Electric Field around a Conductor

Equipment List

<table>
<thead>
<tr>
<th>Qty</th>
<th>Items</th>
<th>Model Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Voltage Sensor</td>
<td>CI-6503</td>
</tr>
<tr>
<td>1</td>
<td>Equipotential and Field Mapper kit</td>
<td>PK-9023</td>
</tr>
<tr>
<td>1</td>
<td>Power Supply, 15 Volts, DC</td>
<td>SE-9720</td>
</tr>
<tr>
<td>1</td>
<td>Silver (nonconductive) Pen &amp; Conductive Ink Pen</td>
<td>PK-9031B</td>
</tr>
<tr>
<td>2</td>
<td>Patch cords</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Alligator clips</td>
<td></td>
</tr>
</tbody>
</table>

Introduction
The purpose of this activity is to determine the shape and magnitude of the electric field and equipotential lines around point charge configurations and, and parallel plate configurations on a piece of conductive paper.

Background
An electric field is the effect produced by the existence of an electric charge, such as an electron (negative charge), proton (positive charge), or ion (charged atom) in the volume of space or medium that surrounds it. Another charge placed in the volume of space surrounding the “source” charge has a force exerted on it. The electric force applied by two charges, $q_1$ and $q_2$, on each other can be obtained from Coulomb’s Law:

$$F = k \frac{|q_1| |q_2|}{r^2}.$$ Where $k = \frac{1}{4\pi\varepsilon_0} = 8.99 \times 10^9 \text{Nm}^2/\text{C}^2$, and $\varepsilon_0 = 8.85 \times 10^{-12} \text{C}^2/\text{Nm}^2$

Where $k$ is Coulomb’s Constant, $\varepsilon_0$ is the Permittivity Constant, and $r$ is the separation distance between the two charges.

The force of attraction or repulsion between point charges at rest act along the lines joining the two charges. If there are more than 2 charges, the equation above hold for each pair of charges and the net force can be found on each charge by using the superposition principle of vector addition as the vector sum of the forces exerted on the charge by all of the other charges.

The electric field, $E$, at any point is defined by the electrostatic force that would be exerted on a positive test charge $q_0$ placed there such that $E = \frac{F}{q_0} = \frac{kr}{q_0}$. The SI units for Electric Fields are Volts/Meter, V/m. Electric Fields are vectors since they have both a magnitude, and a direction. Point charges generate electric fields that point in the radial directions. Positive charges create electric fields that radiate radially outwards, while negative charges create electric fields that radiate radially inwards.
As mentioned earlier, electric field lines help provide a means for visualizing the magnitude and direction of electric fields. Similarly, equipotential lines show where every point on that line has the same potential, for example 5V, similar to that of a topographical map showing elevation, as shown above.

It is important to note that the electric field vector at any point is tangent to a field line through that point as you can see with the right angle indicators. Likewise, equipotential lines that are closer together show a strong electric field and as you become further from the charges, the electric field will become weaker shown by the distance between the field lines becoming greater.

**SAFETY REMINDER**

- Follow directions for using the equipment.
- Don’t exceed 10 volts from the power supply.
- Always have the corkboard beneath the conductive paper during the activity.
Setup

1. A Conductive Paper with two charge configurations will be provided. One will be two point charges, and the other will be two parallel line charges.

2. Lay the Conductive Paper onto the Equipotential and Field Mapper kit with the side with the charge configurations facing upwards.

3. Take two of the push-ins, and insert one into each of the points of the two point charges configuration.

4. Open the PASCO Capstone software.
   - Click on Hardware Setup
   - If the image of the 850 PASCO Interface isn’t in the Hardware Setup window then click on Choose Interface (if it is there skip to step 5)
   - Click on Automatic Detect
     - In the Hardware Setup window an image of the 850 PASCO Interface should now be there.

5. On the picture of the 850 PASCO Interface click on the Ch(A) of the Analog Inputs, then scroll down, and select the Voltage Sensor. Now plug in the Voltage Sensor to the Ch(A) of the Analog Inputs.

6. At the bottom of the main screen, set the sample rate of the Voltage Sensor to 10.0 Hz.
   - Click Signal Generator
   - Click on 850 Output 1.
   - Set the Waveform to DC, and set the DC Voltage to 5V.
   - Under the Voltage Limit section, set the Voltage Limit to 5V.
   - Set the Signal Generator to start when capture is started by clicking AUTO. (NOTE: When changing the voltage of the signal generator, the Signal Generator must be stopped and restarted for the change in the voltage to occur. This can be done by stopping the capture if AUTO is selected, or by clicking OFF and then ON.)
     - On the right side of the main screen click and drag the Digits display into the work area.
     - Select Voltage (V) as the measurement.
     - On the Digits Display tool bar, click the icon with red arrow pointing left (should be the second icon from the left), to reduce the displayed decimals to two.

7. Attach the cable from the red (positive) port of the power supply, on the right side of the 850 PASCO Interface, to one ‘point’ charge on the conductive paper located at 2.00 cm.

8. Attach the cable from the black (negative) pot of the power supply, on the right side of the 850 PASCO Interface, and the black cable of the volt meter to the other ‘point’ charge on the conductive paper located at 18.00 cm.
Procedure (Point Charge Configuration)

Part 1: Measuring the Electric Field directly between the two charges

1. Click ‘record’ to start the Voltage Sensor.
2. Starting at the positive point charge itself use the red cable of the voltage sensor to measure the voltage every 2.00 centimeters along the straight line between the positive and negative point charges. Record your data as $V_i (V)$ in Table 1 below.
   - The voltage reading at the negative charge itself will be something to the negative fourth power. This reading is due to ‘noise’ in the data set. Record it as ‘0.00 V’.

Part 2: Finding Equipotential lines

1. Click ‘Record’ to start the Voltage Sensor.
2. Using the red probe of the voltage sensor find a location on the conductive paper that has voltage measurement of 1.00 V, or as close as you can get to 1.00 V.
   - Mark this spot with the provided silver pen.
   - Find at least 6 more locations on the conductive paper where the voltage is 1.00 V, or as close as you can get, and mark each of them with the provided silver pen. Make sure the locations you find are spread out, and not all right next to each other.
   - Using the provided silver pen draw a nice smooth curved line connecting all the dots that mark a voltage value of 1.00 V. If you are capable of drawing a complete ‘circle’ on the conductive paper with these dots do so.
   - Then repeat this for voltages 2.00 V, 2.50 V, 3.00 V, & 4.00V equipotential lines are.

Part 3: Finding Electric Field lines

1. Remove the black probe of the voltage sensor from the negative point charge.
2. Hold together the ends of the voltage probes of the Voltage Sensor so that the two tips are a fixed distance apart.
3. Set the voltage of the power supply to 5 Volts.
4. Hold the voltage leads at an angle so the tips of the black voltage lead touches the conductive paper at the point of an arrow and the tip of the red voltage lead does not quite touch the paper.
5. Tilt the voltage leads upright so both tips touch the conductive paper. Now pay attention to the voltage in the Digits Display in Capstone.
6. Keep the black tip stationary while slowly pivoting the red tip side-to-side. When the displayed voltage is the highest, stop moving the tip of the red voltage lead.
7. Draw an arrow on the conductive paper from the tip of the black lead to the tip of the red lead.
8. Move the tip of the black lead to the head of the arrow you just drew.
9. Repeat steps 3 – 7 as many times needed till you have crossed the conductive paper all the way to the other charge.
10. Then move the voltage leads back to the negative pushpin and select a new point near the push pushpin at which to place the tip of the black lead.
11. Repeat this whole process till you have 7 lines of arrows going from one charge to the other charge.
12. After you have mapped the electric field, click on ‘stop’ in the Signal Generator Tab.

Procedure (Parallel Line Charge Configuration)
1. Repeat Part 1, Part 2, and Part 3 for the configuration of two parallel line charges and enter the data in Table 2.
   • When measuring the voltage every 2.00 centimeters between the parallel lines start from the middle of the positive line charge, and go straight to the middle of the negative line charge.
Analysis

Table 1

<table>
<thead>
<tr>
<th>( V_i ) (V)</th>
<th>( X_i ) (m)</th>
<th>( E ) (V/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.040</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.060</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.080</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.180</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Complete the chart by calculating the average magnitude of the electric field between each two consecutive locations by dividing the difference in the magnitude of the voltages at each of the two locations by the displacement between the two locations. Then find their average value and record it in the last row. (10 points)

2. Calculate the average value of the electric field along the straight line between the two point charges by dividing the difference in the magnitude of the voltages at the two point charges by the displacement between the two point charges. Then take the % difference between your two values for the average electric field between the two point charges. (5 points)
Table 2

<table>
<thead>
<tr>
<th>V(_i) (V)</th>
<th>X(_i) (m)</th>
<th>E (V/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.040</td>
<td></td>
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<tr>
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<tr>
<td>0.120</td>
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<td></td>
</tr>
<tr>
<td>0.140</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.160</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.180</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E(_{avg}) (V/m)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3. Complete the chart by calculating the average magnitude of the electric field between each two consecutive locations by dividing the difference in the magnitude of the voltages at each of the two locations by the displacement between the two locations. Then find their average value and record it in the last row. (10 points)

4. Calculate the average value of the electric field along the straight line between the two parallel line charges by dividing the difference in the magnitude of the voltages at the two parallel lines by the displacement between them. Then take the % difference between your two values for the average electric field between the parallel line charges. (5 points)

5. A straight electric field line is supposed to represent a constant electric field. Does your data for both configurations, more or less, agree with this? If not what are some plausible explanations? (5 points)
6. Why is your data for the parallel line configuration much more consistent than your data for the two point charge configuration? (5 points)

7. Using one of the blank copies of the grid paper included in the hand out sketch the field lines based on the data you obtained during this experiment for each configuration. Do your experimental results match your expectations for these two configurations? If not, explain possible reasons why your expectations and your experimental results are not in agreement. (15 points)

8. What is the relationship between the density of the equipotential lines, the density of the electric field lines and the strength of the electric field? (10 points)

9. What would happen if you placed your hand on the conductive paper while taking a measurement? Does it affect the measurement? Why or why not? (10 points)

10. Sometimes the units for an electric field are written as N/C, while other times the units are written as V/m, using dimensional analysis show that N/C is equal to V/m. (5 points)