The Equipotential Surfaces of a Dipole
Spring 2024

Introduction

The purpose of this lab is to directly measure a system that simulates the equipotential surfaces between two charges. Since this is the first experiment in which you will use a multimeter, be sure to read the document "Using a Digital Multimeter". *Be sure to bring these multimeter instructions with you to lab for the next few weeks.*

Note: *Each person in the group will produce their own map of the potential field. Also, the multimeter will be referred to as a* ***voltmeter*** *(for measuring voltage) in today's experiment.*

Learning to Use a Multimeter as a Voltmeter

0. You will first collect some simple measurements to familiarize yourself with the basic operation of the multimeter as a voltmeter. Note that the black wire is in the negative (labeled COM) terminal of the multimeter, and the red wire in the positive (V/Ω) terminal. Follow the directions on the last page of the document "Using a Digital Multimeter"; *briefly* record what you did and your measurements in your journal. When you have completed the multimeter exercise, return to this document for the rest of the experiment.

Experiment Background

Figure 1 at right shows the equipment you will use to simulate the potential surfaces around two charges: a conducting paper with wires that connect a voltage source to two metal pins on the paper. The pins are attached to two connectors (red and black) on the lab bench power panel, and the negative (COM) terminal of the voltmeter is attached to the green (ground) connector. The positive (V) terminal of the voltmeter has a free wire that you will use to measure the potential (voltage) at different points on the paper.

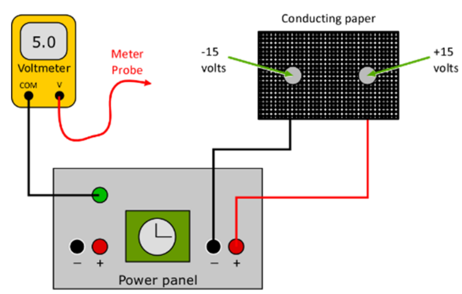

Figure 1: Conducting Paper Connection

The red and black connectors on the power panel are connected to a voltage source that maintains one pin on the paper about +15 V (red) above, and the other about –15 V (black) below the 'reference' potential (the green connector), which is 0 V (**Figures 2 & 3**).

The assumption is that the electric current in the paper (due to these voltage sources) will cause a potential at each point on the paper, which is the same potential you would calculate if the pins were charges in a vacuum.

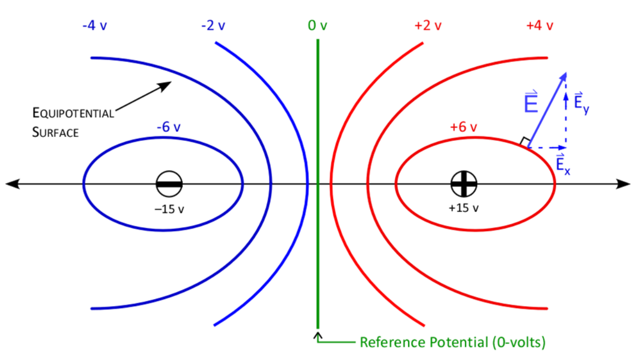

Figure 2: The equipotential surfaces around two charges

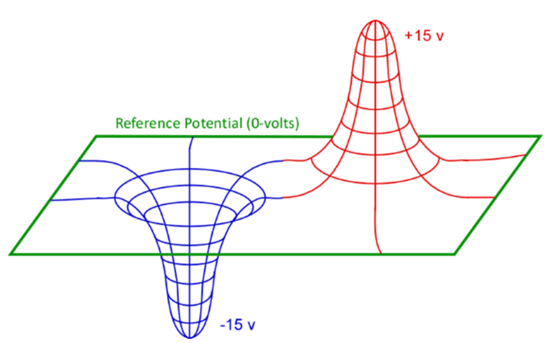

Figure 3: Topographic representation of the equipotential surfaces around two charges

Experiment

1. You will plot your equipotential surface map using the grid supplied in lab. The grid corresponds to the crosses on the conducting paper, with each major division on the graph equal to two crosses on the conducting paper (x ranges between ±6 units, y between ±4 units). Small dots on the grid indicate the positions where you will take your measurements.
2. Reconnect the very long black wire from the negative terminal (COM) of the voltmeter to the green terminal on the lab bench panel. The positive terminal (labeled V/Ω) is connected to the red meter probe that you will use for your measurements.
3. Turn the voltmeter on. Choose a setting so that the meter will read *Direct Current voltage* (DCV) with a precision of one-tenth of one volt (refer to step 2 of "Using a Digital Multimeter"). Record this meter setting in your journal.
4. Touch the probe to the conducting paper. The voltmeter reading, *which is the potential at that point*, will depend on where you touch the conducting paper. The voltage along the y–axis (between the charged pins) should be close to zero. Drag the probe across the paper while watching the voltmeter to get a sense of how the potential behaves. Try to keep your hand off the conducting paper while measuring voltage – it can affect the reading!
5. *Mapping the potential field:* Now measure the potential for each integer x–y pair (the dots on your grid) and *record them on the map*. Be sure to also measure and record the voltage across each pin. <u>You don't need to record the units near each measurement; indicate the units used at the top of the field map</u>.

   If the charges were exactly equal, and the conducting paper uniform, the 0-volt equipotential line would be exactly vertical and an equal distance from both charges. Don't be concerned if this equipotential line does not follow the central vertical axis.
6. If needed, collect a few more measurements to find where the electric potential equals zero volts; mark these positions on your map.
7. *Drawing equipotential lines*. You will now use your previous voltage measurements to draw additional equipotential lines. **Figure 4** shows the voltages for several coordinates on the field map, through which you want to draw an equipotential line for +2 *V*. Mark your map with a small × to indicate the approximate position of the equipotential line with respect to the measured voltages. Note that this position will be closer to points with a voltage near +2 *V*. After the positions are marked, connect the points with a smooth curve and label appropriately. Do this for equipotential lines of 0, +2, +4 and +6 *V*, as well as -2, -4 and -6 V (that's *seven* equipotential lines).

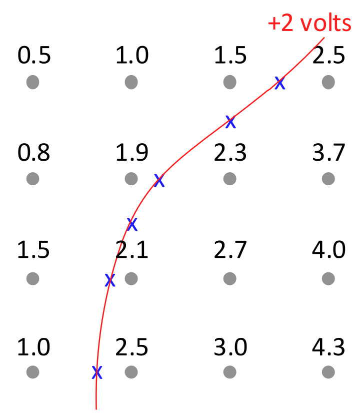

Figure 4: Determining the position of the +2*V* equipotential line

Calculation of Electric Field Vectors

8. *The electric field $\vec{E}$ from the potential V*: The direction of $\vec{E}$ is away from the + charge, towards the – charge, and perpendicular to the equipotential lines at any point. The point at coordinates (2, 1) typically is close to an equipotential line. Copy your measured potentials around point (2, 1) in your journal (**Figure 5a**) and use them to find the components of $\vec{E}$ for your map (**Figure 5b**). Note that Δx and Δy are differences in the *coordinate* position, and there is a negative sign in each equation:

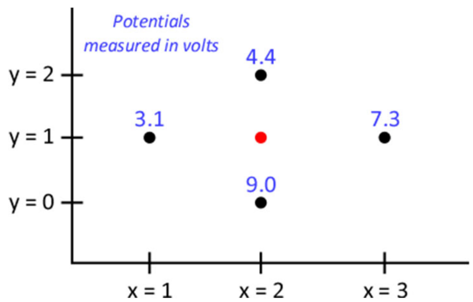

Figure 5a: The measured potentials around (2,1)

$$E_x = -\frac{\Delta\phi}{\Delta x} = -\left(\frac{7.3-3.1}{3.0-1.0}\right) = -2.1\,\tfrac{V}{cm}$$

$$E_y = -\frac{\Delta\phi}{\Delta y} = -\left(\frac{4.4-9.0}{2.0-0.0}\right) = +2.3\,\tfrac{V}{cm}$$

Figure 5b: Calculating E around point (2,1)

9. After finding the components of $\vec{E}$, sketch them *on your field map* at the point (2, 1), using a scale of $1\,\tfrac{V}{cm} = 2\ cm$ drawn on graph (record this scale in the appropriate place of your field map). The vector sum of $\vec{E}_x$ and $\vec{E}_y$ (the value of $\vec{E}$ at that point) should be *perpendicular* to the nearest equipotential surface (as shown in **Figure 2**). Be sure to place the components of $\vec{E}$ tip to tail, as shown in **Figure 6a**.

   Note that the scale of the printed field map is compressed a little bit, so you should use a ruler to measure the component lengths!

10. Repeat steps 8 and 9 for two more of your measured points within 1 *cm* of an equipotential line. **Don't choose points too close to the edge of the paper** since $\vec{E}$ is very weak near the edge.

    Draw Figure 5a for each point *and follow the same pattern for calculating the components as shown in Figure 5b, no matter which quadrant potential points are located.*

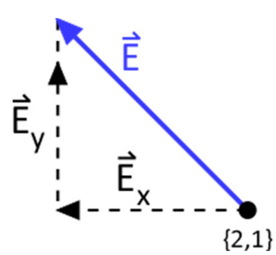

Figure 6a: Correct graphical addition of vectors

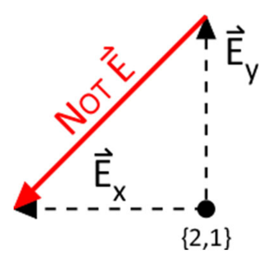

Figure 6b: Incorrect – Don't do this!

Discussion

- Briefly summarize what you did and observed in this experiment (*not the multimeter exercise*).
- In what direction do you expect the $\vec{E}$ vectors to point? Does this agree with the directions you plotted?
- How does your map of the equipotential surfaces compare with an 'ideal' map (**Figure 2**)? Briefly discuss the similarities and differences.

PLEASE TURN OFF THE MULTIMETER WHEN FINISHED!