Static Electricity from http://science.howstuffworks.com/transport/engines-equipment/vdg.htm

To understand the Van de Graaff generator and how it works, you need to understand static electricity. Almost all of us are familiar with static electricity because we can see and feel it in the winter. On dry winter days, static electricity can build up in our bodies and cause a spark to jump from our bodies to pieces of metal or other people's bodies. We can see, feel and hear the sound of the spark when it jumps.

In science class you may have also done some experiments with static electricity. For example, if you rub a glass rod with a silk cloth or if you rub a piece of amber with wool, the glass and amber will develop a static charge that can attract small bits of paper or plastic.

To understand what is happening when your body or a glass rod develops a static charge, you need to think about the atoms that make up everything we can see. All matter is made up of atoms, which are themselves made up of charged particles. Atoms have a nucleus consisting of neutrons and protons. They also have a surrounding "shell" that is made up electrons. Typically, matter is neutrally charged, meaning that the number of electrons and protons are the same. If an atom has more electrons than protons, it is negatively charged. If it has more protons than electrons, it is positively charged.

Some atoms hold on to their electrons more tightly than others do. How strongly matter holds on to its electrons determines its place in the **triboelectric series**. If a material is more apt to give up electrons when in contact with another material, it is more positive in the triboelectric series. If a material is more apt to "capture" electrons when in contact with another material, it is more negative in the triboelectric series.

The following list describes the triboelectric series for many materials you find around the house. Positive items in the series are at the top, and negative items are at the bottom:

1) Human hands (usually too moist, though) *Very positive*
2) Rabbit fur
3) Glass
4) Human hair
5) Nylon
6) Wool
7) Fur
8) Lead
9) Silk
10) Aluminum
11) Paper
12) Cotton
13) Steel *Neutral*
14) Wood
15) Amber
16) Hard rubber
17) Nickel, Copper
18) Brass, Silver
19) Gold, Platinum
20) Polyester
21) Styrene (Styrofoam)
22) Saran Wrap
23) Polyurethane
24) Polyethylene (like Scotch Tape)
25) Polypropylene
26) Vinyl (PVC)
27) Silicon
28) Teflon *Very negative*

(The above list is adapted from the book Nature's Electricity by Charles K. Adams.)

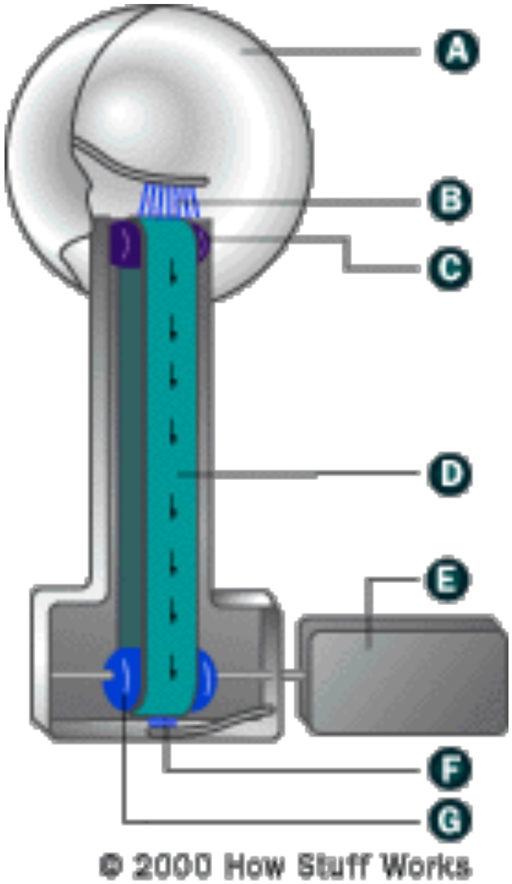
The **relative position** of two substances in the triboelectric series tells you how they will act when brought into contact. Glass rubbed by silk causes a charge separation because they are several positions apart in the table. The same applies for amber and wool. The farther the separation in the table, the greater the effect.

When two non-conducting materials come into contact with each other, a chemical bond, known as **adhesion**, is formed between the two materials. Depending on the triboelectric properties of the materials, one material may "capture" some of the electrons from the other material. If the two materials are now separated from each other, a **charge imbalance** will occur. The material that captured the electron is now negatively charged and the material that lost an electron is now positively charged. This charge imbalance is where "static electricity" comes from. The term "static" in this case is deceptive, because it implies "no motion," when in reality it is very common and necessary for charge imbalances to flow. The spark you feel when you touch a door knob is an example of such flow.

In the next section we'll look at the many factors that affect the size of a static electricity shock.

Shock Factors

You may wonder why you don't see sparks every time you lift a piece of paper from your desk. The amount of charge is dependent on the materials involved and the amount of surface area that is connecting them. Many surfaces, when viewed with a magnifying device, appear rough or jagged. If these surfaces were flattened to allow for more surface contact to occur, the charge (**voltage**) would most definitely increase.



Another important factor in electrostatics is **humidity**. If it is very humid, the charge imbalance will not remain for a useful amount of time. Remember thathumidity is the measure of moisture in the air. If the humidity is high, the moisture coats the surface of the material, providing a low-resistance path for electron flow. This path allows the charges to "recombine" and thus neutralize the charge imbalance. Likewise, if it is very dry, a charge can build up to extraordinary levels, up to tens of thousands of volts!

Think about the shock you get on a dry winter day. Depending on the type of sole your shoes have and the material of the floor you walk on, you can build up enough voltage to cause the charge to jump to the door knob, thus leaving you neutral. You may remember the old "static cling" commercial. Clothes in the dryer build up an electrostatic charge. The dryer provides a low-moisture environment that rotates, allowing the clothes to continually contact and separate from each other. The charge can easily be high enough to cause the material to attract and "stick" to oppositely charged surfaces (your body or other clothes, in this case). One method you could use to remove the "static" would be to lightly mist the clothes with some water. Here again, the water allows the charge to leak away, thus leaving the material neutral.

It should be noted that when dirt is in the air, the air will break down much more easily in an electric field. This means that the dirt allows the air to become ionized more easily. Ionized air is actually air that has been stripped of its electrons. When this occurs, it is said to be **plasma**, which is a pretty good conductor. Generally speaking, adding impurities to air improves its conductivity. Having impurities in the air has the same effect as having moisture in the air. Neither condition is at all desirable for electrostatics. The presence of these impurities in the air usually means that they are also on the materials you are using. The air conditions are a good gauge for your material conditions -- the materials will generally break down like air, only much sooner.

The Generator

Now that you understand something about electrostatics and static electricity, it is easy to understand the purpose of the Van de Graaff generator. A Van de Graaff generator is a device designed to create static electricity and make it available for experimentation.

The American physicist Robert Jemison Van de Graaff invented the Van de Graaff generator in 1931. The device that bears his name has the ability to produce extremely high voltages -- as high as 20 million volts. Van de Graaff invented the generator to supply the high energy needed for early **particle accelerators**. These accelerators were known as atom smashers because they accelerated sub-atomic particles to very high speeds and then "smashed" them into the target atoms. The resulting collisions created other subatomic particles and high-energy radiation such as X-rays. The ability to create these high-energy collisions is the foundation of particle and nuclear physics.

Van de Graaff generators are described as "**constant current**" electrostatic devices. When you put a load on a Van de Graaff generator, the current (amperage) remains the same. It's the voltage that varies with the load. In the case of the Van de Graaff generator, as you approach the output terminal (**sphere**) with a grounded object, the voltage will decrease, but the current will remain the same. Conversely, batteries are known as "constant voltage" devices because when you put a load on them, the voltage remains the same. A good example is your car battery. A fully charged car battery will produce about 12.75 volts. If you turn on your headlights and then check your battery voltage, you will see that it remains relatively unchanged (providing your battery is healthy). At the same time, the current will vary with the load. For example, your headlights may require 10 amps, but your windshield wipers may only require 4 amps. Regardless of which one you turn on, the voltage will remain the same.

There are two types of Van de Graaff generators: one that uses a high-voltage power supply for charging and one that uses belts and rollers for charging. Here we will discuss the belts-and-rollers type.

This kind of Van de Graaff generator is made up of:

- A **motor**
- **Two rollers**
- A **belt**
- **Two brush assemblies**
- An **output terminal** (usually a metal or aluminum sphere)

A Output terminal — An aluminum or steel sphere
B Upper brush — A piece of fine metal wire
C Upper roller — A piece of nylon
D Belt — A piece of surgical tubing
E Motor
F Lower brush
G Lower roller — A piece of nylon covered with silicon tape

When the motor is turned on, the lower roller (charger) begins turning the belt. Since the belt is made of rubber and the lower roller is covered in silicon tape, the lower roller begins to build a negative charge and the belt builds a positive charge. You can understand why this charge imbalance occurs by looking at the triboelectric series: Silicon is more negative than rubber; therefore, the lower roller is capturing electrons from the belt as it passes over the roller.

The Concentration of Charge

It is important to realize that the charge on the roller is much more concentrated than the charge on the belt. Because of this **concentration of charge**, the roller's electric field is much stronger than the belt's at the location of the roller and lower brush assembly. The strong negative charge from the roller now begins to do two things:

1. **It repels the electrons near the tips of the lower brush assembly.** Metals are good conductors because they are basically positive atoms surrounded by easily movable electrons. The brush assembly now has wire tips that are positively charged because the electrons have moved away from the tips, toward the connection at the motor housing.
2. **It begins to strip nearby air molecules of their electrons.** When an atom is stripped of its electrons, it is said to be plasma, the fourth state of matter. So we have free electrons and positively

charged atoms of air existing between the roller and the brush. The electrons repel from the roller and attract to the electronless brush tips while the positive atoms attract to the negatively charged roller.

The positively charged atomic nuclei from the air molecules try to move toward the negatively charged roller, but the belt is in the way. So now the belt gets "coated" with the positive charge, which it then carries away from the roller.

As long as there is air between the lower roller and brush assembly, the Van de Graaff generator will continue to charge the belt. Theoretically, the Van de Graaff generator can continue to charge forever. Unfortunately, dirt and other impurities in the surroundings will limit the actual charge that develops on the sphere.

Let's return to the belt. The belt, as we left it, is positively charged and rolling toward the upper roller and upper brush assembly. Since I used nylon for my upper roller, it wants to repel the charge on the belt. The upper brush assembly is connected to the inside of the sphere and hangs near the upper roller and belt location. The electrons in the brush move to the tips of the wires because they are attracted to the positively charged belt. Once the air breaks down as before, the positive atomic nuclei of air are attracted to the brush. At the same time, the free electrons in the air move to the belt. When a charged object touches the inside of a metal container, the container will take all of the charge, leaving the object neutral. The **excess charge** then shows up on the outside surface of the container. Here, our container is the sphere. It is through this effect that the Van de Graaff generator is able to achieve its huge voltages. For the Van de Graaff generator, the belt is the charged object, delivering a continuous positive charge to the sphere.