CENTRAL
SCIENTIFIC
COMPANY

OPERATING INSTRUCTIONS

Electrostatic Accessories
No. 71899

1. Introduction

The Electrostatic Accessories are designed for use with an Electrostatic Generator such as Cenco's 78688. They may also be used with other static machines such as the Wimshurst Static Machine (54165). These accessories can be used for demonstrating a wide range of electrostatic phenomena.

2. Description

The Electrostatic Accessories set consists of eleven items (see figure 1). These items are:

1) Leyden Jar: Consists of a plastic jar which has removable inner and outer aluminum cans.
2) Pith Balls: Two pith balls are contained in a cylindrical plastic jar which has insulated metallic bases.
3) Electrostatic Mill: This is a light metallic piece made in the shape of a 3-arm cross.
4) Faraday's Cup: (Sometimes referred to as "Faraday's Ice Pail.") This is a metallic cylindrical cup.
5) Electrostatic Bell: A small sphere is suspended by a nylon thread between two bells, one of which is placed on an insulated rold.
6) Paper Streamers: The streamers are held at the end of a rod between a brass nut and a small sphere. The radial field of the sphere orients the streamers when this accessory is charged.
7) Handle and Sphere: This accessory provides a convenient means of testing the charge on a surface by drawing a spark. It can also be used to rapidly discharge an object by grounding it.
8) Insulated Handle: This accessory is designed to support almost all of the other accessories without grounding them.
9) Neon Tube: This tube permits students to "see" the discharge of electricity.
10) Smoke Precipitation Tube: This is a tube with two removable stoppers into which smoke may be blown.
11) Clip Leads: Two insulated clip leads are supplied — one to connect any apparatus to the sphere of the generator, and the other to make a connection to ground.

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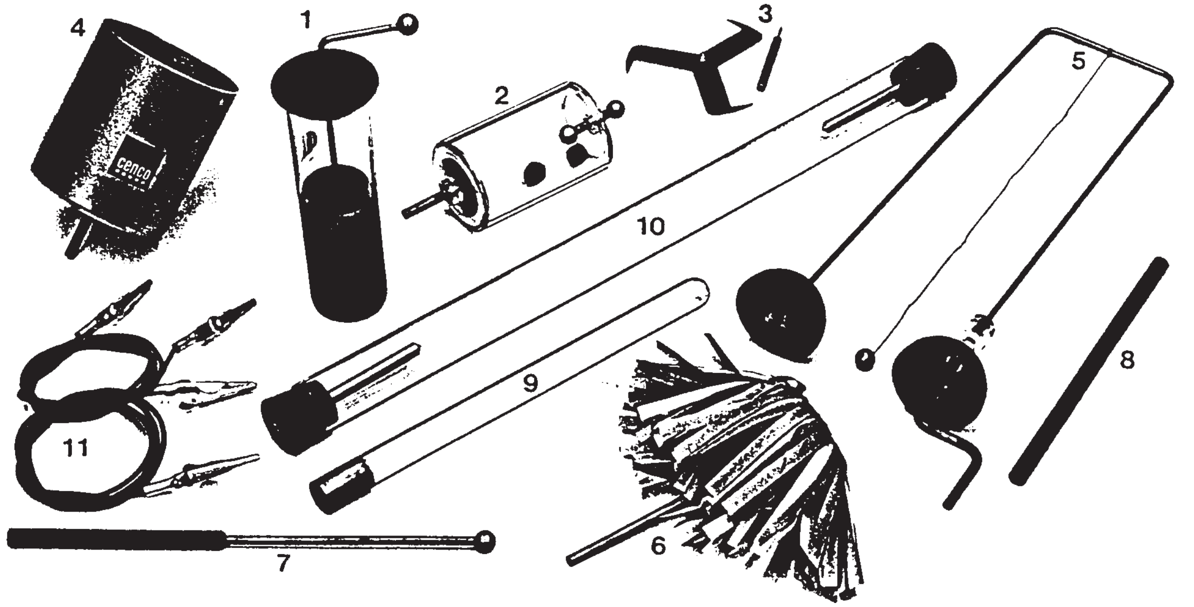


Figure 1 Electrostatic Accessories Set

A stand for accessories will greatly facilitate the experiments and help prevent shocks to the experimenter. One with a crossbar at about the same level as the generator sphere will be satisfactory.

Caution: To prevent uncomfortable shocks, it is recommended that these accessories be secured to a stand when in use and discharged with a grounded probe before you touch them. Such a grounded probe can be made by connecting the metallic portion of the Handle and Sphere Accessory to any available ground with one of the Clip Leads supplied.

To avoid unwanted corona discharges, keep all metallic objects at least six feet from the sphere and from those elements connected to it.

3. Experiments

3.1 Corona and Spark Discharges

Purpose: To demonstrate two processes by which the charge of a body can be lost.

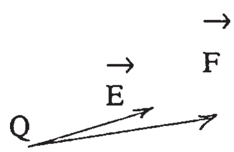
Procedure: Start the generator and darken the room. Place various pointed objects (connect each to ground first!) such as a fork, nail, pencil, or the needle suspension of the electrostatic mill, near the globe of the generator and observe the bluish glow known as corona discharge. As the charge on the generator builds up, notice how the corona appears on farther away objects. The student may notice a change in pitch in the hum of the generator if an object producing a large corona is brought closer to the generator.

Stop the electrostatic generator and touch the discharging sphere of the generator with a lead connected to ground. Connect any of the pointed objects to the sphere of the generator by taping one end of a test lead to the sphere and clipping the other end to the pointed object. Insulate the pointed object from ground. If the electrostatic mill suspension is used, it can be mounted on the insulated handle, and the handle can be held on a stand. Start the generator and a corona will be observed.

Bring any rounded metallic object which is grounded close to the sphere. When it is close enough, sparks will be produced.

Remove all connections made to the sphere and discharge the generator as before — that is, by touching the discharging sphere of the generator with a lead connected to ground. With the sphere completely discharged start the generator and bring the motor to as slow a speed as possible. Connect the metal portion of the sphere on the small handle with a test lead to ground. Slowly bring the sphere close to the generator. Notice at what distance sparks occur. Measure a few times. Now increase the speed of the motor. Repeat the measurement and observe that, while the distance is approximately the same, the frequency at which the sparks occur is greater.

Theory: (For our purposes we will assume static conditions — that is, we will disregard the small currents due to sparks and coronas and their oscillations.) When the generator is charged there is a net positive charge on its sphere. Negative charges will be attracted and positive ones repelled. These effects throughout the surrounding space are commonly described as an electrostatic field. The force on a point charge at a given position is equal to the value of the charge times the field at that point.



$$\vec{F} = (\text{Value of charge}) \times (\text{Field at the point})$$

$$= Q\vec{E}$$

The field is only approximately Coulombic our case. That is, there is a small deviation from Coulomb's law of force because of the deviations in the shape of the generator's "sphere" from a true sphere. On a conducting surface any charges present are free to move. It follows that once a static condition has been attained the field very close to a conducting surface must be normal to it. If it were not, charges would still move due to the sideways component of the force acting on them.

On a conducting surface with a net charge the two following effects have also been observed:

1) Charges tend to accumulate on points
2) Charges tend to avoid indentations or cavities

These activities can be explained as a repulsion effect. Charges tend to "get as far as possible from their neighbors."

It follows that in the vicinity of the points the effects of the charge are greater ("the field is stronger"). It may be strong enough to separate air molecules into positively and negatively charged parts — that is, to ionize the air. This ionization of air is the bluish glow observed. The ions with a different charge from that on the point are attracted to it. Here they "pick" a neutralizing charge and begin the process over again. Those ions repelled do the same thing on the generator sphere. For this reason current flows out from the generator, as can be measured with the microammeter. Consequently, the potential of the sphere is lowered when discharges occur. In the absence of noticeable coronas or sparks the generator may reach a potential of about half a million volts.

The production of sparks follows a similar pattern. Since there are now no points to intensify the field at the test body surface, the generator must build up more charge — in other words, it must raise its potential higher. When the air can finally become ionized there is much more net charge available and the process is more violent. It also ends rapidly, and these rapidly occurring disturbances produce noise. The interval between individual sparks depends on how fast a charge can be built up after being lost. The distance at which sparks occur depends on the potential of the sphere. Since this varies only with the atmospheric conditions and the presence of corona-producing objects, changing the speed of the charging belt will not change the length of the possible sparks.

3.2 Charge of a Leyden Jar

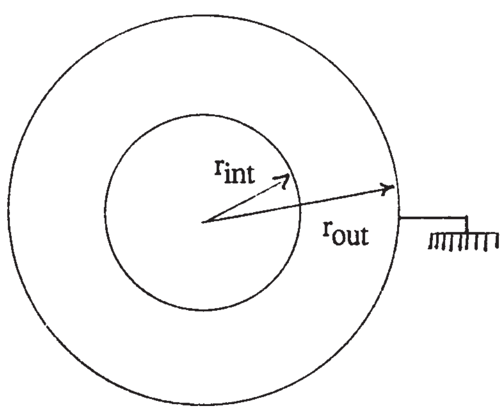
Purpose: To demonstrate the charge of a capacitor.

Procedure: Connect one end of a lead to ground and the other to the outer can of the Leyden Jar. Start the generator. Hold the Leyden Jar in your hand and bring the inner post close to the sphere and let sparks jump for a short while. Then move the jar away from the generator. If the handle of the jar is now brought close to a ground or an uncharged object, a strong spark will be seen.

To make the discharge more visible, connect one end of the neon tube to ground and use the other end to discharge the Leyden Jar. A glow will be seen as the discharge through the tube occurs.

Theory: The Leyden Jar was one of the earliest capacitors. As can be inferred from the size of the sparks obtained, it can store and appreciable amount of charge. Here is a simple argument as to why a capacitor can store more charge than one of its parts. Consider a spherical condenser for simplicity. Let the charge on the inner surface be Q and let the outer surface be grounded. A charge-Q is induced on the inner surface of the outer sphere. The potential difference between the spheres is then:

$$V = -\int_{r_{out}}^{r_{int}} \frac{Q}{kr^2} \cdot dr = \frac{Q\, r_{out} - r_{int}}{r_{out}\, r_{int}} = \frac{Q}{k} \cdot \frac{1 - \frac{r_{int}}{r_{out}}}{r_{int}}$$



For a given set of conditions of the surroundings the potential is limited by the production of sparks and coronas. For a given V:

$$Q = kVr_{int} \frac{1}{1 - \frac{r_{int}}{r_{out}}}$$

For a non-spherical capacitor we can expect a similar dependence. Notice that for r_{int} almost equal to r_{out}, Q is very large. This result corresponds to a thin glass jar in the case of our experiment. Conversely, when r_{out} is very large, Q is not dependent on it and is almost like an isolated body. (Q is comparable to the case of the small body inside a room. For practical purposed the walls of the room are at infinity.) In this sense any conducting body is part of a condenser.

3.3 Electrostatic Mill

Purpose: To make evident the motion of ions under the influence of an electrostatic field.

Procedure: Assemble the electrostatic mill on the insulated handle. Verify that the shaft is vertical and steady. Ground the shaft. Bring the assembly close to the generator and steady it. Start the generator and observe the ensuing motion, particularly the direction of motion. Observe that the mill will not start if it is stopped and the ground lead removed even if the generator is brought closer.

Stop the generator and discharge it. Remove the mill's test lead that is connected to ground and tape it to the globe so that the mill is connected to the globe. Steady everything and start the generator. The rotational speed attained will be greater, and the direction will be the same.

Theory: Whether the mill is connected to ground or to the sphere, a net charge is maintained on it. When the mill is connected to ground, the charges that have been repelled by the charge on the sphere are subsequently bled to ground by electrostaticstatic repulsion. When the mill is connected to the sphere, the sphere and the mill constitute a single conductor, which is charged by the belt. Corona discharges are established around the pointed regions of the mill. The ionized particles with the same kind of charge as the mill are repelled. Consequently, forces are exerted upon those pointed regions of the mill in the opposite direction. The ionized particles with charges of the opposite sign are attracted. Because they have very little distance to travel until they arrive at the mill, the momentum gained is small. It follows that there is a set of net forces acting on the points, which result from a torque acting on the mill as a whole. Notice that the sign of charge is irrelevant, as the experiment has shown.

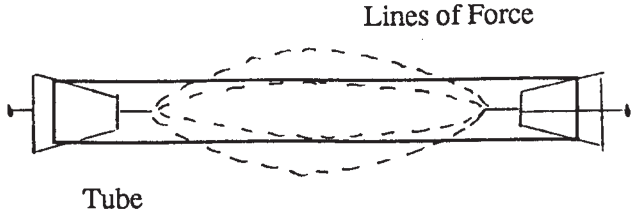
When the mill is isolated, no net charge is maintained on the mill's disk. Therefore, no corona discharge emanates from the disk to provide the torque to move the mill.

3.4 Smoke Precipitation

Purpose: To illustrate the method of smoke control based on the electrostatic removal of solid particles form the smoke stream.

Procedure: Ground the metal at one end of the Smoke Precipitation Tube. Fill the tube with smoke and close it with the other stopper. Start the generator and touch its sphere with the ungrounded end. The smoke rapidly clears.

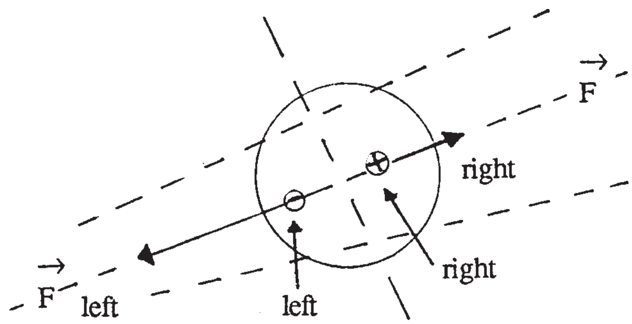
Theory: The electrostatic field between two points has the following general shape:



The smoke particles can be considered to behave in two ways: they lose charge by some of the effects illustrated in the previous demonstrations, or they do not lose charge.

Those particles which lose charge are left with a net charge and the field acts upon them with a force along or against the direction of the lines of force. They then move until they arrive at a wall or a baffle, where they lose their charge and accumulate.

Those particles which do not have a net charge also move when they are in a region of non-uniform field. One way to think about this is to consider any one of them as a small sphere. Divide this sphere by an equatorial plane normal to the line of force going through it.



The force on each half is, approximately:

$F_{left} = E_{left}$ x (charge on the left)
$F_{right} = E_{right}$ x (charge on the right)

Then, if $E_{left} = E_{right}$ it follows that:

$F_{left} = F_{right}$

A better explanation arises from energy density considerations: Any particle without net charge which is motionless in a region of uniform field (i.e., $E_{left} + E_{right}$) is moved away from the field by collisions with particles in motion.

3.5 Electrostatic Repulsion Effects

Purpose: To demonstrate Coulomb's Law qualitatively.

Procedure: Install the paper streamers on the insulated handle and ground the metal portion of the handle. Bring them near the generator's sphere. Start the generator and observe the streamers being attracted toward the generator. Stop and discharge the generator, and tape the handle of the streamers to the sphere. Start again and notice how the streamers diverge. Notice the occurrence of sparks, corona discharges, and the effect of turning the motor off.

Replace the streamers by the pith ball cage. Connect one end to ground and the other to the sphere. In this case sparks can easily be seen between the jumping balls and the bases. The effect is more noticeable in the dark.

Install the Electrostatic Bell. Be fairly careful to have the clapper centered. Ground the support. Connect the insulated bell to the clip of the sphere. Start the generator. As its charge increases, the clapper is attracted to the insulated bell, it discharges upon contact with the bells; then it ceases to be attracted and falls back to strike the other bell. The process is repetitive.

Have a person stand on a short wooden stool and place the palms of both hands on the upper sphere. Turn the generator on. Long dry hair will stand on end as charge build up on a person's body. To discharge without shock, touch the upper sphere with a grounding probe while the person's hands are still touching the sphere and the generator is still running. With the grounding probe still in contact with the upper sphere, the person can remove his or her hands without receiving a shock.

Drop a cotton thread about six inches long on the generator. Observe it bounce.

Theory: Attraction and repulsion effects are demonstrated in these experiments. The effects occur upon induced charges when the bodies used are conductors and have a path to ground to get rid of the repelled charge. They occur upon dipoles or poles of higher order when there is no path to ground or the bodies are nonconductors. Sometimes the dampness of the atmosphere renders dielectrics (nonconductors) slightly conducting and the effects are due to a combination of causes.

The streamers, considered as a body, demonstrate the reason for the effect of points in increasing the field. The charges upon them tend to leave the central body when it has a net charge. Considered as paper streamers attached to a bronze sphere they give an approximate idea of the shape of the field of a sphere. Similarly the pith balls are repelled from the metallic base because they pick their charge from it. Upon losing it on the upper plate they fall due to gravity. They are of course also repelled from the upper plate if they stick long enough to pick up a new charge. The Electrostatic Bell operates under the same principle. The cotton thread experiment combines the actions of the gravitational field with the electrostatic. It falls by its own weight and is repelled upon contact with the sphere. Not being attached like the streamers, it moves away. When it subsequently falls back, the acquired charge acts to slow its motion.

3.6 Faraday's Cup

Purpose: To demonstrate one of the earlier experiments proving that the electrostatic charges "reside" on the exterior surfaces of hollow conductors.

Procedure: Tape one end of a test lead to the upper globe of the generator and connect the other end to the Faraday's Cup stem. Place the stem into the insulated handle and support the stem and cup in a stand. Attach (tape) two pith balls to silk or nylon thread and suspend them from the end of an insulated rod or the Handle and Sphere. With the generator off and discharged, bring the pith balls close to the outside of the Faraday's Cup and notice no effect. Even if the pith balls touch the side nothing happens. Suspend the pith balls inside the center of the cup and touch the inside surfaces. Notice again no result. With the pith balls still suspended in the cup, turn on the generator and charge the cup. Touch the pith balls to the side of the cup and notice no effect. Pull the pith balls out of the cup. If this is done rapidly nothing occurs; if it is done slowly, the pith balls will jump dramatically when they are at the top of the cup. Slowly bring the pith balls close to the outside surface of the cup. Notice that the pith balls swing away from the cup as if being pushed away. Touch the pith balls to the side of the cup and notice that they jump away rapidly.

As charges collect on the Faraday cup, they repel one another, causing the charge to accumulate on the outside surface of the cup. The pith balls experience no effect when in the cup since no charge exists on the inner surface. The pith balls do, however, experience electrostatic forces from the outer surface of the cup. The strong negative charge that exists on the cup repels any negative charge on the pith balls. If the pith balls are uncharged, they can be brought in contact with the cup, at which time negative charges will flow to the pith balls, causing them to fly away from the pail.

Another demonstration that can be done is to suspend two pith balls form nylon string attached to a metallic rod, and have the metallic rod in physical contact with the outside of the Faraday Cup. If you then place a charged object in the cup, such as a rubber or glass rod or a charged Leyden Jar, the pith balls will separate due to the transference of charge from the outer surface of the cup to the pith balls. If the charged object touches the walls of the cup, the pith balls remain separated. If the charged object is removed without touching the walls of the cup, the pith balls will come back together.

Theory: This experiment demonstrates the distribution of surface charges. As the charges repel each other the distribution with the least absorbed energy (the most "agreeable" distribution) is the one in which the charges all go outward from the body in question, thus residing on the surface.

The cup is not perfectly hollow, since it does not have a tight-fitting lid. For this reason the effect is best demonstrated with a low sensitivity indicator, in this case with pith balls. If pith balls and silk or nylon string are not available in the lab, the 78655-01 pith balls work quite well.

3.7 Discharge Through Gases

Caution: Be careful about receiving severe shocks in this experiment. Ground the neon tube by holding the clip lead in the hand that holds the tube.

Purpose: To demonstrate the effects of ionization and excitation of different gases.

Procedure: Bring the neon tube across the corona discharge of a pointed object. The corona discharge can be created in the same way as in the experiment 3.1 Corona and Spark Discharges. Notice the color of the corona inside the tube. The tube glows with its characteristic color.

Theory: In essence this is the same process described when explaining the corona discharge. In both cases something else also occurs. Some atoms or molecules do not receive sufficient energy for ionization. But if the amount received satisfies conditions which can be determined from quantum mechanics this energy is stored for a short time. It follows also from quantum mechanics that when this energy is released it is done in a few determined frequencies. If these frequencies are visible they appear as colored light. The frequencies serve to characterize the substance in the tube.

4. References

Elementary texts covering electrostatics are abundant. One must be careful, though, because the subject is over-simplified in many of them. Intermediate texts generally do not treat electrostatics as deeply as they treat other subjects. For the really ambitious student, treatments based on the statistical approach are recommended. The following list of intermediate and advanced texts is by no means exhaustive.

L. B. Loeb, *Electricity and Magnetism*

B. I. Bleaney and B. Bleaney, *Electricity and Magnetism*

Smythe, *Static and Dynamic Electricity*

Landau and Lefshitz, *The Classical Theory of Fields*

Landau and Lifshitz, *Electrodynamics of Continuous Media*

5. Maintenance

The Electrostatic Accessories require no special maintenance. If you should experience any difficulty with any of the accessories, please contact Central Scientific Company, giving details of the problem. To ensure better service, please do not return any merchandise to Central Scientific Company without authorization.

6. Copyright Notice

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