E&M Laboratory 1106, Spring 2025

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https://www.physics.smu.edu/tneumann/110X_Spring2025/

Lab 3 — Static Electricity — Electric field and potential Max. points: 60

Your preparation: Work through before coming to the lab

- Review chapter 23 "Electric fields" and 24 "Electric potential" in Halliday, Resnick, and Walker [1].
- Prepare by reviewing the lab measurement and report section below and the equipment overview and further introductory material on https://www.physics.smu.edu/tneumann/110X_Spring2025/schedule-em/.

Pre-lab: Upload to Canvas before coming to the lab

A reminder: Upload your answers as a text document (exported as PDF) to Canvas before the lab begins (Canvas uploads are no longer possible after the lab starts!).

Pre-lab 1 7 points

- (1 point) Given a voltage of $5\,\mathrm{V}$, what is its value in milli-joule (mJ) per coulomb (C)?
- (1 point) Look up the definition of a newton (N) and express $3\,\mathrm{N/C}$ in terms of volts (V) per centimeter (cm).
- (1 point) Can two different electric equipotential lines cross? Argue why or why not.
- (2 points) The electric field of a point charge decreases like $1/r^2$ with distance r. What idealized condition has to hold for the electric field between two parallel plates to be uniform between the plates? Argue and explain in a few sentences why that would need to be the case.
- (2 points) Imagine a uniform electric field. How can we use this to measure distance? Briefly explain this. Think about electric field and potential. What would we measure? Hint: $\vec{E} \propto \nabla V$. If $\vec{E}$ is in the same direction as our distance measurement, the field strength can be approximated as a scalar quantity as $E \sim \Delta V/\Delta r$ for a finite distance Δr.

Lab measurements and report: submission by end of class

A reminder: All measurements and steps must be fully documented (using Excel spreadsheets for tables and plots and a text document for the text answers). The final report must be uploaded as a

PDF document to Canvas *by the end of the class* (Canvas will stop accepting uploads 10 minutes after the class ends). If you have not fully completed your report, you must upload the documents as far as you have completed them for grading.

In this lab we study the concept of an electric field. We revisit how it is defined and use the relationship between potential and electric field strength in our measurement.

Measurement 1 *Mapping equipotential and field lines on a field-mapping board* 46 points

Using the overbeck electric field-mapping board we determine equipotential lines and electric field lines of an electric dipole and of electric parallel plates. In the previous lab electric charges would eventually dissipate, and you experienced that as a difficulty in quantitatively mapping the electric field of the static charges. In this lab we use a power supply as a voltage source to maintain a stable electric field.

In principle we could use a digital voltmeter to find points that are at the same potential and lie on equipotential lines, assuming it is sensitive enough and its input resistance is large enough so that it does not disturb the electric field. The electric field lines can then be found as being perpendicular to the equipotential lines. The strength of the electric field can be found by measuring the potential difference between two equipotential lines and dividing by their distance which is measured along the electric field lines that are perpendicular to the equipotential lines. Suggestion: Make a sketch of what this means to fully understand it.

To map the field, we use an ammeter with low resistance to not cause a significant voltage drop. One terminal of the ammeter is connected to a fixed voltage port on the field-mapping board, while the other terminal is connected to a probe that can probe points on the field plate. If the probed voltage is the same as on the terminal, no current will flow, and this allows you to mark equipotential lines.

1. (4 points) Supply a voltage of $8.000\,\mathrm{V}$ to the board and measure and record (in a table) the voltage differences between the voltage source and each of the terminals E_1 through E_7 including uncertainties. Those voltages should be named V_1 through V_7.

   Additionally, tabulate the *voltage differences* between E_1 and E_2, between E_2 to E_3, all the way through to the voltage difference between E_6 and E_7, include uncertainties. Label those voltage differences ΔV_{12} through ΔV_{67}.

2. (4 points) Start the equipotential mapping with the field plate of two point sources. Use the E_4 port to map and draw equipotential lines around both point-charge electrodes and label them with E_4. Before progressing further, include a photo of your mapped equipotential line in your report.

3. (6 points) Use the ports E_1 through E_7 to map and draw equipotential lines and label them with the corresponding port voltage. Before progressing further, include a photo of your mapped equipotential lines in your report.

4. (4 points) Switch out the field plate and use the parallel-plate configuration. Use a new piece of paper to mark the location of the parallel plates and use the E_4 port to map and draw equipotential lines around both parallel-plate electrodes and label them with E_4. Before progressing further, include a photo of your mapped equipotential line in your report.

5. (6 points) Again, use the ports E_1 through E_7 to map and draw equipotential lines and label them with the corresponding port voltage. Before progressing further, include a photo of your mapped equipotential lines in your report.

6. (4 points) Now, for your equipotential map of the point sources, draw at least 12 electric field lines around each of the point-charge electrodes.

7. (3 points) For the point-charge electrode map, label the polarity of the electrodes and assign directions (arrows) to all electric field lines.

8. (4 points) Similarly, for the equipotential map of the parallel-plate electrodes, draw at least 12 electric field lines around each of the electrodes.

9. (3 points) For the parallel-plate electrode map, label the polarity of the electrodes and assign directions (arrows) to all electric field lines.

10. (2 points) When you compare your equipotential and electric field lines with ideal theoretical predictions, they will differ. In terms of the equipment used and uncertainties, what is the reason for those differences?

11. (3 points) Let your instructor label points on your point-charge field map for which you are to calculate the magnitude of the electric field strength, they will be labeled V_1, V_2, $\ldots$, V_7. Through your measurement of the voltages at those points (first task) you know the voltage difference between each of the adjacent points ΔV_{ij}. Measure and record the distance between each adjacent pair with uncertainties.

12. (3 points) For the point-charge map, record and tabulate the distance between the midpoint of V_i and V_{i+1}, $i = 1, \ldots, 6$ and the point charge. Label these distances as d_{12}, d_{23}, $\ldots d_{67}$.

Analysis 1 We now analyze the measurements more closely and calculate the field strength magnitudes. 7 points

1. (3 points) For the point-charge map and for each voltage difference ΔV_{ij} between adjacent points V_1, V_2, ..., V_7, calculate the electric field strengths E_i by dividing ΔV by the distance between them (this is a finite-difference approximation of the analytic derivative ∇V). Include your uncertainties in V_i and the distance and propagate them into E. Your result should be six electric field strength values.

2. (2 points) Tabulate your field strength results. The table should contain one column for your field strength and an additional column for the distance to the middle between the point sources. Since we used a finite-difference approximation to determine the field strengths, we take the distance to the middle between the point sources and the midpoint between the equipotential lines d_{ij} to approximate the position of the field strength.

3. (2 points) Plot the field strength as a function of the distance to the middle between the point sources. Remember to clearly label axes and include units. Is the field strength constant? Would you expect a constant field strength?

References

[1] D. Halliday, R. Resnick, and J. Walker. *Fundamentals of Physics*. Fundamentals of Physics. John Wiley & Sons.