Genecon electrostatic generator.

(Electrostatic High-Voltage Genecon®)

Contents
Introduction ........................................................................................................................................................ 3
What’s in the pack ............................................................................................................................................. 3
Features ............................................................................................................................................................. 4
Practical use ...................................................................................................................................................... 5
Practical accessories ......................................................................................................................................... 6
Charge Collecting Spheres ............................................................................................................................ 6
Making your own collecting sphere ................................................................................................................ 6
Electric pendulum ........................................................................................................................................ 7
Explanation ................................................................................................................................................. 7
Static motor .................................................................................................................................................... 8
Explanation ................................................................................................................................................. 8
Hamilton Flywheel .......................................................................................................................................... 9
Explanation ................................................................................................................................................. 9
Simple experiments ......................................................................................................................................... 10
Pith balls (pith ball electroscope) ................................................................................................................ 10
Using the movement of pith balls to measure the electrostatic force (charge) ............................................ 11
Ping-pong balls ........................................................................................................................................... 13
Electrostatic force lines using paper strips ................................................................................................. 14
Electrostatic force lines using hair ............................................................................................................... 15
Electrostatic fountain .................................................................................................................................... 15
Electrostatic ping-pong ................................................................................................................................ 16
Sorting salt and pepper ................................................................................................................................ 17
Making a flame move by static ..................................................................................................................... 18
Charge only exists on the outside surface of the conductor ......................................................................... 19
Van de Graaff (electrostatic) generator safety ............................................................................................... 20
Read before use.

The Electrostatic High-Voltage Genecon is ready to use as soon as it is unpacked.

Note it is not advised to pull the felt pad away from the drum for examination – the metal blade inside the felt strip may become distorted by bending.

- Discourage over zealous winding of the unit, increasing speed reduces friction between the felt pad and the drum and reduces its output. Damage to the gears can also take place if the unit is wound too fast.
- Take care to not get any liquids onto the felt or drum where they can be transferred to the felt.
- Store the unit between use in a dust free environment, a plastic bag or the original box are ideal for storage.
- Using leads other than the supplied to transfer the static will change the voltage available.
- You will not get the very high voltages that you get from a traditional VDG. The lower voltages generated will be more than adequate for demonstrations of static phenomena.
- Good HT insulation is required to get the biggest voltage and spark jump. Do not assume that an insulator for low voltage will work as a HT insulator. PVC cables, for example, tend to start carrying charge down the outer surface of the PVC insulation. PTFE tape proved to be a good barrier where joins and connections had to be made.

Safety notes.

The Electrostatic High-Voltage Genecon® is a van der Graff generator. It produces a voltage of 10Kv at the output terminals. The same precautions for using a van der Graff should be applied to the use of the Genecon electrostatic generator. The Genecon device is safer than many of the older large static generators. Details on van der Graff safety are included at the end of this document. The Genecon has been designed to provide a safer way to study electrostatics and charges.

Do nots.

1. Do not hold onto the output terminals and wind the handle.
2. Do not use large charge collecting spheres, large spheres hold large amounts of energy.
3. Do not use large collecting apparatus e.g. capacitors, Leyden jars. The energy store and discharge rates make these unsuitable for uncontrolled work.
4. Do not discharge a collecting sphere or any similar device by touching it, use a grounding wire and non-conductive wand.

Electrostatic High-Voltage Genecon® and Genecon® are the registered trade marks of the Narika Corporation of Japan.
Introduction

Movement of dissimilar materials across each other strips of electrons off the surfaces of the materials. In an electrostatic generator, the electrons are harvested and collected. In a traditional Van de Graaff device the harvested electrons are transferred to an attached collecting sphere, the final voltage / charge collected will be proportional to the radius of the collecting sphere.

The Genecon has no collecting spheres, it creates static on demand. Leads from the Genecon will transfer the static produced to a number of devices used for the study of electrostatics.

The Genecon has several advantages over the traditional VDG;
1. The mechanisms of static generation and collection are visible to the user.
2. There is a direct link between the student learner and the practical, the Genecon needs student involvement and is not a passive demonstration.
3. The electrostatic voltages created are lower than the VDG and yet still show the features of electrostatics.
4. The lower voltages / charge densities make it an inherently safer device to work with. Individual study rather than class demonstration is therefore encouraged.
5. The removal of the large top static collector (found on the VDG) makes the instrument much more portable and compact.
6. Accessories can be purchased separately or made by the students.
7. No replacement belts.
8. Wide range of matched accessories.

What’s in the pack

One Genecon High-Voltage static generator
A pair of output cables
One instruction manual

Specifications

<table>
<thead>
<tr>
<th>Main housing</th>
<th>Polycarbonate resin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generator unit</td>
<td>Negative pole (the drum) is made of polyvinyl chloride (PVC) resin. The positive pole is a felt belt</td>
</tr>
<tr>
<td>Gears</td>
<td>Polyoxyethylene (POM) - also known as acetal, polyacetal, and polyformaldehyde resin</td>
</tr>
<tr>
<td>Output cables</td>
<td>High voltage cable resistant to 30 kV</td>
</tr>
<tr>
<td>Output voltage</td>
<td>About 30,000 V (30 kV) at the terminals in the housing; more than 10,000 V (10 kV) at the output end of the cable</td>
</tr>
<tr>
<td>Dimensions</td>
<td>223 x 255 x 75 mm Weight approx 400 g</td>
</tr>
</tbody>
</table>
Features

Unlike a traditional VDG there are 2 output terminals. High-voltage static electricity can be drawn from the output terminals as you turn the handle and generate static.

The polarity of the output voltage remains the same whether you turn the handle to the right or left.

The turning speed of the generator should be slow, so you feel the frictional resistance from the unit. High voltage static is best produced at **one or two turns per second**.

Turning any faster does not increase the static production. If you turn the handle at high speed friction between the PVC drum and the felt is reduced leading to a **decrease** in the produced voltage. Excessive speed of turning can potentially damage the gear system.

Generally, high voltage static electricity is difficult to produce in a humid atmosphere. The GENECON is best used in an environment of 40 to 60% humidity – room humidity. This is because the friction between the felt and the PVC drum increases and the electric charges are smoothly transferred from the felt surface to the internal metal electrode when the felt is slightly moist.

In dry conditions e.g. about 20% or lower humidity, the drum and the felt will slip on each other, making it difficult to generate high voltage. Electric current drawn from the electrodes are also reduced. If this is the case, turn the drum several times while blowing humid exhaled air to the area between the drum and the felt (Fig. 2) to moisten the felt and increase the friction. You will be ready to start an experiment when a sizzling sound comes from near the collecting electrode on the upper part of the GENECON main unit.

**Under no circumstances use a humidifier or similar apparatus - the moisture provided will saturate the felt and reduce friction.**

**Figure 1 The Electrostatic High-Voltage Genecon**

**Figure 2 Breathing on the Electrostatic High-Voltage Genecon to moisten the felt pad.**
Practical use

- Discourage over zealous winding of the unit, increasing speed reduces friction between the felt pad and the drum and reduces its output. The gears will break if unreasonable force is applied to the unit such as turning the handle at high speed.
- **Storage:** Place the unit in a plastic bag or the original box in a dust free environment.
- Take care to not get any liquids onto the felt or drum where they can be transferred to the felt.
- The output leads supplied have different insulation from standard low voltage patch leads. Using a standard patch lead to transfer static will reduce the voltage available.
- You will not get the extremely high voltages (e.g. 450 kV) that you can get from a traditional Van de Graaff generator. The voltages generated by this static generator are more than adequate for demonstrations of static phenomena (about 30 kV at the housing terminals; 10 kV at the cable output end).
- Good HT insulation is required to get the biggest voltage and spark jump. Do not assume that an insulator for low voltage will work as an HT insulator. PVC cables, for example, tend to start carrying charge down the outer surface of the PVC insulation. PTFE tape proved to be a good barrier where joins and connections had to be made.
Practical accessories

Charge Collecting Spheres

Charge spheres are used to accumulate charge and to show the nature of opposite and like charges. Polystyrene formers covered with aluminium foil make simple and effective charge spheres. The spheres do need to be electrically insulated from the ground, bear in mind that high voltages may overcome low voltage insulation.

Making your own collecting sphere
To make a charge collecting sphere, cover non-conducting spheres, e.g. ping-pong balls, Styrofoam spheres with foil. Trap wire in the foil to make a connection to the Genecon. Mount the spheres on a non-conducting support. Connect one from the Genecon to the collecting sphere and connect the other to the support holding the sphere up.

Accessories from standard Van der Graff generators will work with the Genecon electrostatic generator, e.g. collecting spheres, tear drop collecting spheres.
**Electric pendulum**

The electric pendulum is a non-conducting clear plastic tube. A light foam ball of conductive material is placed in the tube. At each end of the tube, electrodes are positioned to be able to contact the ball but not allow the ball to leave the tube.

Connect the electrodes of the pendulum to the outputs of the Static generator. Position the ball to be touching one of the pendulum electrodes, and wind the handle. Without you moving the pendulum apparatus, the ball will move from one end of the tube to other, pause, and move back. The motion will continue as long as the Static generator is active (and perhaps for a short period after until the charges are neutralised).

**Explanation**

The ball collects charge from the electrode it is in contact with. As like charges repel, once the force in the charge is high enough to overcome the friction of the static ball, the ball is repulsed away from the charging electrode. As the ball moves, it enters the electric field of the other electrode and becomes attracted to the opposite charge on other electrode. The ball contacts the electrode and charge on the ball is neutralised and then built back with the polarity of the electrode it is touching. The process repeats in the opposite direction. As long as there is charge polarity difference on each electrode, the ball keeps moving from one end to the other.

You can create a version of the pendulum using a pair of flat discs, parallel to each other with the conducting ball suspended between them. Details later in this document.
Static motor.

The magnetic induction motor is a common motor, what is less common is the electrostatic motor. The operation of the motor is quite simple to understand; it is based upon charges of like polarity repelling and charges of opposite polarity attracting. The motor is shown diagrammatically below.

**Explanation**
An electrode transfers charge of a polarity onto a metal charge carrier on the rotating central spindle. The charge deposited starts to repel the charge carrier away from the electrode, a second electrode removes or neutralises the charge and the process begins again. The speed of the rotation is only limited by the frictional forces present in the machine created.
Hamilton Flywheel

The Hamilton Flywheel is a device that has freely rotating bent arms that finish in sharp points; the points are all in the same direction.

The Hamilton flywheel is used for demonstrating the polarities created in electrostatic generation. The base of the flywheel is connected to the black output (ground) of the Static generator. The central pillar (and therefore the flywheel pins) is connected to the red output. Winding the handle of the static generator will transfer charges of one polarity to the pins and the opposite polarity to the base (ground). As the charge builds, the flywheel will begin to rotate. The rotation is usually better if the charge to the pin tips is +ve.

Explanation.
The device works by a charge building on the tip of the bent pin; this creates a corona discharge to the air. The air at the tip develops a charge of the same polarity, like charges repel so the pin moves away from the air charge. The turning force is slight and friction can be a problem. The proof of the involvement of the pinwheel points can be tested by adding small spherical balls to the pin tips, this disperses the charge and prevents the creation of the corona discharge, the air fails to become charged, and repulsion cannot take place.
Simple experiments

**Pith balls (pith ball electroscope).**
A classic demonstration of electrostatics often referred to as a pith ball electroscope.

A pith-ball electroscope consists of a small ball of some lightweight non-conductive substance (originally pith), suspended by non-conducting thread (e.g. silk) from the hook of an insulated stand.

If a charged object is brought close to the ball it will become polarized by induction and will move towards the charged object. If a pair of balls is used, some of the charge will be transferred by contact to each of the balls and they will then each have half of the original charge of the same polarity. As both balls have the same polarity they will be repelled and move apart to form an inverted V shape. The distance between the balls will be proportional to the charge.

You can use the Electrostatic High-Voltage Genecon to develop and transfer the charge to the pith balls quickly and easily. Simply wind the Genecon a couple of turns and touch one of the outputs to one of the balls. Don’t be tempted to touch both balls or to use one output on one ball and the other to the other ball (why not?).

It is possible to turn the demonstration of like charges repelling or dissimilar charges attracting to a more quantitative practical.

**Gold leaf electroscope.**
The gold leaf electroscope uses a very thin piece of metal foil (the gold leaf) fixed to a stiffer piece of metal rod. The foil and metal rod are within a case (mainly glass) with windows for observation; the case stops air movements from moving the foil. If you apply a charge to the metal rod, the foil will become charged with the same charge as the rod. Like charges repel, so the foil moves away from the metal rod. The amount of deflection is proportional to the charge. Some electroscopes have a graduated metal bar which can be used to take measurements of the deflection displacement due to the applied charge.

The design of the electroscope will vary in some detail, but the rod that has the foil attached to it will extend beyond the case and have a large charge receiving disc outside the case.

Connect the Genecon electrostatic generator to the disc and wind the handle a few times and you will see the foil move away from the rod. The number of handle turns vs. foil displacement can be studied.

The electroscope is much more sensitive version of the pith ball electroscope described above.

You can make your own electroscope using thin foil, the thinner the better. Try different designs to see how good you can make it, i.e. double leaves, single leaf, single leaf support rod etc.
**Using the movement of pith balls to measure the electrostatic force (charge).**

Use the Electrostatic High-Voltage Genecon to charge a sphere that will repel a pith ball hanging freely. You will need to measure the mass of the pith ball and the displacement of the hanging ball.

If we bring a charge sphere to a suspended pith ball, the pith ball collects the charge from the sphere and becomes repelled. We can use the movement of the pith ball away from the sphere to calculate the charge by balancing the forces and force changes.

![Diagram of pith ball and charge sphere](image)

The force acting on the pith ball when it is hanging is $F_g = mg$, it is the vertical force component.

Classic physics tells us that an object remains in motion (or static) unless a force acts upon it. We know several of the physical measurements of the system that are important, mass of the pith ball, length of suspending thread, distance moved and angle. The force acting on the pith ball at non charged equilibrium is the product of the ball mass and gravity.

Any movement from this equilibrium must be due to a unbalancing force. In this activity we assume that the force needed to move the ball is related to the force of the electrostatic charge.

When we bring a charged object close to the suspended pith ball it will moves a small distance $r$ from its old equilibrium position (hanging straight down) to its new equilibrium position at an angle $\theta$ away from its original position (in the presence of the charge sphere).

![Diagram of pith ball and charge sphere](image)

Moving the pith ball, the distance $r$, requires a force. The force comes from the electrostatic repulsion of the two similarly charged spheres. We will define this force as $F_e$. It is the horizontal force component.
We need to resolve the ratio of the horizontal and vertical forces to find $F_t$.

$$F_t = \frac{F_e}{F_g}$$

Or

$$F_e = \tan \theta F_g$$

The only change we have made is to charge the pith ball, the force $F_e$ must be the magnitude of the Coulomb force that displaces (moves) the pith ball.

Coulombs law;

$$F = k \frac{q_1 q_2}{r^2}$$

Rearrange to make $q$ subject of the equation,

$$q^2 = \frac{Fr^2}{k}$$

- You can calculate $F_g$.
- With the measured angle of the displacement of the pith ball and $F_g$ you can find $F_e$.
- Use $F_e$ to calculate $q^2$, it is also $F$ in the equation.
- K is Coulombs’ constant $= 8.99 \times 10^9$
- $r$ is the displacement of the pith ball by the charge.

The theory is simple; the practice of measurement is more difficult and may take patience. Our first problem is that the pith ball has to be very light, the forces are very slight and if the ball had much mass, we would not see the movement. You will need either access to a sensitive balance.

Note that for a given force on the ball, a smaller $m$ means bigger $r$, i.e. easier to see and measure.

Our second difficulty is to make the displacement measurement. You have to be careful to not disperse the charge as you measure! You can use a projected light and a shadow on a board behind; use the shadows to make measurements.
Ping-pong balls.

This is an alternative to using small pith balls.

For a simple demonstration of charges repelling and attracting, use a pair of ping-pong balls. You will need to coat them with a conductive material – the simplest way is to wrap in foil (try to not get too many overlaps or wrinkles). Trap a fine wire under the foil as you wrap the balls, you can use the wire to suspend the balls, if it is fine enough. Watch out for wire that has “spring” with in it, the charge repulsion may be insufficient to overcome the spring in the wire.

You will need
- A pair of ping-pong balls covered in metal foil or sprayed with conductive paint.
- Small piece of tape.
- Light conducting wire, not springy. Uninsulated at either end.
- Collecting sphere.
- Electrostatic High-Voltage Genecon with its connecting leads.

What to do
1. Attach the ping-pong balls to the conducting wire. Make sure there is an electrical connection between the wire and the conductive layer of the balls.
2. Suspend the two balls from separate non-conducting stands using the fine wires.
3. Attach the wire from each ball to the outputs of the Genecon electrostatic generator.
4. Wind the Genecon, you should see the balls at first attracted to each other (each ball will develop a different polarity charge) then repelled. As you continue to wind, the balls will continually attract and repel.

Try connecting one output of the charge generator to earth and one to a single ball. What happens then?

Note: Small pieces of conductive foam (as used to protect electronic components) can be used as a replacement for pith balls.
**Electrostatic force lines using paper strips.**

### You will need
- Some light tissue, loose in texture e.g. single ply of toilet tissue or disposable handkerchiefs (watch out for tissues that have been treated with talc or oils.)
- Small piece of tape.
- Collecting sphere.
- Electrostatic High-Voltage Genecon with its connecting leads.

### What to do
1. Cut or carefully tear the tissue into strips – no more than 0.5 cm wide and as long as possible.
2. Attach the strips to the top of a collecting sphere.
3. Connect the collecting sphere to the electrostatic generator, one lead to the sphere and the other to ground.
4. Wind the static generators handle and watch what happens to the tissue.

As the sphere becomes charged, the charge is transferred to the paper strips, like charges repel and the strips will move away from the surface of the sphere and from each other.

The paper strips will try to position themselves to have the best separation to match the charge they carry. They will try to spread themselves evenly through the space available.

You can use the very fine feathers you find on a feather boa, ostrich feathers.
Electrostatic force lines using hair

A classic variation of the paper strip demonstration is to use hair. The static generator may not provide sufficient voltage to make human hair stand up but polyester hair will.

You will need

- Some long, clean dry polyester hair e.g. a cheap polyester wig or hair extension. A complete "Barbie" doll sat on the sphere will work.
- Small piece of tape
- Collecting sphere
- Electrostatic High-Voltage Genecon with its connecting leads

What to do

1. Use a small piece of tape to hold the hair in place on the top of the collecting sphere.
2. Connect the collecting sphere to the electrostatic generator, one lead to the sphere and the other to ground.
3. Wind the handle, and watch what happens to the hair.

As the sphere becomes charged, the charge is transferred to the hair, like charges repel and the individual hairs will move away from the surface of the sphere and from each other.

Electrostatic fountain

A simple demonstration to show how like forces repel. As the particles in the cup become charged, they will have the same polarity, as will the walls of the containing cup. Like polarities repel, if the particles are light enough they will be pushed apart – the shape of the cup will tend to make them move upward creating a short fountain of particles as they all try to move away from areas of the same charge polarity.

You will need

- Some particles made of a material that is lightweight and will accept a charge e.g. conductive foam pieces, polystyrene beads (expanded), confetti.
- Small piece of tape.
- Small cup with a conductive base (you could make one from aluminium foil).
- Collecting sphere.
- Electrostatic High-Voltage Genecon with its connecting leads.

What to do

1. Place the cup on top of the collecting sphere. Use a small piece of tape to hold in place.
2. Fill the cup with the particles e.g. confetti.
3. Connect the collecting sphere to the electrostatic generator, one lead to the sphere and the other to ground.
4. Wind the handle, and watch what happens to the particles.

As the sphere becomes charged, the charge is transferred to the cup and its particles, like charges repel and the individual particles will move away from the surface of the sphere and from each other.
Electrostatic ping-pong

This demonstration uses the repelling and attraction of charges. The idea is clamp the two metal discs in position so they are parallel to each other vertically. They need to be separated by a gap equal to about 4 diameters of the ball being used. Ideally, the discs should be electrically isolated from everything. However, the demonstration does work if the electrical connection is to the retort stand and these are isolated from table tops and each other.

You will need
- A pair of metal discs.
- A conductive lightweight ball (pith ball, conductive foam ball, foil covered ping-pong ball).
- Small piece of tape.
- Non-conductive thread, as light and fine as possible (traditionally silk thread is used; avoid polyester as it may conduct).
- Small cup with a conductive base (you could make one from aluminium foil).
- Electrostatic High-Voltage Genecon with its connecting leads.
- Retort stands, clamps bosses, etc (wooden would be simpler).

What to do
1. Set up the apparatus as described above.
2. Position the ball so it is suspend just slightly off the halfway between the two metal plates but vertically in the centre of the discs.
3. Connect one disc to one output of the static generator and the other disc to the other output.
4. Wind the static generator to place charge on the discs, if you are lucky, the ball will be pulled to one disc. As it touches the disc, the charges on the sphere will be neutralised and then replaced by the charge polarity of the disc. Like charges repel, as the ball is free to move it will move towards the centre position.
5. If the ball has sufficient momentum it will move past the centre point and into the opposite charge field of the opposing disc. The opposite charges of the disc and ball will attract and the ball will move quickly to the opposite disc.
6. Once the ball touches the disc, the charges will be neutralised and replaced, opposite charges repel and the process continues.
7. The process should continue as long as the static generator is active and provide opposite charge polarities to the two discs.

Note: You may need to suspend the ball very slightly off centre to allow a charge difference to develop on the ball.
### Sorting salt and pepper

In this simple experiment use salt and pepper, it is a cheap mixture and has the potential of being something the students can easily relate to.

Objects that have different charge will be attracted. If the attractive force is large enough the objects will move towards the opposing charge. In some plastics recycling plants they use static charges to pull plastics out of the waste stream, in a similar way to pulling magnetic metal out of a stream of mixed metals using a magnet.

**You will need**

- An object capable of being charged, either a disc made of aluminium foil or a charge sphere that can be moved easily. This is the ‘pepper separator’.
- A conductive base insulated from the table.
- Electrostatic High-Voltage Genecon with its connecting leads
- A mixture of salt and pepper. Ground pepper and coarse sea salt are better – the mass difference in the particles helps.

**Notes:**

- You have to make sure the charge is not lost from the ‘pepper separator’ as you handle it. An insulated handle is advised or you may wish to make the separator a fixed plate and move the salt and pepper under the plate.
- If the salt particles have the same mass or are lighter than the pepper then the salt will move to the disc or sphere instead.

**What to do**

1. Place the mixed salt and pepper on the conductive base. Do not pile in a small mountain, the flatter the better (a peaked pile can allow the charge to spark across).
2. Connect the ‘pepper separator’ to one output of the static generator and the other output to the base holding the mixture.
3. Wind the static generator a few times, if you listen carefully you will hear a slight fizzing noise; this is the charge moving to the air when the generator is fully loaded.
4. Move the charged ‘pepper separator’ close to the pile of mixed salt and pepper. The pepper being lighter will move onto the charged plate leaving the salt behind. If you get too close, the charge will jump as a spark between the base and the pepper separator.

**Questions**

- Does which output is connected to the ‘separator’ make a difference?
- How does the material the separator is made from affect the ability of the salt and pepper to be separated?
- What happens if you place a mixture of salt and pepper in cup that is resting on the top of a charge sphere and then charge the sphere?
Making a flame move by static

A classic experiment to show the ionised nature of particles in flame.

The candle flame is made up of ionised particles, these have a charge. By placing a disc near the flame and applying a charge to the disc the ionised particles will react to the charge and move. If the flame particles are ionised, the result will be a flame that moves when a charge is applied.

What the demonstration shows is the flow of ions away from the charge plate. This creates an ionic wind that moves the flame. In a simple form this mimics the effect of the solar wind from the sun. If the plate is placed very close to the flame, the flame will split, separating the charged particles in the flame.

You will need
- A disc made of aluminium foil or a small flat charging plate
- Retort stand, boss and insulated finger grip. (Usually the rubber on the fingers will be more than adequate, but you may have to add some insulation).
- Electrostatic High-Voltage Genecon with its connecting leads
- Small candle (pillar type) secured to the table so it cannot fall over (by using Blu Tack or plasticine or a candleholder).
- Matches or lighter

What to do

1. Connect the charging plate to one of the outputs of the static generator.
2. Use a finger clamp and retort stand to hold the charging plate perpendicular to the flame. The finger clamp needs to insulate the cable and plate from the rest of the retort stand.
3. Connect the other output of the static generator to the retort stand. This will ground the generator.
4. Place the candle securely on the table and light it.
5. When the flame has become stable (sometimes the wick needs to burn in for short period) position the charging plate so it is close to the flame but not touching the candle. The plate should be at right angles to the flame.
6. Watch the flame and wind the static generator. What happens to the flame?
7. Reverse the output connections and repeat. What happens now?
Charge only exists on the outside surface of the conductor.

A demonstration of how charges accumulate on a surface of a conductor. The experiment will show that charge stays on the surface to which it is added. The ball adjacent to the charged surface will be attracted to the surface; the ball on the uncharged surface will remain static.

How well the experiment works will depend on how good the pail is at preventing the charge from creeping over all surfaces. A metal coffee tin works well, initially, but if the top of the can is left to accept a removable lid you will find the charge starts to creep and the ball inside the pail starts to move as well. A metal ice pail as used for wine cooling is ideal.

You will need
- A Faraday's ice pail (metal wine cooler, ice bucket, can with top removed etc.)
- Retort stand, boss and insulated finger grip. (Usually the rubber on the fingers will be more than adequate, but you may have to add some insulation).
- Electrostatic High-Voltage Genecon with its connecting leads
- Discharge wand.
- A pair of graphite or foil covered ping-pong balls.
- Blu - Tack or masking tape.

What to do

1. Place the pail on an insulating stand.
2. Use the retort stand to suspend the two balls so they just hang beneath the level of the lip of the pail. One inside the pail, one outside. Both should be the same distance from the wall of the pail.
3. Connect the outer surface of the pail to the Genecon electrostatic generator.
4. Connect the other lead from the generator to an earth point.
5. Wind the handle and observe what happens to the balls.

What you will hope to see is that the ball adjacent to the side of the pail being charged (the outside ball) will be attracted to the wall of the pail. As the ball strikes the side of the pail the charges developed on the ball and wall of the pail will be equalised, the ball will be repelled, move away and swing back to pick up more charge, be repelled and so on.

The ball in the inside of the pail will not move, the charge you are adding from the generator only exists on the one side of the conductor, it has not moved through it to arrive on the inner surface of the pail.

If the period of the ball swing is too long or the distance from pail to wall is too large you will find that both balls will start to move, but the movement of the outer ball is always greater. Charge can creep over the edge of the pail especially if the edge is not very smooth.

It is part of the explanation of why a plane is safe in a lightning storm or you will not get a shock if you are in a car in a thunderstorm. The charge flows over the surface it made contact with; it will not flow across to the other surface.
Van de Graaff (electrostatic) generator safety

Basic precautions
- The electrostatic energy stored by a sphere should not exceed about 0.5 J.
- Do not add devices that increase the capacitance.
- It is not advisable for people to participate in practical work with a Van de Graaff generator if they have heart conditions, or a pacemaker, or have other electronic medical equipment fitted.
- The electrical discharge from a Van de Graaff generator can wreck electronic circuits, so equipment such as computers and instrumentation with electronic circuits should be kept well away.

When using an electrostatic generator charge is transferred, typically, to a metal sphere – a capacitor – and very high voltages are achieved between the sphere and ground, typically in the range 200 kV to 300 kV. With the Genecon electrostatic generator the voltages are more likely to be at the lower estimated range. The voltage carried will depend upon the atmospheric conditions prevailing, greater voltages being achieved on dry days.

Using the Genecon electrostatic generator, it is possible to receive a short shock by accidental or intentional contact with the small charging spheres, connecting leads or output terminals. This should be no more than the shock received from leaving a car, walking across carpets or from stroking a pet. Some people are more sensitive than others and can find the shocks very unpleasant and painful; these individuals may feel they are natural static engines and more prone to static generation. The reality is that we accumulate static, but many of us do not notice the discharge. The varying sensitivity of the individual to discharge can create unease in the audience with the most sensitive responders setting the scene of severity of shock. This needs to be managed, perhaps using yourself as the first victim to calm fears. It is a natural reaction to pull back from the discharge spark, the instinct often compounding the impression of pain.

An explanation of why small is safe
Any shock from an electrostatic generator is a single unidirectional pulse of a short duration. The connected dome is a capacitor and the discharge is through the resistance of the body and contacts. The discharge time can be calculated using values typical for human skin resistance and charge on a dome. With a charge on the dome of 10 pF, and body resistance of 1000 ohms, the discharge time through a person will be of the order of nanoseconds and certainly less than a millisecond (use RC = time constant, R = resistance, C = capacitance). The capacitance of the sphere needs to be low enough so that at maximum voltage, the energy transferred by the discharge through the body causes at most no more than an unpleasant or painful sensation. The current flowing and energy transferred should be well below that which could cause any risk of ventricular fibrillation.

For an impulse current I Amps of short duration t seconds (t < 10 ms) through the body, the principal factor for the initiation of ventricular fibrillation is the value of It or It² (IEC 2007). At high applied voltages, the resistance (internal) of the adult body (left hand to right hand) is at least 575 ohms for 95% of the population (IEC 2005). The total body resistance for children is expected to be higher but of the same order of magnitude. The IEC gives a threshold value of Specific Fibrillation Energy, for a 1 ms current impulse, of 2 x 10⁻³ A²s. Below this threshold there is no evidence of fibrillation. The Specific Fibrillation Energy can be regarded as the energy dissipated per unit resistance of the body through which the current flows. Note that ‘specific’ here means ‘per unit resistance’ rather than ‘per unit mass’.

At 575 ohms and discharge time not exceeding 1 ms, the energy stored by the capacitor would need to be at least 1.1 J to reach the Specific Fibrillation Energy. Although this is a very conservative estimate because the discharge time is likely to be much less than 1 ms, Van de Graaff generators that can store more than 1 J of energy electrostatically by the sphere should be avoided. A discharge of 1 J affects everybody severely (BSI 1991).

An estimate of the energy stored by the sphere can be made by calculating the sphere capacitance, \( C = 4\pi \epsilon_0 r \) (where \( C \) is in farads, \( r \) is the sphere radius in metres and \( \epsilon_0 \) is the permittivity of free space), estimating the voltage, \( V \), using the length of spark gap, and calculating the energy \( E \), in joules, from \( E = 0.5CV^2 \).

Generally speaking, sphere diameters of electrostatic generators / devices should be 20 cm or less. Using a sphere diameter of 20 cm and maximum voltage 250 kV, the energy stored would be 0.35 J, well below 1 J.
If this is compared to a sphere diameter of, say, 25 cm and a maximum voltage of 350 kV, then energy stored would be 0.85 J. This would still be below 1 J, but the shocks would be correspondingly more unpleasant and painful, and this may put off some people from using the generator.

To estimate the voltage across the sphere find the maximum spark length. Wait until the sphere is fully charged, then bring up a grounded sphere slowly until you obtain a spark discharge. This technique has limitations and should be repeated several times to get an average. Do the test on a dry day with low relative humidity so the electrostatic generator is working at its best.

Note that the rule-of-thumb 3 kV/mm is only a reasonable rule for voltages below 100 kV.

References
Main reference to safety advice - IOP education website: http://www.practicalphysics.org/

Acknowledgements to CLEAPSS and SSERC.

Other considerations:
CLEAPSS mention in their Secondary Science handbook section 12 (mainly physics) the following additional points:
- Electrostatic discharge creates wideband electromagnetic interference which may adversely affect the operation of nearby electronic equipment. Extended use is therefore not advisable, and may contravene electromagnetic compatibility regulations.
- Some individuals with hearing aids and pacemakers have been instructed to be careful of static discharge. If a student passes comment about closeness of them to a device it must be heeded!
- It is not obvious how repeated discharge of a generator will affect a particular piece of equipment; it is good practice to have devices turned off. Data corruption is a possibility.