.) Our first conclusion from Gauss' Law is that if we draw an imaginary closed surface, measure or compute the flux through the surface, and multiply by ϵ_0, we obtain the <u>net</u> charge (positive minus negative) enclosed by the surface. If the total charge inside the Gaussian surface is zero, then no field lines can exit (that do not reenter later).

Now suppose we take a solid conductor — a chunk of metal — and dump some charge (say, a few billion electrons) on it. The charge will spread out over the conductor until equilibrium is reached and the electrons no longer move. (The movement of the charges takes place in a tiny fraction of a second.)
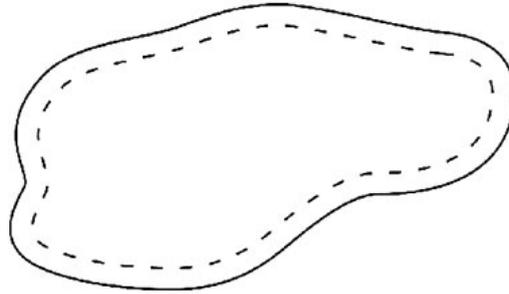
A Gaussian surface just inside a solid conductor
has no field lines in it.

First, note that there are no field lines anywhere inside the conductor. Why? Field lines represent forces on charges. If there were a field line inside the conductor, then charge would move. By definition, charge is always free to move in a conductor. But the charge has stopped moving; it must have arranged itself so that there are no field lines inside the conductor. Now draw a Gaussian surface just inside the surface of the conductor. No field lines penetrate this surface, so according to Gauss' Law, there is no net charge inside the surface (that is, inside the conductor). Under static conditions, <u>all</u> of the (excess) charge resides on the outer surface of the conductor. This is our second conclusion from Gauss' Law. Of course, it is not too surprising. Loosely speaking, the bits of charge repel one another, and they move as far away from each other as possible to the outer surface. We will see this effect in one of the following experiments.

Now consider a hollow conductor of any shape. A hollow metal sphere is an example, although the shape need not be regular. Again, if charge is placed on the conductor, all of it will move to the outside surface.
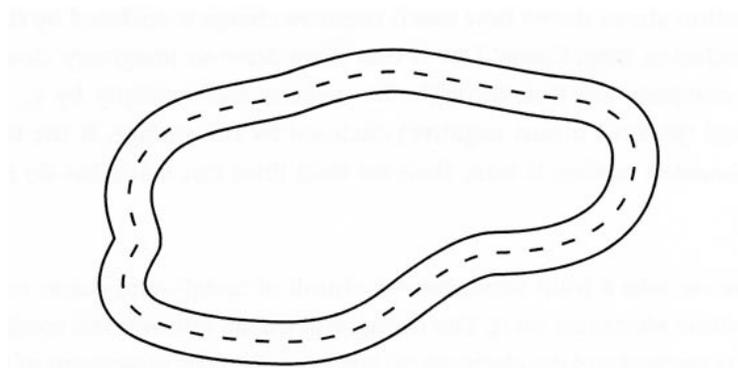
A conductor with a cavity inside and a Gaussian
surface within the conductor.

A Gaussian surface inside the metal, between its outside and inside surface and entirely in the conductor, has no field lines penetrating it; thus, there is no field in the conductor. Any surface inside the cavity has no net field lines exiting it, so no charge is enclosed. Thus, there is no electric

field inside the cavity. (Strictly speaking, you need another law of electrostatics in addition to Gauss' Law to complete the proof that there is no electric field inside a cavity, devoid of charges, in a conductor. See The Feynman Lectures, Volume II, Section 5 – 10.)

When a volume of space is enclosed by a conductor, there is no static electric field penetrating it from the outside. The conductor shields the inner space. This is a very practical example of the standard advice about remaining inside an automobile during a lightning storm. The automobile encloses its occupants with metal. Even if the automobile is itself struck by lightning and the occupants are touching its inner surface, the occupants will not be harmed or even shocked. It does not matter that the metal surface of the automobile is broken by the non-conducting windows. A small electric field may penetrate a short distance at the windows, but the nearly complete metal surface of the automobile shields the interior very well. A wire mesh cage will effectively shield its interior, as long as the mesh hole size in not particularly large compared to the size of the whole cage. We will try a shielding experiment below. Gauss' Law has other interesting consequences, but we now move to a description of the experimental apparatus.

THE VAN DE GRAAFF GENERATOR

The Van de Graaff Generator is a common electrostatic machine which produces voltages of 100,000 V or more on its sphere. Voltage is a measure of energy per unit charge. High voltages can be estimated roughly by how far they will make a spark jump in air. Static charges that jump a centimeter or so, as with the electrophorus, involve 10,000 – 30,000 V. With the Van de Graaff machine, sparks may jump as far as 15 cm. Even though the voltage is high, the total charge transferred is so small that little pain is felt if one of these sparks reaches your body.
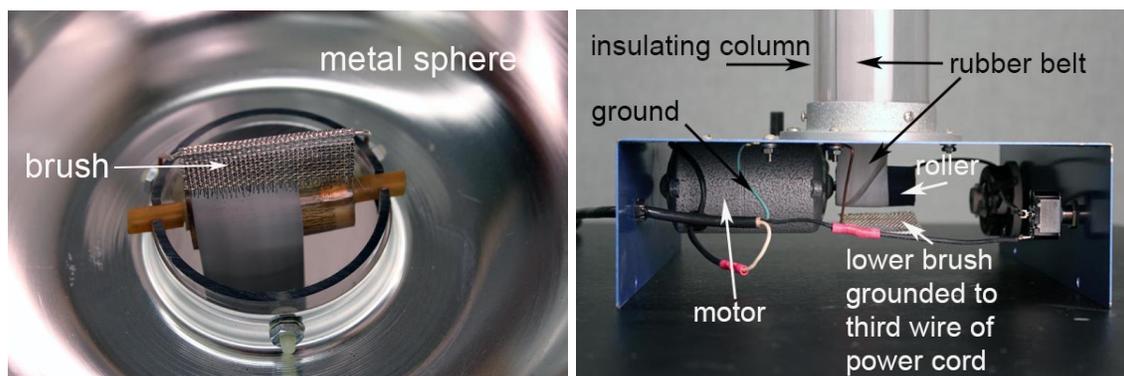
The Generator consists of a vertical rubber belt revolving around two rollers. The belt delivers charge to a large insulated metal sphere. One roller is typically covered with wool, and the other with neoprene. The making and breaking of contact between the rubber belt and the rollers generates a static charge, which imparts to the roller and belt opposite signs of charge. The two different roller materials are chosen so that one roller becomes positively charged and the other negatively charged. Let us imagine that the lower roller becomes positively charged. The right side of the belt will become negatively charged as a consequence, and some negative charges will be carried up the belt. This is not where the majority of the negative charges come from, however. Instead, the negative charges are induced from the brush onto the belt.

Near both rollers are brushes. The brushes are comb-like arrangements of metal points near, but not in contact with, the rubber belt near the rollers. The lower brush is connected to the electrical ground through the third wire of the power cord. The ground — planet Earth — is a gigantic reservoir of electrical charge, both positive and negative. Small amounts of charge can be transferred to and from the Earth without significantly "charging it up". The positive roller attracts negative charges (electrons) from the ground by induction; these charges flow onto the belt and stick there, since the belt is an insulator. The belt then carries the negative charges to the upper roller, which has been negatively charged by the friction of the belt. The negative charges are thus repelled onto the upper brush, where they are conducted out to the Van de Graaff dome.

You might initially think that negative charge would not continue to build up on the dome as it is repelled by the additional charge. But Gauss' Law guarantees that any charge delivered to the inside of the sphere moves to its outer surface. Thus, the upper brush does not charge up, and the belt can continue to deliver charge up to the sphere, where it accumulates until the air around the sphere starts to "break down" and the charge leaks off into the surrounding air.

CAUTIONS IN THE USE OF THE VAN DER GRAAFF GENERATOR

If the Generator sparks directly to your body, it produces a slightly painful sting, but not a dangerous shock. Anyone who has worked with these machines has received several of these shocks. To reduce the number of shocks you receive, keep all parts of your body a meter away from the sphere. When turning the machine on or off, touch the grounding sphere to the Generator sphere, or hold the grounding sphere or wire with the hand that you reach up to the switch. Be sure the Generator sphere has been touched with the grounding sphere after you turn it off; the sphere may

stay charged for many minutes.

On a cold dry day when electrostatics is powerful, charge will actually flow through the air and get on you and any equipment nearby. If you get charged up, sparks will jump from you to the ground when you came near various objects. Continually hold a grounding wire to prevent this from happening. You may need to ground carefully the other equipment to prevent spurious results in your experiments. On a good day, you are almost certain to receive some small shocks.

EXPERIMENTS

I. *TEST THE EFFECT OF HUMIDITY AGAIN*

Equipment

- Lucite rod
- Silk cloth
- Electroscope
- Timer

Procedure

1. Record below the readings of the relative humidity in the room (from the wall meter) and the inside and outside temperature.

   Humidity = _____

   Inside temperature = _____

   Outside temperature = _____

2. For this experiment, do not shine the flood lamp on the electroscope. Be prepared to start your timer. You may use the stopwatch function of your wristwatch.

3. Rub the lucite rod vigorously with the silk cloth. Use a little whipping motion at the end of the rubbing. Touch the lucite rod to the top of the electroscope. Move the rod along and around the top so you touch as much of its surface to the metal of the electroscope as possible. Since the rod is an insulator, charge will not flow from all parts of the rod onto the electroscope; you will need to touch all parts (except where you are holding it) to the electroscope. Start your timer immediately after charging the electroscope.

4. Record the time it takes the electroscope needle to fall completely to $0°$. Time up to five minutes, if necessary. If the needle has not fallen to $0°$ after five minutes, record an estimate of its angle at the five-minute mark. Typically, after charging, the needle might be at $80°$.
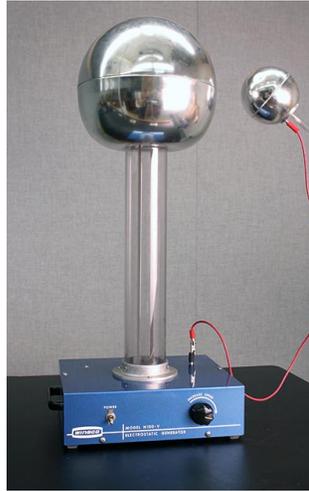

Electroscope needle angles
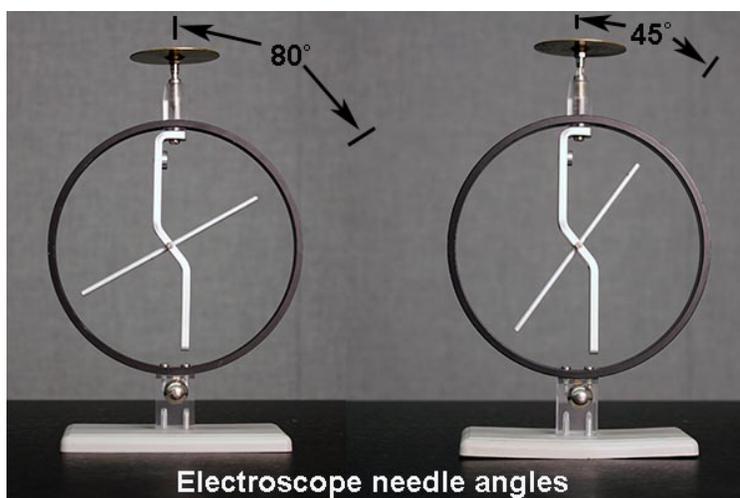
II. *VAN DE GRAAFF PARAMETERS*

The 10-cm spheres on insulating rods are surprisingly expensive and easily dented. Please take care that they do not roll off the table and fall on the floor.

Equipment

- Van de Graaff Generator
- Grounded discharge sphere
- Wire ring with "lightning rod"
- Insulating stand

Procedure

1. Devise a way to measure the radius (r) of the Van de Graaff sphere.

   $r = $ _____

2. Hold the grounded sphere (the one attached to the Van de Graaff Generator base by a wire) by its insulating handle, and bring it into contact with the metal dome of the Generator. Turn on the machine with your other hand, and draw the grounded sphere away until sparks are jumping to it from the Generator dome. Experiment with the motor control speed of the Generator.

   Devise a way to measure the maximum spark length to the discharge ball. How will you do this, since you cannot simply hold up a meter stick while the Van de Graaff is sparking?

   maximum spark length = _____

   Hold the discharge sphere at the maximum distance for continuous sparking, and estimate the spark frequency. (That is, how many sparks are emitted per second? Use you watch, the computer, or the Capstone clock to make a time estimate.)

   spark frequency = _____

3. The "breakdown" electric field is 3×10^6 V/m for dry air. This is the field necessary to make a spark jump through air — for example, between two metal plates with an electric field in the air gap.

   The Van de Graaff belt delivers charge continuously to the sphere. If there is no discharge sphere nearby, the potential of the Van de Graaff sphere (its voltage) rises until the electric field at the surface reaches the breakdown value. Then charge begins to leak into the air (through a corona discharge, with many small sparks). An equilibrium potential for the sphere is reached when the leakage rate from the sphere is equal to the

delivery rate from the belt.

The electric field E at a distance r from a charged sphere (calculated from Gauss' Law) is

$$E = Q/4\pi\epsilon_0 r^2, \tag{10}$$

where Q is the charge on the sphere. To find the potential V of the sphere, we integrate E from $r = \infty$ to $r = R$ (the radius of the sphere):

$$V = -\int E \, dr = Q/4\pi\epsilon_0 R. \tag{11}$$

(We suggest, for purposes of midterm preparation in the lecture part of the course, that you know how do derive the result above. Getting all the signs correct is somewhat tedious.) Using the electric field at the surface of the sphere and eliminating Q, we find

$$V = ER. \tag{12}$$

Using $E = $ breakdown electric field, and your measured value of R, calculate the potential V of the sphere.

$V = $ _____

Advertisements for this type of Van de Graaff Generator typically state that it will produce voltages as high as 400,000 V. Is this a reasonable value, taking into account various leakages? What factors might cause the actual potential to be smaller than calculated?

4. Use your measured maximum spark length and the breakdown electric field to estimate the potential difference necessary to make a spark jump this distance between two parallel metal plates.

$V = $ _____

Is this potential in agreement with your calculated value? How about the advertised potential?

5. Using your calculated potential, calculate the charge stored on the sphere from

$$V = Q/4\pi\epsilon_0 R. \tag{13}$$

Express your answer as a number between 1 and 999 in coulombs (C) with the appropriate prefix, such as m $= 10^{-3}$, μ $= 10^{-6}$, n $= 10^{-9}$, p $= 10^{-12}$, etc. (It may help to remember that $1/4\pi\epsilon_0 = 9 \times 10^9$ in SI units.)

$Q = $ _____

6. The capacitance of a configuration of conductors is defined as $C = Q/V$. The equation above can be manipulated to give the capacitance of an isolated sphere as

$$C = 4\pi\epsilon_0 R. \tag{14}$$

Calculate the capacitance of your Van de Graaff sphere. Express your answer as a number between 1 and 999 in farads (F) with the appropriate prefix, such as m $= 10^{-3}$, µ $= 10^{-6}$, n $= 10^{-9}$, p $= 10^{-12}$, etc.

$C =$ _____

7. Assume the sphere discharges completely with each spark, and use your measured spark frequency to calculate the average discharge current (i) while sparking.

$i =$ _____

Evidently, the discharge rate must be equal to the rate at which the belt is delivering charge to the sphere. A current of 3 mA is considered the minimum dangerous (possibly fatal) current. How does your measured current above compare? Would you rate this Van de Graaff as "safe for student use"? The manufacturer states that the current delivered by the belt is 10 µA. Does this agree with your estimates? Did we make any poor assumptions above?

III. LIGHTNING ROD

Equipment

- Van de Graaff Generator
- Grounded discharge sphere
- Wire ring with "lightning rod"
- Insulating stand
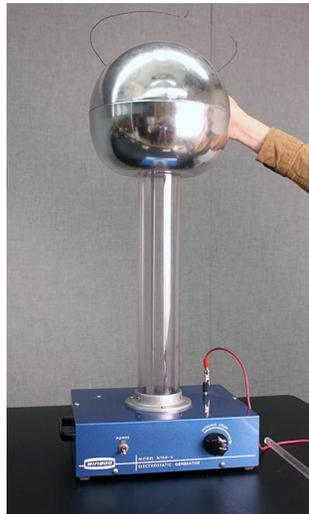
Procedure

1. Place the wire ring on top of the Van de Graaff metal dome. Put the grounded sphere into contact with the dome, turn on the machine, pull the grounded sphere several centimeters away from the dome, and observe whether any sparks are created.

2. While the machine is still running, use the grounded sphere to slide the wire ring off the dome. (Don't bring your hands near or you will be shocked.) Then hold the grounded sphere several centimeters away from the dome, and observe whether any sparks are created.

3. Bring the grounded sphere into contact with the dome again, and turn off the machine.

4. Based on your results, give a clear explanation below of how and why a lightning rod works.

To Try Hair-Raising (optional)

1. Start with a key or other pointed metal object in your pocket (not absolutely necessary).

2. Stand on the insulating stand so that you can easily reach over to place your hand on the Van de Graaff dome, but all other parts of your body are one-half meter away from the benches or other persons.

3. Place your hand firmly on the dome. Have your partner turn on the machine carefully while not getting too close to you. When the machine is running, you will feel a slight tingling sensation, but no pain, as the hairs on your arms and legs are raised. Do not pull your hand away from the dome while the machine is running, or sparks will jump to your hand as you pull back.

4. After the machine has run for 30 seconds or so, shake your head to loosen your hair, but do not remove your hand from the dome.

5. When finished, have your partner turn off the machine carefully.

6. Pull your hand away from the dome. Have your partner discharge the dome. If you step

down immediately, you will get a slight shock (usually not painful). Wait a few moments until the charge leaks away. Or, take the key or pointed metal object out of your pocket and hold it up. You will probably hear the charge hissing off it. Bring the point slowly toward the Van de Graaff base box until you finally touch it with the point. Now all the charge has been grounded, and you can step down without being shocked.

Hair raising produces widely varying results on different persons and also depends strongly on the humidity present during the demonstration. It seems to work best on persons with light, fluffy hair that has been washed recently. Persons with coarse, highly curly, or oily hair, or hair that has been treated with sprays or gels, do not produce the more spectacular results.

IV. **FARADAY CAGE**

This experiment demonstrates the electric-field shielding characteristic of conductors.

Equipment

- Electroscope
- Metal wire cage
- Van de Graaff Generator
- Grounding sphere

Procedure

1. Set the electroscope within approximately half a meter of the Van de Graaff Generator. Turn on the machine, and observe and record the results.

2. Turn off the machine. Ground its dome and the electroscope so that they are completely discharged.

3. Cover the electroscope with the metal wire cage, and repeat step 1. Try moving the cage even closer to the dome (with an insulated rod!). Is there any deflection? How do you explain the results?

V. *FARADAY ICE PAIL*

In the experiments last week, we have shown that a charged rod can induce an opposite charge on a conductor. In this section, we will show that the induced charge is not only opposite in sign, but also equal in magnitude, to the inducing charge.

Equipment

- Van de Graaff Generator
- Two conducting spheres, one grounded
- Electroscope with Faraday pail

Procedure

1. Position the electroscope with Faraday pail away from the Van de Graaff Generator. (When the metal dome of the Generator is charged, an electroscope nearby may deflect from the electric field of the dome, as you found in the last experiment. This deflection will end when the dome is discharged. However, on some days charge will actually move through the air and get on the electroscope, and the electroscope will remain deflected even after the dome is discharged. In this case, you will need to discharge the electroscope with your finger, or perhaps you may need to touch both the top electrode (or pail) and the guard ring of the electroscope with the grounded sphere, to get it completely discharged before performing the remaining steps.)

2. Run the Van de Graaff Generator for a few moments until its sphere is charged.

3. Hold the ungrounded conducting sphere by its insulating handle, and charge it by momentarily touching it to the Van de Graaff dome. Discharge the dome. Make sure the

electroscope is discharged, and lower the small sphere into the pail without touching the side of the pail with the sphere. The goal is to get the charged sphere into the pail without a spark jumping between them. If you find this step difficult, start again as follows: Discharge the insulated sphere and the Van de Graaff dome. Turn the Van de Graaff motor control down and run it very briefly so when you touch the insulated sphere to it, the sphere picks up a smaller charge.

4. When you can get the charged sphere into and out of the pail without a spark jumping, record answers to the following: Is there any deflection while the charged sphere is inside the pail? When the sphere is removed, is there still any deflection?

5. With the sphere charged, lower it all the way into the pail so that no sparks jump (sphere completely inside but not touching the bottom). Touch the pail momentarily with your finger. What happens to the deflection? Remove the sphere, still holding it in your hand. Record any changes to the deflection.

6. The pail and electroscope are now charged by induction. Lower the sphere into the pail, let it touch the bottom, and remove it without touching it to the edges as it goes out. What happens to the deflection? Explain your results.

VI. *GAUSS' LAW*

A consequence of Gauss' Law is that all charge on a conductor moves to the outside surface. This experiment is very similar to the previous one. You will need two electroscopes, so borrow one from another group, or work together.

Equipment

- Van de Graaff Generator
- Two conducting spheres, one grounded
- Two electroscopes, one with Faraday pail

Procedure

1. Position the electroscope with the Faraday pail and the other electroscope away from the Van de Graaff Generator, and somewhat separated from each other. In the procedures below, recall the cautions and advice in steps 1 and 3 of the previous experiment.

2. Run the Van de Graaff Generator momentarily until its sphere is charged.

3. Hold the ungrounded sphere by its insulating handle, and momentarily touch it the Van de Graaff dome. Discharge the dome. Check that both electroscopes show zero deflection.

4. Bring the charged sphere near, but not touching, the electroscope without the pail. It should deflect, indicating the presence of charge.

5. Lower the sphere into the pail on the other electroscope until it touches the bottom. Carefully lift it out without touching the edge of the pail.

6. Bring the sphere near, and into gentle contact with, the top of the other electroscope. Is there any deflection? What is your conclusion?

7. Now touch the ungrounded sphere to the outside of the pail, and then bring it into gentle contact with the other electroscope. Can you remove charge from the outside of the pail?

Additional Credit (3 mills)

When you can perform this experiment well and explain the results clearly, call your TA over and demonstrate and explain the experiment. He or she will award you 3 mills if you can do it without significant assistance.

Note: If the previous week was bad for electrostatics, some experiments may be carried over to this week.