I. ELECTRIC CHARGES

INTRODUCTION

We deal with electricity almost continuously in our everyday life. Electric forces are actually holding our material world together by binding electrons and nuclei into atoms, and atoms into molecules. Among all fundamental forces in nature, the interactions between electric charges are best understood theoretically. This is a result of the intellectual efforts of people over 2500 years. It all started with the discovery by ancient Greeks that some substances can attract objects after being rubbed.

PURPOSE

Like the ancient Greeks you will discover in this laboratory session that there are two types of electric charges. Experiments will also help you understand the phenomenon of electric induction, which is responsible for the attraction of originally neutral objects to charged bodies.

PRE-LAB ASSIGNMENTS

A. Readings:

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 one becomes electrified or charged electrically. Further investigation revealed the existence of two different types of electricity that appeared to react 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 state this as an electrical law, that *like charges repel* each other and *unlike charges attract* each other.

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 positive charge.

Originally, both positive and negative types of charge 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 (positive charge), however, is part of the small compact group called the nucleus which forms the center of the atom. The proton is held very closely in the nucleus and is not free to move. The electrons (negative charge) move around the nucleus at a distance 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 are relatively free to move about from place to place or from atom to atom.

The density or number of "free" electrons and their mobility determine the electrical conductivity of a 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 closely held while the electrons are more free to move, most common electrical phenomena are explained in terms of the movement of electrons. A body that has acquired an excess of electrons over protons is said to be negatively charged and one that has a deficiency of negative charges is said to be positively charged. Any excess or deficiency of electrons in a conductor resides entirely on the outer surface of the conductor. Any unbalanced charge inside the conductor would drive electrons 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 the glass rod is rubbed with silk, electrons escape from the glass rod and are attracted 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 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; no two different substances have the same arrangement.

Atoms of the metallic group of elements, for example, lose electrons so rapidly 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 (deficiency of electrons) is touched to a piece of copper, the electrification appears to spread instantly throughout the metal, and it likewise becomes positively charged. Evidently, the positively charged body draws some of the free electrons from the copper metal in order to supply some of its deficiency of electrons, and thus leaves the copper positively charged. Any material possessing relatively large numbers of such free electrons is called a good conductor, while materials with relatively few free electrons are called poor conductors or (in extreme cases) "insulators". Both the glass and the rubber are classified as insulators and although they lose and 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.

INDUCTION

A conductor may be electrified or charged 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. Thus, if an insulated metallic conductor is brought near a negatively charged body, free electrons in the conductor will be driven away by the negative charge and the side of the conductor nearest the negatively charged body will be left positively charged while the far side will be negatively charged. If the conductor could be separated into two parts while in this condition, the "induced" charges would be trapped and one half of the conductor would be negatively charged and the other half equally positively charged. Nevertheless, the conductor as a whole is still electrically neutral.

A *permanent charge* can be obtained on the metallic conductor by "grounding" it while it is still in the neighborhood of the charged body. *Grounding* means to connect an object to the earth, which acts as a vast reservoir of charge and effectively neutralizes any charge on a metallic conductor. In these experiments, the human body can *usually* act as an effective ground and objects may be grounded by touching them with a finger. When the metallic conductor is grounded in the presence of a negatively charged body, the repelled free electrons in the conductor 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, then the electron deficiency on the conductor will be "trapped" and the conductor will retain a net positive charge. A somewhat reversed procedure will result in a negative charge on the conductor in the presence of a positively charged body.

ELECTROSCOPE

An electroscope is perhaps the simplest device to test bodies for charge. A thin strip of gold is placed next to a rigid metal rod. *The gold leaf and the metal rod always share the same charge.* Therefore, if charge of any sign is present, the gold leaf is repelled from the rod. The rod has a knob at the top for easy access. Charge on the knob may be different from charge on the gold leaf in case of induction. The rod is insulated from the support structure so that the charge on the rod cannot flow away.

B. Exercises:

Please answer the questions on Report Sheet I–1, which will be collected at the *beginning* of the laboratory session and graded by your instructor.

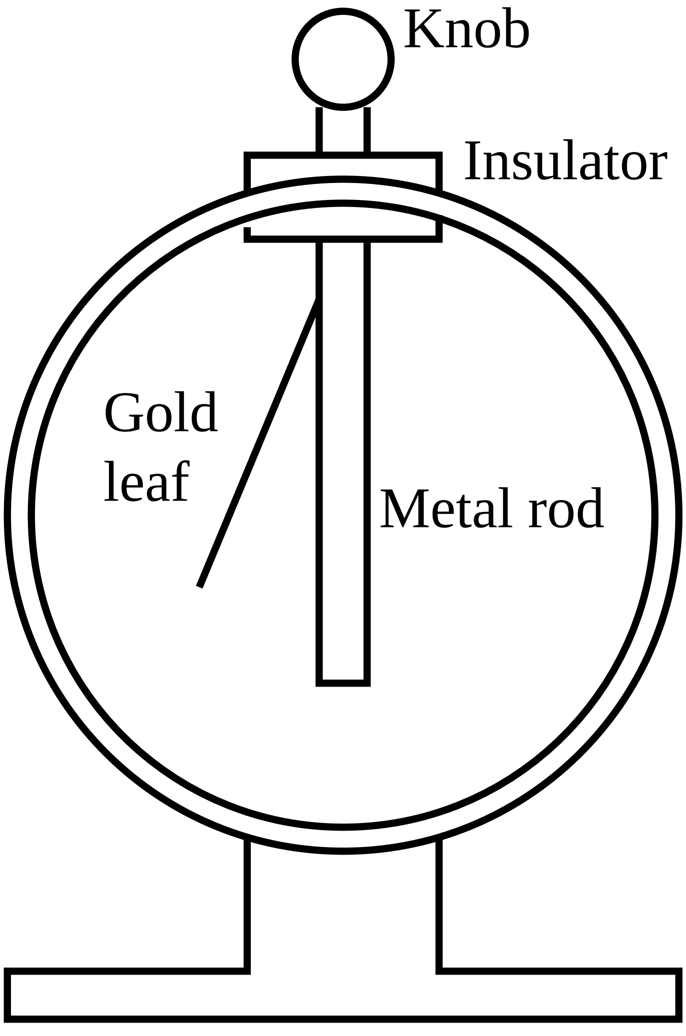

Figure 1. Electroscope.

LABORATORY ASSIGNMENTS

For each experiment, follow the instructions below. Usually a procedure for each experiment is divided into steps.

After each step, please check the report sheets for related questions. Answer the questions in the space reserved on the report sheets. If you need more space, or if you wish to make an additional comment or explanation, you may use the reverse side of the report sheet.

Before leaving the laboratory, please turn the report sheets in to the instructor supervising your laboratory session, whether or not this is your regular instructor. Reports taken home will not be accepted.

Attention : Water and humidity in the air can ruin electrostatic demonstrations by making the surface of an insulator become a fairly good conductor. Moisture from your hands or breath can also cause trouble. The silk and wool cloth should always be held with two fingers, rather than inside of palm. You can also try to "flap" the glass or rubber rod against the cloth rather than rub it.

Excessive charge can rip the gold leaf off the electroscope. Bring charged objects up to the electroscope slowly and do not bring them in contact with it if the charge is evidently too large.

Experiment A-E: *Charging of materials by conduction and induction*

Materials Needed:

- Electroscope
- Glass rod
- Silk cloth
- Rubber rod
- Wool cloth (or fur)

The Task:

A. Observe charging of a body by conduction.
B. Observe effect of induction on a neutral body.
C,D. Observe effect of induction on a charged body.
E. Observe permanent charging of a body by induction.

Procedures

A-1. You may have to remove protective cup from the knob of the electroscope before you begin. Make sure that the electroscope is neutral (the gold leaf should be resting in the vertical position). Discharge the electroscope by touching ("grounding") the knob with your finger if necessary.

A-2. Rub (or flap) a glass rod on the silk cloth.

A-3. Then bring the charged glass rod in contact with the knob on top of the electroscope. The electroscope is now charged by conduction (see Fig.2a). Move the charged glass rod away from the electroscope.

B-1. Make sure that the electroscope is neutral. Discharge it if necessary.

B-2. Rub the silk cloth on the glass rod. Bring the charged glass rod *near* the electroscope. This charges the electroscope by induction (see Fig.2b).

B-3. Move the charged glass rod away from the electroscope.

C-1. Charge the electroscope by conduction from the charged glass rod as in experiment A.

C-2. Recharge the glass rod and bring it *near* the electroscope still charged as in C-1.

D-1. Discharge the electroscope. Charge the electroscope by conduction with the rubber rod after the rod has been rubbed on wool (rubbing or flapping on fur or your hair may work better).

D-2. Bring the charged rubber rod near the electroscope still charged as in D-1.

D-3. Bring the charged glass rod near the electroscope still charged as in D-1. Move the rod in direction of the electroscope slowly, since what you see may strongly depend on how far the rod is.

E-1. Ground the electroscope by touching the knob with your finger.

E-2. While your finger is still on the knob bring the charged rubber rod near the electroscope.

E-3. Remove the grounding and then the rod. The electroscope should become permanently charged by induction.

E-4. Determine the type of charge on the electroscope by bringing the charged rubber rod or charged glass rod near the electroscope still permanently charged by induction as in E-3 (move the rod in direction of the electroscope slowly, since what you see may strongly depend on how far the rod is).

Experiment F-H: *Forces between charges, transfer of charge, induction*

Materials Needed:

- (**F,G**) Suspended ball made of aluminum foil
- (**F**) Rubber rod
- (**F**) Wool cloth
- (**F**) Glass rod
- (**F**) Silk cloth
- (**G**) A pair of insulated metallic conductors on stands (ellipsoids or balls)
- (**G,H**) Van de Graaff generator
- (**H**) Electroscope

The Task:

F. Observe how two charged objects interact.
G. Observation of motion of charged body in an electric field.
H. Induction in electric field of highly charged object.

Procedures

F-1. Discharge the aluminum foil ball by touching it with your finger. Touch the tip of charged rubber rod (use fur or your hair to charge the rod) to the aluminum foil ball. Bring the charged rubber rod near the aluminum foil ball, after it has been touched by the rod.

F-2. With the ball still charged from the rubber rod bring the charged glass rod near it.

G-1. Using the charge generating machine, charge two identical metallic ellipsoids with opposite charges by touching them with the poles of the generating machine (hold the ellipsoids by their insulating supports, and never touch the poles with your bare hands).

Place the conductors next to each other. Be careful not to discharge the conductors by allowing a spark to pass between them. Place the suspended aluminum ball between the conductors. Keep the ball suspended between the conductors for a while. If nothing happens move the ball closer to one of the conductors. Observe motion of the ball.

H-1. Bring the electroscope in the vicinity (0.5-1 m away from the poles) of the generating machine operating at low speeds. Be careful not to strip the gold leaf off the electroscope by bringing it too close to the generating machine. Observe what happens when sparks between the poles are allowed. If sparks are too frequent switch the machine off and induce sparks by moving slowly the smaller pole closer to the bigger pole (use a long wooden stick to push the smaller pole).

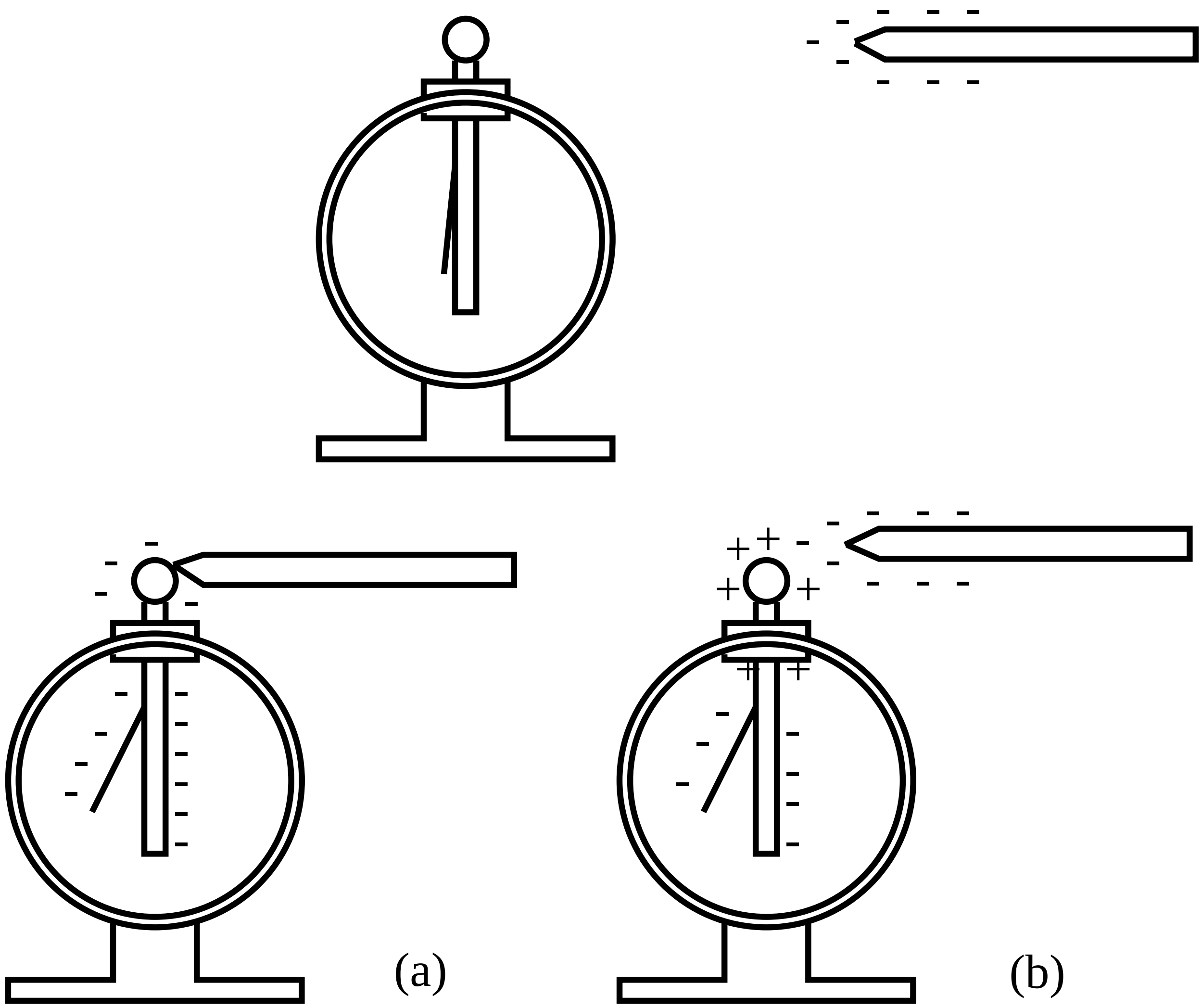

Figure 2. Charging of electroscope: (a) by conduction, (b) by induction.

REPORT SHEET I–1

Date______________________________ Name______________________________

Instructor__________________________

PRE-LAB EXERCISES

Exercise 1.
Describe how positive and negative charges can be defined?

Exercise 2.
Any charge on an electroscope is neutralized when you touch the knob of the electroscope with your finger. If you held one end of the rubber rod in your hand, while rubbing the other end with a wool cloth, will the rod become charged? Explain. Can you keep a glass rod in your hand while trying to charge it by rubbing it on silk? Explain.

Exercise 3.
Charged rubber and glass rods are at your disposition. Describe how to permanently charge an electroscope negatively *without* bringing it in contact (touching) with a charged rod.
Hint: see *Induction*.

REPORT SHEET I–2

Date____________________ Name____________________

Instructor____________________ Partner(s)____________________

Attention:
Below you will answer simple questions concerning the distribution of net charge. In your answers always refer to the amount of unbalanced charge and to changes of absolute value of the unbalanced charge. For example "increased" below, means that the absolute value of the unbalanced charge increased e.g. negative charge became even more negative.

A-2

What is the charge on the glass rod after rubbing it on the silk?

☐ + ☐ − ☐ 0

What is the charge of the silk cloth after rubbing it with the glass rod?

☐ + ☐ − ☐ 0

A-3

What is the charge given to the electroscope by conduction from the glass rod?

☐ + ☐ − ☐ 0

Did electrons flow from the glass rod to the electroscope or vice versa?

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

B-2

What is the charge on the gold leaf of the electroscope?

☐ + ☐ − ☐ 0

What is the charge on the knob of the electroscope?

☐ + ☐ − ☐ 0

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

☐ + ☐ − ☐ 0

B-3

Did the charge on the gold leaf change?

☐ increased ☐ decreased ☐ no change

Did the net charge of the electroscope, as a whole, change?

☐ increased ☐ decreased ☐ no change

REPORT SHEET I–3

Date______________________ Name______________________

Instructor______________________ Partner(s)______________________

C-2

Did charge on the gold leaf of the electroscope increase or decrease when the glass rod was brought near the charged scope?

☐ increased ☐ decreased ☐ no change

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

☐ increased ☐ decreased ☐ no change

Did the net charge of the electroscope as a whole increase or decrease?

☐ increased ☐ decreased ☐ no change

D-1

What is the charge on the rubber rod after rubbing on wool?

☐ + ☐ – ☐ 0

What is the charge of the wool cloth after rubbing it with the rubber rod?

☐ + ☐ – ☐ 0

What is the charge given to the electroscope by conduction from the rubber rod?

☐ + ☐ – ☐ 0

Did electrons flow from the the rubber rod to the electroscope or vice versa?

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

D-2

Did charge on the gold leaf of the electroscope increase or decrease as compared with the step D-1?

☐ increased ☐ decreased ☐ no change

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

☐ increased ☐ decreased ☐ no change

Did the net charge of the electroscope as a whole increase or decrease?

☐ increased ☐ decreased ☐ no change

D-3

Did charge on the gold leaf of the electroscope initially increase or decrease after you started to move the charged glass rod closer to the electroscope.

☐ increased ☐ decreased ☐ no change

How did charge change on the knob of the electroscope?

☐ increased ☐ decreased ☐ no change

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

☐ + ☐ – ☐ 0

REPORT SHEET I–4

Date________________________ Name________________________

Instructor________________________ Partner(s)________________________

E-1

What has happened to the charge that was on the electroscope? Explain.

E-3

Is there any charge on the gold leaf?

☐ yes ☐ no

Is there any charge on the knob of the electroscope?

☐ yes ☐ no

E-4

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

☐ + ☐ − ☐ 0

Explain how you determined it.

REPORT SHEET I–5

Date______________________ Name______________________

Instructor______________________ Partner(s)______________________

F-1

What happens to the aluminum ball when you bring the rubber rod nearby? Explain.

F-2

What happens to the aluminum ball when you bring the glass rod nearby? Explain.

G-1

What happens? Explain why.

We talk about electric current whenever charge is in motion. By definition, direction of electric current is the direction in which a positive charge is or would be moving. Thus if positively charged object is moving, then the direction of the resulting electric current is the same as of the object itself. However, if negatively charged object is moving, the direction of the resulting electric current is opposite to the direction of the object itself. Does electric current in this experiment change its direction or does it always flow in the same direction?

REPORT SHEET I–6

Date____________________ Name____________________

Instructor____________________ Partner(s)____________________

H-1

What happens? Explain the observed effect.