E&M Laboratory 1106, Spring 2025

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

Lab 1 — Measurement uncertainties Max. points: 55

Your preparation: Work through before coming to the lab

- Read chapter 1-1 through 1-7 in Halliday, Resnick, and Walker [1]: Measuring things, International System of Units, Changing Units, Length, Time, Mass.
- Review chapters 26 and 27 in Halliday, Resnick, and Walker [1], in particular about electric current, resistance and Ohm's law in chapter 26, and about "electromotive force", internal resistance, resistances in series and parallel, and single- and multi-loop circuits in chapter 27.
- Read about uncertainty/error analysis, the difference between random (statistical) and systematic uncertainties. Recommended resources: Wikipedia [2, 3, 4], Hughes and Hase [5], Taylor [6].
- Review this lab's measurement and report section below together with the equipment overview and the experiment's introduction on https://www.physics.smu.edu/tneumann/110X_Spring2025/schedule-em/.

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

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) In your own words, explain the difference between random and systematic uncertainties.
- (1 point) In your own words, explain the difference between a measurement uncertainty and a mistake/error caused by the experimenter.
- (1 point) In your own words, explain the difference between accuracy and precision.
- (1 point) In your own words, explain the role of significant figures/digits in specifying a measurement value.
- (1 point) We apply a voltage $V = 5.0 \pm 0.1\,\mathrm{V}$ across an ohmic resistor with resistance $R = 10.0 \pm 0.1\,\Omega$. What is the current flowing through the resistor and its uncertainty? Pay attention to the correct number of significant figures and units.

- (2 points) In your own words, explain the difference between standard deviation of a measurement and the standard deviation of the mean.

Lab measurements and report: submission by end of class

All measurements and steps must be followed in order and 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 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.

The experiments are performed in groups of three, and you should discuss the experiments and questions within your group. Nevertheless, the report submissions are individual, and your submitted answers should be in your own words and not exactly copied from your group members.

Measurement 1 *Dry-cell battery voltage* 11.5 points

We measure the voltage of a dry-cell battery using three different voltmeters: an analog voltmeter, a handheld digital multimeter (DMM) and a benchtop digital multimeter.

For the handheld DMM perform the measurement using the range settings $200\,\mathrm{mV}$, $2\,\mathrm{V}$, $20\,\mathrm{V}$, $200\,\mathrm{V}$ and $600\,\mathrm{V}$ each. For the analog voltmeter use the range settings $3\,\mathrm{V}$, $15\,\mathrm{V}$ and $30\,\mathrm{V}$ each. For the benchtop DMM use the "auto" setting.

1. (9 points) For each device fill a spreadsheet with columns labeling the range setting, the associated measured voltage and uncertainty. Note that each device and each range setting has a different uncertainty! All data columns must state the units.

   While filling the table, obtain and clearly specify and justify (a brief sentence) each of the measurement uncertainties by consulting the device's documentation or, if necessary, via your own reasoning.

2. (1.5 points) Answer and argue: Can you, by averaging all of the measurements above, obtain a more precise average? If yes, what is its value? If no, why not?

3. (1 point) When you set the bench DMM measurement range to $2\,\mathrm{V}$, what is the smallest voltage you can read, and what is the measurement uncertainty of that voltage?

Measurement 2 *Calibration of the handheld DMM* 18.5 points

We now study the accuracy of the handheld DMM. For that, set up the benchtop power supply.

1. (5.5 points)) Use the power supply to generate voltages between $1\,\mathrm{V}$ and $10\,\mathrm{V}$ in steps of $1\,\mathrm{V}$ for 10 different voltages in total. Fill out a spreadsheet for measuring the voltage with both the DMM and the benchtop power supply. Include uncertainties and don't forget units.

2. (4 points) Add one more column for the uncertainty of the power supply's voltage and fill it out.

3. (4 points) Add another column to compute the difference between DMM voltage and benchtop power supply, and add a column for the difference's uncertainty via uncertainty propagation.
4. (2 points) Briefly, in a few sentences at most, describe if the DMM and benchtop measurements agree or do not agree within uncertainties.
5. (3 points) Data visualization: Create a plot of your DMM-benchtop difference data in dependence of the voltage. The x-axis should display the set voltage, while the y-axis should display the difference. The complete plot should have vertical uncertainty bars and axis labels with units.

Measurement 3 *Human resistance* 12 points

Also the human body and the human skin have resistance. In this experiment we will have a look at the resistance between left and right hand.

- (q4 points+$2n$, $n \leq 2$) Measure the resistance from your left to your right hand. Do this for each member of your group. Devise a procedure to define uncertainties of those measurements and obtain uncertainties. Fully document and argue how you obtain those uncertainties.

  Fill a spreadsheet with resistances of each of your group's members and add additional columns for your uncertainties. For each uncertainty add a separate column and argue and describe whether the uncertainties are systematic or random.

  Full points require two different uncertainties and their detailed justification. Your thought process in obtaining the uncertainties must be clear. Two *bonus points* are given for each additional uncertainty that you can think about that is well motivated and argued and justified as systematic or random. Think about different probe positions, moisture and other factors.

  Each one of your group's members should include all the data from the other group members.
- (2 points) Briefly, with a few sentences, discuss in how far the measurements between different people agree or disagree within your estimated uncertainties. If they do not agree, why would that be, and does this constitute another uncertainty?
- (2 points) A random uncertainty is through the variability between people's bodies. Obtain the average of your group's results and compute the standard deviation of the mean as its uncertainty.
- (2 points) Briefly argue if and how the measurement can be improved. Is there a limit to the precision or the accuracy?
- (2 points) Using your group's mean resistance, what voltage is necessary to produce a current of $5\,\mathrm{mA}$ (assuming an Ohmic resistance)? Propagate your *largest* resistance uncertainty (statistical from your group, or a different systematic) to obtain an uncertainty on the voltage, assuming no uncertainty on the $5\,\mathrm{mA}$ current.

Measurement 4 *Resistance measurements* 6 points

Last, instead of voltages we will measure the resistance of some resistors, which are an elementary part of many electronic circuits.

- (3 points) Use the handheld DMM and benchtop DMM to measure the resistances of $R3$ and $R4$ on the PASCO R/C/L network board (UI-5210) with uncertainties. Use and briefly justify the device settings (voltage range) to obtain the best measurement uncertainty.
- (3 points) For both the DMM and the benchtop DMM calculate the deviation of your measurements from the nominal resistor value (which has a tolerance!) and discuss the agreement within your uncertainties.

References

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

[2] URL: https://en.wikipedia.org/wiki/Observational_error.

[3] URL: https://en.wikipedia.org/wiki/Accuracy_and_precision.

[4] URL: https://en.wikipedia.org/wiki/Significant_figures.

[5] Ifan Hughes and Thomas Hase. *Measurements and their Uncertainties. A practical guide to modern error analysis*. Oxford University Press, 2010.

[6] John R. Taylor. *An Introduction to Error Analysis*. University Science Books, 1996.