The Van de Graff Generator

VandeGraaff Machine Safety

Tabletop Vandegraaff machines are very safe. They've been used in classrooms and Science Museums for decades with little difficulty. I've not encountered any literature on hazards associated with VDG machines, so I've put together a bit here.

Note that I'm describing worst-case events, so I might make a VDG machine seem dangerous. They are not. Remember that people are not killed by VDG machines; people are constantly killed by car accidents, by falling off ladders, by slipping in the shower, etc. Don't lose your perspective: riding in a school bus is far more dangerous than playing with a VDG machine.

******* **I'M NOT A DOCTOR, NOR A SAFETY EXPERT!** ********
NOTE: I am not an expert regarding electrical safety. This information is for your information only. It contains common-sense advice; the information here is as reliable as possible but not complete. For accurate safety information, consult an expert in electrical shock hazards.
******* **I'M NOT A DOCTOR, NOR A SAFETY EXPERT!** ********

ELECTRIC VOLTAGE: by themselves, DC electric potential and electrostatic fields cannot harm humans. Rubbing a balloon upon dry fur can produce potentials approaching those of a tabletop VDG generator: 20,000 volts. As far as voltage is concerned, the high voltage produced by a tabletop VandeGraaff generator is about as dangerous as an electrified balloon.

ELECTRIC CURRENT: a tabletop VDG produces an electric current below 100 uA (microamperes), which is about ten times smaller than a human is able to feel. If you lick your fingertips and touch them to the terminals of a 9v radio battery, the level of current in your fingers will be much higher than that produced by a VDG machine. As far as constant currents go, a 9v battery is more dangerous than a VDG.

SPARKS AND IMPULSE CURRENT: here is where there is possible danger.

The peak current during the spark from a VDG machine can be as high as thousands of amperes. However, at this amperage the current lasts for less than a millionth of a second. At a more moderate discharge current of 10mA, the discharge might last up to a millisecond. This is above the threshold of human perception of current, and yes, if you allow the spark to jump to a metal object held in your hand, you sometimes can feel a small twitch in the muscles of your arm. On the other hand, when you feel pain from a "static" spark, the pain comes mostly comes from the high electric current concentrated in a tiny area, and from the microscopic region of burned skin where the spark enters your body. Small sparks might be slightly painful, but there is far more danger from the suprise they can cause if they happen unexpectedly. However, even the smallest spark can trigger a heart attack in a person who has a severe heart condition.

SPARK ENERGY: The danger of a spark can also be rated in terms of spark energy. If you receive a "static" spark from touching a car, the energy can be as high as 500 mJ (millijoules) Typical spark energy $E = 1/2CV^2$, and since human body capacitance might be as high as 400pF, then 50,000 volts on a human body gives an energy discharge of 0.5 Joules. Touching the sphere of a VDG is about as dangerous as touching a car if your own body is electrically charged.

GENUINE HAZARDS

- AVOID SUPRISES: A person who is suprised by the small shock might stumble and fall, especially if they are standing on a rickety chair during the usual "hair raise" demonstration.

- NO LEYDEN JARS OR CAPACTIORS: If you use your VDG to electrify a large Leyden Jar, you can store extremely dangerous amounts of energy and create an electrocution hazard. If you touch the wrong parts of the electrified leyden jar, the discharge through your body can violently tense your muscles, causing you to crash into nearby furniture. The discharge might send you into unconsciousness so that you fall and hit your head. It may even stop your heart (by triggering fibrillations). Don't use Leyden Jars in your demonstrations unless you are trained in dealing with hazardous high voltage. PARENTS: never let children experiment with VandeGraaff machines and Leyden jars together.

- NO HUMAN CHAINS: If you charge up a long chain of people holding hands, the total stored electrical energy can become much larger than that stored on one person. Yes, each individual person does not receive a larger charge than normal. However, if one of the people should touch an electrical ground, they and the people closest to them in the chain can experience a large jolt. The charge of the entire chain of people must flow through the person touching ground. Also, the path for current is through that person's heart (because charge flows in through one arm and out through the other.)

- NO PACEMAKERS OR IMPLANTS: Medical implants could be damaged either by the large e-fields which surround a VDG, or by the powerful pulses of radio waves created during spark discharge. A person with a cochlear implant in their ear, a portable external defibrillator, or other sensitive device, is often advised to steer clear of radio transmitters, microwave ovens, cellular phones, and sparks from doorknobs. They should also steer FAR clear from playing with VDG machines!!!

- UNDIAGNOSED HEART DISEASE: The small spark from a VDG could cause a heart attack in a person having a serious undiagnosed heart condition. Needless to say, this possibility gives nightmares to public science demonstrators. It doesn't matter if that person would have had a heart attack within hours anyway. If YOUR device triggered it, guess who will be blamed! On the other hand, if I myself was going to get hit with a heart attack out of the blue, I'd rather have it happen while inside a building and surrounded by a group of quick-thinking people.

- If a person has flammable liquids or gasses on their skin or clothing, a spark from a VDG might trigger a fire. The classic hazard is the butane gas from a cigarette lighter which is leaking unnoticed in an inside pocket in a jumpsuit. If that person receives a big spark from a doorknob or a VDG machine, the butane could ignite. Yes, this is a rare instance: a smoker wearing a jumpsuit who has a lighter which is leaking.

- Some older VDG machines contain a high voltage power supply. This supply presents an electrocution hazard if the generator's case is opened or if the charged lower comb is touched. Also, if the generator's belt becomes conductive because of built-up dirt, and if both combs electrically arc to the dirty belt, then the generator's upper sphere will become connected to the internal high-voltage power supply. In that case, touching the VDG sphere is the same as touching the high voltage DC supply directly. If the DC supply in the VDG machine does not have safe current limiting, then there will be an extreme electrocution hazard.

- And last: If you operate a VDG next to a computer, and the computer circuitry gets trashed, the owner of the computer might kill you! (grin)

VDG Hints: Solving Humidity Problems

(c)1994 William J. Beaty

Blow-dryer

Always carry an electric blow-dryer with you when doing electrostatics demos in high-humidity locations. When your VandeGraaff machine fails, the usual cause is adsorbed water on the rollers and belt, which prevents the initial charge-separation from occurring where belt touches/peels from the roller surface. Pop open the sphere or the base, run the machine, then direct warm air upon each of the rollers until the upper sphere starts making sparks when touched. Don't give up, sometimes it takes 5 minutes or more to dry the cloth rollers used in the base of the WINSCO Inc. VDG. Another common problem is fingerprints and grime which make the belt and roller become conductive on humid days. Replace the belt with a fresh one. Or, remove the dirty belt, clean both sides with rubbing alcohol, then pat it dry with a clean paper towel. If one of the rollers is plastic, wipe it off with alcohol too. [WARNING: don't wet acrylic plastic with alcohol, it will crack.] Fully dry it by operating the belt in the machine while applying the blow-dryer. Don't wet the felt type of roller, it takes too long to dry again.

"Hotbox" for storage

It is not impossible to perform electrostatic demonstrations in a very high humidity environment. One secret is to build a "hotbox" storage device for your equipment. A cabinet with a tight-fitting lid can be heated with a small light bulb inside. Anything stored in this box will have its conductive surface moisture evaporated by the low heat. In a pinch you can heat your equipment in a trash can containing a light bulb. One science teacher revived a long-dead VDG machine using this method. WARNING! FIRE DANGER! Try different small lightbulbs to find one which produces approx. 110F heat in the box. Too large a bulb in too small a box can start a fire. Also, it is wise to mount the bulb near the top of the box. This makes it less likely that a flammable object will fall against the bulb.

Dessicant

It is also possible to use baked silica-gel dessicant instead of a lightbulb to dry the contents of a sealed case. If you can obtain a couple of pounds of color-change silica gel dessicant, placing the stuff in your box will lower the air's humidity and act to dry your equipment. The dessicant eventually turns from blue to pink as it gets full of moisture. Hours of oven-baking at low temperature according to its supplied instructions will restore its dessicating properties.

Dirt and grease

Occasionally wipe any grime from the vertical column of your VDG using a paper towel slightly dampened with rubbing alcohol, then dry the column thoroughly with the blow-dryer. DO NOT WET THE PLASTIC, it will cause instant cracking. Avoid getting any alcohol near the mounting screws on the column, since the internal stress in the plastic plus alcohol can crack the plastic. [Some people suggest using soapy water only, then blow-drying thoroughly.] It seems like grime builds up on electrostatic devices faster than on any other object. It's no illusion. Electrostatic generators create ion currents in the air around them, and this charged air in turn charges all the dust motes and air pollution particles, which then seek out any available surface. If you live in a big city, your VDG machine will quickly acquire a black coating as all the car exhaust is extracted from the air and coats itself on the machine!

Hi-volt Supplies Still Work

Sometimes the humidity is so high that no amount of debugging can fix your demo. In this case, sometimes a DC power supply can be used in place of a VDG machines. I have several 20,000-volt power supplies bought from surplus mail-order suppliers. They convert 24Vdc to high voltage. They will give a mild shock, but are not as bad as a Leyden jar. Another high-voltage supply: negative ion generators. These devices are actually DC power supplies having 10KV or higher output, but with large current-limiting resistance in series. Touch their output and you feel nothing, but connect the ionizer brush to a pop-bottle electrostatic motor, and it spins like mad. Negative air ionizers are pricey, but I see them for $5.00 frequently at garage sales.

Here's an electrostatic demo which will even work when submerged underwater! (grin) RED AND GREEN ELECTRICITY, This one works because no actual charges are involved. It's really a visual analogy for electrostatics, which uses red and green transparencies to simulate the + and - charge within matter. This article might not look like much, but I highly recommend that you mess around with the red and green plastic anyway. I would estimate that the depth and solidity of my own understanding of Electrostatics was DOUBLED by messing around with these simple plastic sheets.

Sharp dust-motes

One last possibility: if the voltage on your machine seems to drop suddenly during operation, try wiping down the sphere with a damp cloth. Sometimes your machine will attract a sharp, conductive dust mote which then spews charged wind. This presents major current leakage and partially shorts out the sphere voltage. With luck, wiping down the sphere will dislodge it.

Humidity's Effects

Why does high humidity affect electrostatic devices? Simple: it makes surfaces conductive enough to "short out" the devices. Under high-humidity conditions, insulating surfaces can behave as a dead short, almost like metal, even though their resistance remains too high to easily measure. A paradox? No.

Electrostatic effects deal with high voltage at little or no current. Because the voltage is high and the current low, even a fairly insulating object can act like an conductor when used with electrostatic devices. Ohm's Law tells us that high voltage at low current implies high resistance. For normal, non-electrostatic circuitry, low voltage at high current implies LOW resistance. Therefore we can say that "conductivity" in the electrostatic realm involve enormous values of electrical resistance, while "conductivity" in normal circuitry does not.

For example: A generator that produces 1 microamp at 10,000 volts has an inherent series source impedance of 10^10, ten billion ohms. (Compare a 1.5v D-cell, which has far less than one ohm internal series impedance.) If the source-impedance of an electrostatic generator is ten billion ohms, then any material having much less than this resistance will act as a good conductor, while materials having much more resistance will be insulators. (Compare to a D-cell, where 'conductors' must be lots less than one ohm, and 'insulators' must be much greater.)

A dirty surface in a humid environment might have hundreds of millions of ohms across its surface, yet it will act as a good conductor and can short out your generator. You must clean and dry the insulating surface so that its resistance rises to a range of *thousands of billions* of ohms across a few inches, so the generator will see it as an insulator. A wire will have a resistance of less than one ohm, yet a dirty surface, a surface which is more insulating than metal by hundreds of millions of times, will still act as a good conductor. Very strange, no? Electrostatics shows us that the meaning of "Conductor" and "Insulator" is not fixed: it varies depending on the nature of the generator or power supply, and the nature of the electrical load. Electrostatics is not the only place this occurs. For example, in superconducting systems, copper can be used as an INSULATOR. In AC power transmission, step-up transformers are used to make the long power lines act "more conductive." And in electrostatic systems, humid string (in Ben Franklin's kite) can act as a conductor.

Too dry?!

I encountered one instance where the humidity was TOO LOW for a demonstration: I opened a fresh bag of rice-crispy cereal, intending to produce a big messy "Volta's Hailstorm" effect using a VandeGraaff generator and a pie pan, filling the pan with cereal. Fortunately I tried out the demo just before the kids arrived. It didn't work. The rice crispies were too dry, acted as insulators, and refused to pick up a charge and be repelled, and so were attracted instead. Sprinkling water into the cereal box and giving it a good long shaking cured the difficulty.

Another place where humidity can be too LOW: when performing the VDG hair-raise demo, sometimes the VDG generator works fine, but long hair simply won't rise. This is probably because the hair has become an insulator, and charge is unable to leak along the hair shafts and give them an imbalance of alike-charge. Slightly humid hair is required for success; totally dry hair will cling to the head by induction and will not rise.

Humidity hints at U. of Rochester

HINTS AND OBSCURE FACTS USEFUL FOR ELECTROSTATIC SCIENCE PROJECTS

W. Beaty 1997

Electrostatic design is something of a "black art" because there are numerous little-known rules which only become important at high voltage. Below are a few of them. Don't let these rules scare you off from building a device. Many projects work fine the first time. It's when they do not work that the following suggestions start becoming useful.
PROBLEMS WITH LOW-CURRENT GENERATORS

Some types of static electric generators can only supply an extremely tiny current. The lower their current-generating capability, the more sensitive they are to stray leakage paths and the effects of humidity.

In the realm of electrostatics, a millionth of an ampere (uA, or microamp) is a fairly high current. For example, if you power an electrostatic motor with a plug-in DC high voltage supply having a 1000uA (1 milliampere) rating, you probably can violate all the following rules and ignore all the leakage issues. Where electrostatics is involved, 1 mA is a robust power supply with enormous output current. But if you try to use a Kelvin Waterdropper as a power supply, you'll probably have to follow all these rules in order prevent the surface leakage from shorting out your system. Also, if you follow all these rules, your device may tolerate much higher levels of humidity than otherwise.

AVOID WOOD INSULATORS

Avoid using wood, cloth, cardboard, paper, masonite, or other fiberous materials as insulating structures. Their insulating properties will vary unexpectedly because of humidity changes, so on some days they are insulating, other days they become conducting. Stick with plastics and rubber. If possible, avoid glass as well. Glass surfaces tend to absorb a bit of moisture, and become conducting on really humid days. Plastic suffers less from this effect... but even the best insulator is not immune. On wet days, warm your plastic and rubber surfaces with a blow-dryer.

AVOID SHARP-EDGED CONDUCTORS

Sharp metal edges bad! Big rounded edges good! If a sharp-edged object is raised to a high voltage, tiny corona discharges will appear on the sharp parts and will silently and invisibly leak charge away into the air. The higher the voltage, the worse the problem. The closer the sharp edge is to an oppositely-charged object, the worse the problem. Also, generators with very low current capabilities, such as Kelvin Thunderstorm devices, are particularly sensitive to leakage, so sharp edges become a real issue for these. The problem can be partially relieved by keeping air away from the sharp edges. For example, split some tubing lengthwise with a razor, and use it to cover the edges. Even better, apply heavy beads of RTV silicone caulk to cover the exposed sharp edges. (RTV is the vinegar-smelling type. Avoid using water-based silicone.) A 1/4 inch thick layer is good.

PUT BIG SPACES BETWEEN CHARGED PARTS

Keep the metal parts far away from each other and away from "ground." Metal parts includes insulated wires. If oppositely charged parts are close together, or if charged parts are close to grounded parts, the e-field between them becomes extremely intense. This can cause sparks, but even worse, it can cause silent, invisible corona discharges to appear on the metal surfaces. The air between the parts becomes conductive, and the maximum voltage produced by your device will be drastically lowered. Support your connecting wires up off the table with insulating blocks. In general, the distance that causes through-air leakage will be large for large, blunt metal parts, and smaller for small parts, sharp edges, wires, etc. The distance where problems occur also gets smaller as voltages get higher. If you're trying to get to 100,000 volts, you should only be using large smooth spheres and cylinders, keeping them many inches apart, and covering any small protuberances and sharp edges with gobs of silicone caulk.

REDUCE THE CAPACITANCE

Keep the metal parts far away from each other. This includes insulated wires. If oppositely charged parts are close together, or if charged parts are close to grounded parts, they form a capacitor with significant value. This can slow the charge-up time of the device. For any particular current, the lower the capacitance, the faster the device charges to maximum, so you want to reduce the capacitance. The bigger the metal parts, the farther away they should be from each other.

UNEXPECTED CONDUCTORS

I heard recently that ordinary vinyl record albums are poor insulators. I haven't check this out myself, but it does make sense. Electrostatic charging is a problem when cleaning records with a brush, and it causes them to attract dust for hours or days after being cleaned. Therefore, manufacturers might put some conductive chemical in the plastic. Perhaps some records lack this, and only some have problems. So, if you're thinking of building a Wimshurst machine, maybe it's a good idea to use some other type of plastic, and steer clear of old vinyl records for the Wimshurst machine disks.

SUPER INSULATORS

Recently I was playing with metal objects suspended by nylon fishing line. Even in extremely humid conditions, the charge imbalance on the suspended object would not leak away quickly. It seems that the surface of thin fishing line is very small, and since humidity-leakage is across the surfaces of plastic, small surface leads to good insulation. So, if you are building some sort of static electric device, it might pay to suspend the conductive elements by using short lengths of fishing line. As with any device, keep the nylon lines clean by never touching them with greasy salty fingers.

DON'T TRUST WIRE INSULATION

Leakage current can flow through thin plastic insulation, so don't trust a wire's thin insulation to stop leakage. Instead support wires away from each other and away from conductive objects by using plastic supports and glue. You might consider using heavy solid wire, because once this wire is fastened securely at its ends, it can be sculpted to form any desired path directly through the air and away from all other conductive objects.

WIRE, IF BARE, MUST BE THICK

Avoid using extremely thin, bare wire. The thin wire qualifies as a "sharp edge", and corona discharges can appear. These leak charge away to the air. For voltage up to 10,000 volts, bare wire needs to be #12 or greater diameter, like coat-hanger wire. At higher voltages, bare wire must be replaced by copper tubing or pipe. Or, don't use *bare* wire at all, thin wire is OK if surrounded with very thick insulation.

SOURCES OF INSULATED WIRE

Heavily insulated wire is available from some mail-order companies. Look for "high voltage" wire with ratings like 20KV or 50KV. If you cannot find a source, the next best thing is to use the center conductor of cable-TV cable, stripping off the black jacket and the copper braid. The center conductor will have a thick polyethelene or teflon insulation. Next best thing is "test lead wire," available in red and black colors from Radio Shack. Standard plastic-coated wire will usually work temporarily, but support it away from conductive objects such as tabletops. Another trick: give your wires a heavy insulation by sticking them through vinyl aquarium tubing.

KEEP INSULATING PARTS CLEAN

If insulating parts become dirty or dusty, they can become slightly conductive, especially when humidity is high. Store your devices under a cover so they don't collect dust. And periodically clean any device which is used frequently. After all, even invisibly small amounts of corona discharge can emit ions which turn your device into an "electrostatic air cleaner," and it will attract all the dust, soot, and pollution out of the air and onto its insulating surfaces.

INCREASE YOUR "DRYER STATIC CLING"

Those anti-static "dryer sheets" used to prevent static charging... they contain oil. Interesting fact: just a microscopic coating of oil will prevent "frictional charging." If you're rubbing fur on rubber, or passing a

VandeGraaff belt over a plastic pulley, those surfaces need to be extremely EXTREMELY clean. The slightest bit of WD-40 can halt all charging. Just a few drops of spray coming from oily bearings can simulate the effects of 90% humid weather. If your "frictional" electrostatic machine stops working, yet the weather is dry, suspect that your insulating surfaces are no longer made of fur, rubber, plastic. They are made of oil. Fix: a good scrubbing in running water with some detergent (not soap!) will carry away the microscopic oil coating. Blot dry, then thoroughly dry the surfaces with a hair blow-dryer.

WHAT CONSTITUTES "INSULATING"?

In general, the division between "insulator" and "conductor" is determined by the voltages and currents involved. For example, a flashlight might be 3 volts at 1 ampere. 3volts/1amp equals 3 ohms. So for a flashlight, any object with lots less than 3 ohms is a conductor, and any object with lots more than 3 ohms is an insulator. A flashlight "thinks" that a 10K resistor is a good insulator, while a 0.01 ohm wire is a good conductor. For electrostatics the numbers are quite different. A Kelvin waterdrop generator might produce 20,000volts at 1/2 microamp. Dividing this voltage by this current gives 40,000,000,000 ohms. So, if an object is to act as an insulator, its resistance must be MUCH greater than forty billion ohms! For a Kelvin generator, a one-megohm object will act like a very good conductor. Is it any wonder that a bit of surface moisture can convert an insulating object into a conductor? The highest value of resistor commonly available in catalogs is 22 megohms, and most electrostatic devices will see this device not as a resistor, but as a dead short.

HEAR THE TINIEST SPARK

With a robust electrostatic generator, you can test for proper functioning by lightly touching the metal parts and listening for a spark. But for barely-working devices, the sparks are far too small to hear or see. To cure this, place an AM radio within a few feet of your device and tune it to a blank station. The radio will pick up the electromagnetic pulses of even the tiniest sparks. Better yet, wear a "walkman" AM radio, and you turn yourself into a super-being, a Borg with enhanced sensory apparatus who can hear electro-magnetism. I've entertained myself by scuffing my feet on the carpet even in high humidity conditions, then touching grounded objects to make clicking sounds in the headphones.

SEEING THE VOLTAGE

Wouldn't it be a big help if you could *see* voltage while debugging your device? For example, you could adjust your VandeGraaff combs to produce maximum voltage on your machine. A simple trick: cut some short strips of tissue, then stick them to the metal parts of your device with a bit of tape at the top end of the strip, so that the strips hang down along the metal. When the metal becomes charged, the tissue strips will be repelled outwards. The further they rise, the higher the voltage on the metal object. Motion of the tissue makes the voltage "visible." (Note that this might not work in very dry conditions, since charge must leak along the tissue in order to give it an alike charge imbalance. Try painting your tissue with india ink and drying, in order to make it conductive.)

AVOID THE EXPENSE OF SHAPED METAL PARTS

I discovered that India Ink makes a dandy conductor when dry. In cases where metal is expensive, you might consider using ink-coated wood or ink on papier-mache instead. Fancy shapes can be created in wood much more easily than in metal, then painted thickly with India Ink to guarantee a high conductivity. However, the conductivity of ink may not be high enough for use in spark-discharge electrodes. Metal should be used in this case. Try aluminum foil and rubber cement or contact glue, or find some adhesive aluminum foil tape (sold in rolls like duct tape, but with peel-off waxpaper covering the adhesive.)

VDG VERSUS PC

A VDG is a constant current source. During normal operation there is a large e-field around the device, but there is also a flow of charge between the sphere and ground. This flow is composed of charged air, and while some of it manages to get to ground, much of it is attracted to surfaces, and lots of it travels far beyond the region immediately around the machine. If the humidity is low, it will build up on insulating surfaces where it creates large e-fields and high voltages. In other words, an operating VandeGraaff SPEWS CHARGED WIND which wanders around charging up EVERYTHING in the room, including the walls, ceilings, people, etc. The fans on your PC will suck the charged air into the case, where it will electrify all non-metal surfaces, cause huge electrostatic fields and sudden sparks, and generally trash circuitry left and right. It also tends to collect on ungrounded plastic parts such as keyboards. It is wise to avoid doing VDG demos in the same room with an operating computer. If this cannot be avoided, then keep your demo short, keep the VDG as far as possible from your computer, VCR, etc., keep the VDG turned off or shorted with a ground clip except during actual use, and avoid days with extremely low humidity. Better yet, do a Tesla coil demo instead!

Now for the fun

Sky Pie

Place a small aluminum foil pie pan upside down on the dome of your VDG. When you turn on the power, it will levitate and fly off to the side. Alike charged objects repel each other. Big thrills? But wait, what if you place TWO pie pans nested on your VDG? When you turn on power, the top one holds the bottom one down, until the top one flies off, which then allows the bottom one to take off. SOOOO, place an entire stack of thin foil pie pans upside-down on top of your generator, and get ready for a pan storm. When run, your generator will loft each pan in sequence and fling them in various directions. This works best with those little "pie tart" pans about 10cm dia.

DANCING BUBBLES

Blow soap bubbles at your VDG terminal. They will initially be attracted, but then will become charged by ion wind and will then be violently repelled from the generator sphere. They will also be attracted to any other object. With practice you can hold your hand above a charged bubble and keep it aloft by attraction.

ELECTROSTATIC LEVITATION

Place a large metal sheet or foil-covered cardboard on the ground. It should be at least 2 to 3 times the diameter of your VDG sphere. Connect this sheet to earth-ground. Place some small crumpled pieces of foil on the center of the sheet. Pick up your entire VDG machine, turn it on, and while holding it by its base, move the sphere down towards the crumpled foil. With practice you can get the foil to levitate and hang in the air between the sphere and the ground plate. The VDG attracts the grounded foil, but then the corona discharge from the edges of the foil chunk will form a conductive path in the air which allows the metal to acquire a like-charge from the sphere, which increases the repulsion force. As the foil drops away, it loses its charge via corona, and is again attracted upwards. At a particular distance you can get a piece of foil to hang unmoving in space with balanced attraction/gravity forces and continuous corona leakage. (Note: there may be ion-wind filaments associated with this phenomenon. Someone should do the foil-lifting experiment in front of a Schlieren system and look for grey lines in the air.)

Sparks : In a darkened room, just turn it on and watch the parks! This is the most demonstrative way of showing the power of a spark. Introduce the numbers. It takes a potential of 50,000 Volts PER INCH for a spark to be generated in air. On a good dry day, you can get 5 inch sparks! Blue, purple, white!

Flying Pie Plates : Place several aluminum pie plates *face down* on top of the VDG dome and turn on. They fly off one by one! If you're lucky, you can even make one or more "levitate" for a few seconds before flinging into the air. Why? Repulsion since they are both picking up the same charge.

Flying Peanuts : Secure one pie plate on top of the dome with a SMALL amount of tape. Place in a handful of packing "peanuts". Turn on. The packing peanuts levitate momentarily then fly off like popping corn.

Light a Fluorescent Bulb : While on, hold a fluorescent bulb by the middle near the globe, pointing it like a...well, pointer. It will light from the point closest the dome to your hand!
Side note: If you do this with little kids, you know, ankle biters, have a kid who is wearing those annoying shoes that light up when they walk touch the dome and switch on. The little shoes light up!

Blowing Bubbles : While the dome is charged and the VDG is running, blow bubbles at the dome. I use a battery powered bubble gun from WalMart since I have no coordination and a constant stream of bubbles is most effective. The bubbles will approach the dome and then be suddenly rejected and fly off away from the dome! This is a good demo for changing by induction.

Floating Toupe : Obtain the typical cat or rabbit fur clump from any science supply house. Place it on the dome and switch on. The hair piece does a little dance as it becomes hugely negatively charged and tries to get away. As the edges rise, it creates a PD and sparks and falls back down.

Screen Shielding : This one is GREAT! Get a large ALUMINUM screening roll from Home Depot or Loews. Large enough to make a screen "bag" that can fit over your upper body. This can be done by just sewing or even stapling the edges of two sides of a folded over sheet of screen. CAUTION: Don't be stupid or cheap and get the nylon screening! I did... Now, place the screen "bag" over your head and shoulders and approach a charged VDG. Sparks will jump from the dome to the screen. The audience will think you are getting zapped. But you aren't! The charges spread out over the metal of the screen and no charge enters where you are! From inside, all you see are little blue sparks that LOOK like they are coming for your nose.

Stop a liquid in its proverbial tracks : This one is freaky! Mix up a thick cornstarch and water goop in a beaker; about the consistency of Elmer's glue. Now, while the VDG is running and charged, pour a small stream from above the dome like you are going to pour it so it falls right beside the dome. Watch. Go ahead! I'll wait.... As the goop comes out of the beaker and approaches the dome, you will notice the stream actually ***STOPS in midair***! The pouring stops even though you have the beaker tilted!
Why, you ask? The goop is nothing more than long chain polymers that are electro-rheostatic. Whew! Big word that simply means "electrically reactive". So, as the polymers, long chain molecules, approach the Electric Field around the dome, they align to its presence and actually solidify the stuff like grabbing a pile of pick-up-sticks! Cool!