PHY 112L Activity 1

Electric Charges, Potentials, and Fields

Name: ____________________________  ID #:__________________________
Section: ___________________________  Date: _________________________
Lab Partners: ___________________________ TA initials: ________

Objectives

1. Understand the basic properties, such as the magnitude and force, of electric charges
2. Understand the relationship between electric forces, fields and potentials
3. Illustrate the processes of triboelectric, inductive, and conductive charging
4. Experimentally determine equipotential lines; use them to determine electric field lines
5. Compare experimental and theoretical values for electric potential (lab report)

Materials & Resources

1. Computer with DataStudio software and a Pasco charge sensor
2. Ice pail and triboelectric charge wands
3. Power supply and multimeter
4. Metallic pins, banana leads and voltage probes
5. Cork board, conductive sheet, and graph paper

Introduction

Electric Charge - All atoms are composed of some combination of three fundamental particles: protons, electrons and neutrons; protons have a positive charge, electrons have a negative charge, and neutrons have no charge (neutral). This fundamental property of electric charge is responsible for the chemical reactions and electrical phenomenon at the heart of modern life, everything from the food we eat to the fuel in our cars and the messages on our phones.

The net electric charge on any object can be positive, negative, or zero (neutral), but may only occur in multiples of the smallest amount of charge found in nature, which is referred to as the elementary charge |e| and equals 1.602 × 10⁻¹⁹ coulombs (C), in SI units; 1 Coulomb contains 6.28 × 10¹⁸ electronic charges. The magnitude of charge on a proton is +1.602 × 10⁻¹⁹ C; the magnitude of charge on an electron is -1.602 × 10⁻¹⁹ C.

An electric force that depends on the strength and sign of the charges involved, as well as the distance that separates them, always exists between any two charged particles. This force is attractive between two unlike charges (one positive and one negative), while two like charges (2 positives or 2 negatives) repel each other.

The force between two point charges can be expressed mathematically as \( F = \frac{kq_1q_2}{r^2} \)
where \( k \) is the proportionality constant 8.99 × 10⁹ N·m²/C², \( q_1 \) and \( q_2 \) are the magnitudes of the charges, and \( r \) is the distance that separates them. The sign of the charges determines the direction of the electric force (positive for repulsive and negative for attractive force), while their magnitudes and separation determine its strength.

In principle, the net charge of a closed system is always conserved so that the total charge must be constant with respect to time, i.e. charge cannot be created or destroyed. However, the charge on any object can be modified by three methods: triboelectric, inductive, and conductive charging. By rubbing certain types of materials together, charges can be transferred from one to the other. This process is known as triboelectric charging, wherein some of the electrons are freed from one material by the frictional energy of rubbing and become attached to the other. This results in one material becoming more positively charged and the other becoming more negatively charged. For example, rabbit fur becomes positively charged during this process; but Teflon becomes negatively charged. In nature, this type of charging is responsible for building the charge required for things like lightning or the shock from touching a door knob or closing your car door on a cold winter day.
When a neutral conductor, with as many positive as negative charges, is brought into close proximity with another charged object, the forces between the charges on that object and the positive and negative charges on the conductor will cause the charges on the conductor to separate as the charges that are like the ones on the new object move away from it (because of the repulsive electric force) and the unlike charges move toward it (because of the attractive electric force). Although the total charge on the conductor is not changed by this; and so it remains neutral, there are now regions of positive and negative charge on the conductor. This process is called induction.

The process of conduction occurs when an imbalance of charge or potential difference that is strong enough to cause charge to move from one object to the other exists between two oppositely charged objects. This generally occurs when such objects come into direct contact with one another and results in the balancing of charge distributions and the reduction or elimination of the potential difference between them. But direct contact is not required, as when lightning strikes.

Electric Potential - Since two charged objects exert a force on each other, it is natural to consider the energy imparted to charged objects when an electric force causes them to move across some distance. The concept of electric potential is a convenient way to describe this relationship between charge, distance, and energy.

Electric potential is a scalar quantity (magnitude only) that has units of volts (V), which represents the amount of energy/charge (J/C). It is created by a given distribution of charges and is determined by the specific spatial configuration, number and strengths of those charges. In general, the measured value of the electric potential, or voltage, decreases as the distance from the charge distribution increases. Similar to all types of potentials, it makes little sense to refer to an “absolute” potential; only the potential difference or voltage between two locations in space has a well-defined meaning, much like gravitational potential.

The electric potential of a point charge can be expressed mathematically as $V = (kq)/r$
where $k$ is the proportionality constant $8.99 \times 10^9 \text{Nm}^2/\text{C}^2$, $q$ is the magnitude of the charge creating the potential, and $r$ is the distance between this charge and the point in space that the potential is measured. If multiple point charges are creating the potential at the point of measurement, then the potential created by the individual charges must be added to get the total potential at that point.

Electric Fields - As mentioned previously, charged objects exert force on each other. However, charged objects do not necessary need to come into contact with each other to experience this force like a baseball and bat or a golf ball and club do. Rather, charged objects will experience an electric force if they are located within the electric force field, or simply electric field, created by another charge distribution somewhere nearby. This field is a vector quantity (with both magnitude and direction) that represents the amount of voltage/distance and has units of volts/meter (V/m).

A set of rules exists to help visualize these electric fields. Electric field lines always point from positive to negative charges, they never intersect, and are always perpendicular to the equipotential lines. Also, how close they are to one another at a given location represents how strong the field is at that point.

These ideas are shown in Figure 1, where the electric field lines touch both charges; the equipotential lines enclose them and represent the points in space where a constant potential difference may be measured. The shape of the equipotential lines always depends on the strength and configuration of the charge distribution creating the potential, but no matter the shape, these equipotential lines must always form a closed loop around a given set of charges.

The electric field is represented mathematically by $V = Ed$
where $V$ is the voltage, $E$ is the electric field, and $d$ is the distance from the charge distribution creating the field.
1. **Charge Induction on a Metal Surface**

   **Procedure:**
   1) Open the DataStudio software; click “Create Experiment” and setup the charge sensor in DataStudio for this experiment.
   2) Plug the charge sensor into the selected channel on the interface.
   3) Select the “Digits” and “Graph” options from the Display menu.
   4) Touch the inner and outer parts of the ice pail with your finger at the same time for a few seconds to neutralize any charges on it, and then zero the charge sensor as in Figure 3 to the right.
   5) Connect the red and black leads of the sensor as shown in Figure 2 so that the amount of charge induced on the inner part of the ice pail is measured.
   6) Click “Start” in DataStudio and verify that the initial reading for the charge sensor is actually zero on the digital readout.
   7) Pick up the charge creator wands and rub them together. This will cause some of the charge on one to be transferred to the other. *For the remainder of this part of the lab, do not let either of the wands touch anything unless specifically instructed to do so. If it does, then you will need to start this part over.*
   8) Insert the positive (white) wand into the ice pail as shown in Figure 4 without touching the sides and hold it there for a few seconds.
   9) Remove this wand and after a few seconds insert the negative one (blue) into the pail in the same way. Notice what happens to the charge reading as you insert and remove each wand.
   10) Click “Stop” in DataStudio and title this graph “Induction”
   11) Print out this graph and use it to answer the following questions.

   **Questions:**
   1) Does the charge induced on the inner section of the pail have the same or opposite (circle one) charge as the wand that is used? Explain why below.

   2) True or false (circle one): The induced charge returns to zero each time the wand was removed from the ice pail. Explain why below.
2. Charge Conduction on a Metal Surface

Procedure:
1) Delete your previous data (after printing it), then repeat steps 4, 6, and 7 from part 1 above.
2) Insert one of the wands into the ice pail as before and hold it there for 10 – 15 seconds.
3) Gently rub the wand on the inside of the ice pail and remove it. Notice what happens to the charge reading as you rub and then remove the wand.
4) After a few more seconds, insert the other wand into the pail and hold it there as before.
5) Gently rub this wand against the inside of the ice pail and remove it as before. Again, notice what happens to the charge reading during this process.
6) Click “Stop” in DataStudio and title this graph “Conduction”
7) Print out this graph and use it to answer the following questions.

Questions:
1) True or false (circle one): The charge returns to zero when the first wand is removed from the ice pail. Briefly explain why or why not below.

2) True or false (circle one): The charge returns to zero when the second wand is removed from the ice pail. Briefly explain why or why not below.

3) Use your “Induction” and “Conduction” graphs to explain the difference between these 2 processes.
3. **Equipotential and Electric Field Lines (Lab Report)**

**Procedure:**

1) Draw a replica (precise and to scale) of your conductive sheet, as well as a line of symmetry connecting the 2 conductive zones, onto the graph paper; this line should be along one of your electric field lines.

2) Connect the leads between the power supply and conductive sheet as shown in Figure 6.

3) Turn on the power supply and set it to exactly 4.00 V.

4) Set the multimeter to measure DC voltage (VDC or \( \pm \pm \pm \)) and place the red multimeter probe precisely in the middle of the two conductive zones and record the voltage reading at that point on your graph paper. This point should be on the line of symmetry drawn earlier.

   Center Voltage: ____________ V

5) Make a similar reading halfway between this first point and each of the two conductive zones. You should now have 3 potential readings that are evenly spaced along the symmetry line of your graph paper.

6) Use the multimeter probe to find other points on the conductive sheet, as shown in Figure 7, that have the same potential reading as one of the original 3 points on the symmetry line; record them as precisely as possible onto the graph paper replica.

   **Hint:** when you find a 2\(^{nd}\) point of a given potential, it should be relatively easy to find a 3\(^{rd}\) one of that value in a similar place across the symmetry line, and so on.

7) Repeat this process until you have found at least five points for each of the 3 original values for potential, with at least 2 on each side of the symmetry line as shown in Figure 8.

8) Draw in each of the 3 equipotential lines as shown to the right. Do not simply “connect the dots” here, but rather try your best to capture the natural curvature of the equipotential line as shown in Figure 9. When finished, your graph paper should look similar to Figure 10, but should only have 3 equipotential lines, instead of 5 as shown.

9) Verify that your initial symmetry line is perpendicular to each of the equipotential lines that you have drawn onto the graph paper.
10) Draw in at least 4 other lines between the 2 conductive regions (2 above and 2 below the symmetry line) that are also perpendicular to the equipotential lines. Again try your best to capture the natural curvature of the electric field lines and be careful to ensure that each electric field line crosses the equipotential lines at a right angle (90°) as shown in Figure 11.

11) Draw arrows on the electric field lines that represent them as going from the positively charged region to the negatively charged region of your conductive sheet.

12) Since the potential difference between the 2 conductive regions is set to 4.00 V by the power supply, the potential at the center point on the symmetry line exactly in between the conduction zones should be exactly 2.00 V. In the space provided below, calculate the % error using the equation below between 2.00 V and the value for potential that you recorded in the space above. Write your lab report on these values.

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\text{% error} = \left| \frac{\text{measured} - \text{accepted}}{\text{accepted}} \right| \times 100\% =
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= \text{_________________________} = \text{___________} \%
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Questions:
1) Briefly explain below what your % error calculation tells you in this situation.

2) Using the rules discussed above for drawing electric field lines, draw the electric field lines and equipotential lines for the charge configuration below. Be sure to draw the direction of the field lines.