

Principles of the Van de Graaf Generator Plus: Building Toy Van de Graaf

One of a dozen practical projects you can build yourself at home or school.

Introduction:

The Van de Graaf generator is basically a combination of two primitive devices, the **electrophorus** and the **Faraday Cage**. The present-day machine has mechanized the hand operations of the electrophorus. One way to understand it is to review the operation of the electrophorus.

The electrophorus consists of a metal plate on an insulating handle and a block of insulating material. This material is first rubbed so as to produce a charge on it. Next, the metal plate on the insulating handle is placed against the insulating material and thus acquires a similar charge. By touching the plate with the finger, you can remove this charge and then pull the plate away. The plate now has a charge opposite to the insulating material. By taking the charged plate and putting it inside an insulated container (a hollow ball is ideal) you can transfer the charge to the inside of this container where it is promptly conducted to the outside.

The Van de Graaf Generator uses a pulley made of insulating material. Friction against a belt generates a charge on it. The belt functions exactly as the electrophorus plate. To remove the charge from the belt, the Van de Graaf Generator uses a small cloud of ionized air which gathers around sharp points placed in an electric field. As the pulley turns, the belt and its charge are taken away. The belt is not exactly an insulator but, rather, a partial conductor from face to face due to its large lateral area and small thickness. It is a very poor conductor along its length due to small cross sectional area and long length.

When the belt arrives at the top pulley, a similar electrophorus operation takes place. The top pulley has the same

charge as the belt. Again a finger of charged ions removes the charge allowing the belt to leave with a charge opposite to that on arriving.

The top terminal of the Van de Graaf Generator may be made in any shape as long as a few limitations are observed. The top pulley should be placed at least one entry hole diameter inside the terminal. The terminal should have gently rounded edges to minimize corona discharges. The terminal should be a conductor of electricity - even a poor one will do. Terminals may even be made of paper or cardboard, painted with paint that contains graphite or covered with aluminum foil.

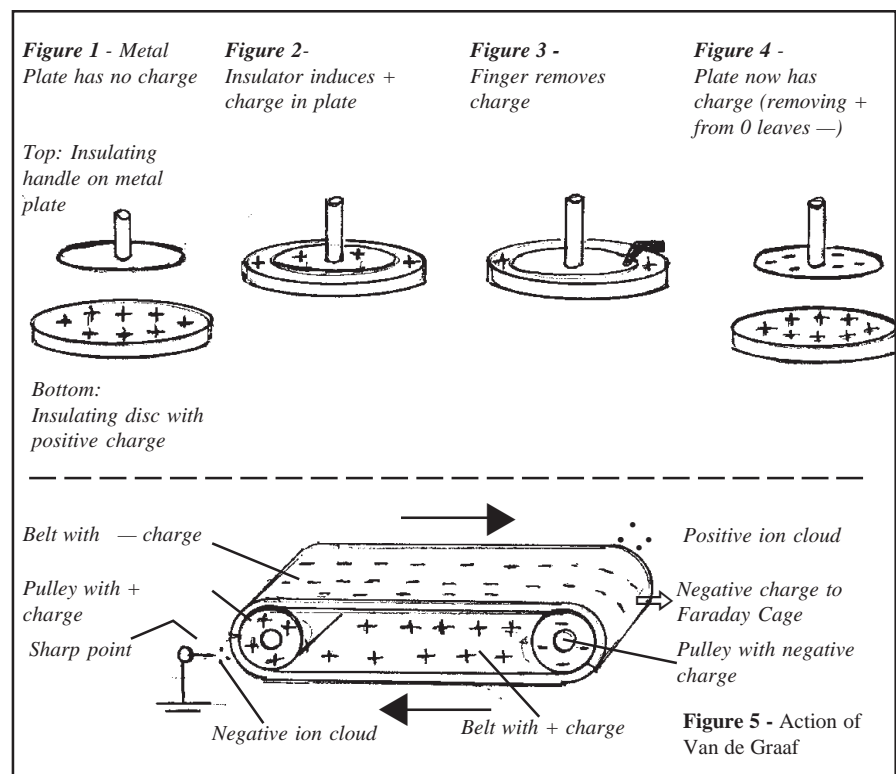
The + charge on the belt and pulley attracts negative ions from the sharp point. When the belt leaves the pulley it takes some of this negative charge with it, and this negative charge is then carried to the other pulley. As the belt passes over the negative pulley, it passes another sharp

point. This point generates positive ions that neutralize the negative charge on the belt. The belt then carries a positive charge back to the first pulley.

The first belt-type electrostatic generators were produced unintentionally. Early textile mills used wooden pulleys and leather belts to operate machinery. On cold days when humidity was low, these materials became good enough insulators to generate electric charges. Workmen received violent electric shocks near some pulleys, or the sparks might be strong enough to start fires. To solve the problem, pieces of barbed wire were placed near the pulleys and connected to metal stakes driven into the ground.

The Van de Graaf known today first appeared around 1933. It was used to accelerate atomic particles used in early atomic studies.

Several articles on the machine appeared in Review of Scientific Instruments about this date.



Building A Toy Van de Graaf

Suggested Materials

• **Tin can.** For collector sphere. Cut to size and cover sharp edges with tape to prevent cuts. Taped edge of tin can rests on top of food container.

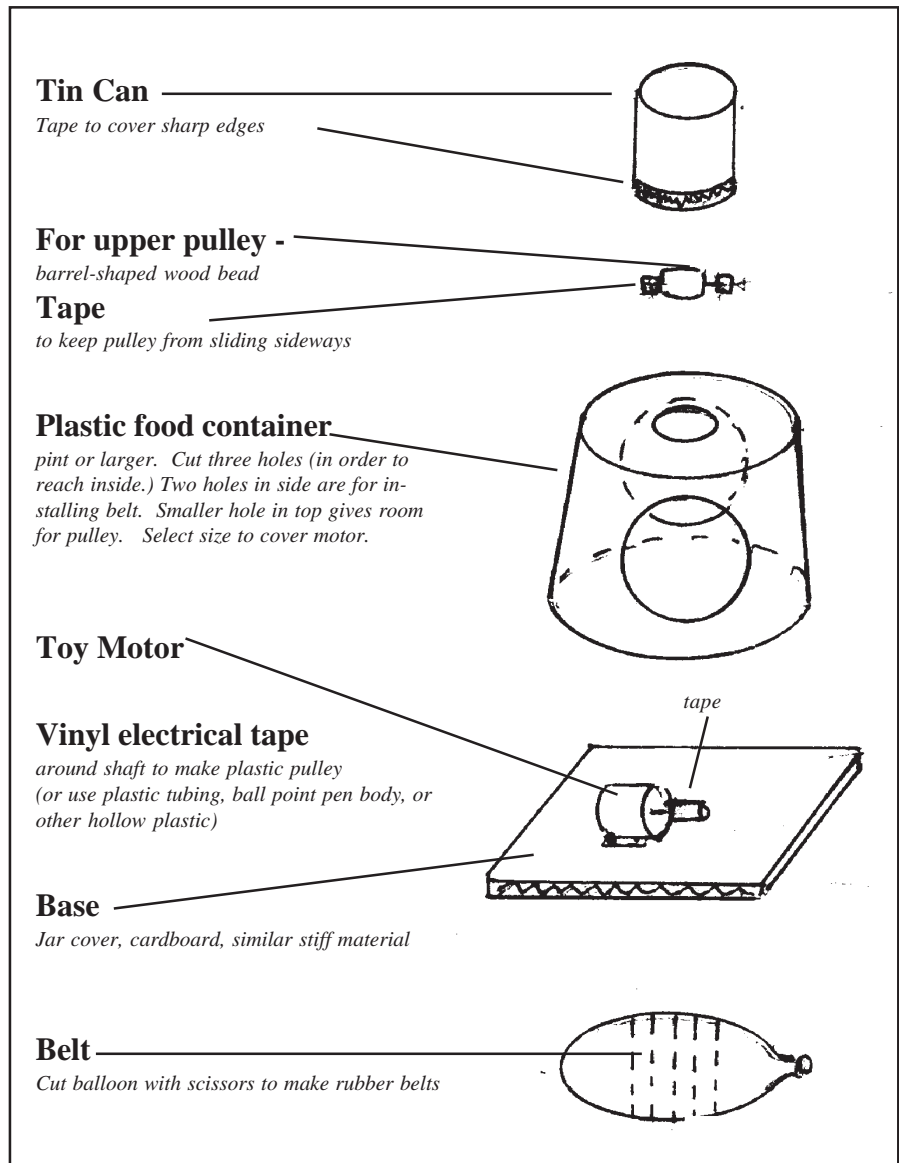
• **Upper pulley** - wood. Barrel-shaped wood bead suggested. Insert need through hole in bead for a shaft. Apply tape to ends of needle to keep 'pulley' in place and prevent it from sliding sideways. Shaft goes over top edge of food container.

• **Plastic housing** over motor. Pint-size or larger food container recommended. Needs to be large enough to cover motor. Use side holes to install belt. Use top hole for pulley. Wind tape on shaft.

• **Lower pulley.** Plastic (vinyl electrical tape, plastic tubing) installed on shaft on motor. Push directly onto shaft.

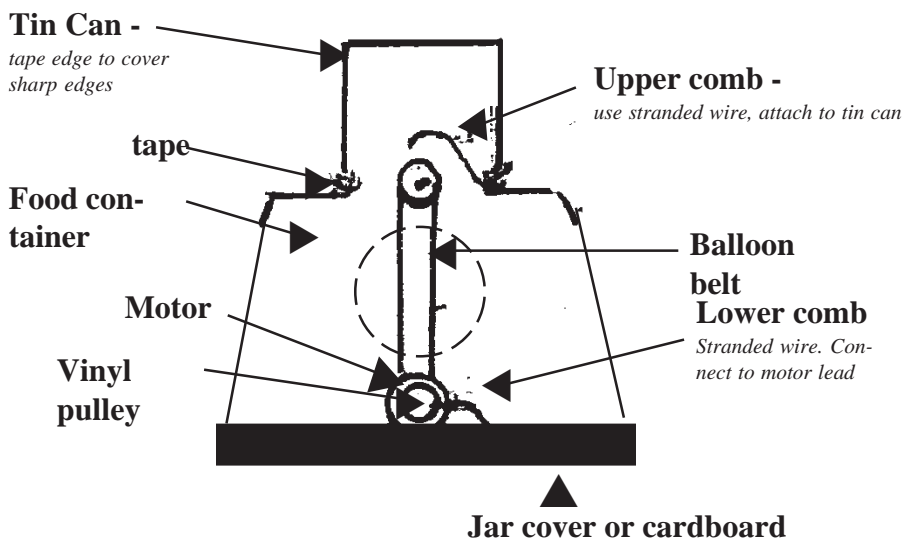
• **Upper and lower combs.** Make from stranded copper wire. Upper brush - use screw or tool to fasten to can. Lower brush - tape or screw to base.

• **Toy motor.** Use any 1.5 to 3 v motor.



About the Author: Franklin B. Lee is founder of **Science First**, (formerly Morris & Lee Inc.) designer and manufacturer of science education equipment since 1960. A college teacher and inventor of electrostatic devices, he continues to design new products and build tools for **Science First** products.

You may be interested in the Van de Graaf Generators and Van de Graaf parts manufactured by **Science First**. See page 4 for a complete parts list. Or, if you prefer, please phone, fax or e-mail for complete information on our Van de Graaf kits, parts, and accessories.



From May 1957 Scientific American's "The Amateur Scientist"

by Science First founder
Franklin B. Lee

Franklin B. Lee, a chemical engineer and faculty member of the Erie County Technical Institute in Buffalo, N.Y. has built a number of small Van de Graaff machines and passes along the results of his experiments to amateurs who prefer to work with generators less bulky than the earth. "Two important pieces of information for the designer of Van de Graaff machines," he writes, "are, first, approximately 50 square inches of belt per second passing over the pulleys will produce one microampere of current; second, the maximum potential developed by the machine will be equal to 70,000 times the smallest radius of curvature of the collector in inches. Thus a perfect sphere 12 inches in diameter will have a theoretical limiting potential of 420,000 volts. Holes made in the sphere to admit the belt assembly alter the pattern of the field and reduce the theoretical maximum. The most effective compromise with the ideal shape for a practical collector is a spheroid slightly flattened at the bottom, with minimum radius of curvature located at a reasonable distance from the insulator to discourage sparking along the insulator surface.

"The designer's choice of maximum voltage determines the size of the collector. To realize a large fraction of the theoretical limiting potential, the collector must be at least two or three diameters removed from other metallic parts. The distance should be greater if sharp-edged metal parts are present, and may be somewhat less if all parts are covered by a rounded metal shield of large radius of curvature. The opening which admits the belt to the collector ought not to be much larger than half the diameter of the collector and should be smoothly curved inward, using a generous radius of curvature.

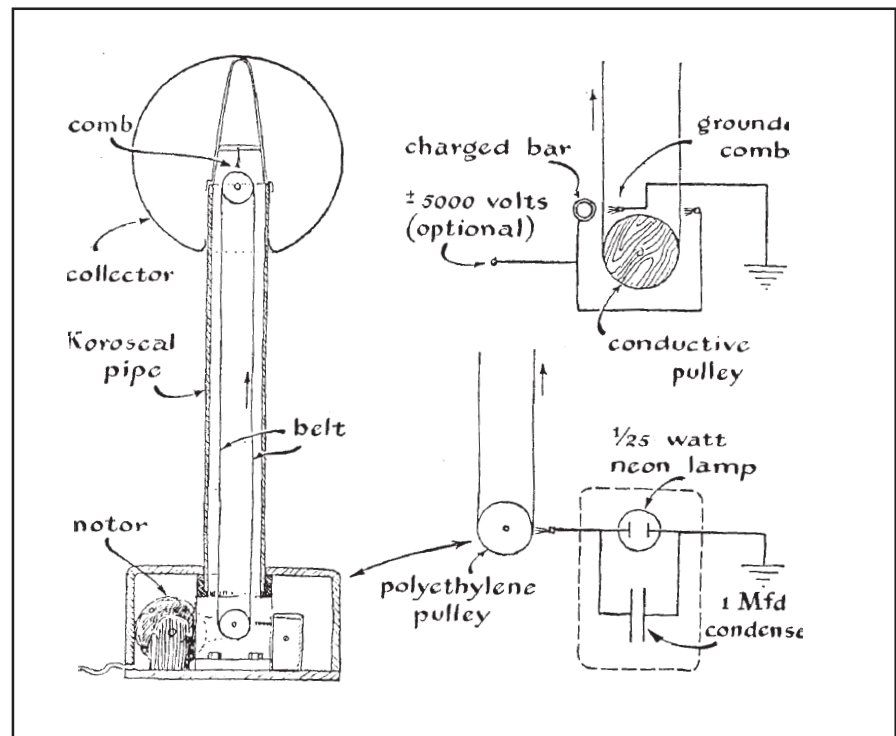
"Although a high polish adds to the attractiveness of the collector, it is not essential. Minor surface imperfections, if well rounded, limit the maximum voltage only slightly. Grind down sharp edges or burrs. Lint and dust particles

will reduce the voltage to 40 percent of the theoretical maximum if they protrude from the surface as much as 1 per cent of the radius. Unpolished commercial aluminum spinings, free of lint and dust, will collect about 85 per cent of the theoretical maximum. A high polish will increase the voltage another 1 per cent. The concentration of charge around the hole through which the belt enters accounts for the remaining 14 per cent, a quantity which varies with the size of the hole and its distance from other conductors.

Selection of the desired current output determines the size of the belt and the speed at which it must run. Meeting this specification is not so simple as it might seem offhand, because the properties of the materials used for the belt and its driving assembly enforce speed limits on both the belt and the shaft bearings. For maximum current one should in theory use the highest possible belt speed. But there are disadvantages in running belts faster than about 100 feet per second. Higher speeds aggravate the tendency of belts to fray at the edges and to come

apart at the splices. At high speeds, particularly in the ease of small pulleys, extreme tension must be maintained; this leads to bearing problems. Lubrication difficulties limit the shaft speed of sleeve bearings to about 5,000 revolutions per minute. The noise level of ball bearings becomes annoying above this speed unless special steps are taken to minimize it. At belt speeds above 100 feet per second appreciable amounts of power are lost through air friction. Finally, part of the charge appears to be "blown" off the belt at excessive speeds - a phenomenon which I do not wish to explain.

"Belts may be made of almost any insulating material; paper, cloth, rubber, plastic and so on. Rubber, because of its poor resistance to ozone, has a limited life, but with used inner tubes costing so little the inducement to improve on it is slight. Rayon, nylon, Dacron and cloth (made into belts with acetone cement) are almost as good. Incidentally, when these materials are substituted for rubber, the position of the corona-collecting combs must be shifted. Cloth belts are



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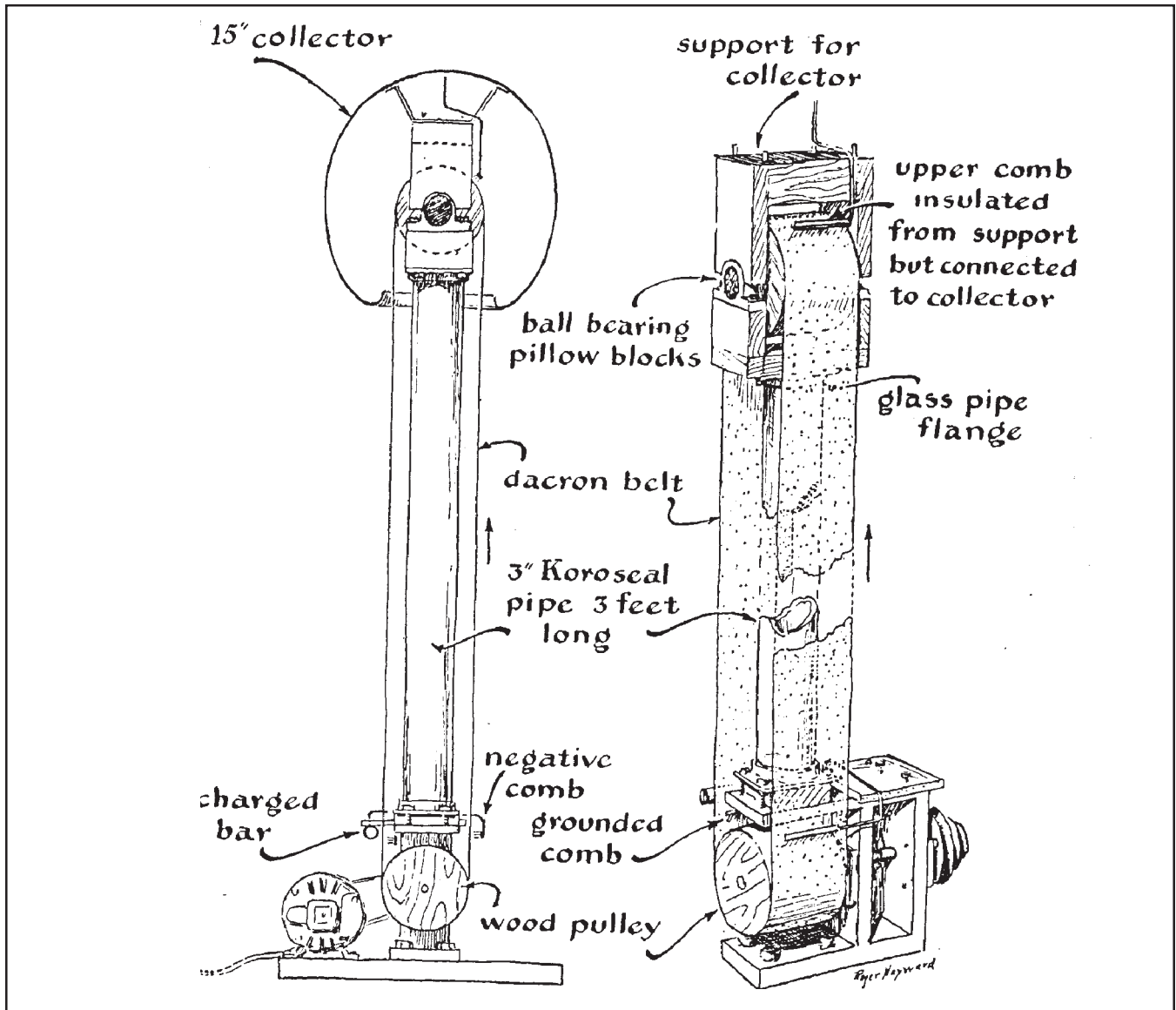
more durable than rubber, are quieter and require less driving power, but tend to fray at the edges. This is easily remedied by a coat of lacquer.

All things considered, I find that belts of neoprene joined with a diagonal splice are a good compromise.

The upper pulley must be made of a material which is a good electrical conductor, such as wood or Bakelite. Surprised? At such voltages these materials are very good conductors for the small currents involved. Scrap plywood may be glued together to make a highly satisfactory wooden pulley. The lower pulley should also be electrically conducting if a separate 5,000 to 10,000-volt D.C. power supply is used for spraying charge onto the belt. If the machine is to be self-

excited (that is, if the belt is to be energized by friction), the lower pulley should either be coated with or constructed of a material of extremely high resistivity. A 1/32-inch thickness of polyethylene makes a splendid covering for small wooden pulleys. The pulleys should be turned with a slight crown, the edge making a snug fit with the inside of the polyethylene tube. The tube may be made by cutting the ends off a round squeeze bottle. The tube is simply pushed over the wooden core. The choice of pulley and belt material for self-excited machines determines the polarity of the collector charge. A rubber belt running on a lower pulley of polyethylene or polystyrene will usually pump electrons from the collector and charge it positively.

The belts may run on either the inside or the outside of the insulating support. Economy, simplicity and high currents favor running them on the outside. Appearance and neatness of construction require them to be on the inside. The former arrangement permits the use of a small, relatively inexpensive insulator with low current leakage and minimum deterioration due to corona discharge (the source of ozone). It also permits use of the widest belt possible for a given opening in the collector. Problems arising from unequal potentials throughout the insulator are similarly minimized. All hygroscopic or fibrous materials should be avoided in the selection of the insulating column because they invite leakage through the moisture which forms on the



surface. The material must also be selected with an eye to its mechanical properties: strength, stiffness and toughness.

Finally, it should be readily available at a reasonable price. Tubing of polyester glass-fiber laminate or polyvinyl chloride meets these requirements and is available in standard pipe sizes. In the three-inch (diameter) size, it costs \$2.60 per foot. Polyvinyl chloride is the less hygroscopic of the two and may be flanged or formed to other contours by heating it to its softening point in hot paraffin.

"Combs or corona points for applying charge to the belt may be contrived in great variety. Often a common pin or a single phonograph needle can be as effective as the most elaborate comb. A tuft of wire, bound at one end and sheared like a broom at the other, makes a satisfactory comb, as does a small rectangle of wire screening. Care must be taken to avoid spraying areas of the belt with unwanted charge. This may happen if charges are permitted to mix on the front and back of the belt near the pulleys.

The problem is met by mounting the combs on fixtures which provide easy adjustment over a wide range of positions, and by selecting comb sizes which restrict the areas that are sprayed with charge."

Science Fair Kits and Plans

written by Franklin B. Lee

12-001 High Vacuum

• Creating a Frictionless Environment • Production of Very Low Temperatures • Construct a Discharge Tube • Estimate the Relative Mass of the Electron • Construct a Radiometer

12-008 Make a Homemade

Electrophorus

Plus experiments in electrostatics

12-010 Electric Field Mapping

Outdoors

12-015 Make a Differential

Barometer

from two large glass bottles, rubber stopper, tubing, cardboard box, insulation and newspaper!

12-002 Build a Giant Tesla Coil

from neon sign transformer & easily obtained materials from building supply stores

Van de Graaf Parts

As a manufacturer of Van de Graaf Generators, we sell parts that may be useful to you in building your own machine. We regret there is no refund on sales of components as we cannot guarantee our parts will fit machines not of our manufacture.

10-060, 10-065 (200,000 v)

24-1060	Instructions
80-0169	Motor, 110 v w/tefl.pulley
29-1016	Belt (3/4" wide)
29-1070	Hose Clamp
36-1062	Motor Mount
36-0605	Lower Pulley (Teflon)
60-0601	Globe (Oblate) (7")
80-0160	Upper Pulley Ass'y
80-0161	Upper Comb Ass'y
80-0162	Lower Comb Ass'y
80-0164	Column Ass'y
56-6060	Molded Ring
80-0163	Base
80-0166	Cord Set
80-0167	Housing
50-0609	Upper Pulley
51-1002	Shaft
56-1016	Shaft Collar, pr
26-9016	Copper Wire
51-1004	Collector Support
26-1005	Lower Comb Terminal
22-6025	Rubber Feet

10-085, 10-086 (Large)

50-0804	Upper Comb Assembly
21-9015	Flanged Bearing
24-1060	Instructions
80-0166	Cord Set, N.America
26-2030	Motor, 120 v
26-2040	Fan
29-1480	Belt
50-0805	Lower Comb
56-0808	Lower Pulley
60-0604	Collector (oblate) (14")
51-0800	Chassis
81-0801	Aluminum pulley Assembly
56-0806	Butyrate Column
51-0802	Cover
56-0805	Shaft collar
26-2032	Motor, 220 volt
80-0168	European cord set

Tesla Coil Parts

10-205 Tesla Coil

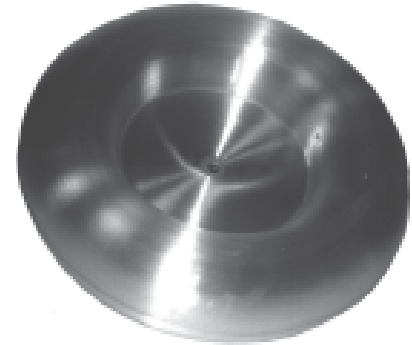
26-1008	Neon Bulb
26-2010	Generator
26-2012	Capacitor, .05 MFD 1600V
26-9114	Copper wire, 5 " (primary)
29-1020	Lampshell Socket
50-0201	Electrode
50-0208	Disc electrode, 3"
50-0209	Disc electrode, 6"
50-1020	3/4" aluminum ball
60-0205	Coil Assembly

New! Plasma Tube

Attach to coil, watch streamers move.

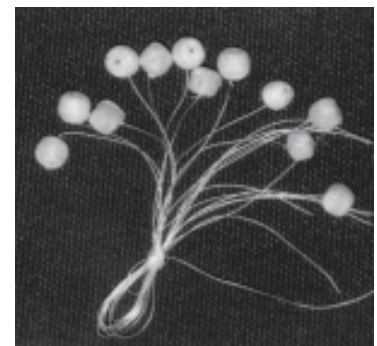
New! 8-inch Toroid

Improve performance and terminal capacitance of your custom-built Tesla Coil. Radiate charge in all directions for an outstanding demonstration. Spun aluminum in doughnut, elmed, polished.



10-209 8" Toroid -

• 10-209 - 8" diameter, 2" high, raised portion 2" wide, 1/4" center hole.



New! Pith Balls

- 29-1044 6 Pith Balls on strings. Balsa wood, 3/8" in diameter, with hole for threading. Great for experiments with Van de Graafs, electrosopes.
- 29-1049 - Pith balls with attached silk thread.

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