

VANDEGRAAFF MACHINE: Belt and Rollers

The standard classroom VandeGraaff machine contains no power supply. Open one up, and you'll find that its AC cord leads to a simple electric motor. If you had a gearbox and a crank, you could build a hand-cranked VandeGraaff machine with no electric cord at all!

Although they look simple at first glance, the belt, combs, and rollers invisibly combine to form an electrostatic device called a Continuously Operating Electrophorus. This device harnesses an effect called Electrostatic Induction in order to pump electric charge between the metal comb and the surface of the moving belt. Overall, the "electrophorus" works like this:

- The roller becomes strongly electrified
- The roller attracts opposite charge into the comb teeth
- The electric field between the roller and teeth becomes intense
- The field shreds air molecules into conductive plasma called "corona"
- The air conducts, and charges in the comb leap towards the roller
- The moving charges hit the belt surface and stick to it
- The roller turns, and the charges are carried away on the belt
- The process repeats...

CHARGING THE ROLLER

In the first stage of operation the roller's surface becomes strongly electrified. This happens as it contacts the belt surface, and it occurs for the same reason that a balloon becomes electrified when rubbed upon hair. Notice that the belt and the roller are made from two different materials. When the rubber belt touches the plastic roller, chemical bonds form and the charges in the surface atoms of the two materials share unequally. As the roller rotates, the belt peels away and the surfaces separate again. The belt and roller surfaces take their equal and opposite charges with them. This whole process is called "frictional charging", but since no friction is actually required, it's more accurate to call it "electrification by contact." (Note: in the example below, the roller receives a positive surface charge, but this is not always true. The roller's polarity depends on the materials used for the belt and roller, and in some VandeGraaff machines the roller becomes negative.)

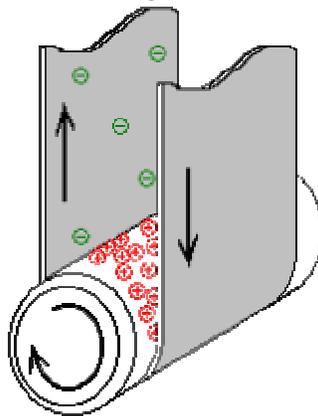


Fig. 1 HOW THE PLASTIC ROLLER BECOMES ELECTRIFIED

After operating for awhile the belt will become weakly negative and the roller will be strongly positive. Areas of equal and opposite charges were created, but since the negative charge is spread widely on the belt, it is much weaker than the concentrated charge on the roller. The weak charge on the belt can be ignored for now, since it doesn't figure into the next step.

CHARGES LEAP THROUGH THE AIR

A metal needle is held near the surface of the belt at the place where the belt passes over the roller. Metals are composed of a solid grid of positive atoms immersed in a movable "fluid" of negative electrons, and when the metal needle comes close to the roller, the positive surface charge on the roller attracts the negative electron-fluid of the metal. But no electrons leave the metal yet.

The electron fluid of the metal migrates toward the tip of the needle. The needle tip acquires an intensely strong negative charge, and this negative charge affects the air. Any air molecules which come near the needle tip are torn into separate electrons and positive atomic nuclei by the intense electric attraction/repulsion forces. The freed electrons of the air are strongly repelled, and they strike other air molecules and rupture them as well. A mass of shattered air and free electrons forms at the needle tip. This stuff is called "corona discharge" or "St. Elmo's Fire", also "plasma", the fourth state of matter. Plasma has movable electrons like metals, and like a metal it's a fairly good conductor.

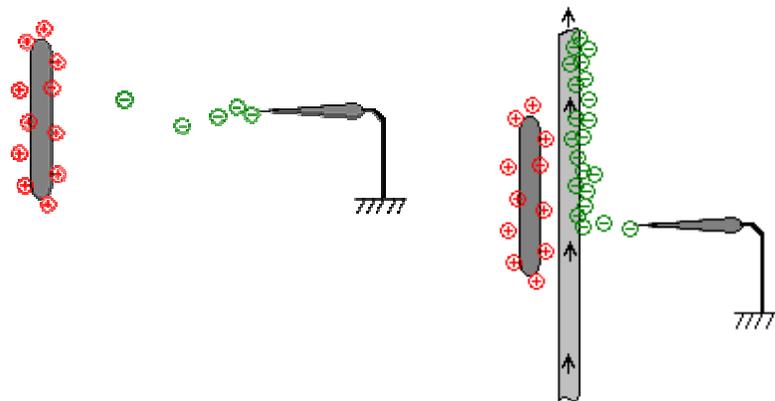


Fig. 2 POSITIVE OBJECT MAKES GROUNDED NEEDLE SPEW CHARGED WIND

Next, negative electrons from the plasma stick to neutral air molecules, making them negative. The negative air is repelled from the negative needle. At the same time, positive air molecules from the plasma collide with the metal needle and steal electrons from it. On the

average, negative charge moves from the metal and into the air. The plasma creates a conductive bridge between the metal the insulating air, with the result that a "wind" of negatively charged air flows from the needle tip. (Note that VDG machines need air on their needle tips in order to operate. They won't work if operated in a vacuum.)

THE BELT INTERCEPTS THE LEAPING CHARGES

The negatively charged wind is strongly attracted to the positively charged roller surface. However, the rubber belt is in the way. The negative air moves towards the positive roller and coats the surface of the belt, which partially shields and cancels the roller's charge. But then the roller rotates and the belt surface moves upwards, carrying the negative charge with it. Fresh rubber surface is continually re-exposed, which keeps attracting more negative charge from the needle.

Notice that no matter how much negative charge spews from the needle, the belt always intercepts it before it cancels the positive charge on the roller. The roller never loses its positive charge, yet the roller forces charge to flow from the needle to the belt. It almost seems like perpetual motion. This is called "charging by induction", since the positive roller "induces" a charge on the tip of the needle. This is also called "charging by corona wind", since the "corona discharge" plasma allows charges to flow from needle and into the air.

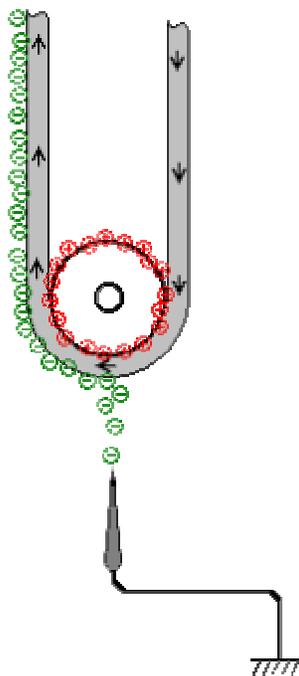


Fig. 3 THE CHARGED ROLLER FORCES THE COMB TO CHARGE THE BELT

The other end of the needle is connected by a wire to the ground or to a large metal object. As negative charges spew from the needle and are attracted towards the positive roller, more are drawn in through the wire. As the roller rotates it maintains its positive charge, which causes the needle to spew negative charge onto the belt, which causes a small electric current to flow

from ground and into the needle. Are there charges in the ground? Yes, because the Earth is conductive. It contains equal amounts of opposite charge, and so the wire can suck one polarity of charges out of the Earth. Overall, the system acts as a miniature charge-pump by forcing charge to flow from the neutral earth and onto the surface of the belt.

CHARGES EXIT AT THE TOP

The belt carries charge up the column of the VandeGraaff, then passes by another roller and needle assembly. This second roller acts in reverse to the first, and the charge on the belt is dumped into the upper needle tip. This second roller must **not** be positively charged. In order to work in reverse, it either must have a negative charge, or it must be neutral. In many classroom VDG devices this second roller is neutral metal.

As the negatively charged belt passes over the upper roller, it repels the "fluid" electrons of the metal needle tip and pushes them away from the tip. This exposes the positive metal atom nuclei. The surface charge at the tip of the needle is intensely positive, and the electrical attraction/repulsion forces tear apart the nearby air molecules into conductive glowing plasma. This time the free electrons of the plasma are attracted into the needle, leaving behind positively charged air molecules which rush away. The positive air is attracted to the negative charge on the rubber belt, and it combines with the belt charge and mostly cancels it out. The needle is connected to a wire, which is connected to the inside of the hollow VDG sphere. As the belt repels the plasma electrons into the needle, the "icepail effect" sucks the excess charge to the outside of the sphere. On average, the negative surface charge on the belt has "leapt" onto the needle and flowed to the surface of the VandeGraaff sphere.

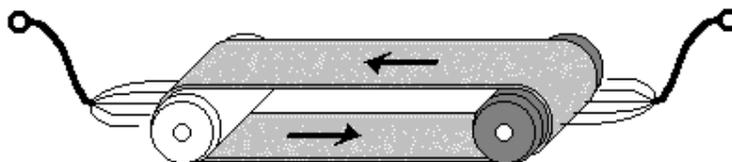


Fig. 4 A BELT, TWO COMBS, AND TWO DIFFERING ROLLERS

Overall, the VDG machine looks very simple to the eye. A belt passes over two rollers. The rollers must be made from two different materials (e.g. plastic and aluminum.) Two "combs" of wire are held near the belt surface. Add a hand-crank or a motor and a couple of hollow spheres, and that's everything. Or simplify it further by connecting one end to the earth and put a hollow sphere over the other end.

Above is the basic explanation of the VDG operation. **Real** VandeGraaff generators have added complexity, and commercial units will often have differing details.