PHYS 1P92 Experiment 06

Electrostatics: Electric fields and electric potential

Notes

- Words in blue are links to additional reading or videos.
- Text in gray boxes are hints and things to take note of.
- Text in red boxes are important instructions or prompts that guide you to DISCUSS some of the key RESULTS and CONCEPTS learned in the lab. These prompts may not be the only items that need to be included in your report.

1 Objectives

- Measure and plot the electric potential of a parallel plate capacitor.
- Visualize the electric field of a capacitor from derived field lines.
- Learn about experiment planning, when faced with collecting large amounts of data.

IMPORTANT: This is a conceptual lab and does not require you to calculate any values

This means that you DO NOT need to submit the error propagation sheet for this lab.

2 Introduction

Field lines help us visualize *vector fields*, mathematical constructions which are used to model the strength and direction of some force, such as electric, magnetic or gravitational forces.

The concept of field lines was advanced by Michael Faraday (1791-1867), who conceived of lines of force by noting that electric and magnetic forces have a direction and magnitude that can be measured and mapped *everywhere in space!* In fact, Faraday believed in their physical reality, rather than just as a helpful model.

James Clerk Maxwell (1831-1879) took a more of mathematical approach, stating:

> As I proceeded with the study of Faraday, I perceived that his method of conceiving the phenomena was also a mathematical one, though not exhibited in the conventional form of mathematical symbols. I also found that these methods were capable of being expressed in the ordinary mathematical forms...
>
> For instance, Faraday, in his mind's eye, saw lines of force traversing all space where the mathematicians saw centres of force attracting at a distance... [1]

Thus today we say that "a field is a way of conceptualizing and mapping the force that surrounds any object and acts on another object at a distance without apparent physical connection." (Openstax: Electric Field)

Likewise, electric potential is a type of potential energy that can exert a force on charged particles, such as electrons in a conductive material. The potential energy (at a point in space) is equal to the kinetic energy a test particle would gain if we let go it.

The electric potential V is the electric potential energy per unit charge

$$V = \frac{PE}{q}. \tag{1}$$

and has the units of

$$1V = 1\frac{J}{C}. \tag{2}$$

We can represent electric potentials (voltages) pictorially, just as we can draw pictures to illustrate electric fields, such as in Figure 1. While we use arrows to represent the magnitude and direction of the electric *field*, we use contour lines to represent places where the electric *potential* is constant. *Think about it;* by definition these lines must cross.

[1] A Treatise on Electricity and Magnetism (1873) James Clerk Maxwell

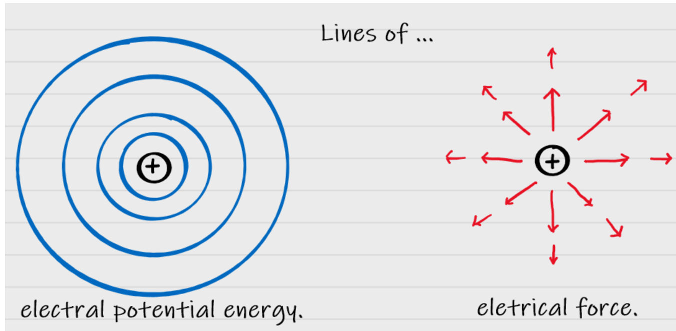

Figure 1: If you place a positive-charged test point particle near the charges in the figure, the test particle will both: (1) have same **potential energy** at any point along the blue circles, decreasing in magnitude the farther you are from the center; (2) experience a **force** in the direction of the red arrows, decreasing in magnitude the farther you are from the center.

We will use the iOLab to measure the electrical potential everywhere in 2-dimensional space around two charged objects, then from that data, draw the electric field lines that define the force an infinitesimal positive test charge at rest would feel at that point.

3 Procedure

In this lab, you will need an ordinary sheet of paper, a ruler, and items from the 1P92 kit:

- The black sheet of conductive paper
- The white pencil
- The metallic copper tape
- Three alligator-to-pin wire leads

3.1 Setting up the test area

3.1.1 Determining Conductive side of paper

IMPORTANT The conductive paper is only conductive on one side. First you must determine which side is conductive for you by doing the following!

- Take the conductive paper and clip one end of the alligator to pin connectors to one side of the paper.

- Repeat this step on the other side with a new alligator to pin connector.
- plug one of these connectors into the `DAC` and the other into one of the `GND` plugs.
- in iOLab online check the `DAC` box and set it to 3.09V
- connect one more pin to alligator connector into the `A7` pin. Make sure that the plastic is around the alligator is secure, if it has fallen down the wire you must bring it back, it is important that you do not touch the metal of the `A7` alligator clip!
- your setup should now look like Figure 2
- take about 10 seconds of `A7 Sensor` data dragging the clip across the paper from the `DAC` to `GND` side of the paper.
- If it looks like Figure 3 RIGHT SIDE ie the data follows an easy to distinguish trend where the points are close together then you have just dragged the detector on the good side of the paper. Using the white pencil put a small 'G' on one corner of this side of the paper so you don't forget.
- If it looks like Figure 3 LEFT SIDE ie there isn't really a trend it is just noise then use the white pencil to write a 'G' on the **other side** of the paper, as you just ran the A7 detector across the bad side.
- If you cannot tell which one it is try dragging the A7 sensor across the other side of the paper and compare your two graphs. The one that looks most like Figure 3 RIGHT SIDE corresponds to the good side of the paper

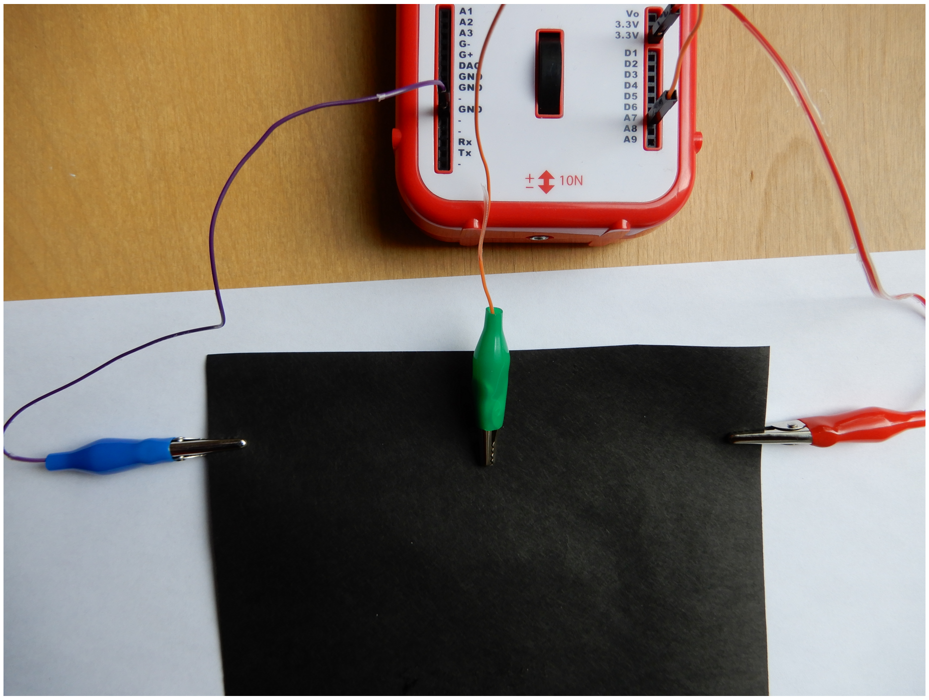

Figure 2: Experimental setup to test the conductivity of the paper

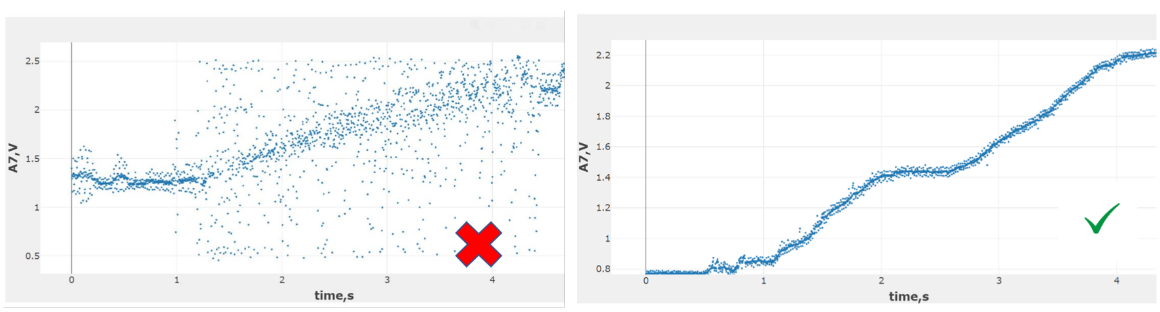

Figure 3: A7 sensor output as it is dragged along the paper from the GND to DAC side. Left image is when A7 is dragged across the BAD side of the paper, where the voltage reading jumps by more than 1V on average from point to point. Right image is the good side where the voltage reading jumps by less than 0.1V from one point to the next.

3.1.2 Setting up the experiment

On a non-conductive surface (i.e. not metal), tape down the piece of regular paper. On top of that, tape down your black conductive paper**Good side facing up - ie you can see the**

letter 'G' you made when it is taped down. Smooth and flatten the conductive paper as much possible and neatly tape around the edges to hold it flat.

> Many fibrous materials can be made to conduct electricity such as fabric and paper. The conductive paper is black because of its high carbon content.

Use the white pencil and a ruler to lay out a 12 cm×10 cm grid of dots on the paper. **Do not start at the corner, but try to center the grid on the black paper. It doesn't need to be exact**

> How many grid points total are there on a 12 cm×10 cm grid?

> You will be taking data at each grid point, so to keep track of them all, we suggest labeling them. One suggestion is to think about how a computer spreadsheet program such as Excel keeps track of its grid of data cells.

Cut two strips of copper tape 4 cm in length each. Using the procedure below we will attach the strips with two wire leads to the black paper; with the tape aligned with the grid. **Plan ahead, look at Figure 4, then follow these steps:**

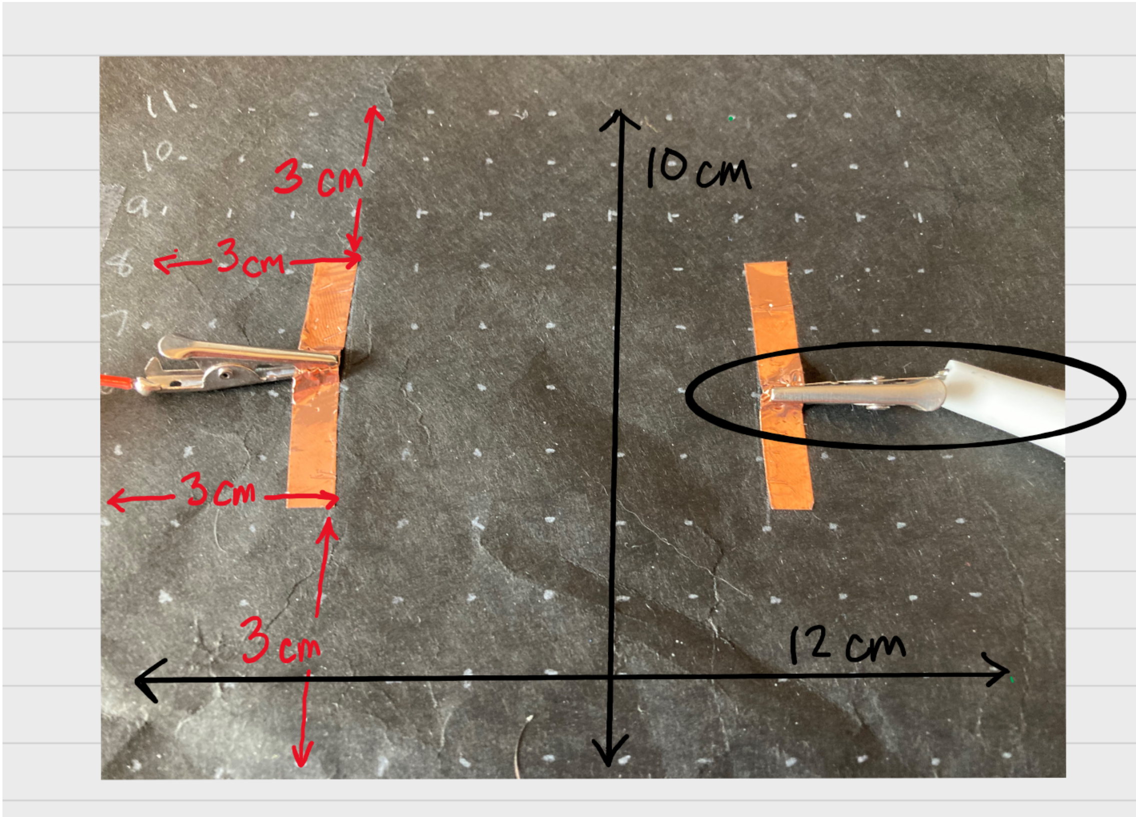

Figure 4: The copper tape and leads should be taped to the conductive paper in the shown locations. Try to lay the clips as flat as possible; the clip in the black circle is maybe twisting a little too much. (Please ignore how wrinkled the paper is.)

- Completely pull back the rubber cover of the alligator clip of one wire lead, revealing the "lower jaw" connected to the wire.
- Peel the paper backing from the copper strip. (**Careful!** The copper is softer than the paper, and will curl easy. Try to keep it flat.)
- Take one wire lead and grasp the copper tape with its jaws.
- With the sticky side of the copper tape, place the "lower jaw" to the paper, lining up the copper to run along the narrow direction, and two corners of the strip 3 cm from each edge. **Refer to Figure 4 for the placement.**
- Place the second tape opposite the first in the same way.

> **Help! I didn't get it exactly right!** Don't worry, this is a qualitative lab, this gives you more to talk about in your lab, especially if

> your end result doesn't match perfectly to theory!

Congratulations on creating your first paper-based electrical device!

3.2 Preparing the iOLab

Place the iOLab near, but not on, the black conductive paper. Connect the pin end of one wire lead to one of the `DAC` terminal. (It doesn't matter which wire is connected.) Turn on your iOLab, and connect it to iOLab Online. Set the value of the voltage output of the `DAC` output to 3.09 V in iOLab Online. Connect the other wire lead to either of the `GND` terminals.

Take the third wire lead, connect its pin end in the `A7` terminal. It will be your test probe, "a physical device used to connect electronic test equipment (iOLab) to a device under test (conductive paper with circuit)." Note the `A7` sensor cannot measure more than 3 V.

> **IMPORTANT** If you get a lot of 0's for your values feel free to lower the voltage to 2.98 V but you will have to start the measurement over again

For the PROBE: keep the alligator clips plastic cover where it is. All you need is a tiny bit of the metal of the clip sticking out the end. You need to be able to hold and maneuver the clip by the plastic cover ONLY when taking the measurements

You can measure the electrical potential at any point of the black paper surface, if you hold the test probe by the rubber jaw cover and touch the paper while collecting data with the `A7` data sensor. **Do not let your hand touch the conductive paper or metal of the wire while you are measuring!** You will not get a shock, but you are conductive like the wire and paper, and touching the paper might change the way current flows through it.

Do not forget to turn on the voltage supply by clicking the check box next to the `DAC` output on iOLab Online.

> Measure the electric potential of the two copper strips? Is it the same anywhere along the total length of the strip? Why or why not?
>
> Set the iOLab Online to take about 5 seconds of the `A7` sensor data. While collecting data, start the test probe on the positive voltage strip, and slowly drag the test probe to the ground strip. **Don't lose contact with the paper, but do not gouge the paper**

either.

What did you find? Save a voltage-time graph for your report, and describe what it shows.

Set the test probe at one grid point **on the paper**, and take 1 second of the `A7` sensor data. What is the uncertainty (standard deviation) of the voltage at this point?

3.3 Take data

Now collect and record the voltage at **each** of the grid points!

Here is how to do it:

1. Place your test probe on a grid point, and collect 1 second of `A7` data.
2. Record the average of the $\bar{y}$ data.
3. Repeat at the next grid point.

Here is what you should consider:

1. Where will you record all this data? (By hand on paper, a Word document, an Excel spreadsheet, etc.) Please tell us in your report.
2. You do not need to collect the uncertainty of each data point, **but**, how many decimal places should you record the data average? Please tell us in your report how many and why.
3. The jaws of the wire lead will obscure 3 grid points each. You don't want to disturb the wires, so what will you do to fill in the missing values? Tell us what you did in your report.

3.4 Data analysis

Once you have collected all your data, open a new web page to an online 2D plotting tool we have made for you. Link here.

At the top of the page is a grid for your data values. You can either type them in, and add rows and columns as needed, or you can import all the data from a "CSV" format file, which is a file type that can be saved from any spreadsheet program. The page **will not** read Excel formatted files.

> Do not click "Randomize data"; it will overwrite your data! That button will fill the data grid with random data to check how the plotting feature works.

The graph below the data grid will make a contour plot; anywhere along the lines have the same voltage potential. The areas of color show where different levels of voltage. You can add more levels to the plot by increasing the `Maximum Contour Levels`.

With your mouse, you can also draw on the graph!

1. Create a graph of equipotential lines for your paper electrical device.

What are the dimensions and units of the x and y axes?

2. Using your mouse, *draw* in where the copper strips are located.

3. Using your mouse, *write* the voltage values of the copper strips that you measured perviously.

4. Using your mouse, *draw* a few electric field lines between the copper strips.

With all these annotations on the graph, click the `Save plot with drawing` button at the bottom of the webpage for your report.

Find a picture from Chapter 19 of the Openstax text book that most closely resembles this experiment. It should show the electric field lines and equipotential contours. Right click on the image and save it to your computer for inclusion in your lab report.

Briefly compare and contrast the two pictures.

Imagine the paper were much more *conductive*. If you released a negatively charged particle in the region between the copper tapes, what would happen? What if you released it more toward the edge of the paper, but still in between the copper tapes?

Finishing Up

Now that you have completed the lab, be sure you filled out all portions of the data tables (templates found in the Resources Tool on Sakai), include figures, and develop a robust

discussion using prompts found throughout the manual.
Ensure to give yourself enough time to complete the report and to hand it in by the due date as late lab reports will not be accepted! If you have any questions please attend a live lab session to get help from one of the course lab demonstrators, or email Phys1P92@brocku.ca.