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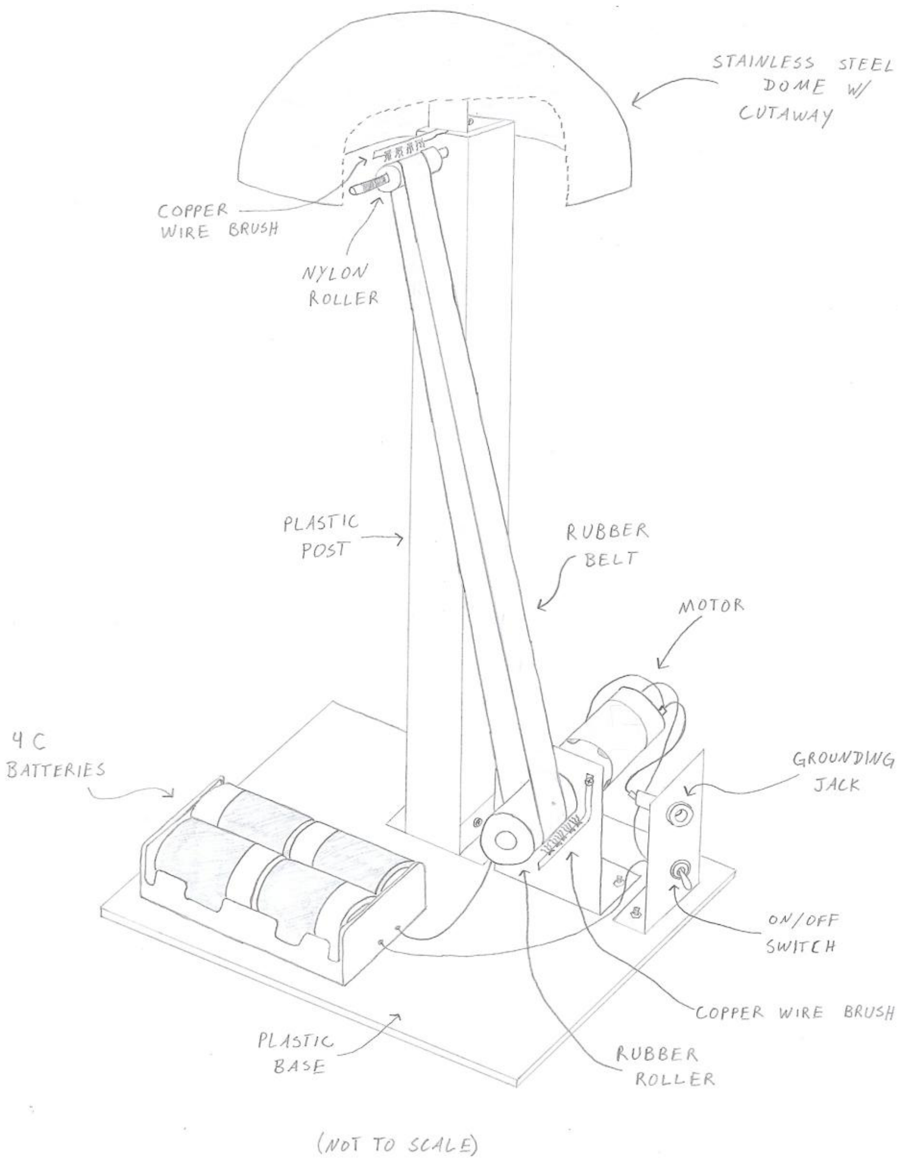
UP II Honors Project
Section H1

Small Van de Graaff Generator

For my honors project, I built a small Van de Graaff generator from a kit that I purchased online from Chaney Electronics, Inc. The manual states that it is capable of producing voltages up to 25,000 volts, but, since it operates at a very low current, the device is not dangerous. The generator consists of a nylon upper roller, a white rubber lower roller, two copper conducting brushes, a motor powered by four C-cells, a rubber belt, and a stainless steel dome supported by an insulated plastic post and is capable of producing ¾" sparks. Below is a drawing I made of the device:



The basic idea behind the invention of the Van de Graaff generator was to have a machine that was able to build up a considerable amount of static electric charge and high voltage on a metal surface. Though American physicist Robert Jemison Van de Graaff originally built his generator to provide the high energy needed for early particle accelerators, the device is quite useful for physics demonstrations in the classroom. It can demonstrate basic properties of charge such as how charges move to the outer surface of conductors as well as how charges can be created on different materials through contact.

Conductors have several unique properties. First of all, charge is able to move in conductors. Though protons of metals pretty much remain where they are, electrons are free to move about and create a separation of charge. Secondly, the net electric force inside a conductor is zero. If a conductor is placed in an external electric field, charge on the conductor would separate in such a way as to have zero total force on the particles on the inside of the conductor. Lastly, charge will move in response to an electric force.

These properties can be used to deduce some interesting laws for the electric field inside of conductors in electrostatic equilibrium. The electric field inside a conductor is zero. If an external electric field is applied to a conductor, charge would flow in the conductor to produce a surface charge that would produce an electric field on the inside of the conductor that would cancel the applied field. This is why net charge in conductors is all on the outer surface. If a net charge existed in a conductor, by Gauss' Law there would be a non-zero electric field in the region around the charge, but, since electric field inside conductors must be zero, charge would flow until the net charge was moved to the outer surface. This explains why the generated charge of the Van de Graaff generator moves to the outer surface of the metal conducting dome.

A second important aspect of charge that must be understood in order to see how a Van de Graaff generator works is the concept that certain materials become charged after coming into contact with each other and then separated. Some materials give up their electrons more easily than other materials. This is how the oven bag was able to charge the PVC rod and the clear plastic rod with different charges in lab. All three materials are at different levels of something called the triboelectric series. The PVC rod becomes negatively charged when rubbed with the oven bag because it is taking some of the bag's electrons. This effect comes into play in the Van de Graaff generator in how charge is first introduced on the top roller by the belt, thus starting a series of events that ends with charge on the outer surface of the metal dome.

Though the generator looks fairly simple and the idea behind it seems pretty straightforward, the actual mechanism of how charge is built up is somewhat complicated. There is a lot of movement of charge taking place in a pretty short amount of time.

The first thing that happens after the generator is turned on and the belt starts moving is the charging of the top roller. Because nylon is in the positive region of the triboelectric series and rubber is in the negative region, the nylon roller gives some of its electrons to the rubber belt and becomes positively charged. The roller's charge is much more concentrated because it has a much smaller surface area than the belt.

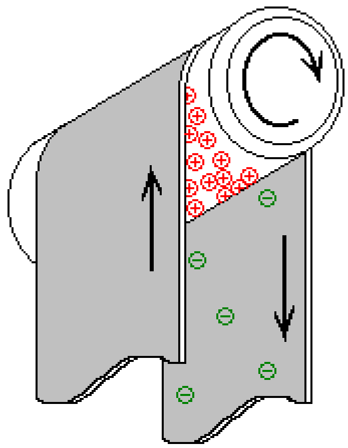
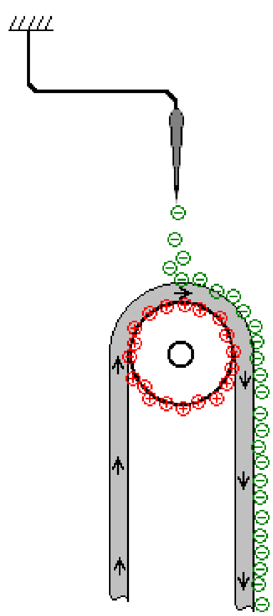


Image from amasci.com

A copper brush connected to the dome is fixed in place with the wire bristles flayed out and pointed toward the belt and the top roller. The bristles are close but not touching the belt. The concentrated positive charge of the roller causes electrons drawn from the dome to migrate to the tips of the bristles. The intense negative charge at the bristles affects air molecules nearby, separating electrons from nuclei. The freed electrons are strongly repelled by the brush, and as they move away they strike other air molecules, thus freeing more electrons. This creates something called plasma, which is also known as a corona discharge or St. Elmo's Fire. Plasma, like metal, is able to conduct electrons. Electrons from the plasma stick to neutral air molecules making them negative. The newly negative air molecules are repelled by the negative brush, creating a kind of negatively charged wind towards the positive roller. As the negative charges move toward the roller, they stick to the belt and are carried off towards the bottom of the generator. Throughout this process, the roller maintains its positive charge and electrons from the brush keep moving toward it.



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At the bottom of the belt, basically the same process occurs but in reverse. The bottom rubber roller is probably neutral since the belt is also rubber; there is little to no triboelectric series separation. The negative charge on the belt induces an intense positive charge on the brush at the bottom. Plasma is created with negative charge moving to the brush and positive charge moving toward the belt, canceling the charge for the most part as the belt moves back up, and the process repeats. A fairly large, positive net charge is now located at the surface of the metal dome, ready to shock anyone brave enough to get near it and donate some electrons.

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