Electric Potential

Physics Topics

If necessary, review the following topics and relevant textbook sections from Serway / Jewett "Physics for Scientists and Engineers", 10th Ed.

- Electric Fields and Field Lines (Serway Sec. 22.4, 22.5)
- Electric field from a plane of charge (Serway Example 23.8)
- Electric Potential (Serway 24.1 - 24.4)

Introduction

Review of Fields Concept

We have seen that for gravity and electromagnetism, it is helpful to understand the *field* as a way to quantify how masses or charges exert forces on each other without touching. Masses/charges feel a force due to the gravitational/electric field. The field is the force on a mass m (or a charge q) divided by that mass (or charge),

$$\vec{g} = \vec{F}_g/m \tag{1}$$

$$\vec{E} = \vec{F}_E/q \tag{2}$$

Another way of saying this is that the gravitational field is the "gravitational force per mass". The electric field is the"electric force per charge".

Introduction To Electric Potential

There is another quantity called electric potential which is also defined on a "per charge" basis. Electric potential is defined as "potential energy per charge". In physics, only *changes* in potential energy matter so we define the *potential difference*, or voltage difference between two points as the change in potential energy of a charge moved between those two points divided by the value of its charge

$$\Delta V = \Delta U/q \tag{3}$$

Note, the units of electric potential are energy per charge or Joules/Coulomb. The name for this unit is the **Volt**. (1V = 1 J/C).

A Gravitational Analogy

The closest analogy to potential for gravity is "height". Lifting up a 1kg mass by 1.0m will increase its potential *energy* by 9.8J. The change in potential energy per mass is 9.8J/1kg = 9.8J/kg. Lifting up a 2kg mass by 1.0m will increase its potential energy by 2×9.8J = 19.6J. The change in potential energy *per kg* is 19.6 J/(2 kg) = 9.8 J/kg. Note that even though the heavier mass has a higher potential energy than the lighter mass, because they are at the same height they have the same *gravitational potential*. We often represent heights on 2D maps with lines of constant elevation (a topographic map).

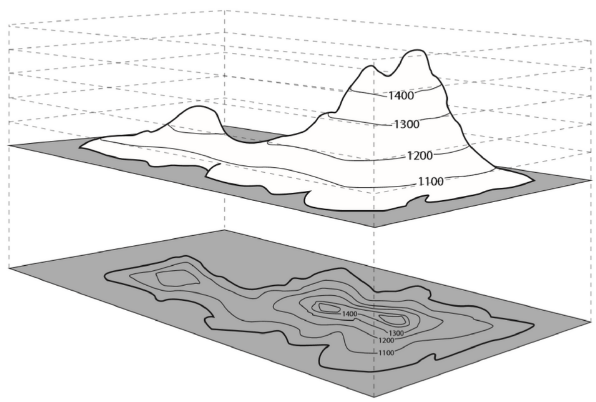

Figure 1 - A Topographic Map. The top part of the image is the actual 3D landscape, the bottom topographic map is a projection of the image with lines representing surfaces of constant elevation. (Source: https://www.greenbelly.co/pages/contour-lines)

We can do the same for electricity. Moving a charge +2C from point A (low potential) to point B (high potential) will require more energy than moving a charge +1C from point A to point B. Thus, the larger charge will have a bigger change in potential energy than the smaller charge, but they will both have the same change in *electric potential* since they start and end at the same points. When drawing a map for electricity, in this case, the lines are not constant height, but lines of constant voltage (electric potential). We call these lines "equipotential lines".

In this lab, you will use metal electrodes (which act like "charges" when they are hooked to a power supply) and conductive paper to try to map the electric potential between two "point charges" and between two metal bars which act like parallel plates. You will also investigate the potential difference as you move along the center line between the charges.

Point charges

In 3-dimensions, the electric potential V at a distance r from a point charge Q is given by

$$V(r) = k_e Q/r \tag{4}$$

If there are multiple charges nearby, the total potential a point P is found by summing the individual potentials $V_{\text{tot}} = \frac{k_e Q_1}{r_1} + \frac{k_e Q_2}{r_2}$ where r_1 is the distance between P and Q_1 and r_1

is the distance between P and r_2. However, in this lab, we will be using conductive paper which is a 2-dimensional surface. On such a surface the electric potential at a point P away from a "point" charge is given by

$$V(r) = 2KQ\ln(r_0/r) \tag{5}$$

where K is a constant, and r_0 is also a constant reference point (note that the potential at position $r_0 = 0$). To find the total potential, you can still add up the potential from two point charges $V_{\text{tot}} = V_1 + V_2 + \ldots.$

"Infinite" Plates

In three dimensions, the field between two large plates of charge is approximately constant. When confined to a 2-dimensional plane, the field between two long lines of charge will also be approximiately constant. In such situations, the potential difference between the bar at lower potential and a point P a distance Δx away from it is

$$\Delta V = |\vec{E}|\Delta x \tag{6}$$

where $|E|$ is the magnitude of the electric field in between the bars/plates.

Pre-Lab Questions

Please complete the following questions prior to coming to lab. They will help you prepare for both the lab and the pre-lab quiz (Found on D2L).

1.) Suppose you are in the vicinity of two point charges <u>in 3 dimensions</u> $+Q$ and $-Q$. The negative charge has (x, y) coordinates $(0, 0)$ while the $+Q$ charge has coordinates $(0, d)$. Using equation (4), write the <u>total</u> electric potential at a point in between the charges (along a line connecting them), a distance r away from the negative charge.

2.) Suppose you are in the vicinity of two point charges $+Q$ and $-Q$ <u>in 2 dimensions</u>. The negative charge has (x, y) coordinates $(0, 0)$ while the $+Q$ charge has coordinates $(0, d)$. Using equation (5), write the <u>total</u> electric potential at a point in between the charges (along a line connecting them), a distance r away from the negative charge.

3.) Simplify your result from the previous question using the rules for logs $\ln(AB) = \ln A + \ln B$ and $\ln(A/B) = \ln(A) - \ln(B)$.

4.) If you took data of V_{total} and r, how could you plot your data so as to form a straight line? What would be the slope of this line?

5.) Suppose you moved a charge of +1C from point A (on a 10V equipotential line) to point B (also on a 10V equipotential line).

(a) How much would its electric potential energy change? Explain.

(b) How much would its electric potential change? Explain.

(c) How (if at all) would the answers to the previous two questions cange if the charge had magnitude 2C? Explain

6.) Suppose you moved a charge of +3C from point A on a 10V equipotential line to point B on a 20V equipotential line.

(a) How much would its electric potential change? Give a value and explain whether it increased or decreased.

(b) How much would its electric potential energy change? Give a value and explain whether it increased or decreased.

(c) How (if at all) would the answers to the previous two questions change if the charge had magnitude 2C? Explain. .

Apparatus

- PASCO Conductive paper
- Power Supply
- Metal electrodes (with embedded magnets to ensure good contact)
- Magnetic board on which paper will be placed
- Banana cables and alligator clips
- Vernier Logger Pro software
- Vernier Computer interface (LabQuest, LabQuest mini, etc..)
- Vernier Differential Voltage Probe

Procedure

Preliminary Setup and Exploration

1.) Connect the differential voltage probe to CH-1 of the Vernier computer interface.

2.) Open the LoggerPro software (no specific file is necessary). You should see a box in the lower right hand corner of the screen reading the voltage difference (electric potential difference between the two leads of the differential voltage probe).

3.) Touch the red and black leads of the differential voltage probe together. When the two leads are touched together, they should be at the same electric potential. Since the probe reads the difference between the leads, it should read zero when the leads are touched together. Select **Experiment** → **Zero** to zero the

Part I - "Point-like" electrodes

Plotting equipotential Lines

1.) Place two of the small circular magnets on the conductive paper and secure in place. Your electrodes should be at least 20 cm apart, lying on the same horizontal line. Record the (x, y) coordinates of each magnet.

2.) Using cables and alligator clips, connect the (+) side of the power supply to the right magnet, and the ($-$) side of the power supply to the left magnet. The magnets are now acting like point charges. **Important: we are using magnets as a simple way to attach a conductive piece of metal to the conductive paper, but this lab does not have anything to do with magnetic fields. We are measuring <u>electric</u> potential. The lab would still work with non-magnetic metals attached to the paper in a different way**.

3.) Set the voltage on your power supply to a value in the range of 2.8 - 3.5 V.

4.) Connect the black lead of the probe to the ($-$) electrode. Touch the red lead to the opposite (+) metal electrode. The voltage reading should match your power supply setting. If this is not the case, make sure all contacts are secure and try again. If your readings are significantly different than this, ask your lab TA for help.

5.) Touch the red lead of the differential voltage probe to the ($-$) metal electrode (but not directly touching the black lead of the probe). Record your observation.

6.) Download and open the Excel Spreadsheet file **PCS125LabPotential.xlsx**. The file is available on D2L.

7.) Immediately save the file with a new file name which includes your name and the word "point", for example: **PCS125LabPotentialSmith_Point.xlsx**

8.) Keeping the black lead of the probe attached to the ($-$) electrode, touch the red lead of the probe to a point directly below the ($-$) electrode. Record the voltage at this point and enter it into the orange box on the spreadsheet. Enter the (x,y) coordinates of the point in green area of the spreadsheet.

9.) By moving to the right and upward, find another point which has the same value of the electric potential as you found in the previous step.

10.) Do your best to estimate the coordinates of the point you found if it does not exactly lie on a "dot" on the conductive paper. Enter the coordinates into the the same column as previously

11.) By systematically moving around the electrode in a counterclockwise fashion, repeat steps (9) - (10), recording the coordinates of at least 5 points which have the same potential as the original point in the Excel spreadsheet. As you enter each of the coordinates into the spreadsheet you should see a line being plotted on a graph. Try to get a good range of points so as to make clear what the shape of the equipotential line is.

12.) Go back a point directly below the $(-)$ electrode and find a different starting point which differs from your previous voltage by at least 0.2V. Repeat steps (8) - (10) for this next equipotential line.

13.) Continue this process until you have plotted at least 3 equipotential lines. Try to keep the interval between your equipotential lines constant (for example, every 0.2V).

14.) Save your file after you have finished taking data and make sure to copy it to a USB or e-mail it to yourself and/or your partner so data does not get lost.

$V(x)$ **along center line for point like electrodes**

1.) Keeping the black lead of the probe attached to the $(-)$ electrode, place the red lead of the probe 1.0 cm to the right, along the line between the two electrodes.

2.) In a spreadsheet and/or in your lab notebooks, record the voltage reading, and the distance r from the $(-)$ electrode.

3.) Now increase the distance between the read lead and the $(-)$ electrode by 1-2 cm. Record the corresponding voltage. Continue taking data until you have a set of data r vs. Voltage. Stop when you are 1cm away from the $(+)$ electrode.

4.) Save your file after you have finished taking data and make sure to copy it to a USB disk or e-mail it to yourself and/or your partner so data does not get lost.

Part II - "Bar-like" electrodes

Plotting equipotential lines

1.) Place two of the longer metal bars (oriented vertically) on the conductive paper and firmly secure in place. Your electrodes should be at least 20 cm apart, with their centers on the same horizontal line. Keep the bars the same distance apart as you had your "point charges". Record the (x, y) coordinates of centers of the bars in your notebook.

2.) Using cables, connect the $(+)$ side of the power supply to the right electrode, and the $(-)$ side of the power supply to the left electrode.

3.) Touch the red lead to the opposite $(+)$ metal electrode. The voltage reading should match the reading on your power supply. If this is not the case, make sure all contacts are secure and try again. If your readings are still significantly outside of this range, ask your lab TA for help.

4.) Touch the red lead of the differential voltage probe to the $(-)$ metal electrode (but not directly touching the black lead of the probe). Record your observation.

5.) Download another copy of the the Excel Spreadsheet file **PCS125LabPotential.xlsx**. The file should be available on the physics lab website.

6.) Immediately save the file with a new file name which includes your name, and the word "bars" for example **PCS125LabPotentialBars_Smith.xlsx**

7.) Repeat all steps as you did previously for the "point-like" electrodes for these "bar" electrodes. Plot at least 3 equipotential lines. Save your file after you have finished taking data and make sure to copy it to a USB disk or e-mail it to yourself and/or your partner so data does not get lost.

$V(x)$ along center line for bar electrodes

1.) Keeping the black lead of the probe attached to the $(-)$ electrode, place the red lead of the probe 1.0 cm to the right, along the line between the two electrodes.

2.) In a spreadsheet and/or in your lab notebooks, record the voltage reading, and the distance r from the $(-)$ electrode.

3.) Now increase the distance between the read lead and the $(-)$ electrode by 1-2 cm. Record the corresponding voltage. Continue taking data until you have a set of data r vs. Voltage. Stop when you are 1cm away from the $(+)$ electrode.

4.) Save your file after you have finished taking data and make sure to copy it to a USB disk or e-mail it to yourself and/or your partner so data does not get lost.

Analysis

1.) Using MS Excel (or any program you choose), plot a graph of V vs. distance r away from the $(-)$ electrode along the center line connecting the electrodes.

2.) On the same graph, plot the data for the point-like electrodes and the bar electrodes.

3.) Using your answers to the pre-lab questions, on a different graph, plot your "point like" electrode voltage vs. distance graph in such a way as to form a linear graph.

4.) Fit the graph you made in the previous part with a linear line. Assuming K has the same numerical value as Coulomb's constant in 3D (but different units) ($K = 9 \times 10^9\,\mathrm{N \cdot m/C^2}$), how much positive charge Q is on the $(+)$ electrode?

5.) Fit the graph of the "bar" electrodes voltage vs. distance with a line. Determine the approximate value of the electric field between the bars.

Wrap Up

The following questions are designed to make sure that you understand the physics implications of the experiment and also to extend your knowledge of the physical concepts covered. Your report should answer these questions in the noted section in a seamless manner.

1.) [Theory] Equipotential lines cannot cross. Explain why not. .

2.) [Discussion] Compare your voltage vs. distance graphs for your point electrodes and your bar electrodes. Which is more linear? Does this make sense according to equations (5) and (6)?

3.) [Discussion] Looking at your equipotential lines for the bar electrodes, what would the lines look like if you used bars which were twice as long? What would the lines look like if the bars were *extremely* (infinitely) long? Explain.

4.) [Discussion] Set up your bar electrodes again and hook them to the power supply as before. Now, using your circular conductor, create a closed "loop" in the middle of the conductive paper. With the black lead of the probe on the ($-$) electrode measure the electric potential at various points inside the ring. Record your observations. Do you have any explanation for what you see?

Report

Labs will be completed in groups, you will enroll in a group with your lab partner at the beginning of each lab session. Each group will submit a single report through the assignment section on D2L.

- **Introduction**
  - What is the experiment's objective?
- **Theory**
  - You may be able to show a derivation of the physics you're investigating, or you may want to reference a source that provides a description/equation representing the physics you're investigating.
  - You may want to provide graphs that illustrate or predict how you expect the system under study to behave.
- **Procedure**
  - Explain the systematic steps required to take any measurements.
- **Results and Calculations**
  - Tabulate your measurements in an organized manner.
  - Based on your procedure, you should know what your tables

  - Provide examples of any calculations.

- **Discussion and Conclusions**
  - Discuss the main observations and outcomes of your experiment.
  - Summarize any significant conclusions.
- **References**
- **(Appendices)**