

VAN DE GRAAFF GENERATOR (VDG)

SSE PHYSLAB

1. Introduction
2. Calculations
3. VDG demonstrations

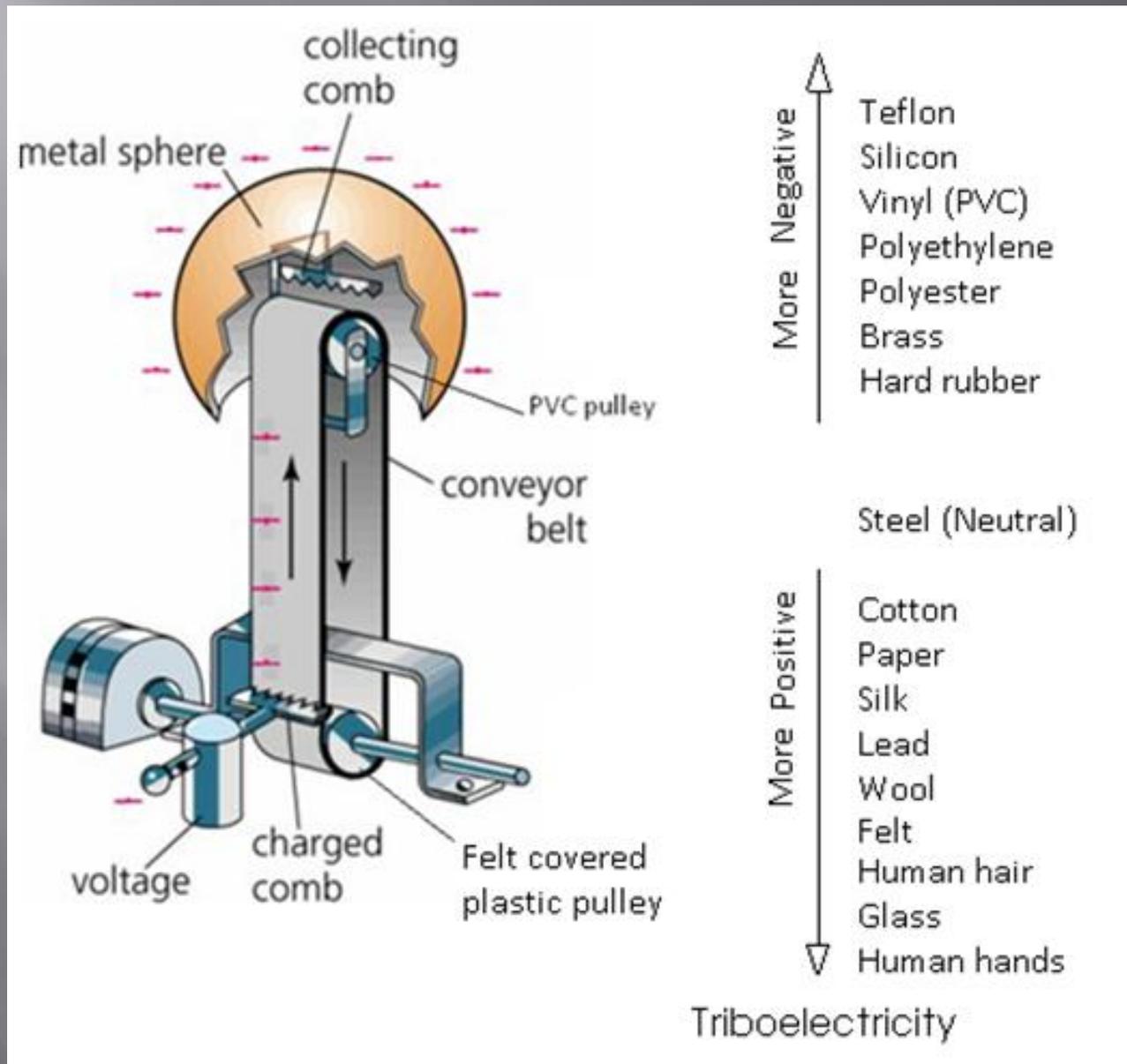
Van de Graaff Generator and its Educational use

- ▣ VDG is a mechanical device that produces electricity at high voltage and low continuous current. It is described as "**constant current**" electrostatic device. The VDG that works using the Triboelectric effect can produce voltages in the range of 350,000 volts.
- ▣ It can be used to demonstrate:
 - ❖ Electric fields and electrostatic forces.
 - ❖ Voltage, capacitance, current
- ▣ These electric fields are strong enough to be measured, manipulated, felt directly, played with, and finally grasped at an intuitive level.

Triboelectric effect

- ▣ Triboelectric effect is a type of contact electrification in which certain materials become electrically charged after they come into contact with one another and then separated.
- ▣ The polarity and strength of the charges produced differ according to the materials, surface roughness, temperature, strain, and other properties.

Schematic Diagram of a VDG

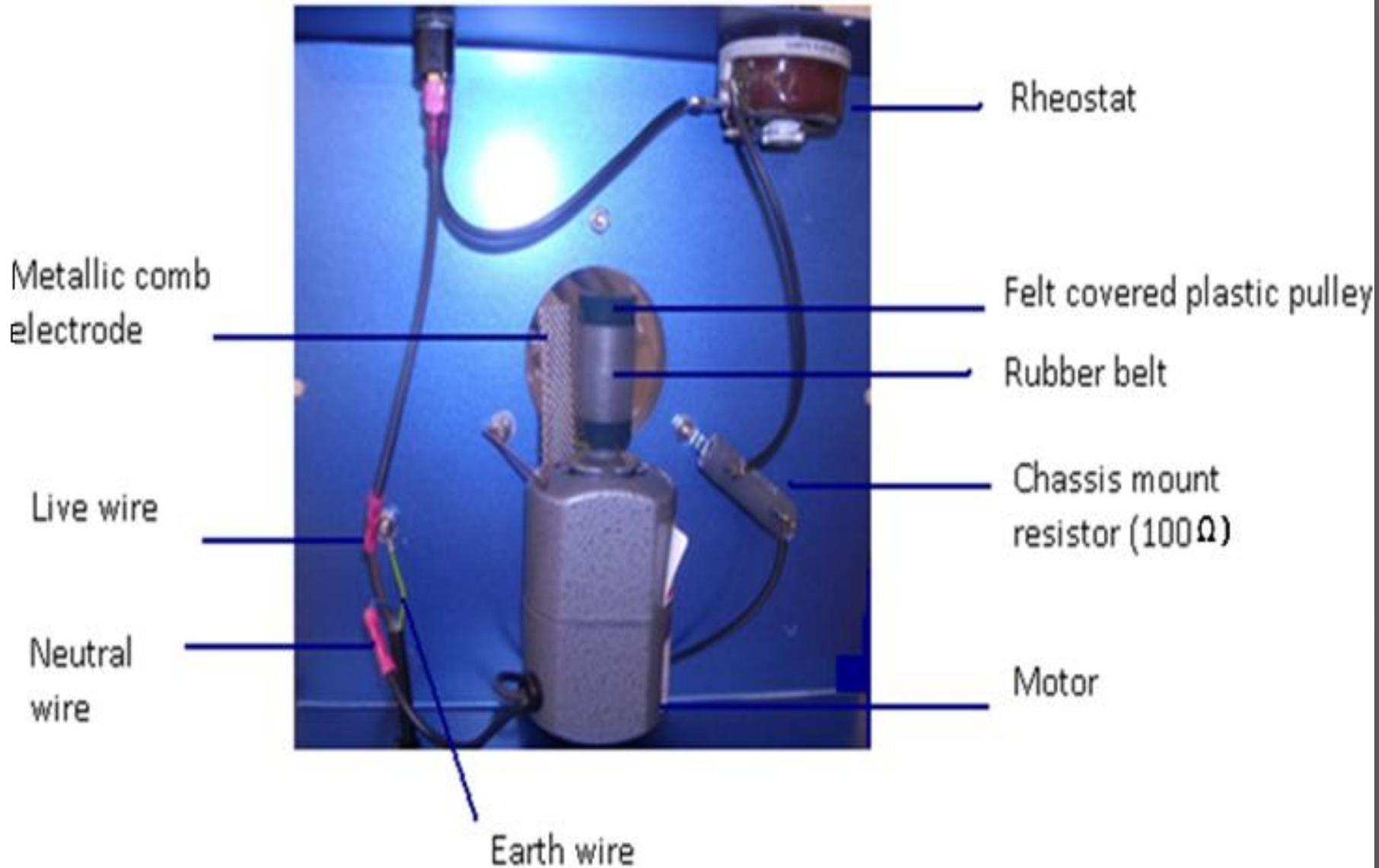


Components of a Triboelectric VDG Model: N-100 (Winsco)

VDG working on the principle of triboelectricity uses belt and rollers in its construction. It consists of:

1. A motor
2. A lower pulley (felt covered, positive in triboelectric series)
3. Lower electrode/charger (metallic comb)
4. A conveyer belt (Rubber)
5. An upper pulley (PVC, negative in triboelectric series)
6. Upper electrode/collector (metallic comb)
7. An output terminal (hollow aluminum sphere)

Internal Circuitry of the N-100 VDG



Working

- By turning on motor, the lower roller begins to build a positive charge and the belt builds a negative charge at its inner surface.
- The outside surface of the rubber belt acquires positive charge by induction. The lower electrode drains these charges to ground. Negative charges at the inside surface of the belt travel upwards.
- At the top, belt runs over a PVC pulley which picks up these negative charges and retains them.
- Positive charges build up on the belt and are carried down to the lower pulley.
- As the belt keeps running heavy buildup of charges occur on pulleys. Soon this buildup reaches ionization intensity and a large number of negative and positive charges are generated.
- Negative charges are transferred to the collector dome by the upper electrode and the positive charges are drained to the ground by the lower electrode.

Voltage, current and energy calculation

Calculation of maximum Voltage and Charge by VDG

- The electric field E of a sphere with a charge Q is given by
- $E = Q / (4\pi\epsilon_0 r^2)$ (1)

- The capacitance of an isolated sphere of radius r is :
- $C = 4\pi\epsilon_0 r$ (2)
- At the radius ' a ' of the sphere, using (1) and $Q = CV$, Electric field is:
- $E = CV / (4\pi\epsilon_0 r^2) = V/a$
- $V = Ea$ (3)
- For dry air at standard temperature and pressure, the maximum sustainable electric field is about 3MV/m, thus
- $V_{Max} = (3 \times 10^6 * a)$ volts ; $a = (25/2)$ cm = 0.125m (for N-100 VDG)
- Thus $V_{Max} = 375,000$ volts
- Potential difference is high enough to make a spark across a narrow air gap.
- However, the total charge is so tiny that only a small shock is received when the dome is touched since
- $Q_{Max} = CV_{Max} = 5.2\mu C$

Charging Current calculation

- Let I is the belt current, assuming the belt operating at the maximum charge density and transporting current upwards only, I is given as:
- $I = \epsilon_0 E_{\max} w v$ (4)
- where ' w ' is the effectively used belt width (0.034m) and ' v ' is the belt speed.
- For N-100 VDG, driving pulley has diameter ' d ' (0.025m), turned at ' b ' rotations per minute (5000 rpm), thus $v = (b/60)\pi d$, resulting in
- $I = \epsilon_0 E_{\max} (\pi/60) w d b = 6\mu A$
- Thus a VDG machine generates high voltage at very low current, we can say that it is an electrostatic device. The low current and low energy-storage of Van de Graaff machines make them safe for student use.

Energy stored in a VDG

- The danger of an impulsive shock by VDG is proportional to the energy that it discharges with about 10 J of energy being considered dangerous. We can calculate the energy 'E' as:
 - $E = 0.5CV^2$ (5)
 - From (2)
 - $C = 4\pi\epsilon_0 a = (111.2 * a) \text{pF}$
 - Since $V_{\text{Max}} = (3 \times 10^6 * a) \text{volts}$
 - Maximum Energy, $E_{\text{Max}} = 500.4 * a^3$ (6)
 - Thus $E = 7.82 \text{ J}$ would then correspond to $a = 0.125 \text{ m}$.
- A machine with a larger dome, small losses would be dangerous, with the danger increasing rapidly, with the cube of the radius.

Demos with the VDG

1. Spark production
2. Electric wind
3. Electrostatic repulsion
4. Flying aluminum foils
5. Turn off VDG without shock

1. Sparks

- ❑ Connect the lead of the Discharge wand to the earth/ground connection of VDG. Hold the wand in hand by the acrylic rod.
- ❑ Turn on the VDG and let it charge for 10-20 seconds in order to have sufficient charge build up.
- ❑ Bring the discharge wand 1-2 inch near the dome of the VDG, a bright blue colored spark will be seen in the narrow air gap between the dome and the discharge wand followed by a cracking sound.
- ❑ Actually the charge on the dome and the charge on the wand are opposite in polarity. The wand contains positive charge since connected to the lower electrode through ground terminal whereas dome has negative charge as discussed earlier.
- ❑ The attraction of opposite charges causes negatively charged electrons on the dome to move from the dome, through the air, to the wand. As electricity moves through the air, it excites air molecules, causing them to give off light.
- ❑ The cracking sound of the spark is from air expansion as it heats due to spark.

VDG with the grounded Discharge wand



Electric wind

- ❑ Stick a pointed pin or an unbent paper clip to the side of the sphere of VDG.
- ❑ When the VDG is running, a stream of charged wind spews forth. This stream is a genuine electron Beam.
- ❑ The reason is that a sharp point on a charged conductor has a higher surface charge density which will generate a stronger electric field.
- ❑ This electric field ionizes the air molecules surrounding the sharp point
- ❑ The positive ions will be attracted towards the sharp point, while electrons will be repelled. This phenomenon is called the point effect.
- ❑ The moving electrons drag air molecules into motion, producing an electric wind that can blow a tissue paper away and bend a candle's flame as shown in figures below.

Ionized air molecules
blowing the tissue
paper away



Bending of candle flame



3. Electrostatic repulsion

- ▣ Use 4-6 ribbons placed in a bundle with one end tied together.
- ▣ Attach the tied end to the dome with tape and start the generator.
- ▣ All strands will be charged negatively and will stand erect, moving as far away from one another as possible.

Note:

- ▣ Initially the ribbons will stick to the conducting sphere. Use the ungrounded, pointed probe to lift them off. The ribbons will arrange themselves so that they follow the field lines.

Ribbons undergoing
Electrostatic repulsion



3. Flying aluminum foils

- ▣ Cut an aluminum foil square nearly 2" across and place on the dome of the VDG and turn on the power. Foil piece will levitate and fly off to the side.
- ▣ Then place an entire stack of foil squares on top of generator. When generator is run, it will loft each square in sequence and fling them in various directions.

Aluminum foil ready to take off flight from the VDG dome



Turn off VDG without pain

- ▣ Always hold onto a ground/earth wire when you turn the machine on, and never let go of ground.
- ▣ All objects near a VDG will become electrified because of the charged wind emitted by the metal sphere, but if you keep touching a ground wire, you will stay neutral, and will not receive a shock when touching the switch.

Precautions and Safety Measures

- ❑ People with cardiac pacemakers should never operate the generator or come in contact with it.
- ❑ Stay about three feet away from the collector while it is charged.
- ❑ Always discharge the collector dome between experiments and when you are finished. Use the discharge wand for this.
- ❑ Hold the discharge wand by the handle. The voltage is so high that the current can pass through the insulation into your hand.
- ❑ Do not run the generator continuously for long periods of time.
- ❑ Keep the entire device clean and dry.
- ❑ Never direct the ion beam towards a computer.