

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

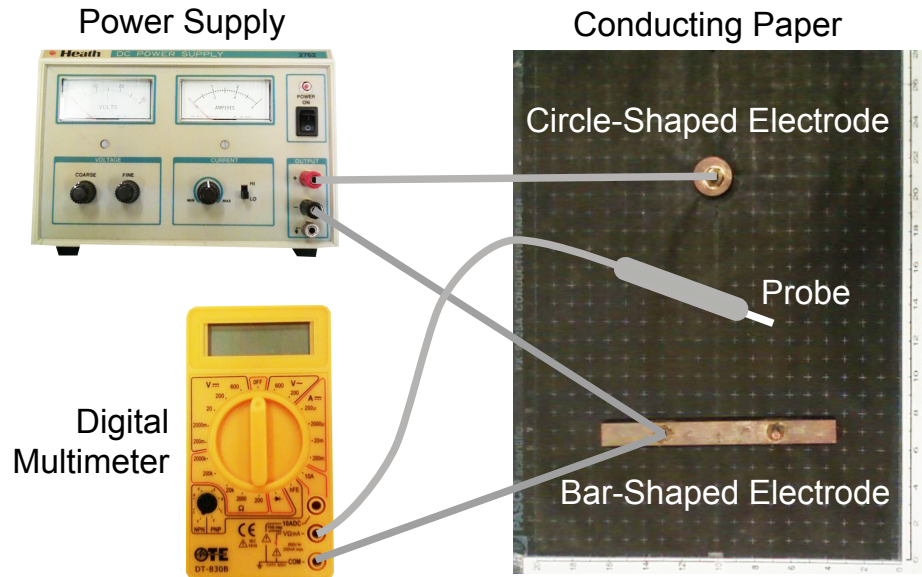


Figure 2.1. Electrical connections.

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:

$$|\mathbf{E}| = \frac{\Delta V}{\Delta s} \quad (2.1)$$

where ΔV is the difference in voltage between two equipotential lines and Δs 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.

	No Effort	Progressing	Expectation	Scientific
SL.A.a Is able to analyze the experiment and recommend improvements Labs: 1-3, 5, 7, 9, 11, 12	No deliberately identified reflection on the efficacy of the experiment can be found in the report	Description of experimental procedure leaves it unclear what could be improved upon.	Some aspects of the experiment may not have been considered in terms of shortcomings or improvements, but some are 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.
SL.B.b Is able to explain patterns in data with physics principles Labs: 1-3, 5, 7, 9-11	No attempt is made to explain the patterns in data	An explanation for a pattern is vague, OR the explanation cannot be verified through testing, OR the explanation contradicts the actual pattern in the data.	An explanation is made which aligns with the pattern observed in the data, but the link to physics principles is flawed through reasoning or failure to understand the physics principles.	A reasonable explanation is made for the pattern in the data. The explanation is testable, and accounts for any significant deviations or poor fit.
SL.B.c Is able to explain steps taken to minimize uncertainties and demonstrate understanding through performance where able. Labs: 2, 6	No explicitly identified attempt to minimize uncertainties and no attempt to describe how to minimize uncertainties present	No explicitly identified attempt to minimize uncertainties is present, but there is a description of how to minimize experimental uncertainty.	An attempt is made and explicitly identified for minimizing uncertainty in the final lab results, but the method is not the most effective.	The uncertainties are minimized in an effective way.
CT.B.a Is able to describe physics concepts underlying experiment Labs: 1-3, 5, 7, 9-12	No explicitly identified attempt to describe the physics concepts involved in the experiment using student's own words.	The description of the physics concepts underlying the experiment is confusing, or the physics concepts described are not pertinent to the experiment for this week.	The description of the physics concepts in play for the week is vague or incomplete, but can be understood in the broader context of the lab.	The physics concepts underlying the experiment are clearly stated.
QR.B Is able to identify a pattern in the data graphically and mathematically Labs: 1-3, 5, 7, 9-11	No attempt is made to search for a pattern, graphs may be present but lack fit lines	The pattern described is irrelevant or inconsistent with the data. Graphs are present, but fit lines are inappropriate for the data presented.	The pattern has minor errors or omissions. OR Terms labelled as proportional lack clarity - is the proportionality linear, quadratic, etc. Graphs shown have appropriate fit lines, but no equations or analysis of fit quality	The patterns represent the relevant trend in the data. When possible, the trend is described in words. Graphs have appropriate fit lines with equations and discussion of any data significantly off fit.

	No Effort	Progressing	Expectation	Scientific
QR.C Is able to analyze data appropriately Labs: 1-4, 6, 7, 9-12	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 for the data gathered, but contains minor errors or omissions	The analysis is appropriate, complete, and correct.
IL.A Is able to record data and observations from the experiment Labs: 1-12	"Some data required for the lab is not present at all, or cannot be found easily due to poor organization of notes. "	"Data recorded contains errors such as labeling quantities incorrectly, mixing up initial and final states, units are not mentioned, etc. "	Most of the data is recorded, but not all of it. For example measurements are recorded as numbers without units. Or data is not assigned an identifying variable for ease of reference.	All necessary data has been recorded throughout the the lab and recorded in a comprehensible way. Initial and final states are identified correctly. Units are indicated throughout the recording of data. All quantities are identified with standard variable identification and identifying subscripts where needed.
WC.A Is able to create a sketch of important experimental setups Labs: 1, 2, 4-8	No sketch 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, or subscripts are missing/inconsistent. Majority of key items are drawn with indication of important measurements/locations.	Sketch contains all key items with correct labeling of all physical quantities and has consistent subscripts. Axes are drawn and labeled correctly. Further drawings are made where needed to indicate precise details not possible in the scale of initial sketch.

Print this page. Tear in half. Each lab partner should submit their half along with the lab report and then retain until the end of semester when returned with evaluations indicated by TA.

Lab 2 Electric Fields:

Name: _____

Lab Partner: _____

EXIT TICKET:

- ☐ Turn off your multimeter
- ☐ Quit any software you have been using.
- ☐ Straighten up your lab station. Put all equipment where it was at start of lab.
- ☐ Required Level of Effort.
 - ☐ Complete the pre-lab assignment ☐ Arrive on time
 - ☐ Work well with your partner ☐ Complete the lab or run out of time

SL.A.a	
SL.B.b	
SL.B.c	

CT.B.a	
QR.B	

QR.C	
IL.A	
WC.A	

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