# Chapter 10 Some Qualitative Facts About Electricity

This chapter gives us a first look at electrical phenomena. We have previously studied mechanical forces and how they can change the motion and energy of an object: here we will look at their electric counterpart. We will find that electrical forces arise due to the presence of a property of matter called CHARGE and that there are two kinds of charges. Because of these two different kinds of charge the electrical forces, unlike their gravitational counterparts, can be repulsive as well as attractive. We will also see how large objects acquire net electrical CHARGE and how the presence of charge can be detected. We will determine that most bodies usually become charged by the surplus or lack of very tiny negatively charged particles called electrons which are a basic constituent of all matter. This concept in turn lays the foundation for a view of electricity that is basic to an understanding of the structure of the atom.

Finally, we will see that when a body is charged, the amounts of electrical charge on that body can not be continually divided into smaller and smaller parts. This is a very fundamental result: there is a smallest amount of charge that can be added to, or subtracted from matter, called the elementary charge. This notion leads us to the concept of quantization, which is one of the main theoretical ideas upon which our understanding of the universe is based.

## PERFORMANCE OBJECTIVES

After completing this chapter, you should:

1. Knowing the charge of two objects, be able to explain whether the two objects will attract or repel each other.

2. Using a charged rod, be able to give an electroscope:
   (a) A like charge using the process of conduction
   (b) An unlike charge using the process of induction.
3. Be able to explain with the aid of diagrams how an electroscope is charged by induction.

4. Be able to use a charged electroscope (of known sign) to determine the sign of unknown objects.

5. Be able to charge an electrophorus and use it as a source of electric charges.

6. Be able to explain evidence for a fundamental unit of charge and the conservation of charge.

7. Be able to explain how a Van de Graaff generator works.

8. Explain the significance of Millikan's Experiment.

1. Experiment 14 ELECTRIFIED OBJECTS page 27

   a. Do only that which appears to be of value to you.

   b. The vinyl is white, the acetate is clear.

   c. Which rod is positive and which rod is negative? Trouble? See text.

   d. Report findings to your instructor.

2. Experiment 15 ELECTROSTATIC INDUCTION PAGE 28

   a. Use two graphite coated spheres on insulated stands rather than metal rods and beakers.

   b. Use a small graphite coated sphere fastened to a nylon thread in place of a piece of foil.

   c. Report your findings to your instructor.

3. Read: Section 10-1 Electrified Objects page 195
   Section 10-2 Some Experiments with Charged and Uncharged Objects

4. Problems: page 196: #1 #2

5. Read: Section 10-3 Electrostatic Induction page 201

   Problem: page 203: #6

Perform the following experiments. Items beginning with 'E' are items from DEMONSTRATION EXPERIMENTS IN PHYSICS by Sutton (which is out of print). See enclosed discussion for each item which is enclosed in this packet.

7. E-19 Charging an Electroscope

   a. You will need a rubber band, rubber stoppers, a piece of stiff wire and an electroscope.

   b. How do you know what charge the electroscope possesses?

8. E-24 Identifying Positive and Negative Charges

   a. Is it possible to obtain wrong information about the charge on an object when using an electroscope?

9. E-8 Electrostatic Induction

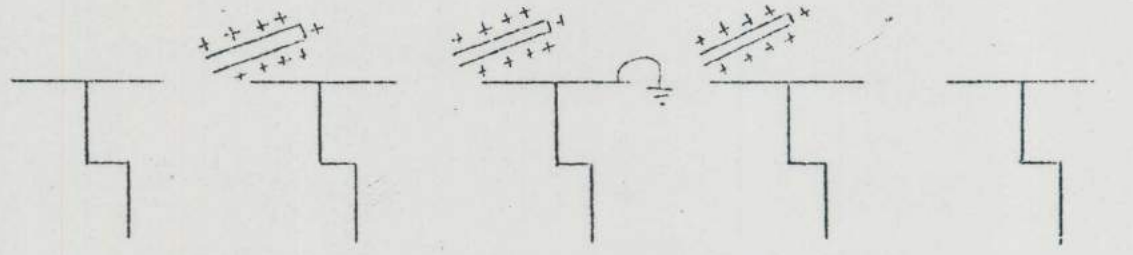
   a. Be sure to place the cylindrical conductor on an insulated base.

   b. What are your findings?

10. E-23 Charging Electroscope by Induction

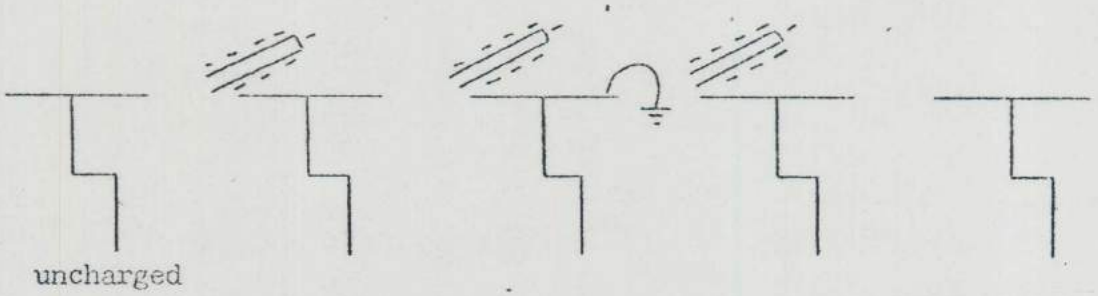
    a. Use vinyl and acetate rods to provide the charge.

b. Use the diagrams below to show the location of the pointer on the electroscope that you find while experimenting using both a positive and a negative rod.



uncharged rod near grounded ground removed rod removed

Identify the location of unbalanced charges on the electroscope in the above diagram.



uncharged

c. Did you identify the location of unbalanced charges?

d. Have instructor evaluate your findings.

11. Hang a plastic coat hanger and a metal rod from a horizontal support using a silk thread which insulates the objects from the support.

a. Bring a charged vinyl rod near the end of the plastic coat hanger and then near the end of the metal rod.

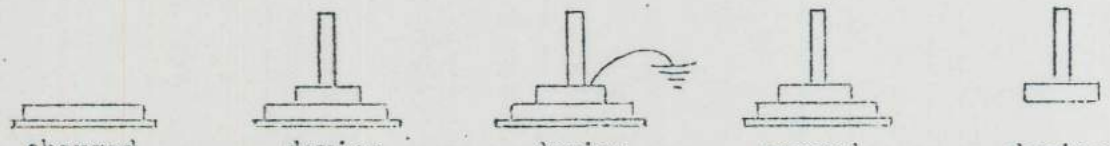
b. Repeat using a charged acetate rod.

c. Results? Reasons? Report to your instructor.

12. E-10 Electrophorus (Ancient charging device)

a. Use an electrophorus that is available for your use.

b. Using the diagrams below, show the location of any unbalanced charge.



charged base device on base device grounded ground removed device removed

13. E-13 Electrostatic Induction-Faraday's Ice Pail Experiment

    a. Use metal coffee can on top of electroscope.

    b. Use either electrophorus directly, or use a graphite coated sphere charged by the electrophorus.

    c. After you touch the inside of the can with the charged object, touch an uncharged electroscope to see if any charge remained on the object.

    d. Your findings?

14. E-50 Discharge of a Conductor by Surrounding Gaseous Ions

    a. Were you able to BURN OFF the charge when you brought a lighted match near the charged electroscope?

    b. Does it matter which charge POSITITVE or NEGATIVE is on the electroscope?

15. Fasten a piece of vinyl tape to the top of an electroscope which is uncharged. Holding the electroscope by its side, grasp an end of the tape and RIP OFF some charge being careful not to touch the top of the electroscope.

    a. Were you able to RIP OFF a charge?

    b. What charge was RIPPED OFF?

    c. What charge was left on the electroscope?

    d. What happens if you carefully lay the RIPPED OFF tape back on the electroscope with out touching the top of the electroscope with your hands.

16. Van de Graaff Generator

    a. Information about the Van de Graaff Generator and some demonstrations are included in this packet. See Study Notes 1 for background information.

    b. How dangerous is the machine? (Voltage) (Current) (time) = (energy)

    _____volts x _____amps x _____sec = _____Joules

    Information can be found in the study notes.

    c. Do as may of the Van de Graaff Generator demonstrations as you desire and time allows.

17. E-38 Electric Reaction Wheel

18. E-39 Electric Chimes

19. E-37 Electric Wind

    a. A bent pin, taped to the top of the Van de Graaff generator will cause the flame to bend in which direction?

20. E-34 Discharge of Electricity from a Point

    a. A paper tassel with stand is available which can be taped to the top of the generator. Use caution.

21. E-16 Electrically Charged Student

    a. This can be accomplished only if an old piece of fur is obtained. Got any?

22. E-29 Surface Distribution of Charge

23. E-30 Absence of Electric Field within a Closed Container

24. E-31 Electric Shielding

25. E-46 Human Electroscope

    a. Instructor must be present when this is attempted.

26. Read: Section 10-4 A Model For Electric Charge page 204

27. Problems: page 205 #8 #9 #10
    page 212 #17

28. Read: Section 10-5 Batteries page 205

    a. See study Notes: BATTERIES

29. How does a battery produce charge? Discuss with your instructor.

30. Optional...Measuring Small Electric Forces page 29

Ernie Bushmiller

(more)

31. Read: Section 10-6 Measuring Small Electric Forces page 207
Section 10-7 The Elementary Charge page 210

a. Have instructor discuss how a battery can be used to create an electric field between parallel plates and how this field exerts a force on a charged object.

b. In a certain Millikan experiment the batteries are adjusted until a given charged sphere is motionless. The batteries are switched off, and the sphere falls 1 mm in 3 sec. The sphere is raised with a strong electric field; x-rays are applied; and the original field is restored. The sphere now falls 1 mm in 9 sec. The procedure is repeated several times, yielding the following data:

| | |
|---|---|
| a. With no electric field applied: | falls 1 mm in 3.00 sec |
| b. With standard field applied: | does not fall or rise |
| c. | falls 1 mm in 9.00 sec |
| d. | rises 1 mm in 3.00 sec |
| e. | rises 1 mm in 9.00 sec |
| f. | falls 1 mm in 2.25 sec |

(1) What was the probable initial charge on the sphere?

(2) What was the probable last charge on the sphere?

c. See Study Notes 2: ELECTRIC FIELD OF PARALLEL PLATES.

32. Optional...Film: MILLIKAN EXPERIMENT 30 min [Film notes provided.]

Note...Check film notes. You may have seen this film last year in chemistry and may not wish to see it again.

33. Optional...A Millikan Apparatus is available for you to experiment with if you so desire.

34. Problem: page 210 #12

35. Read: Section 10-8 The Conservation of Charge page 211

a. See Study Notes 3 Conservation of Charge

36. Complete enclosed written exercise.

## ANSWERS Chapter 10

4. (1) the sign is the same
(2) negative

6. (6) neutral or positively charged

16. 350000 volts $1.5 \times 10^{-5}$ amps $1.5 \times 10^{-5}$ sec $7.9 \times 10^{-5}$ J

27. (8) adding negative or removing positive
(9) no
(10) outer is negative, middle is positive
(17) see answer book

34. (12) (a) $7 \times 10^{-14}$ N (b) $1.4 \times 10^{-14}$ N

*from the desk of*

Dick Heckathorn

"[redacted] Go Better With Science"

☺☺☺ cheer up smile!

✓ 1. vinyl rods, acetate rods, wool, cotton
metal supports, masking tape
(silks, glass rods) not tee.

✓ 2. Graphite Coated Sphere and Stand
small graphite coated sphere on silk thread

7. Electroscope, RUBBER BAND ON ROD 11 out

9. CYLINDRICAL CONDUCTOR

11. PLASTIC COAT HANGER
METAL ROD VINYL & ACETATE RODS

12. ELECTROPHORUS

13. COFFEE CAN

14. MATCHES

[redacted] VINYL TAPE

16. Van de Graaff Generator

17. REACTION WHEEL

18. ELECTRIC CHIMES

19. BENT PIN

20. PAPER TASSLE

25. FLOOR INSULATOR

22. EGG SHAPED CONDUCTOR

23. CLOTH - NO CHARGE INSIDE

# PART IV

# ELECTRICITY AND MAGNETISM

## ELECTROSTATICS

**E-1. Electric Charges on Solids Separated after Contact.** A hard rubber rod or a stick of sealing wax is rubbed with fur and then placed in a stiff aluminum-wire stirrup hung by a silk thread. The suspended rod will move away from another rod that has been rubbed with fur but toward a glass rod that has been rubbed with silk. This behavior is interpreted in terms of two kinds of charge and the forces exerted between them. Positive electricity is defined (arbitrarily) as that which appears on glass when rubbed with silk.

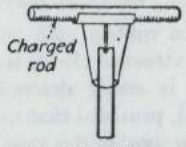


FIG. 207.—Torque-free support for charged rod.

Another method of supporting a charged rod so that it is free to turn is shown in Fig. 207. The rod is laid on a metal trough to which is attached a pivot supported by a vertical rod. The trough also carries a wire framework that forms a collar surrounding the support rod and so prevents the charged rod from falling.

A 10-ft plank (well dried) is suspended by a wire or strong cord at the middle so that it hangs horizontally. An ebonite rod is rubbed with fur and one end of the plank also brushed with the fur. The plank is set into rotation by repulsion when the charged rod is brought near to its charged end.

**E-2. Large-scale Electroscopes.** There are many ways of detecting the presence of a charge on a body; all depend on the forces exerted between charges. In this sense, small bits of paper or pith, cork filings, sawdust, and other light objects attracted toward charged bodies are electroscopes, as are also the torsion pendulums described in E-1.

An "electrical pendulum" consists simply of a small ball of pith or a ping-pong ball, coated with metallic paint and suspended by a long silk thread. It is a more sensitive detector of charge than the torsion pendulum. An inverted electrical pendulum is made by tying a gas-filled balloon to the table top or to the floor by a thread 3 or 4 ft long. The balloon is charged by rubbing on the demonstrator's hair, or by stroking with cat's fur.

Two gilded ping-pong balls are hung from the same point on a sealing-wax rod by fine wires. When the system is charged, the balls fly apart, and the magnitude of their separation may be made an indication of the amount of the charge, on an arbitrary scale. Two similarly treated rubber balloons separate in the same way.

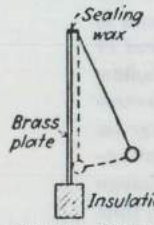


FIG. 208.—Pendulum electroscope.

A simple and sensitive electroscope is provided by suspending a gilded ping-pong ball by a No. 40 copper wire, which passes over a piece of sealing wax for insulation and is connected to an insulated plate of brass or aluminum mounted vertically so as to be tangent to the ball when the system is uncharged (Fig. 208). This arrangement permits many electrostatic experiments to be performed before a large class without the use of projection apparatus.

**E-8. Electrostatic Induction.** A cylindrical conductor with hemispherical ends, mounted on an insulating stand, is provided with two wire supports, one above each end, from which metallized pith balls are hung by silk threads so as just to touch the ends of the conductor when it is uncharged. When a charged rod is brought up toward one end of the conductor, the pith balls are both deflected away from the ends, showing that charges are now present there. A third similar pith ball charged by contact with the charging rod is brought near each of the other balls in turn to show that the charges on the ends of the conductor are of opposite sign and to determine their signs with respect to that of the charge on the rod.

**E-10. Electrophorus.** The electrophorus, described in all elementary textbooks, is easy to make. Melt a layer of sealing wax in a pie plate, and let it harden. Provide a flat metal disk, slightly smaller than the surface of the wax, with an insulating handle of pyrex or ebonite. Give a negative charge to the wax by rubbing it with fur. Place the disk in contact with the charged wax, which induces a positive charge on the lower side and a negative charge on the upper side of the disk. The usual method of removing the induced negative charge is for the demonstrator to touch the disk with his finger. A variation of this method is to use a neon-discharge-tube "wand," which is held so that the hand makes contact with one electrode. Touch the electrophorus disk with the other electrode of the tube. When the negative charge flows to ground through the demonstrator's body, the neon tube flashes brilliantly. A second flash is obtained by similarly touching the wand to the charged disk after it is removed from the wax plate. For best results, the metal disk should be at least $\frac{1}{4}$ in. thick, with its edge smoothly rounded.

**E-13. Electrostatic Induction—Faraday's Ice-pail Experiment.** This well-known experiment proves the equality of the induced and the inducing charges. A hollow conductor open at the top (a tin can will do) is mounted on an insulating stand and connected to an electroscope. A metal ball hanging by a silk thread is given a charge of known sign by contact with a charged rod or electrophorus disk. The ball is then lowered into the hollow conductor without touching it. The divergence of the electroscope leaves demonstrates the presence of an induced charge on the outside of the conductor. The demonstrator may call attention to the fact that the divergence of the leaves does not change as the inducing charge is moved about inside the conductor, thus showing that all of the lines of force from the inducing charge end on the inside of the conductor, regardless of the location of the inducing charge, provided that it is not too near the opening. If the ball is removed without touching the conductor, the electroscope leaves collapse, showing that no charge was transferred to the conductor. But if the ball is allowed to touch the bottom of the hollow conductor, the fact that there is no further change in the divergence of the leaves indicates that there must have been a charge induced on the inside of the hollow conductor exactly equal to that on the ball. This equality is further proved if the ball is withdrawn, the electroscope then discharged, and the ball returned to its original position within the hollow conductor without having been in contact with any body outside the conductor. The electroscope now shows no divergence, demonstrating that the ball was completely discharged by contact with the inside of the hollow conductor and establishing the equality between the inducing and the induced charges.

**E-14. Equality of Charges on Solids Charged by Contact.** The simple Faraday ice-pail apparatus (E-13) allows one to show that the two charges produced by contact between dissimilar bodies are equal and opposite in sign. A hard rubber rod has a piece of woolen cloth wrapped around one end and securely tied. This rod and another one having nothing attached to it are held inside a hollow conductor connected by a wire to an electroscope. When the end of the plain rod is rubbed against the woolen cloth, the electroscope leaves do not diverge; but if either rod is withdrawn, there will be a divergence of the leaves, of the same amount. The experiment may be varied by rubbing the two rods together outside the conductor, then inserting one after the other separately, then both together (see also E-52).

**E-16. Electrically Charged Student.** If a student stands on an insulated platform—an inverted battery jar will do—and is struck several times on the back with a piece of fur, his body becomes charged to a potential of several thousand volts above ground, and a 2-cm spark can be drawn from knuckles or ear, greatly to the amusement of the class. If the student holds a key tightly in his hand, sparks may be drawn from the key without causing him discomfort. The instructor may present to him a grounded Bunsen burner and let him ignite the gas by the spark. The sign of the charge on the student may be tested by a proof plane and an electroscope to which a known charge has been given (E-24).

**E-17. Charging Metals by Contact.** The charging of metals by contact may be shown and the signs of the charges determined. It is only necessary that the metal be held by an insulating handle and be rubbed with wool. If a hard rubber rod with woolen cloth attached (E-14) is used, then the sign of the charge on each body is easily determined by placing it within the ice pail (E-13), provided that the electroscope has been given a charge of known sign; in this case, increased or decreased divergence of the electroscope leaves indicates the sign of the unknown charge (E-24). If a substance in the following list of materials is rubbed with one below it in the list, it becomes charged positively, the other substance negatively: fur, wool, quartz, glass, silk, wood, metals, hard rubber, sealing wax, rosin, sulfur, guncotton. Surface conditions may change the above order to some extent.

**E-18. Neon Discharge from Rug Scuffing.** Charges may also be separated by several other means, such as rubbing dry paper with the hand, passing a rubber or bakelite comb or fountain pen through the hair or rubbing it on the sleeve, drawing a rubber band across the edge of a board or desk. Charging the human body by scuffing the feet across a rug is a familiar parlor trick that may be varied by discharging the accumulated charge through a neon discharge tube. The operator holds one end of the tube and, after scuffing his feet on a rug, presents the other end of the tube to an uncharged person or, better still, to a radiator or other grounded conductor.

**E-19. Electric Charges from a Stretched Rubber Band—Charging Electroscope by Contact.** A piece of stiff wire is bent into the form of a miniature violin bow, and rubber stoppers are fitted over its ends. An ordinary rubber band becomes charged positively when stretched across the ends of this frame. This charge may be conducted to an electroscope by sliding the band along the knob. The device is convenient because any desired quantity of charge may be obtained by sliding a suitable length along the knob. If the stretched rubber band is rubbed along a grounded conductor, the positive charge will be removed; after the band has been allowed to contract to its original length, it will be charged negatively, thus enabling one to conduct a negative charge to the electroscope.

**E-23. Charging Electroscope by Induction.** Hold a charged rod near the knob of an electroscope. A charge of opposite sign is induced on the knob, while a charge of the same sign is induced on the electroscope leaves. Charge on the leaves is conducted away by touching the knob (grounding) while the inducing charge is near. Break the ground connection, and remove the inducing charge. The electroscope is thus left with a permanent charge of sign *opposite* to that of the inducing charge. Any insulated body may be similarly charged by induction, giving a resultant charge opposite to that brought near it.

**E-24. Identifying Positive and Negative Charges.** The electroscope charged with electricity of known sign, either by contact (E-19) or by induction (E-23), may be used for testing the sign of an unknown charge. A charge of the same sign as that on the electroscope, when brought near the knob, will cause increased divergence of the leaves, while a charge of opposite sign will cause decreased divergence. It is instructive to bring a charge of opposite sign so close that the leaves not only collapse but begin to diverge again. In determining the sign of an unknown charge, one must remember that the approach of any grounded conductor, for example, the demonstrator's hand, toward the electroscope knob, will cause decreased divergence of the leaves since some of the charge on the leaves flows to the knob as a result of the attraction caused by the charge induced on the grounded conductor (condenser effect). This difficulty is largely avoided if the charge being tested is brought up on a proof plane attached to the end of a long pyrex rod. Another source of trouble is the charging of the demonstrator's body, especially in dry weather and on dry wood floors. This charge can be removed by touching a gas or water pipe.

**E-27. Van de Graaff Generator.** The principle of generating high potentials by the mechanical separation of electric charges, upon which the operation of the Kelvin water dropper (E-25) is based, is likewise shown in the Van de Graaff electrostatic generator. A small model of this generator may be constructed at low cost. The generator consists of one or more endless belts of silk or paper driven at high speed by a motor. The belts become charged when they pass pointed wires connected to a 10,000-v transformer and kenotron rectifier and carry their charge to the inside of an insulated sphere, where they give it up to other pointed wires connected to the sphere and return "for another load." The insulated sphere thus acquires charge, and its potential builds up to a high value, higher in general than can be obtained by an ordinary rotating-plate static machine. The charging transformer and rectifier can be omitted, and the device can be made self-sustaining when once started by a static

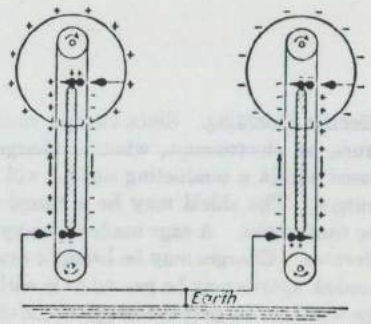



FIG. 213.—Van de Graaff electrostatic generator.

charge by using two insulated spheres and two belts, with appropriately arranged points as shown in Fig. 213.[1]

**E-29. Surface Distribution of Charge.** An egg-shaped conductor on an insulating stand is charged. Proof plane and electroscope are used to compare charge densities at various points on the surface of the conductor. It is found that the charge density (and hence the charge acquired by the proof plane) is greatest at the point of greatest curvature. (Care must be exercised that the proof plane itself does not disturb the charge distribution by its presence.)

Instead of the ellipsoidal conductor, an insulated aluminum cooking pan may be charged. The charge density is greatest at the corners and edges and least where the pan is flat, being greater on the outside of the bottom than on the inside of it.

**E-30. Absence of Electric Field within a Closed Conductor.** A cylinder of coarse-mesh screen (galvanized-iron wire of ¼-in. mesh serves well) about 4 in. in diameter and 8 in. long, open at both ends, is set on an insulated metallic plate connected with one terminal of the electrostatic machine. A metal-coated pith ball is suspended by a fine wire from the top of the cylinder so as to hang against the cylinder on the inside about half-way down, a similar ball being suspended from the top so as to hang about half-way down on the outside. When the machine is started, the outer ball deflects outward, the inner one remaining motionless. In the absence of an electrostatic machine, the electrophorus may be used.

**E-31. Electric Shielding.** Since charges reside on the outside of conductors, an electroscope, whether charged or uncharged, when enclosed within a conducting surface will be unaffected by outside charges. The shield may be a closed metal vessel but need not be continuous. A cage made of heavy wire screening is entirely effective. Charges may be brought near the screen and, if it is grounded, sparks may be passed to it without affecting the electroscope within. Project the image of the electroscope leaves to show the absence of any effect.

**E-34.** A tinsel tassel is hung from one knob of a static machine, and the machine is started. The strands of the tassel stand apart because of repulsion, but when the point of a needle held in the hand or otherwise earthed is brought near the tassel, the strands collapse. If the needle is not earthed but is held in an insulated handle, its effect is negligible.

**E-37. "Electric Wind."** A candle flame held near a pointed conductor connected to the *positive* terminal of a static machine is strongly repelled from the point *as if* a breeze of ions were actually issuing from the point. If the flame is held near the negative terminal, it is attracted toward it. The phenomenon is one of electrostatic repulsion and attraction rather than of any strong ion current issuing from the positive point. In the luminous part of the flame, positive ions predominate.

**E-38. Electric Reaction Wheel.** The "electric whirl" is another device illustrating discharge from a point. Two wires are crossed at their midpoints, and their pointed ends are bent at right angles so that they form a swastika. The device is pivoted at the crossing and connected to either terminal of a static machine. Rapid rotation is caused by reaction forces due to the repulsion of ions from the points.

**E-39. "Electric Chimes."** This is an old demonstration, but still effective. The action depends on attraction and repulsion of charges, involving induction. It may be understood by reference to the case of two bells supported at the same level, with a small metal clapper (ball) suspended by an insulating thread midway between them. One of the bells is connected with one knob of an electrostatic machine or a charged Leyden jar, while the other is earthed. Attraction between the charge on the first bell and that induced by it on the clapper causes the latter to strike the bell. The clapper now becomes charged with the same sign as the bell and is repelled with enough force to strike the earthed bell, to which it loses its charge. The process is repeated indefinitely, as long as the charge is maintained on the first bell.

**E-46. Human Electroscope.** A student (with fine dry hair) stands on an insulating stool and takes hold of one terminal of the static machine (previously discharged to prevent shock). When the machine is run, his hair tends to rise and extend along the lines of force of the field about his head. This hair-raising experience is accentuated by placing a grounded metal plate horizontally above his head at a distance greater than the spark gap. Each time a spark passes, this "hair electroscope" will collapse, then rise again. There is no danger to the student if the terminals of the spark gap are short-circuited before he takes hold. He will have no unpleasant shocks so long as he continues to hold to the terminal, but he may experience sparks if he lets go or touches grounded objects. It is best to cut out the condensers during this experiment.

**E-50. Discharge of a Conductor by Surrounding Gaseous Ions.** A charged conductor (positive or negative) is connected with an electroscope. When a flame (candle or lighted match) is brought near it, the deflection of the electroscope falls rapidly to zero, showing that the charge has been dissipated. The electroscope is quickly discharged by blowing the gases of combustion from a flame upon the conductor. A sample of radium gives the same effect (A-112), and so do x-rays (A-103).

**E-51. Ions Formed in Flame.** Two metal plates supported vertically on insulating stands are set parallel and 2 to 3 cm apart and are connected to the terminals of a static machine. A candle flame is held just beneath the plates. The hot gases rising between the plates are made visible by shadow projection (H-137). When the static machine is operated, the gases will be seen to divide into two streams as ions of opposite sign are attracted to the charged plates.

## Chapter 10 STUDY NOTES

### 1. The SC-21-V Magna Graaff self charging Van De Graaff Electrostatic Generator

This generator provides a variable rate of charging the high voltage electrode. This is accomplished by the aid of a rheostat control mounted in the base and operated by a knob on the outside of the base. To operate, first make sure the rubber belt is in place. Second, ground the base to some object that is grounded such as the gas pipes. Third, set the rheostat knob fully counter-clockwise. Fourth, plug in the cord and turn on the switch. Fifth, adjust rheostat control knob to achieve desired motor speed. By increasing the speed of the drive motor and thus the charging belt, the charging current of the generator is increased. Unfortunately, the type of belt material which is best for charge generation is not the best material for stable driving. The charging belts supplied are of the best material available for charge generation, but may tend to be unstable and cause a certain amount of chattering at highest speed. When this happens, the drive speed should be reduced slightly until smooth belt operation is again achieved.

#### Principle of Operation

The generator deposits the charge directly into the top sphere. The design is based on the principle that if a charge is brought into internal contact with the hollow sphere, regardless of how high the potential of the sphere may be, all of its charge transfers to the outside of the hollow top shpere. If it were not for insulation difficulties, the charge and hence the potential of the hollow conductor could be raised to any desired value by successively adding charges to it by internal contact. The potential existing on the top sphere is, therefore, limited by the dielectric strength of air and the resistance and dielectric strength of the insulating column and charging belt.

#### The Electrode

The hollow spherical electrode on which the charge is deposited serves also as a storage capacitance and discharge electrode. This electrode is composed of two matched hemispheres, of approximately 10 inches in diameter. Charge can leak off the electrode by means of an electrical discharge through the air, known as corona. This discharge is greatest from surfaces of small radius of curvature. The larger the radius of curvature, the higher the voltage that can be maintained on the electrode. With the 10 inch diameter electrode the maximum voltage, under ideal conditions is about 350,000 volts. Any sharp corners or points on the surface of the electrode will favor corona discharge and thus will cause lower voltage on the electrode. The surface of the electrode should be maintained clean and free of small particles of dust, etc. by frequent wiping with a clean lintless cloth.

#### The Discharge

During the normal operation of the generator, the discharge lasts for a period of from 1-15 microseconds, depending upon the conditions of the discharge. A discharge through a low resistance path, such as from the electrode to ground, may produce rather large currents in the initial stages of discharge. This current being oscillatory in nature and of short duration, cannot endanger the operator. The high resistance of the human body and the low capacitance of the electrode serve as additional safety factors.

There is a basic difference in pattern between a positive and a negative spark occuring when air breaks down at maximum electrode potential. A breakdown spark from a negatively charged electrode shoots off in a straight line, while that from a positively charged electrode follows a fan pattern. For this reason, if one is using only one machine it will be found that negative electrode charging will provide more

spectacular demonstrations than positive charging. The generator can be converted fr one polarity to another by substitution of upper and lower rollers having the wool and plastic coatings in opposite positions. With plastic on the top roller and wool on the bottom, the electrode takes on a negative potential. If the materials are reversed, the eledtrode potential is positive.

## Warning

A capacitor should never be connected across the output of the generator, as the additional charge stored might endanger the operator of the machine.

## The Generator

The column used in the generator is constructed of lucite. It has a high coefficient of surface resistivity, which makes it ideal for use as an insulating column. It is transparent and the operation of the machine is visible at all times. The surface resistance of the lucite column can be substantially reduced by surface contamination. The column must be maintained clean and free from dirt and grease. Carbon tetrachloride may be used to clean the surface of the column.

The charging system used in the Van de Graaff generator consists of a continuous belt which carries charge up inside of the upper electrode. Charge is taken from the belt by a collector plate which is bolted to the upper electrode at the top of the lucite column. This plate has a sharp edge of small radius of curvature. An air discharge is set up between the belt and this sharp edge, and the charge is transferred from the belt to the collector. In a similar manner charge is sprayed onto the belt inside the base of the generator from a collector plate which is mounted on the lower roller drive assembly.

The charging belt is made of rubber. After a long period of investigation it was found that rubber was the most desirable material for the purpose. Unfortunately, the electrical discharge between the belt and the collectors generates ozone, which is a strong oxidizing agent and attacks the rubber. After a considerable period of operation the rubber loses its desirable mechanical properties and must be replaced.

## The Charging Mechanism

The charge is generated by contact between the rubber belt and the material with which the rollers are covered. At the contact between the wool covered lucite roller and the rubber belt, negative charges are sprayed onto the belt. At the other roller a plastic coating on the lucite roller creates a positive charge on the belt. Thus a double action is provided, in which a negative charge is deposited onto the belt and carried from the base up into the electrode. There this charge is removed from the belt and added to the charge on the electrode. At the same time a positive charge is sprayed onto the belt and is carried down into the base, leaving additional negative charge on the electrode.

This charging system is reasonably stable under all climatic conditions, and will develop a current of from 10 to 15 microamperes under normal conditions. Even under conditions of high humidity this charging system is satisfactory, the insulation of the lucite column being sufficient to maintain a high potential on the electrode. However, when the generator has been standing for a considerable period of time, especially in cold humid weather, moisture may be absorbed onto the surfaces of the belt or rollers. If the generator is placed in a warm room for a short period of time the moisture will be driven off these surfaces. Also, if the generator is run, the moisture will be driven off and the charging action will be improved.

## Chapter 10 Van de Graaff Generator Demonstrations

1. DIELECTRIC BREAKDOWN or "spitting": When the maximum electrode potential is reached, the electrode will engage in a lively "spitting", demonstrating the dielectric breakdown of air. This discharge is visible in a darkened room.

2. SPARK DISCHARGE: Due to the large electrostatic field produced by the generator, 10 inch sparks are obtained easily under average conditions: under excellent conditions 14 inch sparks are obtained. These sparks can be especially beautiful in night-time demonstrations.

3. HAIR RAISING: The demonstrator must stand on a well-insulated stool. The legs are preferably made of lucite or polystyrene and should be 8 to 12 inches in length. The generator is placed on a table of sufficient height to enable the demonstrator to place one or both hands on the electrode. If the demonstrator places his hands on the electrode before the generator is started, he will be unable to feel the current. As his body accumulates charge, its potential will rise and his hair will rise on end in the spectacular hair raising stunt.

4. PIN WHEEL: The remarkable electrostatic field produced by the generator is well demonstrated by the use of a grounded pin wheel. (It is not necessary to place the wheel on the electrode, although to do so makes the experiment more dramatic.) The discharge to the generator from the points of the grounded wheel is sufficient to turn the pin wheel when placed several feet from the electrode.

5. ATTRACTION: Neutral particles acquiring induced charge are attracted to the electrode.

6. REPULSION: Any light object placed on the machine is repelled as the electrode potential rises, and the particle acquires charge.

7. INDUCTION: Due to the large electrostatic field, charges can be induced in insulated conductors placed several feet from the generator.

8. FLYING THREAD: Place several free particles of thread on the electrode, from where they can fly back and forth to nearby objects; or place particles of silk thread between the upper and lower hemisphere and observe the aerobatics.

9. PENDULUM: A large pendulum can be made to oscillate between the electrodes of a positively charged machine and a grounded insulated sphere, or between a negative charged machine and a grounded insulated sphere.

10. CHARGE SPRAYING: The discharge to and from the belt is visible as a luminous glow in the vicinity of the charge collectors. This glow can be readily seen in the dark. While observing this phenomenon the upper hemisphere should be removed and the generator grounded by connecting a wire from the upper collector to the base.

11. ELECTRICAL WIND: Bend a pin at right angles and insert the head end in the joint between the upper and lower hemispheres so that the point extends outward horizontally from the sphere. Start the generator. Mount a lighted candle on the end of a long wooden (meter) stick and place the candle flame in the vicinity of the point of the pin. The candle flame will be deflected due to air current off pin end.

12. GLOW LAMP: Hold one end of a fluorescent lamp in the hand and bring the other end of the lamp to the discharge electrode of the generator. A glow will appear in the tube which will be especially bright when the generator discharges through the lamp.

FILM NO. 0404

# TEACHER'S GUIDE TO THE PSSC FILM

## MILLIKAN EXPERIMENT (30 min.)

Francis L. Friedman, M.I.T., and
Alfred Redfield, International Business Machines

A version of the classic Millikan experiment is performed in this film showing that charge comes in multiples of a natural unit.

### Summary:

Professor Friedman introduces the experimental apparatus and provides a running commentary which describes and interprets the experiment as it is performed by Dr. Redfield. In this experiment a small charged plastic sphere of known mass is introduced between two horizontal, parallel metal plates, and its motion is observed with the help of a microscope. The plates are charged by batteries and the number of batteries is adjusted until the charged sphere is motionless. In this situation the electric force on the sphere is equal and opposite to the gravitational force on the sphere. By comparing the distance the sphere falls in five seconds with no electric force acting on it to the distance it falls with the above electric force reversed, pulling downward with the gravitational force, it is established that the terminal speed of the sphere in air is proportional to the net force acting on it.

The charge on the balanced sphere is altered with X rays; the electrical force on the sphere is no longer balanced by the gravitational force. The speed of the sphere is measured under these conditions. The speed provides a measure of the change of electric force and, consequently, of the change of charge on the sphere. This whole process is repeated several times. The measured speeds fall into definite groups separated by a common speed difference equal to the smallest speed measured. These data indicate that the addition or loss of charge on the sphere occurs only in whole-number multiples of a natural unit.

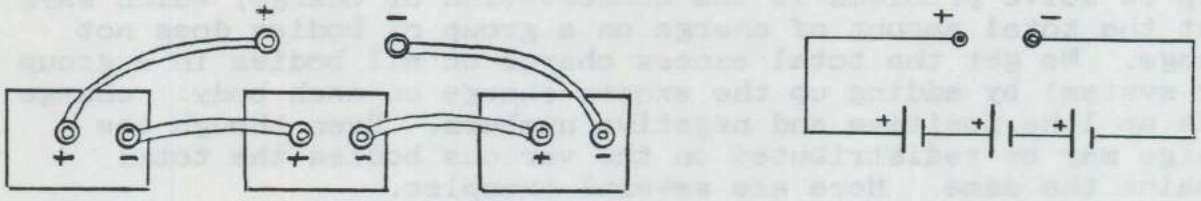
### Points for Discussion and Amplification:

(a) The terminal speed of the plastic sphere moving in air is reached in approximately $10^{-5}$ sec, after the force is applied. This time interval is negligible compared to that used to measure its speed.

It should be emphasized that, in general, the terminal speed of a sphere moving in air is not always proportional to the force acting on it. The proportionality is, however, very accurate in the range of speeds used. In fact, this was demonstrated in the film; doubling the driving force doubled the terminal speed.

(b) The fact that charged, parallel plates produce a uniform electric force on a small charge between them is demonstrated geometrically in Section 28-3 of the PSSC text. Experimental proof of this is given in the film where, with the "set charge" on the plates, the sphere is shown to be balanced at different points in the field of view.

1. Batteries in Series: In this chapter we encounter the idea of connecting batteries in series. What we mean is to connect a wire from the positive (+) terminal of the first battery to the negative (-) terminal of the second, and then, if more than two batteries are placed in series, connect the positive terminal of the second battery to the negative terminal of the third battery, etc.



Then the negative terminal of the first battery and the positive terminal of the last battery are connected to the plates of a Millikan type apparatus or whatever it is that we want to charge with these batteries. Instead of drawing pictures of batteries we will use the symbol ⊣⊢ where the long bar represents the positive terminal of the battery and the short bar the negative terminal. The diagram on the right side above is equivalent to the drawing on the left. The more batteries connected in series, the greater will be the electric potential (energy per charge). Thus if each battery has a potential of 1.5 volts (Joules per Coulomb), then two batteries in series will provide energy per charge at the rate of 3 Joules per Coulomb (volts). If we connect three batteries in series, then 4.5 volts will be the energy per charge made available.

2. Electric field of Parallel Plates: The value of the force on an elementary charge determined in the Millikan experiment described in Sections 10-5 and 10-6, is $1.4 \times 10^{-14}$ Newtons/elementary charge. This value is the result of a specific set of experimental data: the parallel plates were 3.1 mm apart, and they were charged with a specific set of batteries (3 90-volt batteries). If these experimental conditions are changed, then the force per elementary charge changes as well. We saw that to produce any other uniform electric field which would have the same force per elementary charge we would have to scale the experimental apparatus so that, for each change in plate separation, we must make an identical change in the number of batteries connected to the plates. For example, if we double the separation we must double the number of batteries to maintain the same force per elementary charge: if we diminish the separation by a factor of one-third, we must use only One-third the number of batteries. Saying this correctly, the force per elementary charge varies directly as the number of batteries and inversely as the separation. (Remember this is only for parallel plates.)

If the Millikan experiment had been done with, say, a spacing of 5.0 mm and one 90-volt battery, we would have gotten a completely different value for the force per elementary charge in that new situation. However, that force would be the same as what we would get if we scaled our original experiment: (1) the force, F, would be decreased by a factor 1/3 because the number of batteries was decreased from three to one; and (2) the force would be further

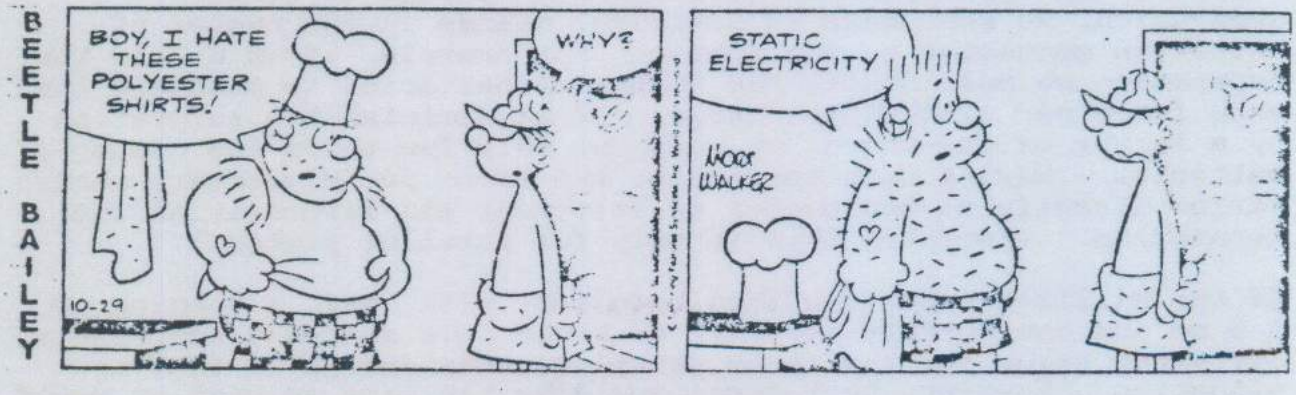
decreased by a factor of 3.1/5.0 because the plate separation was increased from 3.1 to 5.0 mm. As long as we use the proper relationship in scaling our charged parallel plates for an experiment, our final result of any experiment will always be correct.

3. Conservation of Charge: Another useful law of physics which can help us solve problems is the conservation of charge, which says that the total amount of charge on a group of bodies does not change. We get the total excess charge on all bodies in a group (or system) by adding up the excess charge on each body: charge adds up like positive and negative numbers. Even though the charge may be redistributed on the various bodies the total remains the same. Here are several examples.

   Take a glass rod and a silk cloth. Initially both are neutral: the total charge on the rod-cloth system is zero. Now rub the glass rod with the silk. The silk rubs an arbitrary number of electrons off the glass, leaving the glass with a positive charge of +N elementary charges and the silk with a charge of -N elementary charges. Final total charge of (+N) + (-N) = zero, so the total charge did not change.

   We start with two identical metal spheres, one neutral and the other with an excess of 40 negative elementary charges. Initial total charge on the two spheres is 0, and -40 which equals -40. Then we touch the uncharged sphere to the charged sphere and they both share the charge equally (because they are identical spheres). Now the charge on each is -20 elementary charges. Final charge is still -40; the same charge as originally on the two spheres except that it is redistributed.

   Again we start with two identical metal spheres, one with + 10 charges and the other with -2 charges. Initial total charge is (+10) + (-2) = +8. Now touch the two charged spheres together; the available net charge will be distributed equally on the two spheres. Thus, each sphere will now have + 4 charges. Total charge still remains +8.



A flash. A crack. Lightning bolts sparked by angry gods? An archaic theory, but until recently scientists were at a loss to explain just what does trigger lightning.

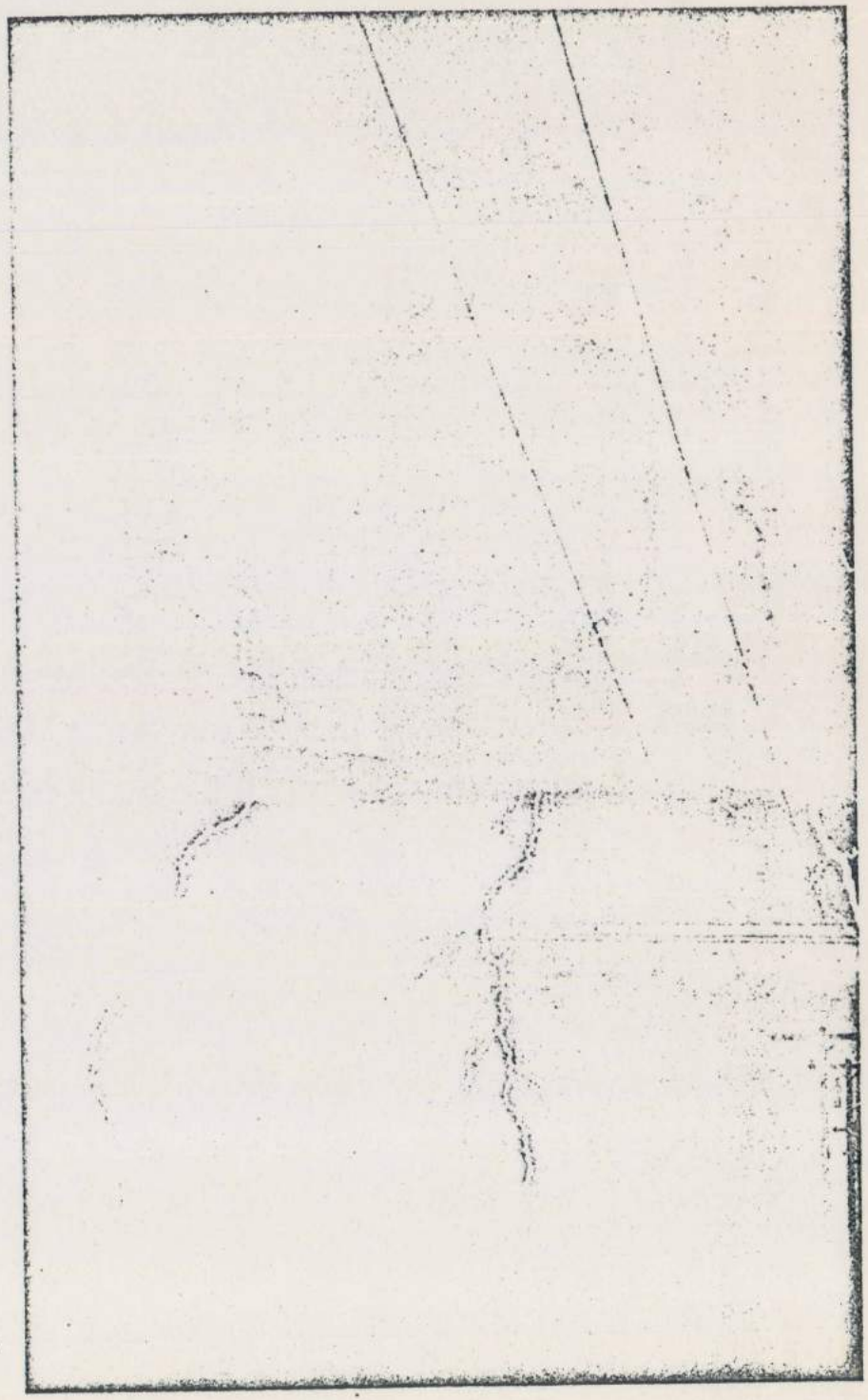
There is no disagreement that the bolts are electrical discharges between clouds and the Earth after enough electrical potential—about 100 million volts—has built up between the clouds and the ground to overcome the resistance of the insulating air that separates them. Neither is there disagreement about the voltage build-up that results from a migration of electrons to the bottom of the clouds giving them a strong negative charge. This strong charge repels electrons in the ground below, producing a strong positive charge. When this build-up continues, electrons burst across the barrier, completing the electrical circuit.

But what causes the cloud's electrons to flock to the bottom of the cloud, generating the tremendous potential required? In a paper entitled "The Connection Between Cosmic Rays and Thunderstorms" presented at the meeting of the American Geophysical Union last fall, Dr. James. W. Follin, Jr. of the Applied Physics Laboratory of Johns Hopkins University suggested that cosmic rays from space act to trigger the bolt.

Cosmic rays, which consist chiefly of protons traveling at about the speed of light, strike the Earth's upper atmosphere as they travel through space. When they collide with the atmosphere, the rays are shattered into high-energy fragments called secondary cosmic rays or "air showers." According to Follin's theory, these showers pass through thunderhead clouds, ionizing oxygen and nitrogen. The resulting free electrons are accelerated by the already-existing electric field in the cloud and settle at the bottom. There they generate enough potential in the thunderhead to initiate a lightning bolt.

As the electrons explode from the cloud, other secondary cosmic showers intercept at various angles, forming the zig-zag path of the bolt. When this "leader stroke" is about 50 yards above the Earth, a second electric discharge, this time from the ground, jumps up to meet it. Generally, this leader stroke is not seen, but it clears the path for the subsequent, powerful one we do see.

Follin's theory is one of the first attempts to assess the role of atmospheric electricity in weather and also to account for the link between sunspot cycles and drought. Sunspots regulate the solar wind which in turn determines the number of charged particles from the Sun and from cosmic rays that enter the Earth's atmosphere. When sunspot activity is low, the number of charged particles reaching the atmosphere is greatly increased. Some scientists believe that such electrical activity aids in raindrop formation.



# INVESTIGATIONS
# WITH
# STATIC ELECTRICITY

Revised by
Dick Heckathorn
5 May 1988

Taken from materials written by
Robert A. Morse and Charles Toth

## INTRODUCTION

In these investigations, you will be using the laboratory to learn what makes things behave the way they do. Specifically you are to try to learn how nature's laws of electrification work and to seek some pleasure in speculating on the how's and why's. The essential element of laboratory work is honest, perceptive, and accurate observations. Any preconceptions that you may possess should be ignored when making observations.

Record observations when you see them. At the same time, you should write down any questions and/or ideas for further investigation. In addition you should write some conclusions based on investigations to date. But first and foremost, you must set down your observations in a manner in which you could expect to understand two months later. It is a good plan to keep your lab record in the form of a diary with the date on each page. In this way, it should be clear to you what observations are made and recorded in the lab and won't be confused with inferences and conclusions made subsequently on the basis of additional lab work and/or other work. The apparatus used is quite simple. However, don't be fooled. The phenomena are not necessarily simple, and certainly not trivial.

There is an old saying in science that the easiest things to observe are the hardest to understand. Care, patience, and persistence are often required to determine which is reproductible from that which is accidential. Investigations rarely prove anything, but should teach you something. (The complaint that the "experiment doesn't work" or the "apparatus doesn't work" is usually as apt as complaining that the pencil doesn't work when it is out of lead.) Keen eyes, skilled hands, open minds, and judicious, accurate observations are the hallmarks of good investigations.

Now begin your investigation and see if you can reach the same conclusions as others including your teacher.



## SECTION 1 ELECTROSTATIC INTERACTIONS

1.1 Tear part of a piece of paper into small bits. Take a plastic drinking straw and bring it close to the bits of paper. Can you lift the bits of paper by touching them with the straw?

1.2 Now rub the straw briskly with fur or wool or against your hair and try to lift the bits of paper from the table.

1.3 Can the scraps of paper be lifted even if you do not allow the rubbed straw to touch them first? Repeat this using the styrofoam coffee cup, trying to lift the paper bits before and after rubbing the cup on wool, fur or your hair.

1.4 Apparently, after the straw has been rubbed there is an interaction between the straw and paper which is capable of lifting the scraps of paper. What can you say about the size of this interaction compared to that of the earth's gravitational interaction with the scraps of paper?

1.5 The force involved in this interaction is called an electrical force, and was first observed by the Greeks, who found that pieces of amber (in Greek, elektron) attracted other things after being rubbed with fur. The materials which are capable of attracting the bits of paper are said to be electrically charged.

1.6 Can you conclude at this time that the bits of paper are charged? Why do you think what you do? Are they charged according to the definition in section 1.5? How could you test for this? Record your findings.

## SECTION 2 CHARGED STATES OF MATTER

### A. Interaction between charged and uncharged objects

2.1 Take a piece of 15-cm piece of scotch magic tape and make tabs by folding the first few centimeters of tape on each end, sticky side together. Stick the tape to a block of wood and press and rub it down well with your finger. Now peel the tape carefully but briskly from the wood.

2.2 Will either or both sides of the tape attract the scraps of paper?

2.3 Does the tape meet the definition of being charged?

2.4 Roll a piece of paper into a tube and bring it near the tape. Is there an interaction between the paper tube and the tape?

2.5 Does the paper tube meet your definition of being charged? Why or why not? Record all answers.

B. Interaction between two charged objects.

2.6 Make a second tape strip like the first one. Press them both down on the piece of wood separately, and then peel them loose from the wood. Try bringing the tapes near each other. How does one affect the other? Does the sticky or non-sticky side make a difference?

2.7 Make a third strip of tape, press it to the wood and remove. Bring it close to the other two. What do you observe?

2.8 What is your present definition of an electrically charged object based on observations to date? Record all findings.

2.9 Make a stand by taping the long end of a flexible straw to an upside down styrofoam cup with masking tape. Bend the top of the straw horizontally and stick one of the pieces of charged tape to the straw so that it hangs down. (This will be called the test tape.)

2.10 Make two new pieces of tape as before. Label one 'A' and press it to the block of wood. Label the second one 'B' and press it firmly down on top of 'A'. Peel the two pieces of tape from the wood making sure that they remain stuck together. Bring them near the test tape. What do you observe? Bring the combination near some paper bits. What do you observe? Is the combination tape charged? Record your findings.

2.11 Now run the non-sticky side of the tape combination across your lips or across a water pipe or gas jet. Again bring the combination tape near the test tape and bits of paper. Record your findings.

2.12 Carefully peel apart the two tapes. Hold one in each hand and bring them slowly toward each other. Record your findings.

2.13 Bring each tape separately towards the test tape. Record your findings.

2.14 Can you tell with certainty from this experiment that both tape 'A' and 'B' are charged. Record your findings.

2.15 Can you devise any additional experiments that will show convincingly that both 'A' and 'B' are charged. Try any that you devise. Results?

2.16 Now, write your definition of a charged object based on all investigation to date?

2.17 You have been using attractive and repulsive interactions to test for charged objects. How reliable do you feel the tests are? Would either test alone be sufficient? If so, which one? Again record your findings.



2.18 Make another test stand with a cup and straw and hang tape 'A' from one stand and tape 'B' from the other. Try rubbing various objects including your straw and a foam cup against various materials and test them by bringing them near 'A' and 'B'.

2.19 Which objects affect 'A' and 'B' differently? Which object(s) affect 'A' and 'B' similarly? Keep track of all findings.

2.20 Which objects are charged? Record your findings.

C. Charges and charged states.

2.21 If two charged objects behave the same in their interactions with all other objects, we will describe them as being in the same charged condition. We will suppose that a charged object is charged because of the presence of something called charge. With this hypothesis, we need to account for the charged states of tapes 'A', 'B', and the bits of paper in terms of the kind(s) of charge present.

2.22 How does one tape 'A' react with another tape 'A'? One tape 'B' with another tape 'B'?

2.23 Based on one's experience to date, would you say that the two 'A' tapes have the same or different charge? What about the two 'B' tapes? What about a tape 'A' compared to a tape 'B'? Record your findings.

2.24 Now consider the paper. How does one piece of paper react to another bit?

2.25 Considering how the paper interacted with the tape, could one assume the paper has a third type of charge? Why or why not?

2.26 Based on these observations, can you conclusively say that the paper bits have absolutely no kind of charge?

2.27 If we assume that there are only two kind of charges, one associated with tape 'A' and the other with tape 'B', how would one explain the charged state of each tape and the interactions of the tapes and paper bits? Record your findings.

2.28 Prepare another set of 'A' and 'B' test tapes. Briskly rub a foam pad or foam paper plate with the wool or fur. Bring the foam pad or plate and then the wool or fur near the test tapes. Is either charged? If so, which tape has the same charge as the charged objects?

## SECTION 3 BUILDING ELECTROSCOPES

3.1 Take a small piece of aluminized paper straw and fasten a 10-cm piece of polyester sewing thread to the straw. (We will refer to the piece of aluminized straw as the "pith ball" in the remainder of this packet.)

3.2 Make a stand to hold the pith ball by taping a flexible drinking straw to an upside down foam coffee cup with masking tape. (You may modify one of the stands you made earlier to hold tape 'A' or 'B'.) Bend the top of the straw horizontal and cut a vertical slit (with a razor blade) in the end of the horizontal segment. Slip the string of one or more "pith balls" into the slit and adjust their lengths to suit your needs.

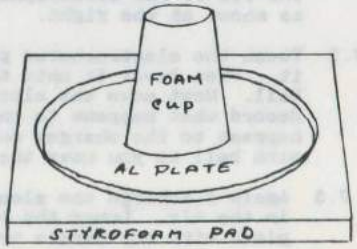
3.3 Set up your stand with a pith ball hanging from it on about 10-cm of thread. Rub a plastic drinking straw with wool or fur and bring it near some paper bits. Is the straw charged? Now bring the straw near the pith ball. What happened? How can you use the pith ball to test for a charged object?

3.4 Now you will build a more sensitive electroscope. This is a very inexpensive version of the gold leaf electroscope. Modify the other stand you made for your test tapes by fastening the shorter end of the straw to the cup with masking tape and bending the straw so the long end is vertical. Bend the paper clip so the two U-shaped sections lie in perpendicular planes as in the diagram. Tape the paper clip to the top of the straw so that the longer U-shaped leg is now sticking out horizontally from the straw. Cut two strips of aluminum foil about a centimeter wide by five centimeters long and smooth them with your fingernail. Bend the top of each strip loosely around one of the horizontal bars of the paper clip, so that the strips swing freely from the bars.

3.5 Take a plastic drinking straw and rub it with wool or fur. Touch the pith ball with the straw. Is the straw charged? Touch the straw to the top of the paper clip on the electroscope. What happens to the foil leaves? How can you tell if an object is charged using the foil leaf electroscope?

## SECTION 4 THE ELECTROPHORUS: A DEVICE FOR GENERATING STATIC ELECTRICITY

4.1 To make an electrophorus, take a styrofoam pad or disposable styrofoam picnic plate for the base. Take a disposable aluminum pie plate (6" or 9") and fasten an insulating handle to it by taping a styrofoam cup upside down in the center of the pie plate. You will also need to make a second pie plate with a foam cup handle for some of the experiments.






4.2 Rub the top surface of the foam with fur or wool to charge it. Slowly lower the electrophorus pie plate (henceforth called the electrophorus plate) to a height of a few millimeters above the foam while holding it by the cup handle. Be careful not to touch the pie plate with your hand or arm unless instructed to do so.

4.3 Still holding the electrophorus plate by the cup, raise it away from the foam. Touch the electrophorus plate to your leaf electroscope. Is the electrophorus plate charged?

4.4 Again lower the electrophorus plate to a point just above the foam, and this time touch the electrophorus plate briefly with your finger while it is on or just above the foam. What happens?

4.5 Slowly lift the electrophorus plate by the handle removing it from the foam. Do you feel any interaction between the electrophorus plate and the foam as you lift? Is it attractive or repulsive?

4.6 Touch the electrophorus plate to your leaf electroscope. Is the electrophorus plate charged?

4.7 Touch the electrophorus plate to your pith ball. What does the pith ball do? What can you say about the charge on the pith ball and the charge on the electrophorus plate?

4.8 Now bring the foam near the pith ball. What can you say about the charges on the pith ball and the foam pad?

4.9 Design an investigation that would determine the sign of the pith ball relative to the styrofoam? Do so and record the results.

4.10 Clearly the electrophorus is an effective, interesting and slightly puzzling charging device. Temporarily you will use it to supply charges for other experiments before trying to develop a better understanding of how it works.

4.11 Tape both a plastic straw covered with aluminum foil and a second regular straw with masking tape to the rim of the electrophorus plate so that both stick out horizontally. Set up the pith ball electroscope and briefly touch the pith ball with your finger. Rub the foam pad or foam plate with the wool or fur. Pick up the electrophorus plate by its handle, set it on the foam and touch it with your finger. Lift the electroscope plate by its handle, being careful not to touch the plate or the straws. Move the plate so that first the outer end of the plain straw touches the pith ball. Next touch the pith ball with the outer end of the foil covered straw. Record what happens.

4.12 Repeat the investigation but this time use the foil leaf electroscope. Again record the results.

4.13 Record how you feel the foil covered straw and the pith ball received the charge. Offer evidence that this is similar or different from the way that the tapes 'A' and 'B' received their charge.

4.14 Rub the foam with the fur or wool again. Pick up the electrophorus plate by its handle, set it on the foam and touch it with your finger. Lift the electrophorus plate from the foam, being careful not to touch

the plate or the straws. Touch the end of the plastic straw briefly with your finger. Now bring the electrophorus plate near the hanging pith ball. Is the plate still charged?

4.14 Now touch briefly the end of the foil covered straw with your finger. Bring the electrophorus plate near the pith ball. Is the plate still charged? Explain in writing why things behaved as they did.

4.15 Objects that behave like the plastic straw, the foam and the tape are called insulators. Objects that behave like the foil covered straw and the pith balls are called conductors. We will continue to look at the differences in their behavior and try to account for it while developing a model of electric charge. In a conductor we may imagine that one or both types of charge are free to move (in reality it is only one of the charges most of the time), whereas in an insulator neither type of charge can move very much or very readily.

4.16 Now use the electroscope and electrophorus to investigate a variety of materials of your choice to see if they behave like conductors or insulators. Record your findings.

4.17 Using the model described in the next to last paragraph above, can you explain the findings of your investigation in 4.1 through 4.3. You might consider using cartoon strips and/or other creative ways to record your results.

## SECTION 5 THE BEHAVIOR OF THE ELECTROPHORUS

5.1 Rub the top surface of the foam with fur or wool to charge it. Touch the electrophorus plate (with both straws now removed) with your finger while it is in the air. What happens? Slowly lower the electrophorus plate to a height of a few millimeters above the foam while holding it by the cup handle. Be careful not to touch the aluminum plate with your hand or arm unless instructed to do so.

5.2 Still holding the electrophorus plate by the cup, raise it away from the foam. Touch the electrophorus plate to your leaf electroscope. Is the electrophorus plate charged?

5.3 Again lower the electrophorus plate to a point just above the foam, and this time touch the electrophorus plate with your finger while the electrophorus plate is on or just above the foam. What happens?

5.4 Take your finger away and lift the electrophorus plate by the handle. Do you feel any interaction between the electrophorus plate and the foam pad as you raise the plate?

5.5 Touch the electrophorus plate to your leaf electroscope. Is the electrophorus plate charged? What is the charge on the electrophorus plate? Is it like the charge on the foam? How can you tell?

5.6 Touch the electrophorus plate briefly with your finger while it is in the air. What happens when you do this? Is the plate still charged? Again lower the electrophorus plate this time letting it rest on the foam, and touch the electrophorus plate with your finger while it is on the foam. What happens?



5.7 Take your finger away and lift the electrophorus plate by the handle. Is the interaction between the electrophorus plate and the foam pad as you lift it the same as before?

5.8 Touch the electrophorus plate to your leaf electroscope. Is the electrophorus plate charged? Is the charge like that on the foam? Did it matter if the electrophorus plate was in contact with the foam?

## SECTION 6 FORCE AND DISTANCE

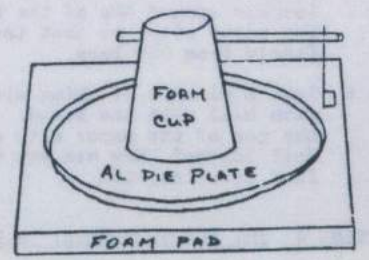
6.1 Let's now investigate how the electrical interaction or force between charged objects depends on distance. To estimate the reaction, you will "feel" the interaction. First place the electrophorus on the foam. Take the electrophorus plate by the handle, touch it briefly with your finger and then raise the electrophorus plate from the foam. You may have to hold the foam to the table. Can you sense any difference in the force as the plate is moved further away?

6.2 Repeat the above but this time not holding the foam to the table.

6.3 Take your stand with one pith ball hanging from it. Touch the pith ball briefly with your finger. Take the electrophorus plate by the handle, touch the electrophorus plate briefly with your finger, set the electrophorus plate down on the foam, touch it briefly with your finger, then lift the plate from the foam and touch it to the hanging pith ball. What happens to the pith ball as you vary the distance the electrophorus plate is from it? Record how your findings. Anything new?

## SECTION 7 THE INDICATING ELECTROPHORUS

7.1 Take a plastic straw and using masking tape, fasten it horizontally to the top of the cup that serves as the handle of the electrophorus plate so that it extends over the edge of the pie plate. (Or you could take a pencil and poke holes in the cup near the top and slide the end of the straw into the holes.) Cut slits in one end of the straw and suspend a pith ball so that it is just touching the rim of the electrophorus plate as shown at the right.




7.2 Touch the electrophorus plate briefly with your finger to discharge it. Then lower it onto the foam. Record what happens to the pith ball. Next move the electrophorus plate up and down above the foam. Record what happens to the pith ball. Also record what you think happens to the charges on the rim of the electrophorus plate and the pith ball as you move the plate closer to the foam.

7.3 Again discharge the electrophorus plate with your finger while it is in the air. Lower the plate onto the foam and bring a second aluminum plate with cup handle near the pith ball. What happens?

7.4 Move the aluminum plate closer to the electrophorus plate until nothing more happens. Based on your observations, record what you feel is happening.

7.5 Once again, discharge the electrophorus plate with your finger while it is in the air and lower it onto the foam. Discharge the aluminum plate and once again bring it closer to the electrophorus plate until nothing happens. Move the aluminum plate away. Now raise the electrophorus plate from the foam and observe the position of the pith ball as you move the electrophorus plate above the foam. Record how (if any) the behavior of the pith ball relates to the force that you feel.

7.6 What can you conclude about the amount of charge on the rim of the electrophorus plate as you move it away from the foam? Account for the change(s). Is the charge on the electrophorus plate the same type as the charge on the pith ball?

7.7 Now bring the aluminum plate near the pith ball being careful not to let them touch. What happens? Is the aluminum plate charged? Test this by touching it to the leaf electroscope.

7.8 Is the charge on the aluminum plate the same as that on the electrophorus plate or the same as that on the foam pad? Test this by touching the aluminum plate to your pith ball electroscope and then bringing the foam near the pith ball electroscope. Make any other investigations that you wish. When completed, record your findings regarding the charged states of the foam, the electrophorus plate and the aluminum plate.

7.9 Rub the foam with the wool or fur to "refresh" the charge. Hold the electrophorus plate by its handle and discharge it by briefly touching it. Carefully lower the electrophorus plate onto the foam while watching the behavior of the pith ball. Bring the discharged aluminum plate near the pith ball as the electrophorus plate sits on the foam. Observe the pith ball as you do this. Was there a movement of charge?

7.10 When electric charges move from one place to another, we say that there is an electric current. Was there an electric current between the plates? Does the behavior of the pith ball tell you anything about how fast the charge is transferred? Or, about the size of the current that is flowing? Record your findings.

7.11 Once again take both plates away from the foam and discharge them with your finger. Lower the electrophorus plate onto the foam. Watch the behavior of the pith ball. Bring the aluminum plate near the pith ball as before while the electrophorus plate is sitting on the foam. Move it closer until the pith ball ceases to move. Remove the aluminum plate but do not set it down or touch it. Next lift the electrophorus while watching the behavior of the pith ball. What happens? Does a current flow? Record your findings.

7.12 When nothing more is happening, test the plates for charge by touching each of them in turn to the leaf electroscope. Also test the foam for charge. Record your findings.

7.13 Also record how you explain the behavior of the electrophorus.



## SECTION 8 THE NEON BULB AND A CONVENTION FOR CHARGE

8.1 A NE-2 neon bulb has been fastened to a piece of plexiglas with two leads extending from the plexiglas. To use the neon bulb, touch the second lead with your hand while touching the other lead to a charged object while watching the electrodes.

8.2 Refresh the charge on the foam pad. Hold the electrophorus plate by its handle and discharge it. Lower it onto the foam and touch the electrophorus plate with a lead from the neon bulb while holding onto the other. Do you see a flash? Did it flash from the electrode coming from the plate or your hand? Repeat the experiment until you are sure. Now turn bulb around and repeat the experiment holding the bulb by the other lead. Does the flash occur at the plate or hand electrode? Record your findings.

8.3 Now try the following sequence. Refresh the charge on the foam. Discharge the electrophorus plate. Lower the plate onto the foam and touch the plate with one lead of the neon bulb while holding the other lead. Watch for the flash. Remove the bulb, and then lift the electrophorus plate from the pad. Now touch the electrophorus plate again with the lead from the neon bulb. Did the same electrode flash as before? Repeat the experiment until you are sure of your results. Record your findings.

8.4 When one lead of the neon bulb is held in the hand and the other end touches a charged object, it is the cathode (more-negative) terminal that glows. Thus the lead associated with the glowing terminal identifies the more NEGATIVE surface. This glowing terminal will also identify the direction of electron flow (from the glowing to the non-glowing terminal) as electrons always move away from the more negative and toward the more positive object. Of course, if positive charges move, they will move in the opposite direction. This definition turns out to be in complete agreement with Benjamin Franklin's arbitrary decision to call the charge on a glass rod rubbed with silk - POSITIVE charge. We can now use the neon bulb to determine the charge on any object.

8.5 Refresh the charge on the foam and see if you can determine its charge. Whether you will be able to see a flash depends on how highly charged the foam surface is. Record your findings.

8.6 Next lower an uncharged electrophorus plate onto the foam. Touch it briefly with your finger and then remove the electrophorus plate. Determine the charge of the plate. Is it the same as that of the foam? You have now seen how one can use the neon bulb to indicate the type of charge and the direction that charges move.

8.7 You are now ready to make a final investigation of the behavior of the electrophorus. To do this, take a bit of masking tape and tape one electrode of the neon bulb to the rim of the second pie plate so that the bulb and the other lead stick out horizontally perpendicular to the rim. You may now use this bulb to investigate the direction of charge transfer in the charging and discharging of the pie plates.

8.8 Refresh the charge on the foam pad, and once again discharge the pie plates. Lower the electrophorus plate onto the foam. Watch carefully while you bring the second pie plate near the first so that the untaped lead of the neon bulb touches the electrophorus plate while the electrophorus plate is sitting on the foam. Observe which electrode flashes. Move the second plate away, lift the electrophorus plate, and while they are in the air, bring the plates together so that the untaped lead of the neon bulb again touches the electrophorus plate. Observe which electrode flashes. When did currents flow? In which direction did they flow? What was the state of charge of the electrophorus plate at each stage of the experiment? Of the second plate at each stage?

8.9 At this point you have investigated the effect of distance on the electrical interaction, the difference between the behavior of charged conductors and insulators, and accounted for three charged states of objects with two kinds of charge. Use the features of this model to account for the behavior of the electrophorus plate and the second plate. Consider especially the type of charge you found on each plate, the direction of the charge flows and the changes that occur in the charged state of the plates as you carried out the procedure of charging and discharging the electrophorus. Make a diagram that shows the sequence of charging and discharging and the charge state of the foam, the electrophorus plate and the second plate at each stage. Record your findings and share with your instructor.

8.10 At the beginning of these activities, we used the attraction between neutral bits of paper and a charged object as part of our initial test for an object being charged. Bring a charged plastic straw near bits of paper. Also bring it near some foil bits. Bring it near the uncharged pith ball electroscope. Bring it near the leaf electroscope. Record you findings and specific explanation for each investigation.



8.8 Refresh the charge on the foam pad, and once again discharge the pie plates. Lower the electrophorus plate onto the foam. Watch carefully while you bring the second pie plate near the first so that the untaped lead of the neon bulb touches the electrophorus plate while the electrophorus plate is sitting on the foam. Observe which electrode flashes. Move the second plate away, lift the electrophorus plate, and while they are in the air, bring the plates together so that the untaped lead of the neon bulb again touches the electrophorus plate. Observe which electrode flashes. When did currents flow? In which direction did they flow? What was the state of charge of the electrophorus plate at each stage of the experiment? Of the second plate at each stage?

8.9 At this point you have investigated the effect of distance on the electrical interaction, the difference between the behavior of charged conductors and insulators, and accounted for three charged states of objects with two kinds of charge. Use the features of this model to account for the behavior of the electrophorus plate and the second plate. Consider especially the type of charge you found on each plate, the direction of the charge flows and the changes that occur in the charged state of the plates as you carried out the procedure of charging and discharging the electrophorus. Make a diagram that shows the sequence of charging and discharging and the charge state of the foam, the electrophorus plate and the second plate at each stage. Record your findings and share with your instructor.

8.10 At the beginning of these activities, we used the attraction between neutral bits of paper and a charged object as part of our initial test for an object being charged. Bring a charged plastic straw near bits of paper. Also bring it near some foil bits. Bring it near the uncharged pith ball electroscope. Bring it near the leaf electroscope. Record you findings and specific explanation for each investigation.

Materials for Electrostatic Interactions

1. Pieces of paper
2. Plastic Drinking Straw - Regular (4)
3. Plastic Drinking Straw - Flexible (2)
4. Fur
5. Wool
6. Styrofoam Coffee Cup (4)
7. Scotch Magic Tape
8. Block of Wood
9. Sheet of paper
10. Styrofoam Pad
11. Styrofoam Picnic Plate (2)
12. Aluminum Covered Straw (2)
13. Duct Tape
14. Large Paper Clip (1)
15. Aluminum Foil
16. Aluminum Pie Pan (2)

SHEET # _____ ELECTRICAL CHARGE Name _____

1. Use thread to hang the vinyl strip about 25 cm from a ring stand. Rub one end of the strip with a piece of wool. Rub the end of another strip of vinyl with wool and then slowly bring the rubbed ends of the two strips together. What happens?

2. When you rubbed the strips with the cloth, you gave them a "charge" (i.e., the ability to repel similar things). Since the two strips are made of the same material and were rubbed with the same cloth, do you think both of the strips had the same or different "charges?" Why?

3. Hang a strip of acetate as you did in step 1. Rub one end of the strip with cotton; then rub the end of another strip of acetate with cotton and again slowly bring the rubbed ends together. What happens?

4. Again, do the strips appear to have same of different charges?

5. Now try a combination of rubbed vinyl and rubbed acetate and observe and record what happens.

6. How do object having the same or "like charges" affect each other?

7. How do object having different or "unlike charges" affect each other?

8. Summarize findings into a general statement or rule.

9. Use either a charged vinyl or acetate strip (experiment and find which works best) and bring it slowly up to two uncharged (you have to "ground" them to be sure -- ask how to do it if you don't know) pith balls that you have suspended close to each other. What is the observed reaction?

10. Find some way to make the pith balls stay apart. Do they stay apart after you changed and used a different kind of strip? See if you can charge the pith balls seperately i.e. one "vinyl" and one "acetate", both "vinyl", or both "acetate". Generalize your findings.

Part 2 Electroscope

1. Using a charged vinyl strip, describe the effect on the electroscope as the strip is place close to the metal disk on top of the electroscope. What does the distance of the strip have to do with the effect?

FROM THE DISK

2. Take the charged strip and place it very near (don't actually touch) the disk. Listen closely as the strip comes very close to the disk. What do you hear? What happens to the electroscope?

3. Repeat the process in part 2 many times to get a maximum effect. Describe what happens. Is there a limit to the effect?

4. Touch your finger to the metal disk. Now, bring the charged strip very close and transfer the charge to the disk. Now touch the disk again. What happens? How is this different than part 3? What causes the difference?

Static Electricity Questions -1-

1.1 Does regular plastic straw (not rubbed) attract bits of paper?

1.2 Does plastic straw rubbed with fur or wool attract bits of paper?

1.3 What if plastic straw is near but not touching?

1.4 What will a foam cup rubbed with wool do to bits of paper?

1.6 Based on this information, are the bits of paper charged?

2.2 Does either side of scotch magic tape attract bits of paper?

2.3 Does the tape meet the definition of being charged?

2.4 Is there an interaction between the rolled paper and the tape?

2.5 Does the paper tube meet the definition of being charged?

2.6 How does one piece of tape affect the other?
Does the sticky or non-sticky side make a difference?

2.7 What does a 3rd piece of tape do when brought near the other two?

2.8. What is your present definition of electric charge?

2.10 How do the 2 pieces of tape stuck together affect tape electroscope?
How does it affect bits of paper?
Is the combination tape charged?

2.11 How does touching the non-sticky side affect the results in 2.10?

2.12 How does one of the pieces affect the other after being pulled apart?

2.13 How does each affect the tape electroscope?

2.14 Are you "positive" that both tape 'A' and 'B' are charged?

2.15 What experiment can you devise to give convincing evidence?

2.16 What is your definition of charge to date?

2.17 How reliable do you feel the tests you have done are?
Would either test be sufficient?

2.18 What objects did you test against tapes 'A' and 'B' electroscopes?
Results?

2.22 How do two tape "A"'s react with another? Two tape "B"'s?

2.23 What can you say about the charges on each tape 'A'? each tape 'B'?
What can you say about tape 'A' compared to tape 'B'?

2.24 How does one bit of paper react with another?

2.25 Could the paper have a third kind of charge?

Static Electricity Questions -2-

2.26 Are you sure that the paper has no charge?

2.27 If only 2 kinds of charge, how can you explain behavior of tape?
paper?

2.28 Does the foam and the fur or wool have a charge like tape 'A'? 'B'?

3.3 How does the rubbed straw affect the pith ball electroscope?
How can you use the pith ball to test for charged objects?

3.5. How does a rubbed straw affect the foil electroscope?

4.3 Does bringing the electrophorus plate near the foam give it a charge?

4.4 What happens when you touch the aluminum plate when it is on the foam?

4.5 What interaction (if any) exists when you lift the aluminum plate?

4.6 Was the electrophorus plate charged? How do you know?

4.7 How does the electrophorus plate affect the pith ball electroscope?
How does the charge on the ball compare to that on the plate?

4.8 How does the foam affect the charged pith ball?

4.10 What investigation can you perform to show the sign of charge on the pith ball and foam?

4.11 How does the plastic straw affect the pith ball? aluminumized straw?

4.12 How does replacing the pith ball with the foil electroscope affect the results?

4.13 Does touching the plastic straw affect the electrophorus plate?

4.14 Does touching the aluminumized straw affect the electrophorus plate?

4.16 How can you check if other objects are insulators or conductors?

4.17 How do you think the electrophorus work?

5.8 Explain how the electroscope becomes charged.
What charge is on it? On the foam plate?

6.3 What happens to the electrostatic force as the distance between charged objects increases?

7.13 What conclusions can you write after completing section 7?

8.2 When touching the foam, which electrode flashed?

8.3 When touching the electrophorus, which electrode flashed?

8.5 What is the charge on the foam?

8.6 What is the charge on the electrophorus?

# CHAPTER 10 WRITTEN EXERCISE

1. A round balloon is made conducting by a coat of aluminum paint or graphite and is placed on top of an electroscope. The balloon and electroscope are given a charge which causes the indicator to deflect from its equilibrium position. What will happen to the indicator if the air is allowed to escape rapidly from the balloon? (No charges escape from the balloon and electroscope as the air escapes.)

2. An electroscope has a positive charge. Explain how this charged electroscope may be used to determine the electrostatic condition of various objects.

3. If you rubbed a metal rod with a piece of wool, what charge would you find on the wool? On the metal rod? Explain.

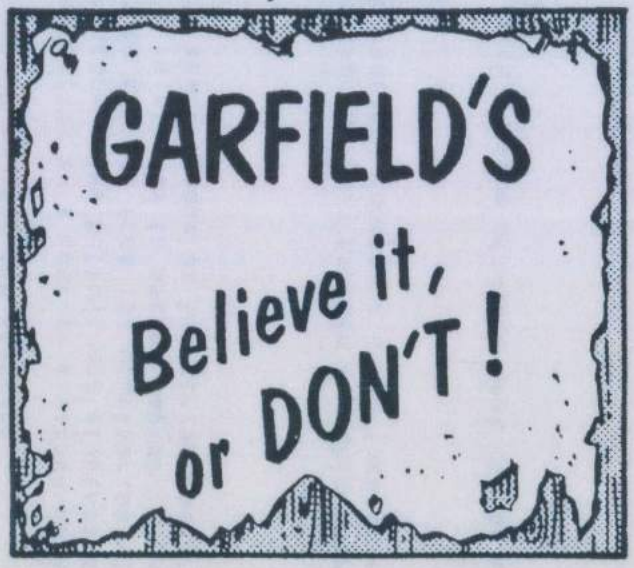
4. Draw a diagram showing a graphite covered sphere suspended by an insulating thread with an acetate rod nearby. Explain the attraction of the pith ball to the acetate rod. What will happen if the pith ball touches the acetate rod? Why? Explain fully.

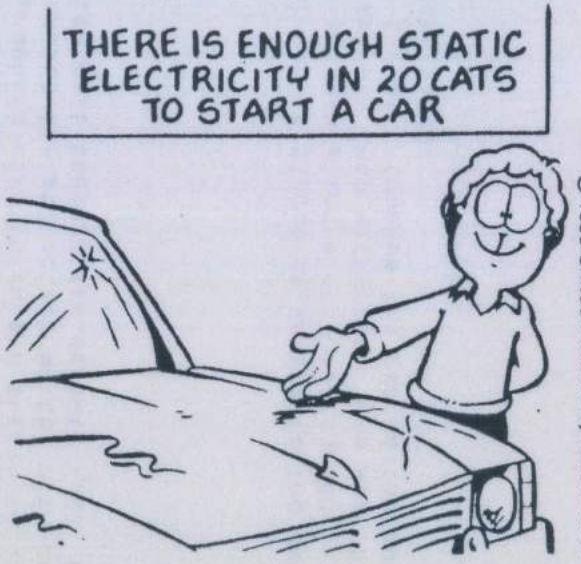
5. Suppose an uncharged metal can is placed on an insulating support, and a charged graphite coated sphere on an insulating string is lowered into the can, allowed to touch the inside of the can, and then withdrawn. How much charge would you expect left on the ball? How much if the ball touches the can on the outside instead of the inside? Explain why in both cases.

6. Explain each of the following observations:
   a. walking across a carpet is sometimes followed by a shock.
   b. gasoline trucks usually have chains that drag on the highway.
   c. violent motion of the air or raindrops is often followed by lightning.

7. Two graphite coated spheres mounted on insulating stands are initially in contact. When a vinyl rod that has been rubbed with wool is held close to, but not touching the spheres, the one farthest from the rod is removed. The rod is then removed. What is the charge on each sphere. Explain.

**GARFIELD**/By Jim Davis

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# Chapter 18 Test

1. A round balloon is made conducting by a coat of aluminum paint or graphite and is placed on top of an electroscope. The balloon and electroscope are given a charge which causes the indicator to deflect from its equilibrium position. What will happen to the indicator if the air is allowed to escape rapidly from the balloon? (No charges escape from the balloon and electroscope as the air escapes.)

The indicator will move out further. There will now be a greater charge density.

2. An electroscope has a positive charge. Explain how this charged electroscope may be used to determine the electrostatic condition of various objects.

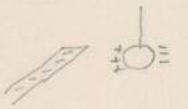
if object - negative - bring near - pointer move inward
" " positive " " " further out
" " neutral " " " slightly inward

3. If you rubbed a metal rod with a piece of wool, what charge would you find on the wool? On the metal rod?

wool → guess - positive

metal → none

4. Draw a diagram showing a metal covered pith ball suspended by a silk thread with a charged vinyl rod nearby. Explain the attraction of the pith ball to the vinyl rod. What will happen if the pith ball touches the vinyl rod? Why?



Attraction due to induced effect of (-) vinyl rod on neutral ball.
Upon touching - some negative charges transfer from rod to sphere, making sphere negative (too).

5. Suppose an uncharged metal can is placed on an insulating support, and a charged metal ball is lowered on silk thread into the can, allowed to touch the inside of the can, and then withdrawn. How much charge would you expect left on the ball? Why? How much if the ball touches the can on the outside instead of inside? Why?

Ball inside. No charge ever left on the Ball. - Net charge inside can always = zero. Shielding

Some charge left on ball. Geometry tells how much.

6. Explain each of the following observations: (a) walking across a carpet is sometimes followed by a shock when the hand touches a metal object; (b) gasoline trucks usually have chains that drag on the roadway, and cars are brushed by metal strips upon approaching a toll gate; (c) violent motion of air or raindrops is often followed by lightning.

a. charge separated as walk across rug - transferred to metal object (which is neutral)
b. want gas truck, car at same potential as roadway - rubber tires build up charge.
c. air movement creates charge separation

7. Two metal spheres mounted on insulating stands are initially in contact. While a vinyl rod that has been rubbed with wool is held close to, but not touching, the spheres, the one farthest from the rod is removed without touching it; then the rod is removed. Draw sketches to represent the steps and the charge distributions during the process.

35 possible

Change

TEST CHAPTER 10 Name Key

1. The leaves (dial) of a positively charged electroscope diverge more when a charged object is brought near the knob of the electroscope. The object must be:
   a. a conductor
   b. an insulator
   (2) c. positively charged
   d. negatively charged
   e. neutral

Jones

Kovar

Kontra

C

Explain in words and with or without diagrams how & why you know.

DIAL WILL GO OUT AS MORE "-"S ARE BROUGHT NEAR THE "KNOB"

(5)

2. You are given a plastic ruler which has been ~~charged electrically~~ rubbed by ~~rubbing it with~~ a cloth.

Consider the following procedures:

I. Bring the ruler toward a positively charged pith ball.
II. Bring the ruler toward a negatively charged pith ball.
III. Bring the ruler toward a neutral pith ball.

Which of the above procedure(s) ~~can be used~~ must be used to determine the sign of the charge on the ruler?
   a. I only
   b. II only
   (2) c. III only
   d. I and II only
   e. I, II and III

D

Explain how the chosen procedure(s) can tell you the sign of the ruler.

(5) allowable answer "d"

3. Two neutral metal spheres, L and M are in contact. A negatively charged rod is brought close to but not touching L. (M is further from the rod than L.) The spheres are then separated while the negative rod is kept near sphere L.

After the spheres are separated and the charged rod is removed:

L M
+ -

E

   a. both spheres will be neutral
   (2) b. both spheres will be positively charged
   c. both spheres will be negatively charged
   d. sphere L will be (-) charged and sphere M will be (+) charged
   e. sphere L will be (+) charged and sphere M will be (-) charged

Chapter 19
"Electrostatics"

Modern Physics
Name Theriault

1. Describe, in terms of electrons, what accounts for negative and positive charges in materials that are said to possess "static electricity":

2. a) Describe the process of charging an object by conduction:

b) Describe the process of charging an object by induction:

3. Describe the difference between conductors and insulators, and list 3 examples of each:

4. a) A small sphere is given a charge of plus 30 microcoulombs a second sphere of equal diameter located 10 cm away is given a ch of negative microcoulombs. Is this force attraction or repulsion?
20 Compute the force of attraction between the charges:

K is $9 \times 10^9 \frac{\text{nt-m}^2}{\text{coul}^2}$ Ans: _____

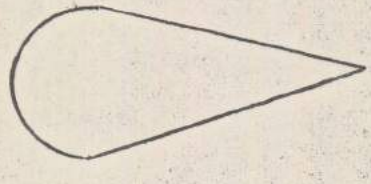
b) The 2 spheres are then allowed to touch and are again spac 10 cm apart. What force exists between them?
Is this force attraction or repulsion? _____
Ans: _____

5. A charge of .75 microcoulombs is placed in an electric field where the field intensity is $4.5 \times 10^5$ nt/coul. What is the magnitude of the force acting on the charge?

Ans: T

6. Assume you have been driving a car, and some high tension wires snapped and fell on the car, describe why it would be safe to touch metal objects inside the car, yet you would probably lose your life if you attempted to step outside the car:

7. Sketch the "equipotential lines" around the object below, and also the lines of force from it (the electric field). Identify which is which.



8. A capacitor of 25 microfarads is touched to a 90 volt battery. How much charge is stored on the plates of the capacitor?

Ans: _____

9. Another capacitor, rated at .33 microfarads, is desired to have 20 microcoulombs of charge stored in it. What voltage would do this?

Ans: _____

10. Sketch 3 capacitors, of 15, 30 & 45 microfarad rating connected in parallel

Compute the net capacitance of this arrangement:

Ans: _____

11. Three capacitors are connected in series: a ~~5, 10, 15~~ micro-farad. Sketch the wiring of this combination:

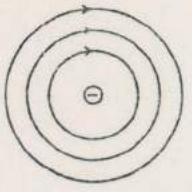
Compute the net capacitance of this arrangement:

Ans: _____

12. Describe the analogy between voltage (or "potential difference") and its counterpart with gravity:

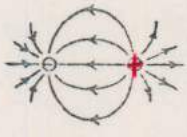
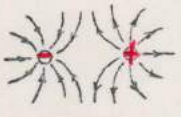
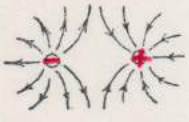
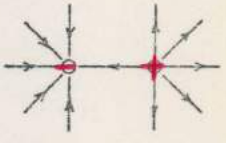
8. Which of the following diagrams most accurately represents the electric force field about a small isolated negatively chaged sphere

(2) 8. B

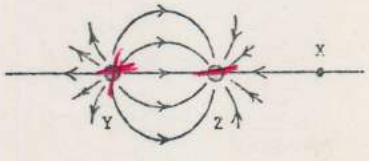
(A) (B) (C) (D)  (E)

9. Which of the following diagrams most correctly diecribes the electric field in the vicinity of two small isolated oppositely charged spheres?

(2) 9. A

(A)  (B) (C)  (D)  (E) 

10. The diagram shows the electric field lines in a region of space containing two small charged spheres, Y and Z. Which of the following statements is true?




(2) 10. D a. The charge of Y is negative and the charge on Z is positive.
b. The strength of the electric field is the same everywhere
c. The electric field is strongest midway between Y and Z.
d. A small negatively-charged object placed on X would tend to move toward the right.
e. Both charged spheres Y and Z carry the same type of charge.

Explain why you chose the answer that you did.

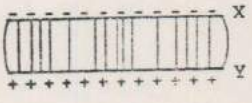
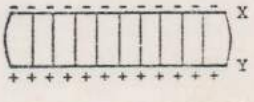
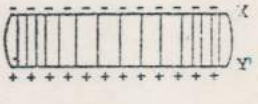
(4) Y must be "+" Z must be "−"

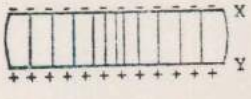
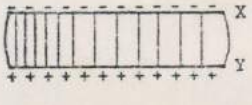
+ at X moves ←

∴ − (→)

11. Which of the following diagrams most accurately describes the electric field in the region between two oppositely charged plates, X and Y?

(2) 11. C Redo

(A)  (C)  (E) 

(B)  (D) 

(12)

1. When two small charged spheres are separated by 2.0 m, the electrical force of attraction between them is 6.0 N. If the charge on each sphere is doubled and the separation is reduced to 1.0 m, the force of attraction will now be

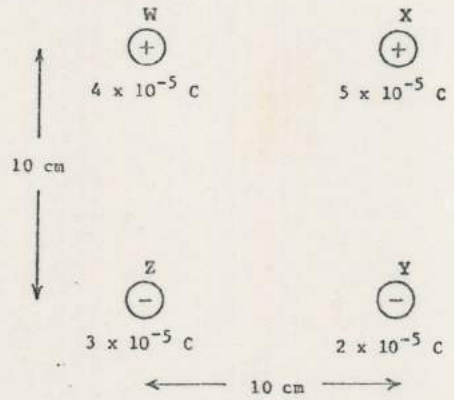
(2) a. 6 N b. 16 N c. 24 N d. 48 N ● 96 N

(4) Explain how you arrived at your answer.

| ORIGINAL | NEW |
|---|---|
| $F = 6\ N$ | $F = ?$ |
| $r = 2\ M$ | $r = 1\ M$ |
| $Q = Q$ | $Q = 2Q$ |

ORIGINAL $F = \frac{KQQ}{r^2}$ NEW $F = \frac{K\,2q\,2Q}{(\frac{1}{2}r)^2} = \frac{16\,KqQ}{r^2}$

2. Four charged spheres, W, X, Y and Z are arranged as illustrated in the diagram at the right. The sign and magnitude of each charge is shown.




Which two spheres exert the smallest force on each other?

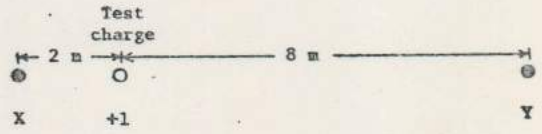
a. W and X b. Z and Y
● W and Y d. X and Z
e. W and Z

What is the magnitude of this force?

(4) $F = \frac{KqQ}{r^2} = 9\times10^9\ \frac{N\,M^2}{C^2} \times \frac{4\times10^{-5}\,C \times 2\times10^{-5}\,C}{14.1\,cm \times 14.1\,cm} \times \frac{10^2\,cm}{1\,M} \times \frac{10^2\,cm}{1\,M}$

$= 3.62\times10^2\ N$

3. Two small spheres, having positive charges of X units and Y units respectively, are located 10 m apart. A test charge of +1 unit is located between them as illustrated. The net electrical force on the test charge is zero. The ratio of X:Y is



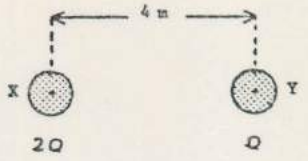

$F_{Y\text{ on }O} = F_{X\text{ on }O}$

(2) a. 1:1 b. 4:1 c. 1:4
d. 16:1 ● 1:16

Explain how you arrived at your answer.

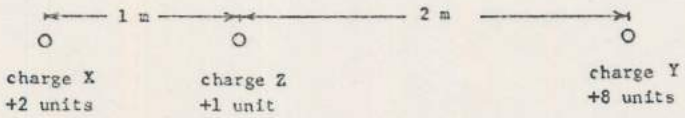
$\frac{KQ_X Q_q}{(2M)^2} = \frac{KQ_Y Q_q}{(8M)^2}$ $\frac{Q_X}{Q_Y} = \frac{(2M)^2}{(8M)^2} = \frac{4}{64} = \frac{1}{16}$

4. Two spheres, X and Y, are 4 m apart. A charge of 2Q is distributed over sphere X and a charge of Q is distributed over sphere Y. The magnitude of the electrostatic force on X is




a. 4 times that on Y
b. 2 times that on Y
(2) c. the same as that on Y
d. one-half that on Y
e. one-quarter that on Y

5. The charges X, Y and Z are arranged as shown below.




The ratio of the magnitude of the electrical force of X on Z to the electrical force of Y on Z is

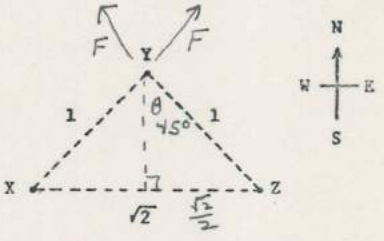
(2) a. 1:1 b. 1:4 c. 2:1 d. 16:1 e. 4:1

Explain how you arrived at the answer.

(4)

$$\frac{F_{x\,on\,z} = \frac{\cancel{k}\,2\cancel{Q}\cancel{Q}}{(1m)^2}}{F_{y\,on\,z} = \frac{\cancel{k}\,8\cancel{Q}\cancel{Q}}{(2m)^2}} = \frac{2}{8}\,\frac{4}{1} = \frac{1}{1}$$

6. Three identical point charges, X, Y and Z are located at the vertices of a triangle as shown. If the force exerted by X on Y is 'F', and the force exerted by Z on Y is also F, what is the resultant force on Y?

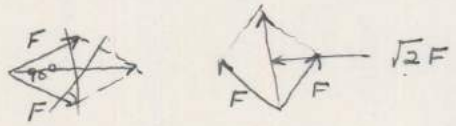



(2) a. 2F {S} b. 2F {N} c. $\sqrt{3}$F {N}
d. $\sqrt{2}$F {S} e. $\sqrt{2}$F {N}

$\sin\theta = \frac{\sqrt{2}}{2} = .707$

Show how you arrived at your answer.

(4)



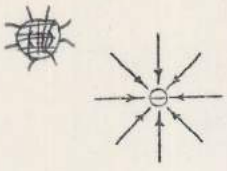

7. The electric field at a point near a charge Q represents

(2) a. the energy possessed by a unit positive charge
b. the force acting on a unit positive charge
c. the energy possessed by a unit negative charge
d. the force acting on a unit negative charge
e. the amount of work which could be done by a unit positive charge.

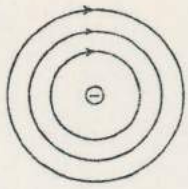
8. Which of the following diagrams most accurately represents the electric force field about a small isolated negatively chaged sphere

(2)

(A)



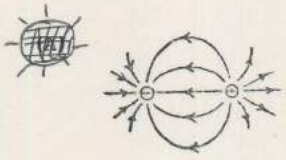
(C)

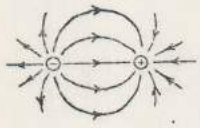
(D) 

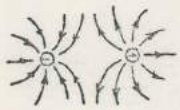
(E)

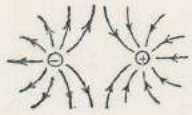
9. Which of the following diagrams most correctly describes the electric field in the vicinity of two small isolated oppositely charged spheres?

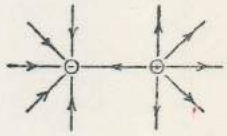
(2)



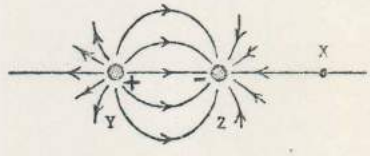
(B) 

(C) 

(D) 

(E) 

10. The diagram shows the electric field lines in a region of space containing two small charged spheres, Y and Z. Which of the following statements is true?




a. The charge of Y is negative and the charge on Z is positive.
b. The strength of the electric field is the same everywhere
c. The electric field is strongest midway between Y and Z.
(2) d. A small negatively-charged object placed on X would tend to move toward the right.
e. Both charged spheres X Y and Z carry the same type of charge.

Explain why you chose the answer that you did.

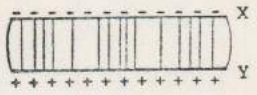
(4) Y MUST BE '+' Z MUST BE '−' ∴ ~~d.~~ ~~e.~~

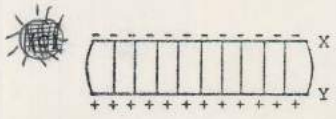
'+' AT X WILL MOVE ←

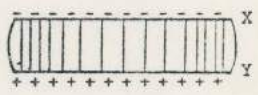
∴ '−' WILL MOVE →

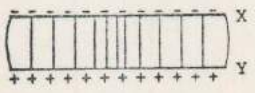
11. Which of the following diagrams most accurately describes the electric field in the region between two oppositely charged plates, X and Y?

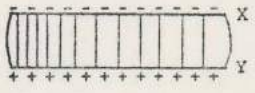
(2)

(A) 



(E) 

(B) 

(D) 

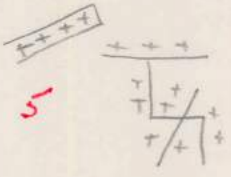
(12)

Name _____ Circle Correct Answer redo

TEST CHAPTER 10

1. The leaves of a positively charged electroscope diverge more when a charged object is brought near the knob of the electroscope. The object must be:
   a. a conductor
   b. an insulator
2 (c.) positively charged
   d. negatively charged
   e. neutral

   Explain in words and with or without diagrams how you know.



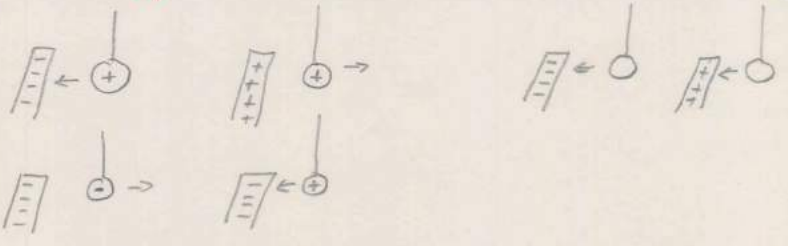
5 When '+' rod is brought near, negative charges in the electroscope are brought near the rod leaving more '+' charges on dial causing it to diverge more.

2. You are given a plastic ruler which has been ~~charged electrically~~ rubbed by ~~rubbing it with~~ a cloth.

   Consider the following procedures:

   I. Bring the ruler toward a positively charged pith ball.
2 II. Bring the ruler toward a negatively charged pith ball.
   III. Bring the ruler toward a neutral pith ball.

   Which of the above procedure~~(s)~~ ~~can~~ Must be used to determine the sign of the charge on the ruler?



   a. I only
5 b. II only
   c. III only
   (d.) I and II only
   e. I, II and III

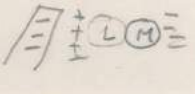
   Explain how the chosen procedure(s) can tell you the sign of the ruler.

   Attraction to ⊕ or ⊖ pith ball indicates opposite sign.
   Repulsion from ⊕ or ⊖ " " " like sign.

3. Two neutral metal spheres, L and M are in contact. A negatively charged rod is brought close to but not touching L. (M is further from the rod than L.) The spheres are then separated while the negative rod is kept near sphere L.

   After the spheres are separated and the charged rod is removed:

2 a. both spheres will be neutral
   b. both spheres will be positively charged



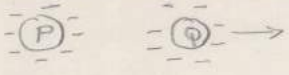
c. both spheres will be negatively charged
d. sphere L will be (−) charged and sphere M will be (+) charged
(e.) sphere L will be (+) charged and sphere M will be (−) charged

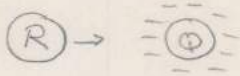
Explain fully why your chosen outcome is correct.

Negative charge on 2 spheres are repelled to side away from (−) rod.

5

4. Object P is negatively charged. An insulated conductor Q experiences a force of electrostatic repulsion when brought near P and a force of electrostatic attraction when brought near a third object R The charge on R




P is −
Q is −

+ or neutral

a. can only be positive
b. can only be negative
c. can only be neutral
(d.) may be either positive or neutral
e. may be either positive or negative

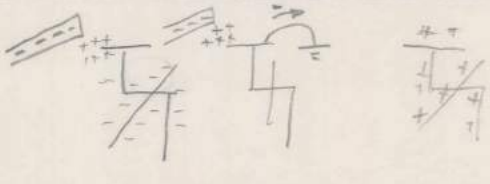
Explain fully the rationale for your answer.

Q must be negative as P repels it.
Q attracts R if R is + or neutral

5. An electroscope is charged by induction with a negatively charged rod. Consider the following statements.

yes I. The electroscope becomes positively charged.
~~II.~~ The electroscope becomes negatively charged.
yes III. Some negative charge moves from the electroscope into the ground.
IV. Some positive charge moves from the ground into the electroscope.

Which two of the above statements are correct?



(a.) I and III
b. I and IV
c. II and III
d. II and IV
e. III and IV

Add Explain!

46 Make Answer Key at Top

TEST CHAPTER 11 page -1- Name _____

1. When two small charged spheres are separated by 2.0 m, the electrical force of attraction between them is 6.0 N. If the charge on each sphere is doubled and the separation is reduced to 1.0 m, the force of attraction will now be

(2) 1. E a. 6 N b. 16 N c. 24 N d. 48 N e. 96 N

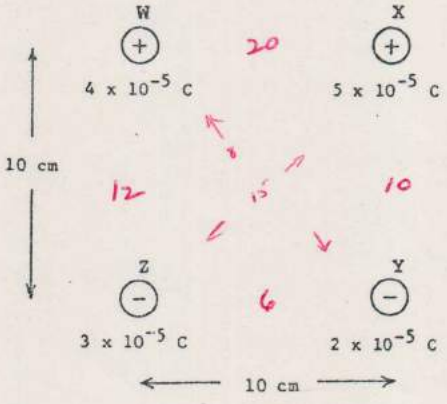
Explain how you arrived at your answer.

(4) ORIGINAL: F = 6 N, r = 2 M, Both Q = Q
NEW: F = ?, r = 1 M, Both Q = 2Q

$F = K\frac{QQ}{R^2}$ $\quad \frac{K \times 2Q \times 2Q}{\frac{1}{4}R^2} = \frac{16KQQ}{R^2}$

16 × 6 = 96

2. Four charged spheres, W, X, Y and Z are arranged as illustrated in the diagram at the right. The sign and magnitude of each charge is shown.




Which two spheres exert the smallest force on each other?

(2) 2. B C a. W and X b. Z and Y
c. W and Y d. X and Z
e. W and Z

What is the magnitude of this force?

(4) $F = K\frac{Qq}{R^2} = 9 \times 10^9 \frac{N\,M^2}{C^2} \times \frac{4 \times 10^{-5} C \times 2 \times 10^{-5} C}{14.1\,cm \times 14.1\,cm} \times \frac{10^2\,cm}{1\,M} \times \frac{10^2\,cm}{1\,M}$

$F = 3.62 \times 10^2 N$

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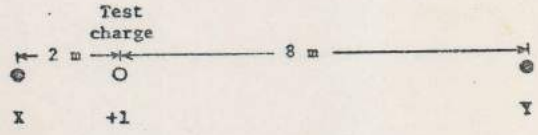
3. Two small spheres, having positive charges of X units and Y units respectively, are located 10 m apart. A test charge of +1 unit is located between them as illustrated. The net electrical force on the test charge is zero. The ratio of X:Y is




(2) 3. E a. 1:1 b. 4:1 c. 1:4 d. 16:1 e. 1:16

Explain how you arrived at your answer.

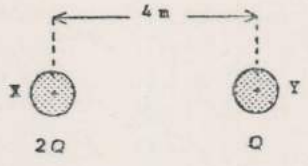
(4) $\frac{K Q_X Q_0}{(2M)^2} = \frac{K Q_Y Q_0}{(8M)^2}$ $\quad \frac{Q_X}{Q_Y} = \frac{(2M)^2}{(8M)^2} = \frac{4}{64} = \frac{1}{16}$

2nd 16/1

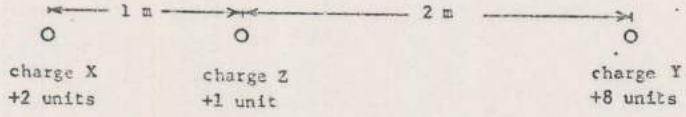
18

4. Two spheres, X and Y, are 4 m apart. A charge of 2Q is distributed over sphere X and a charge of Q is distributed over sphere Y. The magnitude of the electrostatic force on X is

(2) 4. C a. 4 times that on Y
b. 2 times that on Y
c. the same as that on Y
d. one-half that on Y
e. one-quarter that on Y




5. The charges X, Y and Z are arranged as shown below.



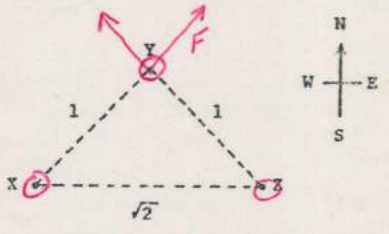

The ratio of the magnitude of the electrical force of X on Z to the electrical force of Y on Z is

(2) 5. A a. 1:1 b. 1:4 c. 2:1 d. 16:1 e. 4:1

Explain how you arrived at the answer.

(4) $\frac{F_{Y\,on\,Z}}{F_{T\,on\,Z}} = \frac{\frac{k\,2Q}{(1m)^2}}{\frac{k\,8Q}{(2m)^2}} = \frac{2}{8}\,\frac{4}{1} = \frac{1}{1}$

6. Three identical point charges, X, Y and Z are located at the vertices of a triangle as shown. If the force exerted by X on Y is 'F', and the force exerted by Z on Y is also F, what is the resultant force on Y?




(2) 6. E a. 2F {S} (south) b. 2F {N} (north) c. $\sqrt{3}F$ {N} d. $\sqrt{2}F$ {S} e. $\sqrt{2}F$ {N}

Show how you arrived at your answer.

(4)

B C E

7. The electric field at a point near a charge Q represents

a. the energy possessed by a unit positive charge
b. the force acting on a unit positive charge
c. the energy possessed by a unit negative charge
d. the force acting on a unit negative charge
e. the amount of work which could be done by a unit positive charge.

(2) 7. B

(16)