615-3140 (10-088) Hand-Cranked Van de Graaf Generator

Instructions by: Dr. Zafar A. Ismail, Professor of Physics, Daemen College, Amherst, N.Y.

Caution:

People with cardiac pacemakers or other such electronic medical implants or devices should never operate the generator or come in contact with it. Discharge of static electricity could cause the electronic device to be damaged or to malfunction.

Description:

This Van de Graaf Generator is cranked by hand to demonstrate the effects of static electricity. Because you control the amount of electricity produced depending upon how hard and how long you crank, this is a true "hands-on" experience for younger students.

Warranty and parts:

We replace all defective or missing parts free of charge. All products warranted to be free from defect for 90 days. Does not apply to accident, misuse, or normal wear and tear.

Included accessories:

- Discharge electrode, 40 cm
- Electric plume
- Electric whirl

How to Assemble:

1. Locate Hand Crank Subassembly (see Diagram 1).

Diagram 1

2. Loosen two screws on base (main assembly with long tube attached) to allow the slots in hand crank subassembly support to slide under the screw heads and washers. (See Diagram 2).

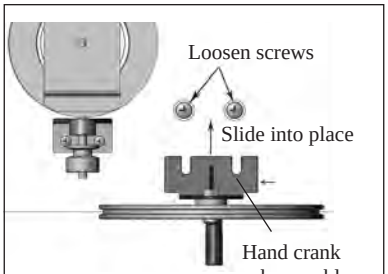

Diagram 2

3. Align large and small pulley so that the belt will run true. (See Diagram 3).

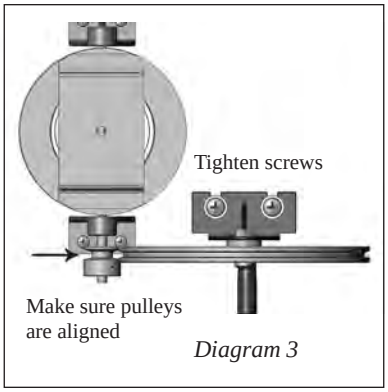

Diagram 3

4. Tighten two screws firmly to hold crank assembly securely in place.

5. Install belt over two pulleys. Note: the belt (O-ring) will have to be stretched significantly to install it. This is normal and necessary.

6. Locate collector support shaft (see Diagram 4).

Diagram 4

Diagram 5

7. Screw collector support shaft into top of upper brush/pulley assembly on main assembly. (See Diagram 5).

8. Place collector on top of support sliding threaded portion through the small hole on the top of the collector.

9. Attach nut to top of collector support shaft to hold collector in place (See Diagram 6).

Diagram 6

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Teaching with Van de Graafs

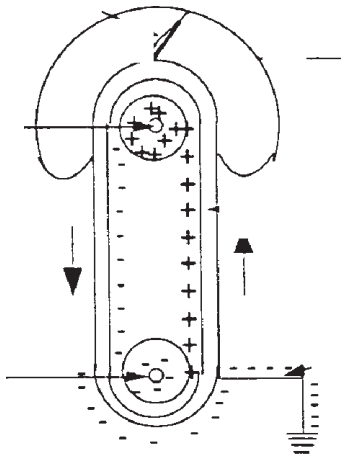
Concepts: Frictional charge generation. Electrostatic repulsion (& attraction.) Charging, discharging. Discharge through sparks. Plasma. Lightning.
Curriculum Fit: Grades 6 - 8, PS/ Electricity and Magnetism. Units: Static Charge. Also, Moving Charge & Magnets.
Concepts: Electrostatic Fields, electric potential. Coulomb's Law demonstration.
Curriculum Fit: Grades 9-12, PS/ Electricity and Magnetism. Unit: Static Charge.

Introduction:

The Van de Graaf Generator deposits a large amount of positive electrical charges on the metallic dome (oblate, globe). This huge volume of positive charges produces spectacular effects!

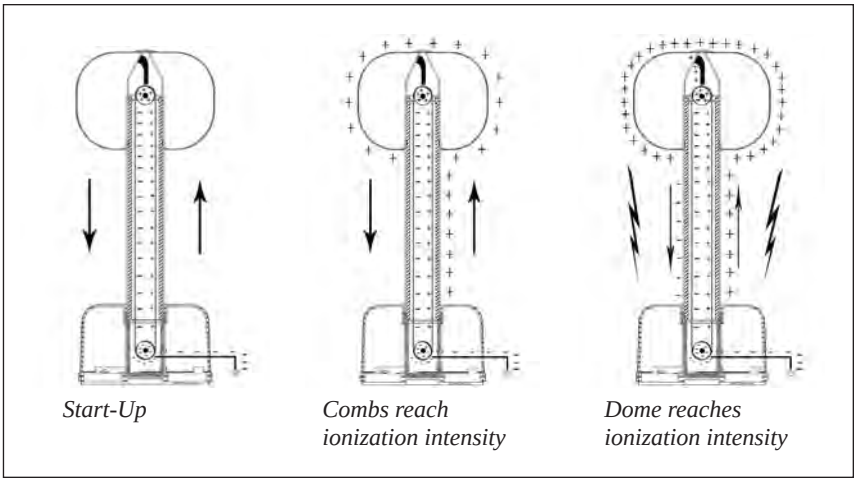
When two insulators are rubbed together, one loses electrons to the other and becomes electrically positive. It has acquired positive electrical charges. The other insulator, having gained excess electrons (negative electrical charges) becomes electrically negative. These charges are **static** because **they do not move on their own**. Walking on a carpet in a dry room with dry feet deposits a large amount of electrical charge on your body; the impact is felt when you touch a door knob. Electrical charges can also be induced on a neighboring insulator or conductor by induction. In the case of a flat insulator, the opposite side acquires opposite electrical charge by induction.

The generator uses a plastic pulley at the lower end of the machine, attached to a hand crank. A rubber belt passes over the pulley. As the pulley turns, rubbing occurs; the pulley acquires negative charges while the inside surface of the rubber belt (near the plastic pulley) acquires an equal amount of positive charge. The outside surface of the belt acquires an equal amount of negative charge by induction. An electrode (comb or brush) is provided to drain away these negative charges from the outside surface of the rubber belt to the "ground."



Schematic shows positive charges carried upward from pulley to collector sphere

A similar comb (electrode) is provided at the upper end where it provides a path taking positive charges to the collector dome. The plastic pulley retains the negative charges that it acquired.



Start-Up | *Combs reach ionization intensity* | *Dome reaches ionization intensity*

Positive charges stay on the inside surface of the belt and travel upwards on the belt. At the top, it runs over a metallic pulley which picks up these positive charges and retains them. Free electrons from the metallic pulley flow on the electron-deficient belt and are carried down to the plastic pulley. As the belt keeps running, more charges are deposited on both pulleys, resulting in heavy buildup of charges on each. Soon this buildup reaches ionization intensity in the vicinity of the two combs and a large number of positive and negative charges are generated. Positive charges are transferred to the dome by the upper comb, and negative charges are drained to the **ground** by the lower comb. The belt transports negative charges from upper to lower comb and positive charges (on the other half of the belt) from lower to upper comb.

Once on the metal dome, the positive charges spread out due to **electrostatic repulsion** and become uniformly distributed because of the dome's spherical shape. The buildup of positive charge on the dome continues until ionization intensity is reached. This is the **equilibrium state** and limits the quantity of charge that the generator can place on its dome. It is measured in **volts.**

Once this limit is reached, the air between dome and base gets ionized and a discharge with spark occurs. The discharge causes the potential to fall below the ionization intensity but is brought up to the limit again in seconds, and another similar discharge occurs. The process continues as long as the generator is running.

Demonstrations:

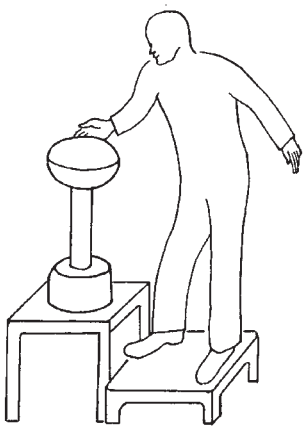
(1) Hair Raising:

Approaching a running generator can be a hair raising experience. This is because the charges are transferred to your body and - specifically - to the hair. Due to electrostatic repulsion between similar charges, every hair tends to get as far away from every other hair as possible. This "raises" hair and can be felt on head, arms and all over the body.

For best results **you need two people and a plastic footstool.** Stand on the footstool and place one hand palm down on the globe of the Van de Graaf before your helper turns the crank. Keep your hand on the globe, with your other hand at your side taking care not to touch anything else, the entire time the machine is running. Shake your hair lightly to loosen the strands; wait 1 - 2 minutes.

You should now feel each individual strand start to lift. Have your helper angle a mirror (taking care not to get too close!) so you can see. Fine, light, long hair works best. Make sure you do not remove your hand from the globe, touch anyone or step down from the footstool while the machine is running. If you do, you will feel a mild shock. This is because, by doing so, you have completed the electrical connection and grounded yourself. (The footstool serves as an insulator.) The static electricity, instead of remaining on your body, passes to earth.

This experiment works best on days when **humidity** is **low**. Water vapor drains static charge.



To raise hair, stand on footstool or other plastic (nonconducting) platform to insulate yourself.

(2) Electric Wind:

Charge distribution on the collector dome is isotropic because the dome is predominantly spherical in shape. The distribution will not be isotropic for irregularly or asymmetrically shaped objects.

This is because narrower parts always carry much greater concentration of charges than broader parts. The effect would be maximum for pointed objects like thin rods or large needles.

Try attaching a conductor in the form of a sturdy, light, thin metallic rod six to eight inches long (for instance, a darning needle) on the body of the collector dome, radially outwards. Use tape or clay to attach. The concentration of charges at the tip of the needle will be so intense that it will ionize air in its neighborhood. Negative ions will rush towards the collector dome and neutralize their charges. Positive ions, however, move away (due to electrostatic repulsion) from the generator and do not get neutralized. As the generator is continuously running, it keeps supplying more and more positive ions at a fast speed. The ions running away form a

wind called “electric wind” which blows away (radially outward) from the generator. By attaching the conductor or needle, you have created an electric wind.

Generate Statics.

The wind is strong enough for its effects to be experienced as far away as 10 feet from the generator. It may not deflect a flame that far away but will certainly impart statics to your clothing which would cling to your body; or to a paper that would cling to your hand or to the wall.

Turn a vane.

Use the included "electric whirl"

Place a vane, such as a pinwheel or the included electrical whirl, in front of the conductor (or, in the case of the whirl, atop the globe using the included adaptor). It will turn in the direction of the wind. See for yourself what the wind direction is and see if you can form some idea of how strong the wind is. Try a vane that is slightly stiff and requires a stronger wind to turn it.

Spin a spinner.

Make a small spinner using aluminum foil about an inch across with four or six blades. Use a sharp pin to act as axis for spinner and mount the pin on a wooden or plastic stick. Try placing 2 beads on each side to localize the spinner. When brought near the conductor, the electric wind will spin it.

Deflect a Flame.

Bring a lighted candle near the conductor. Observe that the flame is deflected away from the generator in the same manner as an actual air draft.

end of the conductor in great numbers and at great speeds. This, according to **Bernoulli's Principle**, produces a low-pressure region in front of the tip of the conductor. The rear end of the conductor (that end attached to the collector dome) remains at normal pressure. This sets up a pressure difference in the neighborhood of the conductor. By using it, you can rotate the dome.

Do this by attaching two identical sharp or rounded conductors tangentially (not radially) to the collector dome at its equator (along the seam) on opposite sides and in opposite directions. Conductors can be attached with clay or tape. Observe how pressure differences in the vicinity of these conductors exert torques on the collector dome which begin to rotate slowly but steadily. The dome continues to rotate as long as the generator is running. The mass of the dome is in excess of 200 grams excluding masses of the conductors. The fact, therefore, that the dome will rotate solely due to the electric wind that is generated is a testimony to the strength of that electric wind.

Carry the Electric Wind.

In this experiment you bring the wind to the candle instead of bringing the candle to the generator to observe its effect on the flame. Prepare a large darning needle by securely attaching a well-insulated copper wire in the needle’s eye. Attach the other end of the wire to the collector dome with transparent tape. Carry the needle as far as the wire will allow you to carry it. Place it near a candle and watch the electric wind (emanating from the needle’s tip) deflect the flame or turn a vane or rotate a spinner.

Rotate the collector dome.

Here is an unusual demonstration that an actual (electric) wind can be created by ionized air molecules running away from the pointed conductor.

The ionized molecules move away from the sharp or rounded

If the collector dome has accumulated full charge and you do not induce lightning, a discharge will automatically occur between dome and base of the generator. You should hear intermittent crackling sounds and see feeble sparks in darkness.

(4) St. Elmo’s Fire:

Electrical discharges from clouds to earth are 3 different types.

a. Point Discharge
   No visible light or sound. Point discharges are responsible for most discharge between clouds and ground.

b. Corona Discharge
   Visible light but no audible sound - known as St. Elmo’s Fire.

c. Lightning Discharge
   Blinding light and deafening sound.

You can create St. Elmo’s Fire in a darkened room by attaching a small, thin sewing needle firmly against the collector, radially outwards perpendicularly. Install it correctly by using a drinking straw or small plastic strip. Tape the needle to one end of the plastic straw. Hold the straw by the other end and press it lightly against the collector dome to avoid a shock as you approach the dome with your hand.

A small but significant glow or fire appears at the tip of the needle.

St. Elmo's Fire can also be created by attaching a 3' long electrical wire (not solid, but stranded) to the eye of a sewing needle.

As the strands are passed across the eye, fold and twist them with pliers to join the needle solidly to the wire's end. Connect the other end of this wire to the ground connector on the base of your Van de Graaf. (This procedure will not work if your receptacle has only two flat holes.) Now tie the needle perpendicularly to one end of a drinking straw using cord or tape. Hold far end of straw and bring needle close to the collector dome to watch the "fire" glow.

With this method, you can study the effect of distance on the glow. The glow will be stronger in the vicinity of the dome. As distance increases, the glow dims.

Determine the "firing distance" - the distance over which the glow is visible.

(5) Lighting:

You can light a variety of light emitting devices with your Van de Graaf Generator - for example, incandescent (filament) light bulbs, fluorescent tubes or lamps, gas filled tubes, old radio tubes, even tiny neon tubes. For best results, do these experiments in a darkened room or at night.

Bring your bulb toward the collector dome as the generator is operating. You may wish to make some sort of nonconducting holder for your light bulb to avoid receiving a shock as you approach the collector dome. The outside glass surface nearest the dome acquires negative charge by induction. The charge builds up on the glass surface to discharge intensity. As discharge occurs, negative charges rush through the entire bulb, lighting it up for the duration of the discharge.

Experiment with distances between bulb and dome. The bulb will light even when 12 inches away from the dome. Here, discharges will be stronger but the intervals between them will be longer. The light bulb will also glow more brightly. When you bring the bulb nearer, the discharges are more frequent but the light is dimmer. If you touch the dome with the bulb, the light may be continuous (or flickering) but the intensity will be low.

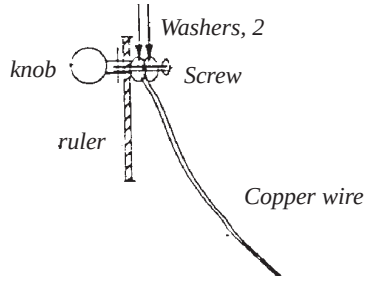
Household (incandescent) bulbs will glow with purple light. Other gas-filled tubes will glow with the characteristic lights of the respective gases.

More Demonstrations:

The experiments that follow require a few simple devices made out of common materials. Here is how to prepare them.

(1) Test Probe

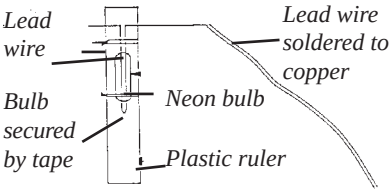
This can be made out of a spherical metallic object, about an inch in diameter, threaded, such as for cabinet Drill a hole in a ruler near one end for a screw. Take a piece of well-insulated copper connecting wire, 2 to 3 feet long, bare one end and fold it around the screw loosely. Fix the knob on the ruler with the wire attached to the probe in between two washers. A solderless crimp terminal can be used. Bare the other end of the wire and ground it by connecting it to the ground connection on the generator base.



Test Probe

(2) Neon Bulb Probe

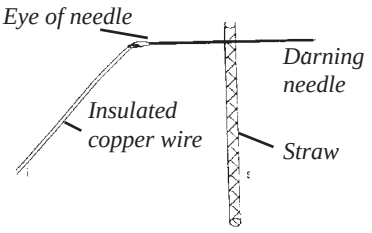
This can be made by mounting a small neon bulb (Ne2, for example) on a plastic ruler. The two lead wires are turned at right angles and one protrudes outside the ruler by about an inch. Solder an insulated copper wire to the other end. Ground this wire by connecting it to the ground connection on the generator base.



Neon Bulb Probe

(3) Movable Electrode

Take a piece of well-insulated copper connecting wire about 3 feet long, stranded, not solid. Bare a length one inch on each side. Pass the strands at one end through the eye of a darning needle about 6 inches long. Twist the wire using a pair of nose pliers until the needle is solidly connected to the wire. Solder the copper parts (optional). Attach the needle to a plastic rod such as a drinking straw by passing the needle right through the straw near one end. Or, use a 6 inch plastic or wooden ruler, attaching the needle with cord or tape. Do not ground this wire.

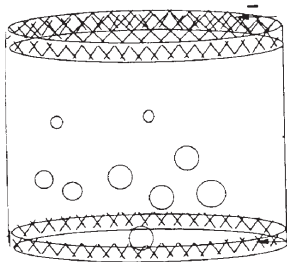


Movable Electrode

(4) Cylindrical Box

Take a piece of clear, strong plastic sheet and roll it into a cylinder or tube about six inches long. Take two metallic caps such as the lids of jam or peanut butter jars and attach the caps to the two ends of the tubes. One cap may be glued or fixed permanently but the other should be removable.

This box will be used to carry foam pieces painted with conductive paint and the upper and lower electrodes will be connected to the generator.



Clear plastic cylinder body

Cylindrical Box

Jar lid: upper, lower electrode

Procedure

1. Effective spark distance of the generator

For best results, perform in a dark room.

When the grounded spherical test probe is brought near the collector dome, lightning discharges will occur, accompanied by a crackling sound. You can enhance the effect by bringing the probe close to the dome. As it is moved farther away, the intensity of light and sound will diminish. To find the maximum effective distance at which visible light and audible sound occurs, move the probe back systematically until all lightning effects can just barely be noticed. This is the effective spark distance of the generator. Repeat the process in different directions. Expect equal effective distances on all sides. Look for any deviations.

2. Electric field intensity around the collector dome.

The grounded neon bulb draws energy from an electrostatic field such as the field around the collector dome. If this energy is sufficient to excite the bulb, the bulb will flow.

Bring the bulb probe close to the dome (without touching it with the exposed terminal of the probe) and find the location where it just barely lights up. Study the extent of the field by moving the bulb in all directions. You should expect the field to be symmetrical but you might wish to look for abnormalities or defects where the intensity diminishes.

3. Jumping balls in a box.

Cut some small foam circles from foam packing material and cover them with electrically conductive material such as soot or graphite (from soft pencils). Or rub them against carbon paper.

Place conductive balls in the cylindrical box (described earlier.) Connect the upper and lower electrodes (caps) of the box to the DOME and GROUND respectively, using well insulated copper connecting wires. The two caps will become electrically charged.

Observe that at first the balls will be on the lower cap. Here they become charged negatively and are repelled away toward the upper cap. The upper cap becomes positively charged and attracts the balls.

The balls continue to move upward until they hit the upper cap. On impact, their negative charge is neutralized and they become positively charged instead.

The balls now fall down to the lower cap where they once again acquire a negative charge. The up and down motion continues as long as the generator is running.

4. Create an aurora borealis

You Need: Pyrex flask

Fill a pyrex flask 1/3 full with water and heat until water boils. When the flask is filled with steam, remove from heat and immediately cork it. Allow to cool. As the steam settles and changes to water, a partial vacuum will be created. It will be saturated with fine water vapor but there will be no air inside the flask. Do not handle the flask directly, even with gloves or plastic as you will not be protected against a buildup of charge. Use a tongs to bring the flask in contact with the collector dome. A greenish-pink glow should develop inside. This is a replica aurora borealis.

5. Electrostatic repulsion

Use metallic streamers such as Christmas tinsel or graphite-coated pith balls placed in a bundle with one end tied together. Attach the tied end to the collector dome with transparent tape and start your generator. All strands will be charged positively and will stand erect, moving as far away from one another as possible. The effect is similar to hair raising and results from electrostatic repulsion.

You can also use long, thin strands of paper coated with graphite from a soft lead pencil. Tape to generator cone; start; watch strips repel each other.

6. Electrostatic spray painting.

You need: food coloring, spray atomizer

The electrostatic field of the generator can be used to direct the fine mist of paint as it comes out of a sprayer nozzle. The particles in the mist are charged electrically which causes them to remain within the electrostatic field. This reduces the loss of paint due to random scatter. The use of this technique in commercial spray painting requires only half the paint otherwise needed.

To test this feature of the electrostatic field, use a perfume atomizer. Fill an empty atomizer with colored water. Spray the colored water in the vicinity of the collector, tangentially across (not radially toward) the dome.

Notice how the spray gets trapped in the electrostatic field and bends toward the collector dome. The spray is localized and there is little waste.

Safety, Operation and Maintenance:

Safety:

People with cardiac pacemakers or other such electronic medical implants or devices should never operate the generator or come in contact with it. Discharge of static electricity could cause the electronic device to be damaged or to malfunction.

This generator is safe when used properly.

1. Since discharge of electricity can damage electronic devices, keep away from appliances such as televisions, computers, stereos, microwave ovens.
2. The shock caused by touching the generator directly is not harmful and is similar to the shock received when walking across a carpet and touching a metallic object. It may feel uncomfortable however and should therefore be avoided.

Getting the Right Output

Output is determined by the number of popping sounds you can hear in a timed interval or by estimating the length of spark produced. The 10-088 should pop once a second.

The size of the globe determines voltage. The voltage determines the spark length. The 10-088 generator should produce a spark length up to 3".

The shape of the globe needs to be smooth and round. Any burrs or sharp points will cause loss of charge. Dents will not materially affect performance as long as dents are smooth and shallow with no rough edges.

Operation:

Best results are obtained under conditions of low humidity. High humidity causes the charges to dissipate, thus lowering the electrostatic field, as the water vapor in the air drains your charge. High humidity also leads to gradual deterioration of the belt.

We recommend that you operate your generator at humidity levels of 75% or less.

Van de Graaf Accessories

The following items may be purchased from most science education distributors or from manufacturer **Science First®**.

615-3116 Mylar Foil - 6 strands
For experiments in electrostatic repulsion. Tape the strands of foil to the collector dome.

Pith Balls

615-3045 Pack of 12 Pith Balls. Balsa wood, 3/8" in diameter, with hole for threading.

615-3050 - Pith balls with attached silk thread. Pack of 6

615-3055 - Graphite-coated pith balls with thread, pack of 6.

615-3120 Footstool
The best way to perform the hair-raising experiment is to stand on our plastic footstool and place your hand on the globe before starting the Van de Graaf. Because you're insulated from the ground, your hair will start to rise as each strand develops a positive charge.

Current Capacity of a Van de Graaf Generator

The following calculations developed by founder F. B. Lee refer to our **615-3130** *400,000 volt Generator. The method can be used for any Van de Graaf.*

Basic Equations:

Capacitance in micro faraday = $.0885 \frac{K A}{T} = C$

K = 1.000 for a vacuum, almost the same for air

A = Area in cm^2

T = dielectric thickness.

Current flow through a capacitor $= I = C \frac{de}{d\theta}$ or $I = \frac{E\, dC}{d\theta}$

C = capacitance in farads

E = potential in volts

I = current in amperes

For air, maximum voltage difference is 30,000 volts/cm. E/T thus is 30,000

Combining:

$I = .0885 \frac{K\, d\, A\, E}{T\, d\theta} \times 10^{-12}$ amp

Since $\frac{E}{T}$ is 30,000 volts/ cm

$I = (.0885)(30{,}000)\, 10^{-12} \frac{dA}{d\theta}$

For 1 microamp:

$dA = 10^{-6} = 339$ cm^2 or 52.5 in^2/sec

For motor speed:

3000 RPM (50 rev/sec)

Pulley diameter 1.5"

Belt width 2"

$I = \frac{(50)(1.5\ p)(2)}{5.25} = 9.0$ microamps *(theoretical)*

Pulley curvature affects this result. It is less at small diameters because 30,000 v/cm is only for flat surfaces.

Between 25cm spheres = 29,400 volts/sec

Between 10cm = 28,500

Between 5cm = 28,200

Between sharp point = 11,500

Pulley at top also generates a theoretical 9 microamps.

Probable cause of short fall from 18 microamps:

(1) Part of 30,000 volt/cm is voltage difference between sides of bolt

(2) Curvature of pulley

(3) Nearby points or edges

P/N 24-0088

Related Products

The following items may be purchased from most science education distributors or from manufacturer **Science First®**.

615-3085 Electrostatic Demonstration Kit - All you need to charge electroscopes, show electrostatic attraction.

615-3090 Electrostatic Charge Kit - Contains electrophorus, proof plane, charge plate, 6 friction rods, acetate cloth, polyethylene film, graphite ball with hook, instructions.

615-3075 Electroscope Kit - contains 2 foil leaf electroscopes, foil leaves, 2 ball terminals, aluminum ice pail, 2 disc terminals.

615-3095 Faraday Cage Kit - Faraday cage, mounted point.

615-3078 Metal Electroscope - Shows how 2 similarly charged objects repel. Glass panels, instructions, 2 pair leaves.

615-3060 Electroscope Assembly - turns 250 ml flasks into simple electroscopes.

615-3205 Leyden Jar - Show how electric charge is stored. 2 cans, polystyrene dielectric, electrode, instructions.

615-3195 Field Map Kit - Learn about electric fields as you plot, compare different electrode configurations on semiconducting paper with conductive ink. Conductive paper, graph paper, 4 clip leads, instructions, ink pen.

615-0310 Lenz Law
Demonstrate a cool concept. Drop strong neodymium magnet down copper tube, then acrylic tube. The magnet slows through the copper - why?