Mapping Equipotential Surfaces and Electric Field Lines

PRE-LAB

Review Chapters 1 and 2 in Purcell, paying special attention to the discussion of electric field and electrostatic potential.

Pre-lab Question 1: Figure 1 is a graph of electrostatic potential ϕ vs. radial distance r for a positive point charge. Represent this graph as a plot of equipotential lines in a plane containing the point charge, with equipotential lines at every volt. Because you are restricting your plot to a two-dimensional slice of space, the equipotential surfaces show up as equipotential lines. How can you tell where the electric field is strongest on such a plot?

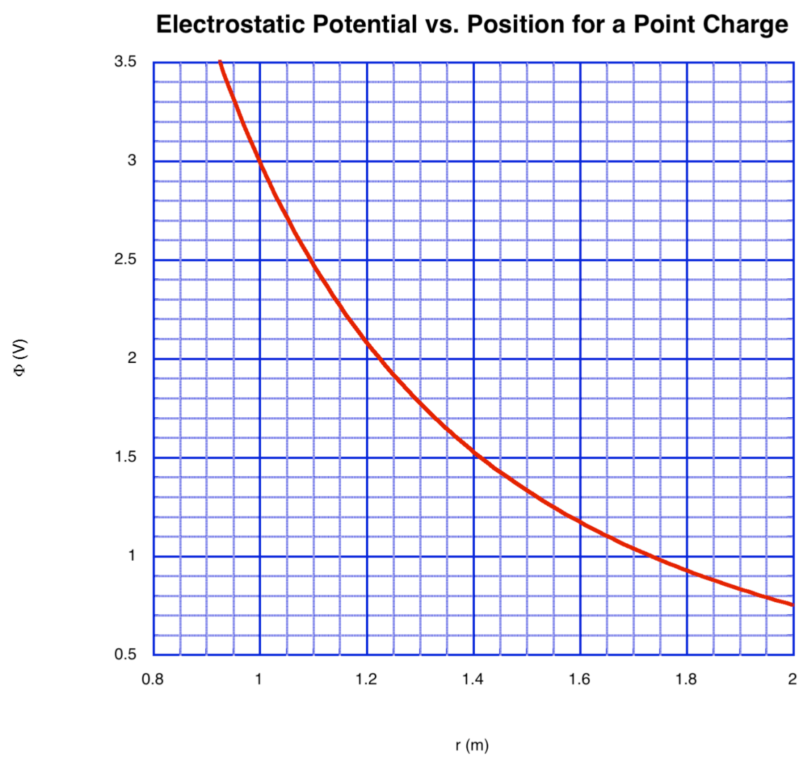

Figure 1. Potential of a positive point charge.

Pre-lab Question 2: Sketch a prediction of the field lines for the arrangement of electrodes shown in Figure 2. The plates are charged so that there is a potential difference of 10 V between them. The center ring is not connected to the voltage source. How does the electric field in the presence of this ring differ from the electric field of the two plates alone?

INTRODUCTION

The electric field **E**(**r**) is a vector function that is proportional to the force on a hypothetical test charge at location **r**. The electric potential ϕ(**r**) is proportional to its potential energy (measured with respect to some reference position). Electric fields and the associated electric potentials arise when there exist arrangements of charge in space. In this lab, you will map the electric potential around two charge configurations using a digital voltmeter. Knowing the relationship between electric potential and electric field, you can find the electric field lines.

PROCEDURE: OVERVIEW

The electrodes are made with silver conductive paint. They are painted on special paper that is impregnated with carbon. While carbon is slightly conductive, it is much more resistive to current flow than a route along the silver electrode. Thus, when the power supply is connected between two different electrodes, each one is essentially at the same potential with the respective power supply terminal. Because there is a potential difference between them, current flows across the sheet from high to low potential just as water flows from regions of high to low gravitational potential.

To map out the electric potential and electric field, you will follow the equipotential lines. That is, you will plot lines showing where the potential is constant. The simplest way to do this is to watch the voltmeter while moving the probe along the paper, attempting to keep the potential constant. It is impossible to do this perfectly, so record how much the meter readings vary. This variation is the uncertainty in your measurement.

The best method is to have one group member trace the equipotential lines with the probe while another group member records the probe's position on the conductive paper with a gel pen. It helps if the person moving the probe stops from time to time to allow his or her partner to record the position. You should record enough data points to sketch a smooth equipotential line. It is vital that you plot the equipotential lines at **regular intervals of potential difference**, such as every 1 Volt. A maximum interval of 2 Volts is recommended. Smaller intervals will give greater detail. Be sure to label each line with the potential it represents.

The electric field is always perpendicular to the equipotential lines. From your maps, you will have enough information to draw in the electric fields produced by the charge configuration. You can also estimate the relative strength of the fields. The electric field is the derivative of the electric potential. (In two or more dimensions, this is called the **gradient**.) In areas where the equipotential lines are closest together, the rate of change in the electric potential is greatest. Therefore, the electric field is strongest in these areas.

First, you will map out the equipotential lines for the electrode configuration shown in Figure 2. Make sure each group member gets experience mapping the equipotential lines with the voltmeter probe. Second, you will determine the configuration of electrodes that produces an equipotential line pattern given to you by the instructor.

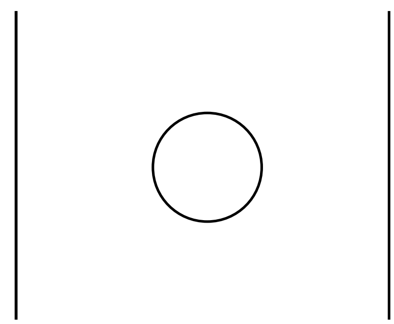

Figure 2. The first electrode geometry.

PROCEDURE: DETAILS

Parallel Plates with Conducting Ring

Connect the plate electrodes to the power supply and apply a potential difference of 10 V across them. Choose the potential of one electrode to be the reference potential (i.e. ϕ=0 V at this electrode.) Using the voltmeter, trace out the equipotential lines, which are given by curves along which the potential stays constant. Make a sketch of this map in your lab notebook. Record the uncertainty in your measurements. Measure the potential at a few locations outside the region between the electrodes as well within the conducting ring, and record your results. Using a gel pen, draw the electric field lines on the equipotential line pattern, with arrows indicating the direction. Indicate the strength of the electric field with the density of field lines. What happens to the field outside of the electrodes?

How well did you predict the shape of the equipotential and electric field lines? Was there anything in the shape that surprised you? What was the electric potential inside the ring? Did it vary? What was the electric field inside the ring? Why?

"Mystery" Configuration

Your instructor will give you the equipotential line pattern for an unknown electrode configuration. Predict what the electrodes must look like and at what potential difference they must be held. Your instructor will then show you how to prepare your electrode pattern using the conductive paint.

While waiting for your pattern to dry completely (this could take as long as 20 minutes), complete the final experiment, "Some Quantitative Measurements".

Once your electrodes are dry, test your prediction, mapping out the equipotential lines as before. If there is some symmetry to the map, take advantage of it when taking data to save time. If your measured equipotential line pattern does not match the one given to you, stop and revise your prediction. Make a new electrode pattern if necessary. Once you have the correct configuration, take enough data to confirm the equipotential line pattern and draw in the electric field lines as in the first configuration.

Some Quantitative Measurements

Return to the parallel plates with the conducting ring. Connect the electrodes to the voltage source as before. Now take some measurements along the center line from one electrode to the other. Record position and potential difference at increments of at least 1 cm (be sure to include measurements inside the conducting ring.) Record estimates of measurement uncertainty.

Enter your data into Kaleidagraph and plot potential difference vs. position (i.e., position is on the x-axis). Use the "General" curve fit to find the slope of each region of the graph. What is the electric field (with uncertainty) at each region?

Compare the electric field **outside** the conducting ring with the electric field for the same parallel electrodes with no conducting ring. If the conducting ring were larger, how would it affect the electric field **outside** the ring?

LAB BOOK CHECKLIST

You should have:

- A detailed sketch of equipotential and electric field lines for Figure 2.
- Predicted electrode configuration for "mystery" equipotential line pattern.
- Results of your predicted electrode configuration for the given equipotential line pattern.
- Data and graph of potential vs. position for Figure 2.
- Responses to questions.