# Lab 2.   Electric Fields

## Goals

- To understand how contour lines of equal voltage, which are easily measured, relate to the electric field produced by electrically charged objects.
- To learn how to identify regions of strong and weak electric fields from maps of electric field lines.
- To quantitatively estimate the magnitude and direction of an electric field using experimental voltage measurements.

## Introduction

The concept of the electric field is useful in determining the force on a charged object due to the presence of other charges. The purpose of this laboratory is to quantitatively map, in two dimensions, a set of equipotential lines for two different charge distributions using a voltmeter. An equipotential line connects the set of points for which the potential difference or voltage has a constant value. The two-dimensional charge distributions will be established by applying a potential difference between a pair of conducting electrodes. The electrodes are attached to a board covered with conducting paper. From these equipotential lines the electric field can be determined. Electric field lines always cross equipotential lines at right angles as a consequence of the definition of electric potential. By convention, electric field lines start on positive charges and end on negative charges.

You will use a voltmeter to locate different points on the black conducting paper for which the voltage differences between the points in question and a reference point (say, at zero potential) are the same. These points are recorded on a white sheet of paper with the same grid pattern as the conducting paper. Then connect these points of equal voltage to form an equipotential line. Be sure to connect points with smooth curves, not straight lines with sharp corners. Verify the equipotential line is roughly accurate by testing a point drawn which was not previously measured.

From a set of equipotential lines you can create a map of the vector electric field following the rules stated at the end of the first paragraph of the Introduction section. Since electric field lines start from and end on electrical charges, higher densities of field lines near the electrodes indicate regions of higher charge concentration. From a complete electric field map, the charge densities on the electrodes themselves can be deduced.

# Electric field of a long plate parallel to a long rod

## Equipment set-up

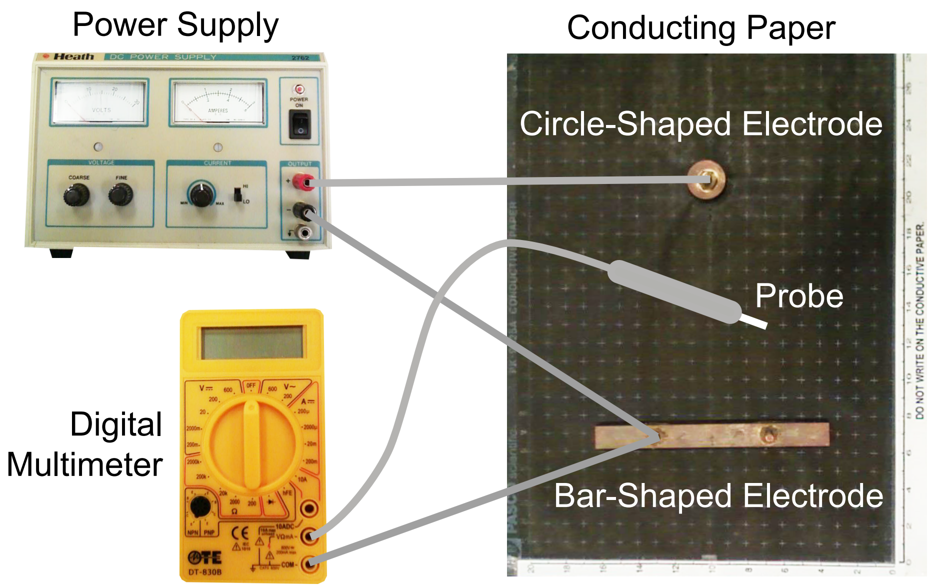


Figure 2.1. Electrical connections.

1. On the white paper grids provided, carefully draw the outlines of the brass electrodes at the same positions as they appear on the black conductive paper.
2. Connect the positive terminal (red jack) of the power supply to the circle-shaped electrode on the conductive paper, as shown in Figure 2.1. This will produce a net positive charge on the circular electrode. Connect the negative terminal (black jack) of the power supply to the bar-shaped electrode on the conductive paper. This will produce a net negative charge on the bar electrode. Use "alligator clips" to connect the wires from the power supply to the electrodes. This configuration simulates the electric field between a positively charged rod and a negatively charged plate.
3. Adjust the current knob on the power supply to the straight-up or 12 o'clock position. Then turn the power supply on and adjust the COARSE voltage control knob to set the voltage to about 5 V as read on the voltmeter on the front of the power supply.
4. Connect the common (COM) terminal of the digital multimeter (DMM) to the bar-shaped electrode. Connect the wire lead with the probe to the V-Ω (volt-ohm) terminal of the DMM, and set the selector knob to measure DC Voltage (V with a solid and dashed straight line). If your multimeter has values listed on the selector knob options, set the range knob to 20 DCV. If no values are listed, then the DMM is auto-ranging.
5. Verify that you have a good electrical connection between the bar-shaped electrode and the power supply by touching the probe to the bar-shaped electrode. The voltage reading should be zero. If this is not the case, ask your TA for assistance.
6. Now fine tune the adjustment of the power supply by: (1) touching the probe to the circle-shaped electrode, and (2) turning the FINE voltage control knob on the power supply until

the voltage reading on the DMM lies between 4.90 and 5.10 V, making sure that the reading is stable. Once set, this voltage should remain constant for the mapping of all the equipotential lines for a given electrode configuration. Check it from time to time as you make your map, and adjust the voltage as necessary to maintain this voltage reading. Be sure to record the actual measured voltage.

7. Touch the probe to the conductive paper at a few random points. The voltage readings on the DMM should lie between zero and the value you measured on the circle-shaped electrode. If this is not the case, ask your TA for assistance.

**Caution: Do not mark the conductive paper with pencils or pens, or poke holes in it with the pointed probe.**

## Data collection

Choose some convenient voltages between 0 and 5 V, say 0.50, 1.00, 1.50, etc.

1. Using the probe find a point on the conducting paper that gives a voltage of 0.50 ± 0.01 V. Mark this point on the white grid paper using a symbol of your choice (such as a small x). Now move the probe 1–2 cm away from the point you just located and search for another point on the conducting paper that gives a reading of 0.50 ± 0.01 V. Mark this point on the white grid paper using the same symbol. Continue this process until you reach the edge of the conducting paper or you run into points already located. Now connect these points with a smooth line (Don't just connect the dots with straight line segments!) and label this line "0.50 V". This is the first equipotential line for this electrode configuration.
2. Repeat the process outlined in (a) above for points with a voltage of 1.00 ± 0.01 V, using another symbol to mark these points on (such as a small o). Alternating the plot symbols will clearly distinguish the various lines of equal potential. Repeat this process for the other voltage values.
3. If you have any large blank regions on your map, choose an intermediate value of potential (one that falls between the voltages of previously drawn equipotential lines) and fill in the "blanks."
4. Each electrode is also an equipotential. Try it by touching the probe to the electrode at various points; you may have to rub the probe on the brass gently to make good electrical contact because of the layer of tarnish that forms on brass. Record the voltage of each electrode on your white grid paper.

## Data analysis

First sketch in the electric field lines associated with the equipotential lines measured previously by following the "rules" for field lines as outlined in the Introduction. Since each conducting electrode is an equipotential surface, electric field lines that start or end on a conducting surface must be perpendicular to the surface where they touch it. A suggestion is to start at a point on the positive electrode and draw a smooth continuous line which crosses all equipotential lines at right angles. Extend each line until you either reach the edge of the paper or the negative electrode. Pick other points on the positive electrode and repeat this process.

From the definition of electric potential, the magnitude of the electric field, $|\mathbf{E}|$, is related approximately to the electric potential (or voltage), $V$, in the following way:

$$|\mathbf{E}| = \frac{\Delta V}{\Delta s} \tag{2.1}$$

where $\Delta V$ is the difference in voltage between two equipotential lines and $\Delta s$ is the distance between the two equipotential lines measured along an electric field line. This approximation becomes exact in the limit as the distance between the two equipotential lines approaches zero. In our case we must be content with approximate values for the electric field. The electric field is perpendicular to nearby equipotentials, and points from high potential to low. Be sure to indicate the direction of each field line with arrows. Don't leave any large regions of your map devoid of field lines.

Pick 8–10 points on your electric field map and calculate the approximate values of the electric field using the above equation. Be sure to use adjacent equipotential lines in order to make the approximation better. When you do this, you are finding the average electric field between the two equipotentials, which will closely approximate the actual value of the electric field midway between the two equipotentials. Use a special plot symbol (a different color pen or pencil would be good) to indicate on your map the locations of the points at which you calculate the magnitudes of the electric field. Label the points $P_1$, $P_2$, etc. Show the calculations for each point in your report. Try to locate the places on your map where the electric field is largest and where it is smallest by this process.

## Another electrode configuration

Replace your conducting board with another board with a different configuration of electrodes.

Choose the polarity of each electrode and connect the power supply appropriately. Some electrodes may be left neutral or unconnected. Your TA will have special instructions for some electrode configurations.

Repeat the process above to create and analyze another map.

## Summary

Based on your electric field maps and calculations of the magnitude of the electric field, make some general observations about where the electric field tends to be largest and smallest. Is it possible to predict from the electric field lines alone where the field will be large or small? Explain your reasoning.

# Grading Rubric

| | No Effort | Progressing | Expectation | Exemplary |
|---|---|---|---|---|
| **AA**<br>Is able to extract the information from representation correctly<br>Labs: 1-12 | No visible attempt is made to extract information from the experimental setup. | Information that is extracted contains errors such as labeling quantities incorrectly, mixing up initial and final states, choosing a wrong system, etc. Physical quantities have no subscripts (when those are needed). | Most of the information is extracted correctly, but not all of the information. For example physical quantities are represented with numbers and there are no units. Or directions are missing. Subscripts for physical quantities are either missing or inconsistent. | All necessary information has been extracted correctly, and written in a comprehensible way. Objects, systems, physical quantities, initial and final states, etc. are identified correctly and units are correct. Physical quantities have consistent and informative subscripts. |
| **AB**<br>Is able to construct new representations from previous representations<br>Labs: 1-12 | No attempt is made to construct a different representation. | Representations are attempted, but omits or uses incorrect information (i.e. labels, variables) or the representation does not agree with the information used. | Representations are constructed with all given (or understood) information and contain no major flaws. | Representations are constructed with all given (or understood) information and offer deeper insight due to choices made in how to represent the information. |
| **AF**<br>Sketch<br>Labs: 1-3, 5, 7-9 | No representation is constructed. | Sketch is drawn but it is incomplete with no physical quantities labeled, or important information is missing, or it contains wrong information, or coordinate axes are missing. | Sketch has no incorrect information but has either a few missing labels of given quantities. Subscripts are missing or inconsistent. Majority of key items are drawn. | Sketch contains all key items with correct labeling of all physical quantities have consistent subscripts; axes are drawn and labeled correctly. |
| **BA**<br>Is able to identify the phenomenon to be investigated<br>Labs: 1, 2, 4, 6, 7, 9, 11, 12 | No phenomenon is mentioned. | The description of the phenomenon to be investigated is confusing, or it is not the phenomena of interest. | The description of the phenomenon is vague or incomplete but can be understood in broader context. | The phenomenon to be investigated is clearly stated. |
| **BE**<br>Is able to describe what is observed concisely, both in words and by means of a picture of the experimental setup.<br>Labs: 1, 2, 4, 6, 7, 9, 11, 12 | No description is mentioned. | A description is incomplete. No labeled sketch is present. Or, observations are adjusted to fit expectations. | A description is complete, but mixed up with explanations or pattern. OR The sketch is present but relies upon description to understand. | Clearly describes what happens in the experiments both verbally and with a sketch. Provides other representations when necessary (tables and graphs). |

| | No Effort | Progressing | Expectation | Exemplary |
|---|---|---|---|---|
| **BF**<br>Is able to identify the shortcomings in an experiment and suggest improvements<br>Labs: 1, 2, 4, 6, 7, 9, 11, 12 | No attempt is made to identify any shortcomings of the experimental. | The shortcomings are described vaguely and no suggestions for improvements are made. | Not all aspects of the design are considered in terms of shortcomings or improvements, but some have been identified and discussed. | All major shortcomings of the experiment are identified and reasonable suggestions for improvement are made. Justification is provided for certainty of no shortcomings in the rare case there are none. |
| **BG**<br>Is able to identify a pattern in the data<br>Labs: 1, 2, 4, 6, 7, 9, 11 | No attempt is made to search for a pattern | The pattern described is irrelevant or inconsistent with the data. | The pattern has minor errors or omissions. OR Terms labelled as proportional lack clarity- is the proportionality linear, quadratic, etc. | The patterns represents the relevant trend in the data. When possible, the trend is described in words. |
| **BI**<br>Is able to devise an explanation for an observed pattern<br>Labs: 1, 2, 4, 6, 7, 9, 11 | No attempt is made to explain the observed pattern. | An explanation is vague, not testable, or contradicts the pattern. | An explanation contradicts previous knowledge or the reasoning is flawed. | A reasonable explanation is made. It is testable and it explains the observed pattern. |
| **GB**<br>Is able to evaluate specifically how identified experimental uncertainties may affect the data<br>Labs: 2, 7, 8 | No attempt is made to evaluate experimental uncertainties. | An attempt is made to evaluate experimental uncertainties, but most are missing, described vaguely, or incorrect. Or only absolute uncertainties are mentioned. Or the final result does not take the uncertainty into account. | The final result does take the identified uncertainties into account but is not correctly evaluated. The weakest link rule is not used or is used incorrectly. | The experimental uncertainty of the final result is correctly evaluated. The weakest link rule is used appropriately and the choice of the biggest source of uncertainty is justified. |
| **GC**<br>Is able to describe how to minimize experimental uncertainty and actually do it<br>Labs: 2, 7, 8 | No attempt is made to describe how to minimize experimental uncertainty and no attempt to minimize is present. | A description of how to minimize experimental uncertainty is present, but there is no attempt to actually minimize it. | An attempt is made to minimize the uncertainty in the final result is made but the method is not the most effective. | The uncertainty is minimized in an effective way. |
| **GD**<br>Is able to record and represent data in a meaningful way<br>Labs: 1, 2, 4-12 | Data are either absent or incomprehensible. | Some important data are absent or incomprehensible. They are not organized in tables or the tables are not labeled properly. | All important data are present, but recorded in a way that requires some effort to comprehend. The tables are labeled but labels are confusing. | All important data are present, organized, and recorded clearly. The tables are labeled and placed in a logical order. |

| | No Effort | Progressing | Expectation | Exemplary |
|---|---|---|---|---|
| **GE**<br>Is able to analyze data appropriately<br>Labs: 1, 2, 4-12 | No attempt is made to analyze the data. | An attempt is made to analyze the data, but it is either seriously flawed or inappropriate. | The analysis is appropriate but it contains minor errors or omissions. | The analysis is appropriate, complete, and correct. |
| **IA**<br>Is able to conduct a unit analysis to test the self-consistency of an equation<br>Labs: 2-9, 10 | No meaningful attempt is made to identify the units of each quantity in an equation. | An attempt is made to identify the units of each quantity, but the student does not compare the units of each term to test for self-consistency of the equation. | An attempt is made to check the units of each term in the equation, but the student either mis-remembered a quantity's unit, and/or made an algebraic error in the analysis. | The student correctly conducts a unit analysis to test the self-consistency of the equation. |
| **SA**<br>Is able to identify an optimally relevant special-case for analysis<br>Labs: 2, 3, 9, 10 | No attempt is made to identify a relevant special case | An attempt is made, but the identified special case is either irrelevant or ill-defined | A relevant special case is identified, but it is not an optimal special case (i.e., there are other special cases which give a stronger, more clear-cut analysis of the solution) | A optimally relevant special case is identified and clearly stated |

**EXIT TICKET:**

- ☐ Quit any software you have been using.
- ☐ Straighten up your lab station. Put all equipment where it was at start of lab.
- ☐ Report any problems or suggest improvements to your TA.
- ☐ Have TA validate Exit Ticket Complete.