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Van de Graaff Generator
#511

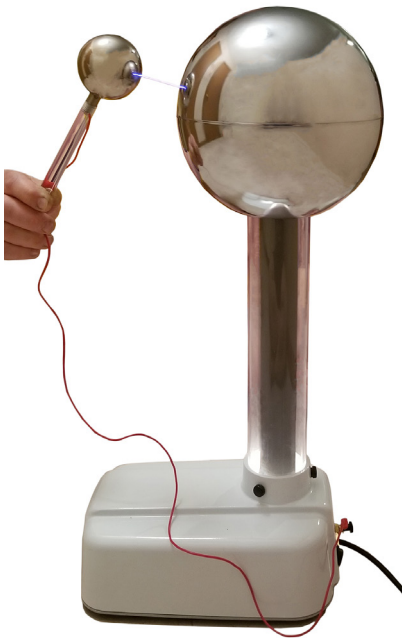
Warning:

- **Not a toy; use only in a laboratory or educational setting.**
- **California Proposition 65 Warning: This product can expose you to chemicals including lead and nickel, which are known to the State of California to cause cancer, birth defects, or other reproductive harm. For more information go to www.P65Warnings.ca.gov.**

Introduction

The Van de Graaff generator was invented in 1931 by American physicist Robert Jemison Van de Graaff as an early particle accelerator. It helped perform experiments that revolutionized particle physics. Though our particle accelerators have gotten a bit more advanced since then, the Van de Graaff generator remains one of the best tools out there for explaining electrostatics, and it finds itself at home, in classrooms, and science museums all over the world.

It consists of a belt that runs between two rollers made of different materials. The belt is encased in a clear column to prevent the build up of moisture or dirt on the belt's surface, which decreases the amount of charge that can be generated by the machine. One roller is connected to an electric motor in order to spin it. The motor spins the roller quickly, allowing for a large amount of charge to be generated. (It is worth noting that other Van de Graaff generators exist that swap out this motor for a hand crank. Keep this in mind to understand that none of the electricity generated by the device comes from the electrical power source that runs the motor). Each roller has a thin metal "comb" beside it positioned with its sharpest edge pointing towards (but not touching) the rubber belt. The comb near the roller by the motor is wired to be connected to earth-ground, meaning that its charge is safely able to bleed off into the ground. The comb near the top roller is wired to contact the inner surface of the large metal globe on top.



When the system is in motion, the belt becomes electrostatically charged at the bottom where it passes between the roller and the comb. The charge is carried by the belt up to the top comb, and the outer surface of the globe gains the same charge as the belt via electrostatic induction. This will be explained in a bit more detail on the following page.

Your Van de Graaff generator comes with everything you need to see sparks and to make your hairs stand on end, but there are a ton of demonstrations that are possible with it. Below are a few simple **additional supplies** that you will need for some of the demonstrations on the following pages:

- A metal pin and some sticky putty or tape
- Paper muffin liners or small, metal pie tins
- A cotton ball and some string

Static Electricity and Electrostatic Induction

Before we go over how your Van de Graaff generator works, its important to first understand some concepts about static electricity and the transfer of electric charge.

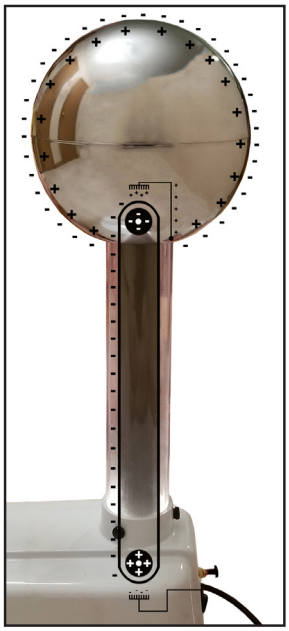
Static electricity refers to the electrical charge in or on an object. Neutrally charged atoms have equal numbers of negative **electrons** and positive **protons**. Protons are bonded to the neutrons in the atoms' nucleus and electrons float around the nucleus. Negatively charged atoms have gained an excess of electrons, and positively charged atoms have lost electrons from their outer electron clouds. Charged atoms are called **ions.** Ions with the same charge will repel each other, and oppositely charged ions will be attracted towards each other. Objects can gain or lose electrons in multiple ways, but the primary process behind the static electricity in your generator is known as the triboelectric effect.

The **triboelectric effect** refers to the process through which objects/materials gain or lose electrical charge through physical contact. All conductive materials have triboelectric properties that can be determined by consulting a triboelectric series table (which is easily searchable online). When two objects with a sufficiently large difference in their triboelectric properties come into contact with each other, a bond known as **adhesion** occurs causing the outer electrons of one material to stick to the surface of other. When these two objects are quickly separated from each other, friction occurs and electrons from one material are left on the surface of the other. One object now has extra electrons and a negative charge, and the other has an electron deficit and a positive charge.

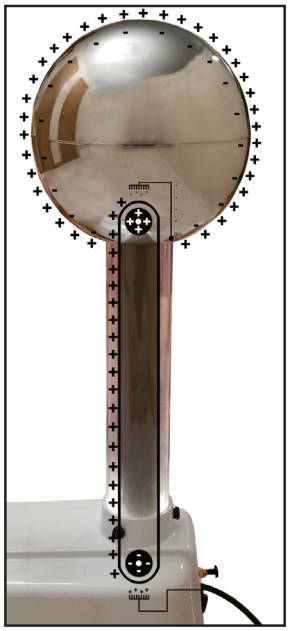
In the case of a Van de Graaff generator, the overall charge present on the surface of the dome is dependent on the triboelectric relationships between the material of the belt and the materials of each roller. Your particular generator produces a positive charge on its dome.

One last important concept to understand is that of electrostatic induction. **Electrostatic induction** occurs when a neutrally-charged insulated conducting material gains a positively-charged region and a negatively-charged region due to the presence of a nearby object that already has an electric charge. The charge of the nearby object generates, or **induces,** an electric field that affects the electrons on the neutrally charged object.

On the next page we'll put these concepts together to explain how your generator functions.



Negatively Charged Generator



Positively Charged Generator

How it Works

Now that you have an idea about how static electricity and electrostatic induction work, it's time to look at how your generator makes use of these concepts to generate thousands of volts of electricity. Below is a numbered diagram of your generator so you can follow along with the steps electrical charges take to end up on the surface of your generator's metal globe.

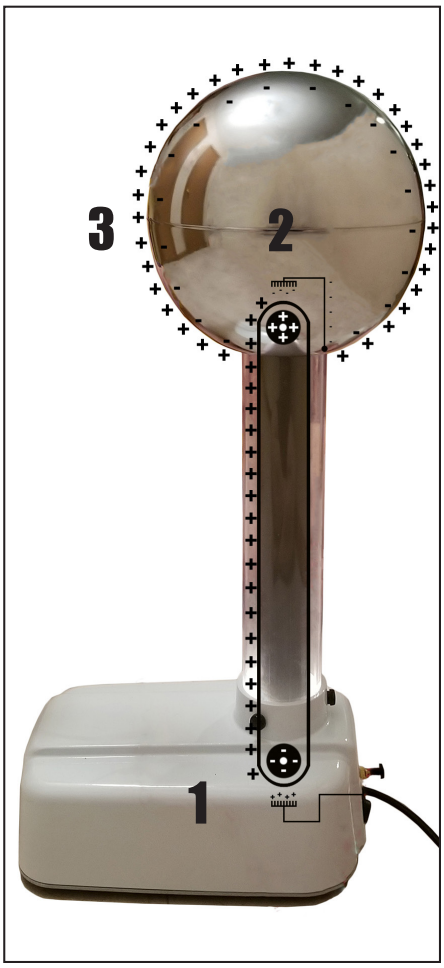
1. The process for generating electricity starts with spinning the bottom roller. This is done by turning on the motor. When the roller spins, it moves the belt, and the triboelectric effect causes the roller and the belt to each gain a charge. The charged roller induces an opposite charge in the comb nearby.

   Charges tend to spread out evenly and stay on smooth surfaces, and they build up on and discharge from sharp points or edges. Because the sharp edge of the comb is what is pointing towards the roller, the charge induced on it wants to discharge towards the roller, but it is blocked by the belt and the air between them. The charge in the comb builds until it is strong enough for the air to go through **electrical breakdown** and, instead of insulating and preventing the flow of electricity, it becomes a conductive plasma in a process called **corona discharge.**

   The ions in the plasma of the corona discharge share the same charge as the one induced on the comb, and are therefore attracted towards the roller. Instead of collecting on the roller, however, the belt blocks the way and these ions stick to it. As the belt rotates, these ions are transported towards the roller and comb at the top of the generator.

   The comb in this step is connected to earth-ground so that no unwanted extra charge builds up in the machine.

2. Once the charged belt makes its way towards the comb at the top, a charge opposite of the belt is induced on the comb. This comb is connected to the inner surface of the large metal globe, and the induced charge on it is carried by conduction across entire inner surface of the globe. The ions in the plasma come off of the corona discharge from this comb stick to the belt and leave it either neutrally or lightly charged so that it is ready to pick up more ions when it returns to the roller at the bottom. Depending on the design of the generator, this top roller must be triboelectrically neutral or opposite of the bottom roller for the machine to work. An oppositely charged roller will result in a generator capable of producing higher voltage.



3. The charge that has built up on the inner surface of the globe finally induces a charge on its outer surface. This induced charge on the outer surface will mirror the one that was built up on the belt.
   This electrical charge will build up on the surface of the generator's globe until it discharges in the form of a dramatic spark when something comes too near to the globe. If nothing comes close enough for the static to discharge as a spark, the charge will continue to grow until it leaks off into the air via corona discharge. The amount of charge that can build up on the globe on a given day is dependent on the relative humidity in the room and the cleanliness of the globe. A dryer day will allow for greater voltage to build up on the generator before it discharges.

How to Use

Below you'll find instructions on how to set up and turn on your generator:

1. Place your Van de Graaff generator on a flat surface, and plug it in to a wall outlet.

2. Take the cord coming off of your grounding wand, and attach it to the ground terminal on your generator. It is located next to where the wall cord enters the generator.

3. Flip the switch on the cord to turn the machine on. Flip the switch next to the ground terminal to light up the support column so that you can see the belt.

4. Have a partner or a lab stand hold the grounding wand near the surface of the globe to control where its electricity discharges.
   (Note: Observe the grounding wand as it is shocked. You will notice the ball move slightly towards the globe until the spark occurs. At this point it will move back to its original position. This movement is because the ball is attracted to the globe until the spark occurs. It is not because of any force coming from the impact of the spark.**)**

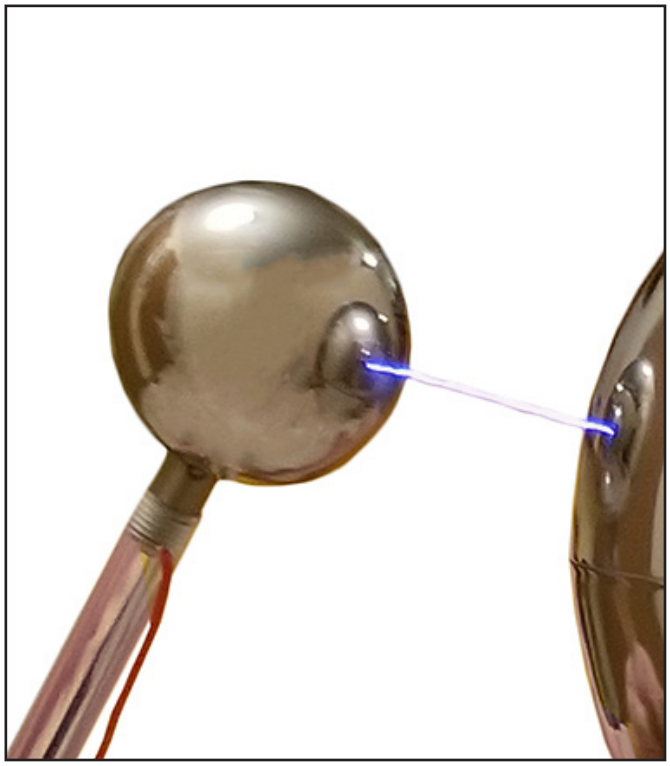
5. See how long of a spark you can get to arc between your generator and grounding wand. The general rule of thumb is that air electrically breaks down 1 cm for every 15,000 to 30,000 volts, so you may see sparks with many thousands of volts!
   (Note: This amount of voltage may seem dangerous, but the capacitance is very low on a generator this size. When the generator discharges a spark and it hits you, the voltage drops very quickly. Despite supplying a large amount of voltage at first, the power of the spark diminishes rapidly to the point where it doesn't hurt us. Power is calculated by multiplying voltage and current. With that in mind, the voltage drops nearly to zero after a spark occurs, so you don't run much of a risk of having electricity pass through you. Large scale Van de Graaff generators with much bigger domes to accumulate charge on, or ones connected to capacitors capable of storing the charge generated, can store much more electrical energy, and can be dangerous, similar to lightning.**)**

Maintenance and Safety

If the sparks are underwhelming, this may be because of high humidity. If the humidity is not the culprit however, you may want to clean the belt with a cloth and alcohol and dry it thoroughly with a blow dryer. The belt is accessible with a Phillips screwdriver via a panel on the bottom. If the belt has become dry or brittle, it is time to replace the belt.

Shocks directly from your generator can be slightly painful, but they are not generally harmful. If you have a heart condition or a pacemaker, it is best to stay back several feet and let someone else operate the machine.

Take off any watch or head phones you may be wearing and place them a safe distance away before interacting with the generator. Place any phones or portable electronics away too. This is for the safety of your devices.



Demonstrations

There are a ton of great demonstrations that you can do with a Van de Graaff generator. Below you'll find instructions on how do some of the most well known demonstations, but don't let this list of demonstrations limit what you get out of your generator.

Making a Your Hair Stand on End

1. Stand on top of a stool or a chair (as long as it isn't metal).
2. Place your hands on the globe of the generator.
3. Ask an assistant to turn the generator on for you.
4. Shake your head around a little while the machine runs. As the generator runs with your hands on it, the same charge on the globe's surface will begin to build up on your body because the stool is preventing you from providing a path to ground for the electricity. As each individual hair on your body becomes similarly charged, they begin to repel each other and stand on end.
5. Ask your assistant to turn off the generator. You will notice that you stay charged and your hair stays up until you step off of the stool.

Making a Lightning Rod

1. Set up your generator like on the previous page so that sparks are flying between it and its grounding wand.
2. Grab a metal pin in your hand. Make sure your skin is in full contact with the metal on the pin and that you are standing on the floor
3. Point the tip of the pin towards the dome of the generator, and watch as the sparks stop. This is essentially performing the same task of a lightning rod. The sharp point of the pin, and its connection to you as a grounding point, make it a better path for electricity to travel to ground than through high-voltage sparks. The charge on the dome bleeds into the ground through you and the lightning rod before it is allowed to build up enough to cause a spark.

Flying Muffin Liners (or Pie Tins)

1. Stack at least five muffin liners or pie tins on top of the generator's dome with the open side down (like a hat).
2. Turn the machine on.
3. Watch as the liners fly off one by one. This is because they pick up a charge and repel each other, much like your hair did earlier.

Observing Electric Wind

1. With your machine off, use some tape or any form of tacky putty to fasten your lightning rod pin to the surface of your dome. Set it up so that the point faces perpendicular to the surface of the dome. **(Note:** This will not work if you pin has a plastic head that prevents its metal from touching the dome.**)**
2. Turn the machine on.
3. Wave your hand in front of the tip of the pin to feel wind coming off of it. This is known as **electric wind**. It is caused by the charge from the ions in the plasma of the corona discharge coming off the tip of the pin and disrupting nearby neutral air molecules. If you turn the lights off, you might even see the pale blue corona discharge.

Bouncing Cotton Ball

1. Set up your generator like on the previous page so that sparks are flying between it and its grounding wand.
2. Tie a cotton ball to the end of a string.
3. Lower the ball into the path of the sparks between the dome and the grounding wand.
4. Watch as it bounces back and forth between the two. This is because the neutral cotton ball is attracted to the dome until it makes contact. Once they touch, the ball becomes charged and it is repelled. When the ball bounces into the grounding wand, it becomes neutral again and the process repeats.