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6. ELECTRIC FIELD MAPPING

Driving Question | Objective

How can the characteristics of the electric field surrounding oppositely-charged electrodes in two configurations, dipole and parallel plates, be determined experimentally? Use the principles of electric fields and electric potential energy to experimentally determine the lines of equal electric potential (isolines) surrounding oppositely-charged electrodes and the shape and direction of the electric field lines in each configuration.

Materials and Equipment

- PASCO Conductive Paper
- Power supply
- Digital multimeter

Background

All charged objects produce electric fields in the space surrounding them. Knowing the shape, direction, and magnitude of an electric field is necessary to determine how a charged particle will interact with the field. Visualization is often helpful when analyzing fields and field forces; however, visualizing a 3-dimensional field can be difficult. A convenient way of representing an electric field is through the use of *electric field lines*.

Electric field lines are drawn lines that follow the path of the electric field, originating from a positive charge (or charged object) and terminating at a negative charge (or charged object). The lines never cross, and the density of lines (the number of lines in a given area) represents the magnitude of the field strength. These rules are written more formally as:

- Electric field lines must begin on a positive charge and terminate on a negative charge.
- The number of electric field lines drawn leaving a positive charge or approaching a negative charge is proportional to the magnitude of the charge.
- No two electric field lines originating from the same source can cross.

Another characteristic of electric field lines is that they always travel perpendicularly across lines of equal electric potential known as *isolines*. If a charged particle were to follow one of these lines, its electric energy (or voltage) would not change. In contrast, if a charged particle were to move in the direction of the electric field, across the isolines of electric potential, work must be done on the particle by the force from the electric field.

In this activity, you will identify different isolines of electric potential surrounding a pair of charged electrodes, and then use those isolines as guides to draw electric field lines and identify the magnitude and direction of the electric field.

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

- Do not connect the terminals of a power supply without a load; this will cause a short circuit.

Procedure

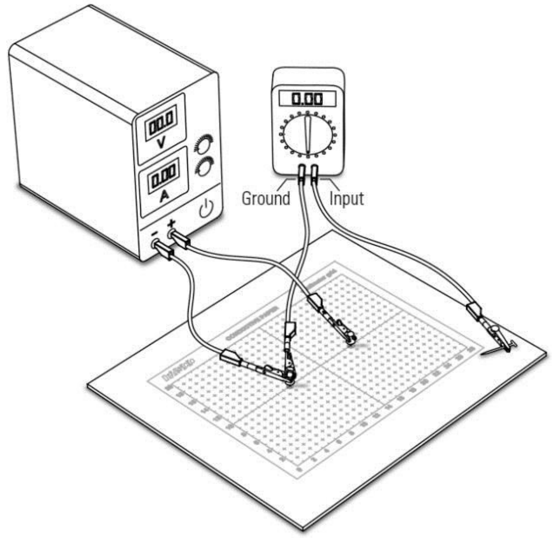
Part 1 – Dipole Electrodes

SET UP

1. Place the sheet of semi-conductive paper with the dipole electrodes drawn on it onto the cork board. Pin each corner of the paper to the cork board using metal pushpins.

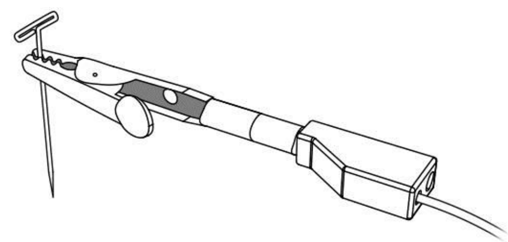
2. Press a metal pushpin into the center of each electrode, making sure that the pushpins are pressed firmly through the paper and into the corkboard.

3. With the power supply off, connect the electrode pushpins to the terminals on the power supply using two patch cords and alligator clips as shown: positive terminal to one electrode (this is the positive electrode), negative terminal to the other (this is the negative electrode).



4. Connect the two remaining patch cords to the DC voltage ports on the digital multimeter (DMM), and then adjust the DMM to measure DC voltage.

5. Attach alligator clips to the ends of the DMM patch cords. Clip the DMM "ground" or "COM" patch cord to the pushpin in the negative electrode (this is now the reference electrode). Connect the alligator clip on the other patch cord to the metal T-pin.



COLLECT DATA

6. Turn on the power supply and adjust the voltage to 30 VDC.

7. Touch the tip of the T-pin to any black space surrounding either electrode on the semi-conductive paper and observe the voltage measurement on the DMM. The DMM should measure different voltages at different points on the paper. If not, make sure all of the alligator clips and pushpins are making good connections and retest.

   NOTE: Touch the tip of the T-pin only to the solid black areas of the semi-conductive paper. Do not touch the tip of the pin to the paper's grid marks.

8. Use the tip of the T-pin to probe different positions surrounding the electrodes until you find a location on the paper where the DMM reads 5.0 VDC. Record this position on the white computer paper copy of the field map with a BLUE PENCIL. **Do not write directly onto the black conductive paper**.

9. Continue moving the probe to different points on the paper, identifying several positions surrounding the electrodes where the voltage is at 5.0 VDC. Mark each new point until there are enough marks to accurately draw a smooth line that connects them with a BLUE PENCIL. Label the line "5.0 V".

   NOTE: Be sure to probe all areas surrounding the electrodes. Isolines of electric potential may connect in a closed path on the paper or extend off the edge of the paper and then re-enter the paper in an unexpected location.

10. Repeat the previous data collection steps, identifying and drawing the isolines of electric potential for each of these voltage values: 5.0 V, 10.0 V, 15.0 V, 20.0 V, and 25.0 V. Label each line with its corresponding voltage.

11. Repeat the previous data collection steps, this time with the parallel-plate electrodes.

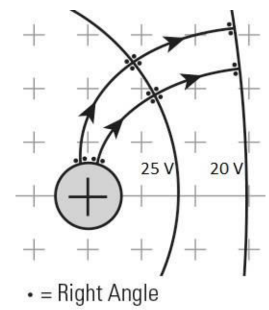
12. Repeat the previous data collection steps, this time with an electrode design of your choosing.

13. Turn the power supply off when finished.

Data Analysis

Use the following steps to draw the electric field lines for each electrode configuration:

Part 1 – Dipole Electrodes



1. Using a RED PENCIL, draw an arrow starting from any point on the surface of the positive electrode and extending to the nearest isoline. Draw the arrow so it leaves the surface of the electrode at a right angle and intersects the first isoline at a right angle. You will find that to meet these requirements, the arrow must curve smoothly.

2. When you are satisfied with the shape of the arrow, draw over it using the felt-tip pen, and then draw a head on the arrow indicating the direction of the electric field: in the direction of decreasing electric potential from the positive electrode to the negative electrode.

3. From the tip of the arrow you just drew, draw another arrow like the previous one that extends from that isoline line to the next, and then another arrow to the next isoline, and so on until you reach the other electrode or the edge of the paper. Each arrow must obey the requirements outlined in the previous steps. Combined, the connecting arrows form one electric field line.

   NOTE: If your field line extends off the edge of the paper, it may also re-enter the paper in another location. Use the isolines of electric potential as your guide, drawing arrows from higher potential to lower potential.

4. Repeat these steps to draw a total of 10 electric field lines originating from the positive electrode, spacing the start of each line evenly along its surface.

Part 2 – Parallel-Plate Electrodes

5. Follow the Part 1 data analysis steps to draw 10 electric field lines from the positive parallel-plate electrode to the negative parallel-plate electrode as follows:

   a. Draw 7 of the 10 field lines leaving the inner surface of the positive electrode, and the remaining 3 field lines leaving the outer surface of the electrode.

   b. Space the 7 lines evenly along the inner surface, and the 3 lines evenly along the outer surface of the positive electrode. Draw each arrow with a smooth curve when necessary, and include arrow heads indicating the direction of the electric field.

   NOTE: This distribution of field lines is representative of the actual charge densities on the inner and outer surfaces of the plates. Because the plates are oppositely charged, there will be a non-uniform charge distribution due to the induction from the opposite plate.

Analysis Questions (Answer individually, not as a group)

❷ 1. What are the primary similarities and differences between the electric fields surrounding each electrode configuration?

No matter the setup, the electric fields always flowed from higher concentration to lower concentration (positive end to negative end). However, in the dipole electrodes, the isolines were shaped in a circle around the electrodes, whereas in the parallel and selected configurations, they were more ovalish. This resulted in the electric fields in the dipole diagram to curve much sooner compared to the parallel and selected ones where they remained fairly linear until the edges.

❷ 2. Where was the electric field strongest in each electrode configuration? Justify your answer.

The electric field was strongest near the positive electrode in every scenario as seen by the more concentrated isolines. This is because the closer the charge is to another positive charge, the more it is repelled, leading to the increased strength in electric field.

❷ 3. What can be said about the voltage at each point of an isoline of electric potential?

The voltage at each point of an isoline is the same as they all symbolize an equal distance away from the central electrode, therefore all having the same potential potential energy.

❷ 4. What do the electric field lines represent?

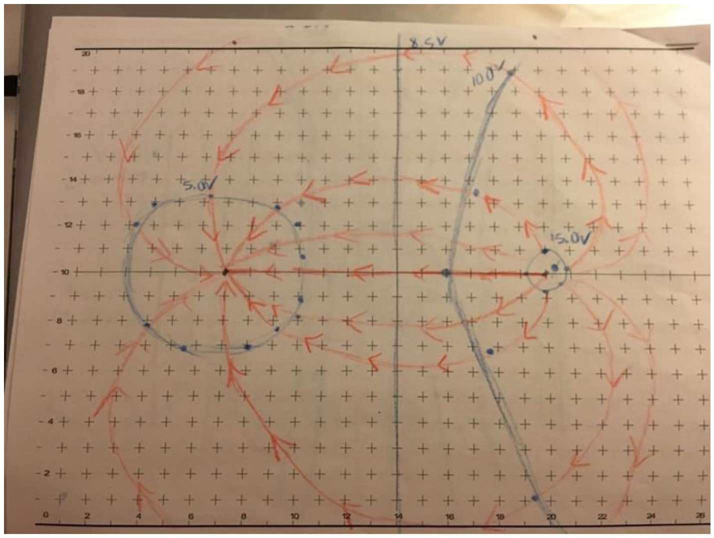
The electric field lines represent the trajectory a charge would undergo at a given point as it is repelled from the positive electrode and attracted to the negative electrode. Since it always has to be perpendicular to the isolines, the charge's trajectory will vary depending on the shape of the electrodes.

❷ 5. How would the shape of the electric field lines in each configuration change if you increased the potential difference between the electrodes? Justify your answer.

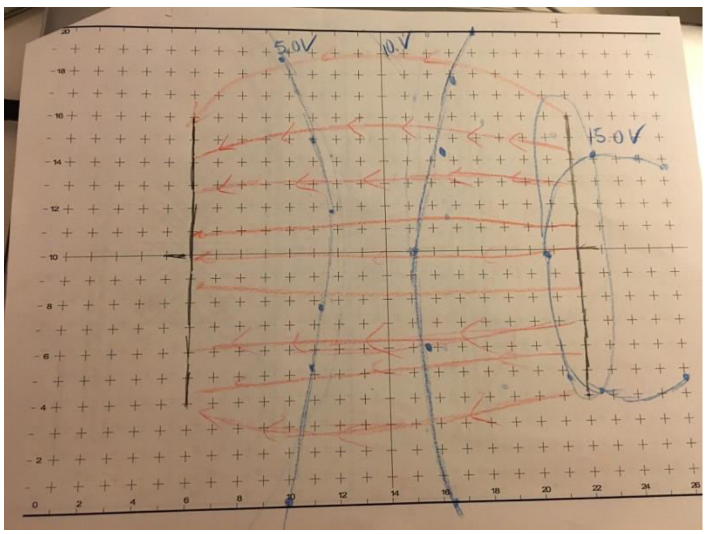
The shape of the electric field lines would not change, however, the voltage at a particular point will be increased. Since the distribution of the isolines will remain the same (just with a larger voltage), the resulting electric field lines will not have its shape altered.

Pictures

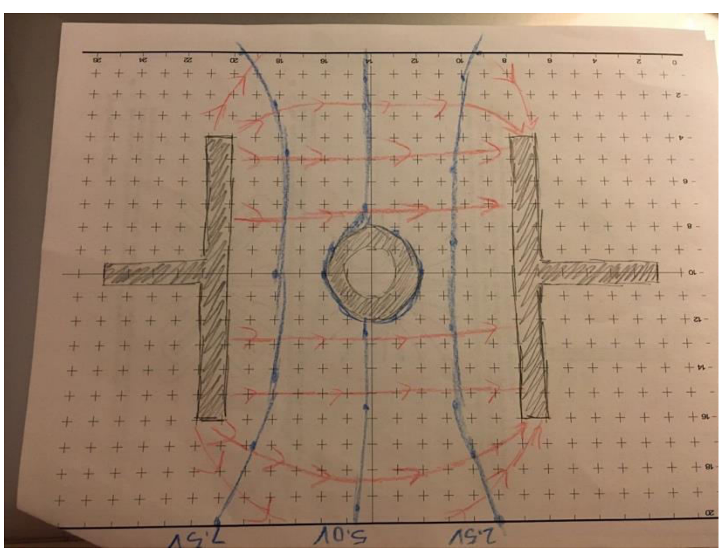
Please attach a (landscape) picture of your field map for the Dipole Electrodes.



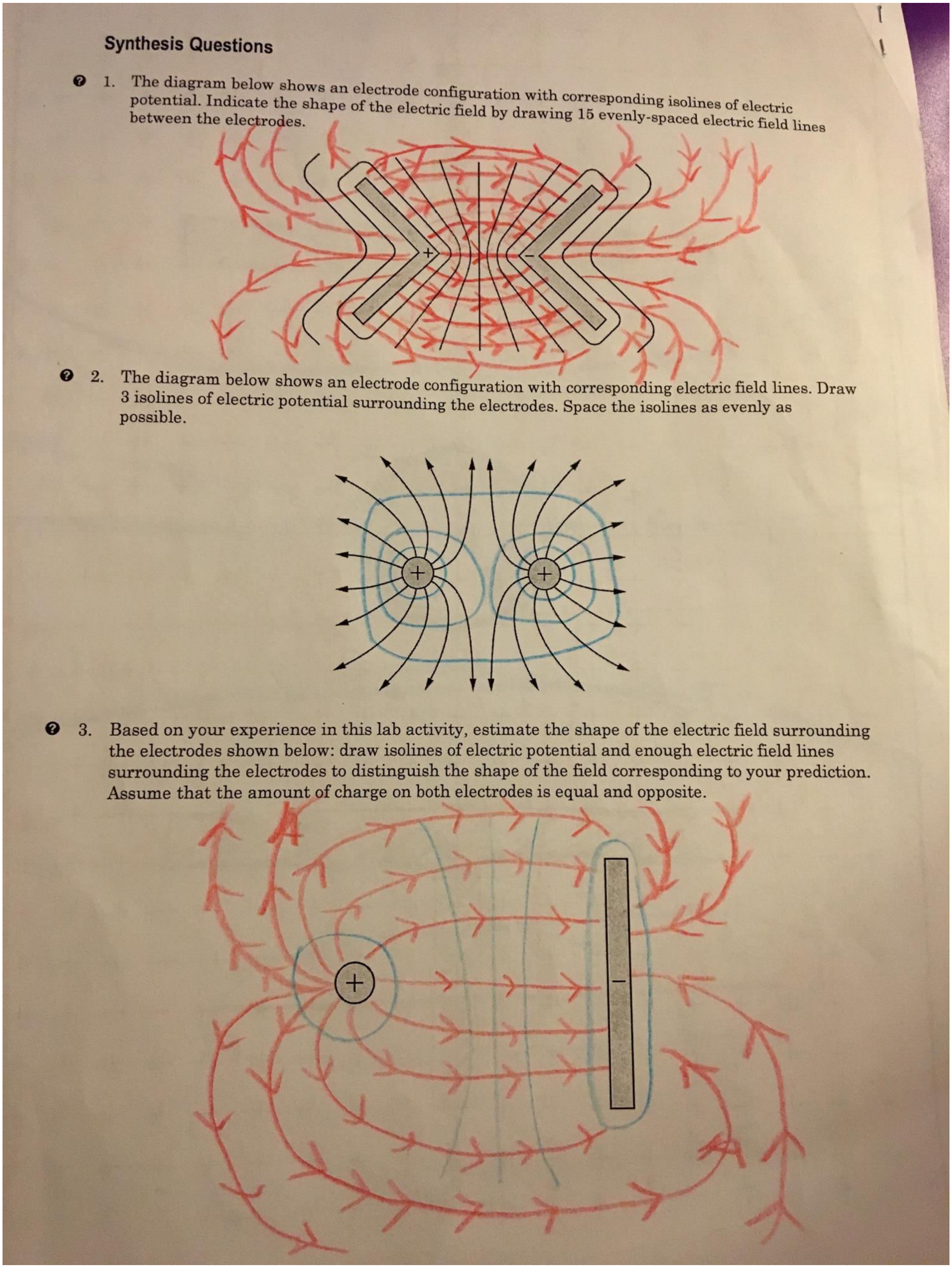
Please attach a (landscape) picture of your field map for the Parallel-Plate Electrodes.



Please attach a (landscape) picture of your field map for the electrodes of your choosing.



Please attach a (portrait) picture of your answers to the synthesis questions. While these questions can be completed as a group, each person should take a photo.



Synthesis Questions

1. The diagram below shows an electrode configuration with corresponding isolines of electric potential. Indicate the shape of the electric field by drawing 15 evenly-spaced electric field lines between the electrodes.

2. The diagram below shows an electrode configuration with corresponding electric field lines. Draw 3 isolines of electric potential surrounding the electrodes. Space the isolines as evenly as possible.

3. Based on your experience in this lab activity, estimate the shape of the electric field surrounding the electrodes shown below: draw isolines of electric potential and enough electric field lines surrounding the electrodes to distinguish the shape of the field corresponding to your prediction. Assume that the amount of charge on both electrodes is equal and opposite.