Electric Charge

Positive and negative electric charge, electroscope, phenomenon of electrical induction

January 2014

Print *Your Name*

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Print *Your Partners' Names*

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Instructions

Before the lab, read all sections of the *Introduction*, and answer the Pre-Lab questions on the last page of this handout. Hand in your answers as you enter the general physics lab.

You will return this handout to the instructor at the end of the lab period.

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0. Introduction

We deal with electricity constantly in every aspect of life. Electric forces are holding our material world together by binding electrons and nuclei into atoms, and atoms into molecules. Of all the fundamental forces in nature, the interactions between electric charges are the best understood theoretically. This is a result of more than 2500 years of observation and study. It started with the discovery by ancient Greeks that some substances can attract other objects after having been rubbed.

In this laboratory session, you will see how it is we know that there are two different kinds of electric charge, and you will observe the phenomena of electric polarization and electric induction.

0.1 *Basic electrical phenomena*

The ancient Greeks discovered that resinous substances such as amber, after being rubbed with wool or fur, would attract various objects. The name given to the unknown cause of this phenomenon was "electricity," which was derived from the Greek word for amber, "electron." Later it was found that any substance when rubbed with another substance becomes electrified, that is, electrically charged. Further investigation revealed the existence of two different types of electricity that appeared to act as opposites. Two bodies with the same type of electricity repelled each other, and two bodies charged with different types of electricity attracted each other. We see this as an electrical law, that *like charges repel* each other and *unlike charges attract* each other.

Originally, a charged glass rod and a charged rubber rod were used as standards of electrical charge. The charge carried by the *glass* rod that had been rubbed with silk was *arbitrarily* called a *positive* charge, and the charge on the *rubber* rod that had been rubbed with wool or fur was called a *negative* charge. Modern knowledge of the construction of the atom has shown that the electron is the basic unit of negative charge, and the proton is the equivalent basic unit of positive charge.

Originally, both positive and negative charges were thought to move much like fluids, and the sign conventions were set up for electricity on the basis of the movement of positive charge. The proton (a positive charge), however, is part of the small compact group called the nucleus which lies at the center of an atom. The proton is held very tightly in the nucleus and is not free to move. The electrons (negative charges) move around the nuclei at a distance of about 10,000 times the diameter of the nucleus and are arranged in groups or shells on the basis of their distance from the nucleus. The electrons of the outermost group are more loosely held, and in many substances the outermost electrons are relatively free to move about from place to place and from atom to atom.

The density or number of such free electrons and their mobility determine the electrical conductivity of the substance. The essential difference between a conductor and a nonconductor lies in the relative freedom of motion of the electrons. Since the protons are very tightly held, while the electrons are more free to move, most common electrical phenomenon are explained in terms of the movement of electrons. A body that has acquired an excess of electrons over protons is negatively charged, and one that has a deficiency of negative charges is positively charged.

Any excess or deficiency of electrons in a conductor resides entirely on the outer surface of the conductor. That is because any unbalanced charged inside the conductor would force electrons to move until equilibrium is reached by distributing excess charges on the exterior surface in a way such that the forces from all these charges cancel to zero inside the conductor and can be felt only outside the conducting body.

When a glass rod is rubbed with silk, electrons escape from the glass rod and become attached to the silk, leaving the glass positively charged and the silk negatively charged. An ebonite or rubber rod, when rubbed with silk, flannel, or fur is left negatively charged. Any two different materials may be electrified in this manner, simply by frictional contact. The reason lies in the relative ease or difficulty with which the atoms of each substance lose electrons, a property depending on the structural arrangement of the atoms.

Atoms of the metallic group of elements lose electrons so easily that vast numbers of these so-called "free" electrons are always present within the body of the material, ready to be acted upon by any electric forces that may be applied. For example, if a positively charged body (having a deficiency of electrons) is touched to a piece of copper, the electrification appears to spread instantly throughout the copper, making the copper positively charged. Evidently, the positively charged body draws some of the free electrons from the copper in order to reduce its electron deficiency, and this process leaves the copper positively charged. Any material possessing relatively large numbers of such free electrons is called a *conductor*, while materials with relatively few free electrons are called poor conductors or, and extreme cases, *insulators*. Both glass and rubber are classified as insulators and, although they lose or gain electrons on contact with other materials, they do not have free electrons, and so the acquired charges are restricted to the area of contact and do not distribute themselves throughout the material.

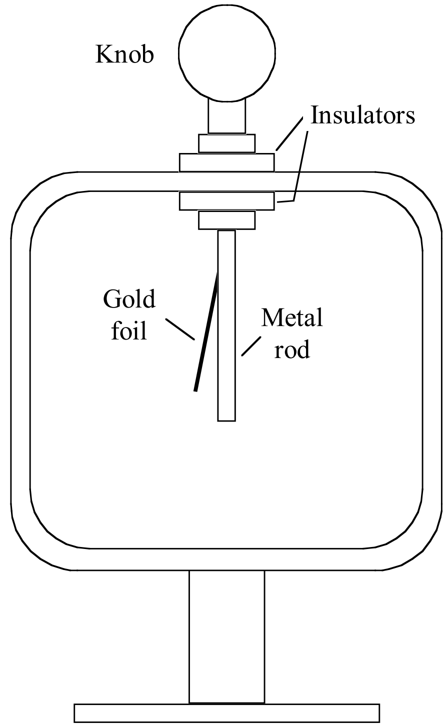


Figure 1

0.2 *The gold foil electroscope*

A gold foil electroscope (Figure 1) is a simple but sensitive device used to test bodies for the presence of charge. A thin gold foil is attached by one edge to a rigid metal rod. *The gold foil and the metal rod always share the same charge*. Therefore, if charge of any sign is present, the gold foil is repelled from the rod, causing the foil to become oriented away from the vertical, as in the diagram.

The rod has a metal knob at the top. The charge on the knob may be different from the charge on the gold foil, as happens in the case of induction. The rod is insulated from the support structure surrounding it, so that the charge on the rod cannot escape.

0.3 *Electrical polarization*

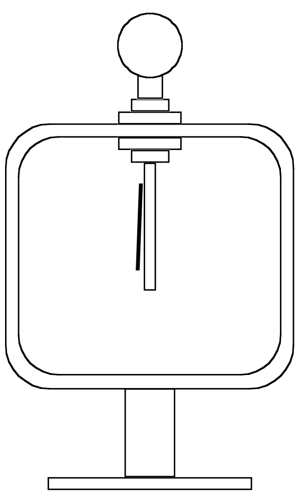


Figure 2 (a) An Uncharged Electroscope The negatively charged rod is distant from the electroscope. There is no net charge on any part of the electroscope, and the gold foil hangs vertically.

A conductor can be *electrically polarized* without actual contact with any other body simply by bringing the conductor into the neighborhood of a charged body. The free electrons within the conductor shift their positions under the influence of the neighboring charge. Figure 2 (a) shows an uncharged electroscope with a negatively charged rod far from the electroscope. Figure 2 (b) shows what happens to the electroscope when the negative rod is brought near to the electroscope without actually touching the electroscope. Free electrons in the conductor will be driven away by the negative charge, and the part of the conductor nearest the negatively charged body will be left positively charged, while the part of the conductor farthest from the negatively charged body will be made negatively charged. In this state, the conductor is said to be *polarized*. If the polarized conductor could be separated into upper and lower parts, the separated charges would be trapped, and the lower part of the conductor would be negatively charged, while the upper part would be equally positively charged. Nevertheless, the parts of the conductor taken together would still be electrically neutral.

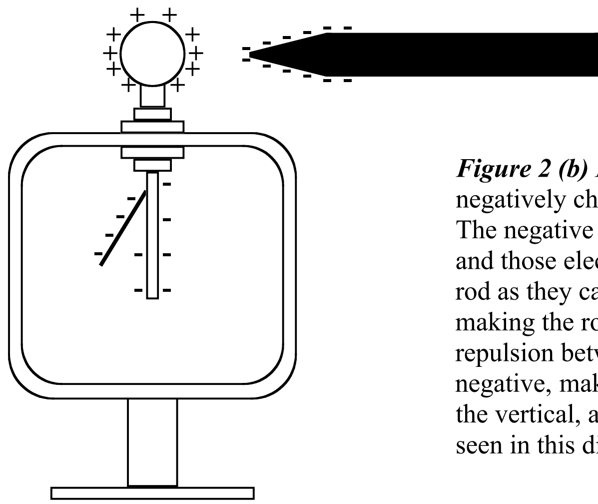


Figure 2 (b) Polarization by Induction The negatively charged rod is near to the electroscope. The negative rod repels free electrons in the knob, and those electrons move as far from the charged rod as they can, leaving the knob positive but making the rod and gold foil negative. The repulsion between the rod and the gold foil, both negative, makes the gold foil deflect away from the vertical, as shown. The separation of charge seen in this diagram is known as *polarization*.

0.4 *Charging by conduction*

If, as shown in Figure 2 (c), the negative rod actually touches the knob on the electroscope, negative charge transfers from the rod to the knob, neutralizing the positive charge on the rod and leaving the conductor with a net negative charge, which the electroscope will retain after the negative rod is withdrawn. This is called *charging by conduction*.

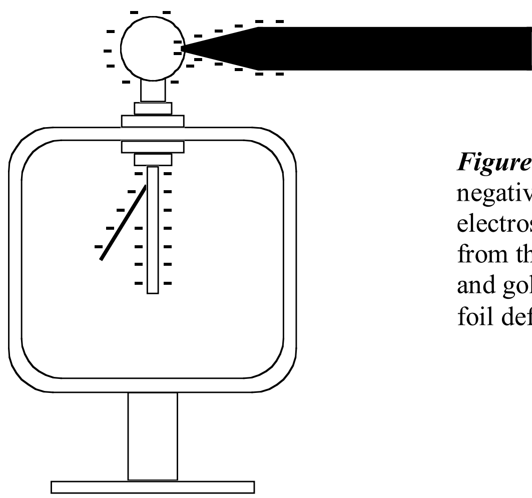


Figure 2 (c) Charging by Conduction The negatively charged rod touches the knob on the electroscope. The result is a transfer of electrons from the rod to the knob, making the knob, rod, and gold foil all negative, and making the gold foil deflect from the vertical.

0.5 *Charging by induction*

It is possible to give a permanent charge to the electroscope without the charged rod touching the electroscope. This is done by polarizing the electroscope, as in Figure 2 (b), and then *grounding* the electroscope's knob while it is still in the neighborhood of the charged body, as in Figure 2 (d).

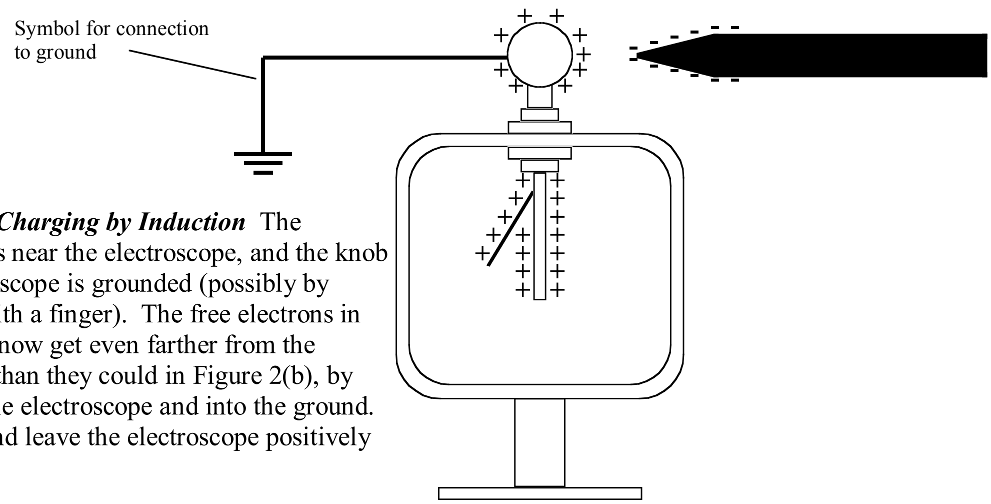


Figure 2 (d) Charging by Induction The charged rod is near the electroscope, and the knob on the electroscope is grounded (possibly by touching it with a finger). The free electrons in the knob can now get even farther from the negative rod than they could in Figure 2(b), by moving off the electroscope and into the ground. They do so and leave the electroscope positively charged.

Grounding means to connect an object to the earth. The earth acts as a vast reservoir of charge and effectively neutralizes any charge on the metallic conductor. In the experiments for this lab, the human body can *usually* act as an effective ground, and objects may be grounded by touching them with a finger.

When a metallic conductor is grounded in the presence of a negatively charged body, the free electrons in the conductor, being repelled by the nearby negatively charged body, will flow off the conductor to ground and leave a net positive charge on the conductor. If the ground is removed from the conductor before the negatively charged body is taken away, the electron deficiency on the conductor will be trapped, and the conductor will retain a net positive charge. This process is know as *charging by induction.*

Following the same procedure but using a positively charged rod will result in a negative charge on the conductor.

0.6 *Precautions*

0.6.1 Water and humidity in the air can ruin electrostatic experiments by making the surface of an insulator a fairly good conductor. Moisture from your hands or breath can also cause trouble. **The silk and wool cloths should always be held with two fingers rather than inside the palm of your hand.** Try beating the glass or rubber rod against the cloth rather than rubbing the cloth on the rod.

0.6.2 Excessive charge can rip the gold foil off a gold foil electroscope. For this reason, **never charge a gold foil electroscope by touching the electroscope knob with a charged rod**. Charging by conduction using a proof plane (to be demonstrated by your lab instructor) is safe, and charging by induction is always safe.

0.6.3 **Never touch a gold foil**. They are very fragile.

*0.7 The meaning of **increase** in the activities of this laboratory session*

When you answer questions while doing the lab activities, the word *increase* is to mean more of whatever charge it refers to. For example, if the charge is negative, *increased charge* means more negative charge. If the charge is positive, *increased charge* would mean more positive charge.

Comprehensive Equipment List

Gold foil electroscope
Glass rod (prior to use, wash with soap and water, then dry)
Rubber rods, at least two per table (also, wash with soap and water, then dry)
Silk cloth
Wool cloth
Proof plane
Pith ball with conductive coating, suspended by a light thread
Two metallic spheres on insulated stands

It may be that washing not only the rods but also the silk and wool cloths will help assure predicable results.

1. Activity #1: Instructor demonstration of how to charge a rod

1.1 The lab instructor shows how to charge a rod: in one hand, hold the cloth between thumb and forefinger; hold the rod in the other hand; swat the cloth with the rod.

1.2 The lab instructor explains how holding the cloth in the palm of the hand eventually causes the cloth to become slightly damp, making it a good conductor and therefore unable to charge a rod.

2. Activity #2: Instructor demonstration of charging by conduction using a proof plane

Never touch the electroscope knob with a charged rod. Instead, always use a proof plane to transfer small quantities of charge from a charged object to the electroscope. Charging an electroscope by induction is always safe.

2.1 Make sure that the electroscope is neutral (the charge indicator should be vertical). Discharge the electroscope by touching (grounding) its knob with your finger, if necessary.

2.2 Charge the glass rod by beating it against the silk cloth.

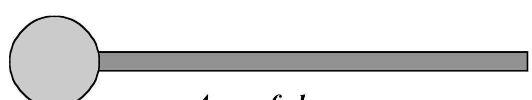
Q 1 What is the charge on the glass rod after charging it?

☐ **plus** ☐ **minus** ☐ **zero**

Q 2 What is the charge on the silk cloth after it charges the glass rod?

☐ **plus** ☐ **minus** ☐ **zero**

A *proof plane* looks like a small flat teaspoon. The disk-like "spoon" is made of conductive metal, and the handle is an insulator, either glass or plastic.



A proof plane

2.3 Touch the proof plane first to the middle of the glass rod and then to the knob of the electroscope. Repeat several times if necessary to give the electroscope enough charge to make the gold foil deflect to about 45º with respect to the vertical. The electroscope is now charged by conduction (see Figure 2 (c)) but in a safe manner, using a proof plane.

Q 3 What is the sign of the charge given to the electroscope by conduction from the glass rod via the proof plane?

☐ **plus** ☐ **minus** ☐ **zero**

Q 4 Did electrons transfer from the glass rod to the electroscope or vice versa?

☐ **electroscope → rod** ☐ **rod → electroscope** ☐ **did not flow**

3. Activity #3: Observe the effect of induction on a neutral body

3.1 Make sure that the gold foil electroscope is neutral. Touch its knob with your finger to discharge it, if necessary.

3.2 Charge the glass rod by beating it against the silk cloth.

3.3 Bring the charged glass rod near the gold foil electroscope without allowing them to touch, as in Figure 2 (b).

Q 5 What is the charge on the gold foil of the electroscope?

☐ **plus** ☐ **minus** ☐ **zero**

Q 6 What is the charge on the knob of the electroscope?

☐ **plus** ☐ **minus** ☐ **zero**

Q 7 What is the net charge of the electroscope as a whole?

☐ **plus** ☐ **minus** ☐ **zero**

3.4 Move the charged glass rod away from the electroscope.

Q 8 Did the charge on the gold foil change as the rod moved away?

Recall (see section 0.7) that "increase" means "more of whatever charge is already present." If there is a negative charge and it increases, there is more negative charge. Similarly, if negative charge decreases, there is less negative charge.

☐ **increased** ☐ **decreased** ☐ **no change**

Q 9 Did the net charge of the electroscope as a whole change?

☐ **increased** ☐ **decreased** ☐ **no change**

4. Activity #4: Observe the effect of induction on a charged body, Part I

4.1 Charge the rubber rod with a wool cloth.

4.2 Charge the gold foil electroscope **by induction** from the charged rubber rod. Method:

4.2.1 Bring the rubber rod near the electroscope knob, but do not allow the rod and knob to touch.

4.2.2 Put your finger on the knob, and then remove your finger.

4.2.3 Remove the rubber rod.

4.3 Charge the glass rod with a silk cloth, and bring the glass rod *near* the electroscope – without touching the electroscope.

Q 10 Did the charge on the gold foil of the electroscope increase or decrease as the glass rod was brought near the charged electroscope?

☐ **increased** ☐ **decreased** ☐ **no change**

Q 11 How did the charge on the knob of the electroscope change?

☐ **increased** ☐ **decreased** ☐ **no change**

Q 12 Did bringing the glass rod near the electroscope cause the net charge of the electroscope as a whole increase or decrease?

☐ **increased** ☐ **decreased** ☐ **no change**

5. Activity #5: Observe the effect of induction on a charged body, Part II

5.1 Discharge the gold foil electroscope.

5.2 Charge the gold foil electroscope by induction with the glass rod after the rod has been charged using the silk cloth.

Q 13 What is the sign of the charge on the glass rod after charging it using the silk cloth?

☐ **plus** ☐ **minus** ☐ **zero**

Q 14 What is the sign of the charge on the silk cloth after it charges the glass rod?

☐ **plus** ☐ **minus** ☐ **zero**

Q 15 What is the sign of the charge given to the electroscope by induction from the glass rod?

☐ **plus** ☐ **minus** ☐ **zero**

Q 16 Did electrons move from the glass rod to the electroscope or vice versa?

☐ **electroscope → rod** ☐ **rod → electroscope** ☐ **did not flow**

5.3 Charge a rubber rod with a wool cloth.

5.4 Bring the charged rubber rod near the electroscope – without touching the electroscope.

Q 17 Did charge on the electroscope's gold foil increase or decrease?

☐ **increased** ☐ **decreased** ☐ **no change**

Q 18 How did the charge on the knob of the electroscope change?

☐ **increased** ☐ **decreased** ☐ **no change**

Q 19 As the rubber rod neared the gold foil electroscope, which way did the electrons move?

☐ **electroscope → rod** ☐ **rod → electroscope** ☐ **did not flow**

☐ **foil → knob** ☐ **knob → foil**

Q 20 Did the net charge of the electroscope as a whole increase or decrease as the rubber rod approached the electroscope?

☐ **increased** ☐ **decreased** ☐ **no change**

5.5 Re-charge the wool cloth with the rubber rod.

5.6 Bring the charged wool cloth near to (but not close enough to touch) the electroscope. One way to do this is to hold the wool cloth like a canopy above the electroscope knob and slowly lower the cloth toward the knob.

Q 21 Did the charge on the electroscope's gold foil increase or decrease when the wool cloth came near the knob?

☐ **increased** ☐ **decreased** ☐ **no change**

Q 22 How did the charge on the knob of the electroscope change?

☐ **increased** ☐ **decreased** ☐ **no change**

Q 23 What is the net charge on the electroscope as a whole now?

☐ **plus** ☐ **minus** ☐ **zero**

5.7 Remove the wool cloth, and set it aside.

6. Activity #6: Determining the sign of an unknown charge

6.1 Discharge the electroscope.

6.2 Charge the rubber rod with a wool cloth, making the rod negative.

6.3 Use the proof plane to transfer charge from the rubber rod to the gold foil electroscope. Having the gold foil at an angle of 30º to 45º with respect to the vertical is ideal.

Q 24 What is the charge on the electroscope?

☐ **plus** ☐ **minus** ☐ **zero**

6.4 Charge the glass rod with the silk cloth.

6.5 Slowly bring the glass rod toward the electroscope knob. As the glass rod gets closer to the knob, the gold leaf will begin to move.

Q 25 Which way did the gold leaf first begin to move as the glass rod approached the knob?

☐ **up** ☐ **down** ☐ **did not move**

Q 26 Explain why the gold leaf moved the way it did.

6.6 Charge the rubber rod with the wool cloth.

6.7 Slowly bring the rubber rod toward the electroscope knob. As the rubber rod gets closer to the knob, again the gold leaf will begin to move.

Q 27 Which way did the gold leaf first begin to move as the rubber rod approached the knob?

☐ **up** ☐ **down** ☐ **did not move**

Q 28 Explain why the gold leaf moved the way it did.

Q 29 Suppose the electroscope is charged, but you do not know the sign of its charge. Explain how you can use the known sign of the charge on either the rubber or the glass rod to determine the sign of the unknown charge on the electroscope.

Q 30 Suppose an object bears an unknown charge. How would you determine the sign of its charge? (Big Hint: Begin by using a proof plane to transfer some of the unknown charge to a previously uncharged electroscope.)

7. Activity #7: Observe permanent charging of a body by induction

7.1 Ground the gold foil electroscope by touching its knob with your finger.

Q 31 What has happened to the charge that was on the electroscope? Draw a diagram as part of your explanation.

7.2 Charge the rubber rod using the wool cloth.

7.3 While your finger is still on the knob, bring the charged rubber rod near the knob of the gold foil electroscope.

7.4 First, remove the ground, and then remove the rod. The electroscope should now be charged by induction.

Q 32 Is there any charge on the knob of the electroscope?

☐ **yes** ☐ **no**

7.5 Determine the type of charge on the electroscope by bringing the charged rubber rod near the gold foil electroscope – without touching the electroscope – while the electroscope is still permanently charged by induction as in paragraph 7.4.

Q 33 What is the net charge on the electroscope as a whole now?

☐ **plus** ☐ **minus** ☐ **zero**

Q 34 Explain how the electroscope became charged. Include a diagram in your explanation.

8. Activity #8: Observe how a charged body acts on charged objects

8.1 First, allow the pith ball to touch the charged rubber rod. Then, after the pith ball has been touched by the rubber rod, bring the charged rubber rod near the pith ball again.

Q 35 How did the pith ball react when you brought the rod near to it after it had previously been touched by the same rod?

Q 36 Explain why the pith ball reacted the way it did.

9. Activity #9: Observe the motion of a charged body in an electric field

9.1 Give the two metallic spheres opposite electrical charges as follows.

9.1.1 Charge one metallic sphere by touching it with a glass rod that has been charged using the silk cloth. Listen for a small spark as the rod gets close to the sphere.

9.1.2 Charge the other metallic sphere by touching it with a rubber rod that has been charged using the wool cloth. Again, listen for a small spark.

9.1.3 Repeat the charging process several times for each sphere in order to build up enough charge for this activity.

9.2 Place the spheres next to each other, separated by about 2 centimeters (around one inch). Place the suspended pith ball between the two spheres. If nothing happens, move the pith ball closer to one of the spheres, allowing it to touch the sphere if necessary.

9.3 Observe the resulting motion of the pith ball.

Q 37 Describe the motion of the pith ball.

Q 38 Explain the motion of the pith ball.

10. Activity #10: Observe the effect of induction on a divisible conductor

10.1 Place a ***highly charged*** rubber rod near to – but not touching – one of the insulated metallic spheres.

10.2 Without moving either the sphere or the rod, use the proof plane and the electroscope to determine the sign of the charge on both sides of the sphere.

Q 39 What is the sign of the charge on the side of the sphere closest to the charged rubber rod?

☐ **plus** ☐ **minus** ☐ **zero**

Q 40 What is the sign of the charge on the other side of the sphere?

☐ **plus** ☐ **minus** ☐ **zero**

Q 41 What is the total charge of the sphere?

☐ **plus** ☐ **minus** ☐ **zero**

Q 42 Explain your answer to the previous question.

10.3 Place two insulated spheres in contact, side to side, so that they combine to form a single conductor.

10.4 Bring a ***highly charged*** rubber rod near one of the spheres.

Q 43 With the rubber rod near one sphere, what is the sign of the charge on the other sphere?

☐ **plus** ☐ **minus** ☐ **zero**

10.5 Hold the charged rod for several seconds at its position near the side of the first sphere, and then separate the two spheres while not moving the charged rubber rod.

10.6 After separating the spheres, remove the rubber rod.

10.7 Use the electroscope to determine the sign of the charge on each sphere.

Q 44 What is the sign of the charge on the sphere that was closest to the charged rubber rod?

☐ **plus** ☐ **minus** ☐ **zero**

Q 45 Do both sides of this sphere have the same sign of the charge?

☐ **yes** ☐ **no**

Q 46 What is the charge on the sphere that was farthest from the rubber rod?

☐ **plus** ☐ **minus** ☐ **zero**

Q 47 What is the net charge of the two spheres?

☐ **plus** ☐ **minus** ☐ **zero**

10.8 Touch the two spheres together again. Then separate them, and test only one for charge.

Q 48 What is the sign of the charge on the sphere you tested?

☐ **plus** ☐ **minus** ☐ **zero**

Q 49 Did the total charge on the two conductors change at any step?

☐ **increased** ☐ **decreased** ☐ **no change**

11. Activity #11: A paradox?

11.1 Discharge the gold foil electroscope by touching the knob with a finger.

11.2 Charge the rubber rod using wool cloth.

11.3 Charge the gold foil electroscope by induction using the rubber rod.

11.4 Observe the gold foil as you bring the rubber rod near to the knob on the gold foil electroscope without touching the knob. You will see the gold foil first slowly relax to the vertical position and then slowly begin to swing up to a non-vertical angle *as the rubber rod* *continues coming closer to the knob*. If you do not see this behavior, consult with your lab instructor.

Q 50 Explain why at first the gold foil relaxed to the vertical as the rod approached.

Q 51 Explain why the gold foil then began to rise to a larger angle as the rod came even closer.

12. When you are done ...

Hand in this handout with all questions answered.

Pre-Lab Questions

Print *Your Name*

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Read the *Introduction* to this handout, and answer the following questions before you come to General Physics Lab. Write your answers directly on this page. When you enter the lab, tear off this page and hand it in.

1. What is the sign of the charge on a rubber rod when the rod is charged using wool or fur? Positive or negative?

2. What is the sign of the charge on a glass rod when it is charged using silk? Positive or negative?

3. Describe a way to define positive and negative electric charge that can be used to determine the sign of unknown charges easily and without complicated equipment.

4. What is an electroscope used for?

5. When there are no other charges nearby, a charged electroscope can be neutralized by touching its knob with your finger. However, when you hold a charged rubber rod in your hand, it does not lose its charge. Why does your hand not neutralize a charged rubber rod?

6. Charged rubber and glass rods are available to you. Describe how to permanently charge an electroscope negatively without bringing it in contact with a charged rod.

7. What kinds of charges attract each other, and what kinds of charges repel each other?

8. Which is true? A body is positive because it has gained extra protons, or because it has lost electrons.

9. Describe *polarization by electric induction*.

Continued on the next page ...

10. When the electroscope is charged negatively by induction, it acquires extra electrons. From where do these extra electrons come?

11. How can you tell if an electroscope is charged?

12. Can an electroscope, by itself, show whether it contains positive or negative charge?

13. In an electroscope, do the gold foil and the knob always have the same charge? If they do always have the same charge, explain why they do; but if they do not always have the same charge, give an example in which they do not.

14. What problems can water, moisture, and humidity cause in this lab?

15. Describe the method of charging rods with cloths or fur that avoids these problems.

16. What is a possible consequence of placing too much charge on a gold foil electroscope?

17. What method of charging a gold foil electroscope must be avoided?

18. Why is that method of charging a gold foil electroscope to be avoided?

19. In the activities of this lab, there is one thing you must never touch. What is that?

20. Explain the meaning of *increase* in the context of this lab.