E&M Laboratory 1106, Summer 2025

Prof. D. Balakishiyeva, Prof. R. Guarino

https://www.physics.smu.edu/tneumann/110X_Summer2025/

Lab 5 — Ohm's law and DC circuits Max. points: 65

Your preparation: Work through before coming to the lab

- Your need to thoroughly prepare for the lab by reading and understanding the measurement and analysis procedures on the worksheet! Photos of the equipment and further introductory material will be made available on https://www.physics.smu.edu/tneumann/110X_Summer2025/schedule-em/
- Collect all your questions and ask your instructor at the beginning of the lab.
- Work through chapter on "Current and Resistance" and "Circuits" in your textbook, e.g., Chapter 26 and 27 of Halliday, Resnick, and Walker [1]. Focus especially on these sections:
  - **Ohm's Law**: Understand the definition of resistance, resistivity, and conductivity. Review the relationship $V = IR$.
  - **Resistors**: Learn about resistors, color codes, and their role in circuits.
  - **Light Emitting Diodes (LEDs)**: Understand basic function of LEDs as non-Ohmic devices and their I-V characteristics, concept of turn-on voltage.
  - **Resistivity and Resistance**: Understand the relationship between resistance R, resistivity ρ, length L, and cross-sectional area A: $R = \rho \frac{L}{A}$.
  - **Ammeters and Voltmeters**: Review how ammeters (series connection) and voltmeters (parallel connection) are used to measure current and voltage in a circuit. Understand the concept of ideal and non-ideal meters and their impact on measurements.
  - **DC Power Supplies**: Understand the function of a DC power supply and how to set voltage and current limits.
  - **Breadboards and Circuit Construction**: Review basic breadboard usage for building circuits.

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 30 minutes before the lab starts!).

Pre-lab 1 8 points

- (1 point) State Ohm's Law in your own words and write down the equation. Explain what each symbol represents and state the units.
- (1 point) Sketch the Current vs. Voltage (I-V) curve for an Ohmic resistor. What is the shape of this curve and what does the slope represent?
- (2 points) Sketch the Current vs. Voltage (I-V) curve for an LED. How does it differ from the I-V curve of an Ohmic resistor? Indicate the turn-on voltage on your sketch.
- (1 point) What is resistivity? How is it related to resistance? Give the formula relating resistance to resistivity, length, and cross-sectional area. Explain each term and state the units of resistivity.
- (1 point) Explain how you would use a Digital Multimeter (DMM) as an ammeter to measure current in a circuit. How should the ammeter be connected in the circuit (series or parallel)? Explain why.
- (1 point) Explain how you would use a DMM as a voltmeter to measure voltage across a component in a circuit. How should the voltmeter be connected (series or parallel)? Explain why.
- (1 point) What is the purpose of setting a current limit on a DC power supply in this experiment, and limiting the voltage especially when working with LEDs?

Lab measurements and report: submission by end of class

A reminder: All measurements must be fully documented . The final report must be uploaded to Canvas *by the end of the class* exported as PDF with plots and tables from Excel embedded as images. 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, you will investigate Ohm's Law using resistors, LEDs, and resistance wires. You will perform three sets of measurements: first, to verify Ohm's Law for resistors, second, to study the I-V characteristics of LEDs, and third, to determine the resistivity of different wire gauges.

Measurement 1 *Verification of Ohm's law for ohmic resistors* 10 points
In this first measurement, you will experimentally verify Ohm's Law using Ohmic resistors and determine their resistance from I-V curves and direct DMM measurements.

Equipment:

- DC power supply (variable voltage, current limit)
- Digital Multimeter (DMM) (to be used as ammeter)
- Digital Multimeter (DMM) (to be used as voltmeter)
- Resistors: 220 Ohm (nominal), 1 kOhm (nominal) (at least 2 of each)
- Breadboard

- Connecting wires/cables

Measurement procedure:

1. **Circuit setup for resistor measurement:** (2 points)
   (a) Set up a simple circuit on the breadboard with a resistor (start with 220 Ohm).
   (b) Connect the DC power supply to the circuit.
   (c) Connect one DMM in **series** with the resistor to measure the **current** (ammeter). Ensure correct polarity.
   (d) Connect a second DMM in **parallel** across the resistor to measure the **voltage** (voltmeter).
   (e) Set the DC power supply's current limit to $0.2\,\mathrm{A}$.
   (f) Have your circuit checked by the instructor before proceeding.
   (g) In your report, draw a circuit diagram of your setup, clearly indicating the positions of the resistor, power supply, ammeter, and voltmeter. Describe how you connected the DMMs as ammeter and voltmeter.
2. **Data recording for 220 Ohm resistor:** (3 points)
   (a) Start with the power supply voltage set to $0\,\mathrm{V}$. Record the voltage and current readings from the DMMs.
   (b) Increase the power supply voltage in steps of $0.5\,\mathrm{V}$ up to $5\,\mathrm{V}$. At each voltage step, record the corresponding voltage and current values. Create a table in your report to record voltage and current values.
   (c) Repeat the voltage variation and measurements for a second 220 Ohm resistor. Record data in your table.
3. **Data recording for 1 kOhm resistor:** (3 points)
   (a) Replace the 220 Ohm resistor in your circuit with a 1 kOhm resistor.
   (b) Repeat step 2 to record voltage and current values for the 1 kOhm resistor, from $0\,\mathrm{V}$ to $5\,\mathrm{V}$ in $0.5\,\mathrm{V}$ steps. Record data in your table, clearly indicating which data is for the 1 kOhm resistor. Repeat for a second 1 kOhm resistor.
4. **Direct resistance measurement with DMM:** (2 points)
   (a) Use one DMM to directly measure the resistance of one of the 220 Ohm resistors and one of the 1 kOhm resistors.
   (b) Record the measured resistance values for both resistors, including units, in your report. Note the DMM setting used for resistance measurement.

Measurement 2 *I-V characteristics of light emitting diodes (LEDs)* 8 points

In this second measurement, you will investigate the Current-Voltage (I-V) characteristics of Light Emitting Diodes (LEDs), observing their non-Ohmic behavior and turn-on voltage.

Equipment (reuse from Measurement 1):

- DC power supply, DMM (Ammeter), DMM (Voltmeter), Breadboard, Connecting wires/cables
- LEDs: Green LED, Yellow LED (at least 1 of each)
- Resistor (e.g., 220 Ohm or 1 kOhm) - **Important: for current limiting, to protect LED**

Measurement procedure:

1. **Circuit setup for LED measurement:** (2 points)
   (a) Set up a circuit on the breadboard with a Green LED in **series** with a current limiting resistor (e.g., 220 Ohm). **Important: Include current limiting resistor to protect the LED.**
   (b) Connect the DC power supply to the circuit.
   (c) Connect one DMM in **series** with the LED (and resistor) to measure the **current** (ammeter). Ensure correct polarity for both LED and ammeter.
   (d) Connect a second DMM in **parallel** across the LED to measure the **voltage** across the LED (voltmeter). Ensure correct polarity for the LED and voltmeter.
   (e) Set the DC power supply's current limit to 0.02 A (20 mA).
   (f) Check the polarity of the LED before connecting it. The longer lead is typically the anode (positive), and the shorter lead is the cathode (negative).
   (g) Have your circuit checked by the instructor before proceeding, especially the LED polarity and current limiting resistor.
   (h) In your report, draw a circuit diagram for the LED measurement, indicating the LED, current limiting resistor, power supply, ammeter, and voltmeter. Clearly indicate the polarity of the LED in your diagram. Describe how you ensured correct LED polarity.
2. **Data recording for Green LED:** (3 points)
   (a) Start with the power supply voltage set to 0 V. Record the voltage across the LED and current readings from the DMMs.
   (b) Increase the power supply voltage in steps of 0.1 V, up to a maximum of 2.5 V reached across the LED. At each voltage step, record the corresponding voltage and current values from your DMM. Create a table in your report to record voltage and current values for the Green LED.
3. **Data recording for Yellow LED:** (3 points)
   (a) Replace the Green LED with a Yellow LED in your circuit (keeping the current limiting resistor).

(b) Repeat step 2 to record voltage and current values for the Yellow LED in $0.1\,\text{V}$ steps, up to a maximum of $2.5\,\text{V}$ reached across the LED. Record data in your table, clearly indicating which data is for the Yellow LED.

Measurement 3 *Resistivity measurement with resistance wire board* 8 points

In this third measurement, you will determine the resistivity of different wire gauges using a resistance wire board and varying the length of the wire segment.

Equipment:

- Digital Multimeter (DMM) (to be used as Resistance meter)
- Resistance Wire Board with slider and interchangeable wire gauges (3 different gauges)
- Connecting wires/cables (short test leads for DMM)
- Meter stick or ruler (integrated in Resistance Wire Board or separate)

Measurement procedure:

1. **Cable and connector resistance measurement:** (2 points)

   (a) Set up the DMM to measure resistance.

   (b) Connect the two test leads of the DMM directly to each other (without the resistance wire board).

   (c) Record the resistance reading. This is the resistance of your cables and connectors, R_{cable}. Note the DMM setting used.

   (d) Explain in your report why it is important to measure the cable and connector resistance in this measurement.

2. **Resistance measurement for varying wire length (Gauge a):** (3 points)

   (a) Start working with the resistance wire board with one wire gauge (e.g., Gauge 32). Note the gauge number and wire material from the board's label in your report.

   (b) Connect the DMM (in resistance mode) to the terminals of the resistance wire board.

   (c) Set the slider to measure the resistance of a $10\,\text{cm}$ length of the wire. Record the measured resistance.

   (d) Increase the wire length in steps of $10\,\text{cm}$ up to $100\,\text{cm}$ (i.e., $10\,\text{cm}$, $20\,\text{cm}$, $30\,\text{cm}$, ..., $100\,\text{cm}$). At each length, record the measured resistance. Create a table in your report with columns for "Wire Length" and "Measured Resistance" for Gauge a.

3. **Resistance measurement for varying wire length (Gauge b & c):** (3 points)

   (a) Now, use a different resistance wire board with a wire of a different gauge (Gauge b, e.g., Gauge 26). Note the gauge number and wire material in your report.

   (b) Repeat step 2 to measure the resistance for wire lengths from $10\,\text{cm}$ to $100\,\text{cm}$ in $10\,\text{cm}$ steps for Gauge b. Record data in a new table for Gauge b.

(c) Repeat step 3 for a third wire gauge (Gauge c, e.g., Gauge 29). Note the gauge number and wire material in your report. Record data in a new table for Gauge c.

Analysis 1 *Analysis of Ohm's law verification (Measurement 1)* 11 points

In this analysis section, you will analyze the data from Measurement 1 to understand Ohm's Law.

1. **Current vs. voltage plots for resistors:** (3 points)
   (a) For each resistor (two 220 Ohm and two 1 kOhm resistors), plot the measured Current (I) vs. Voltage (V) data. Include all four plots in your report, with labeled axes and clear labels indicating resistor values (nominal and measured with DMM).

   (b) Describe the shape of the I-V curves for the resistors. Are they linear, as expected for Ohmic resistors?

2. **Resistance from I-V curve slope:** (5 points)
   (a) For each I-V plot, determine the slope of the curve. Since $V = IR$, the slope of the I-V curve (with I on the y-axis and V on the x-axis) is $1/R$.

   (b) Calculate the resistance R_{IV} from the inverse of the slope for each resistor. Report the resistance values R_{IV} for all four resistors, with units. Show your slope calculation (or slope estimation method) in the report.

3. **Comparison of resistance values:** (3 points)
   (a) For each resistor type (220 Ohm and 1 kOhm), compare the resistance values obtained from the I-V curve slope (R_{IV}) with the resistance values directly measured using the DMM (R_{DMM}).

   (b) Calculate the percentage difference between R_{IV} and R_{DMM} for each resistor.

   (c) Do the resistance values from the two methods agree reasonably? Discuss possible reasons for any differences. Which method do you think is more accurate and why?

Analysis 2 *Analysis of LED I-V characteristics (Measurement 2)* 8 points

In this analysis section, you will analyze the data from Measurement 2 to understand LED characteristics.

1. **Current vs. voltage plots for LEDs:** (2 points)
   (a) Plot the measured Current (I) vs. Voltage (V) data for both the Green LED and the Yellow LED. Include both plots in your report, with labeled axes and clear labels indicating LED color.

   (b) Describe the shape of the I-V curves for the LEDs. Are they linear? How do they differ from the I-V curves of Ohmic resistors?

2. **Turn-on voltage of LEDs:** (3 points)

(a) From the I-V curves for each LED, estimate the turn-on voltage. The turn-on voltage is the voltage at which the current starts to increase significantly. Explain how you estimated the turn-on voltage from the graph.

(b) Report the estimated turn-on voltage for both the Green and Yellow LEDs, with units. Are the turn-on voltages different for the two LEDs? Do your results make sense based on the typical turn-on voltages for different LED colors (research typical values if needed)?

3. **Non-Ohmic behavior of LEDs:** (3 points)

   (a) In a few sentences, explain why LEDs are considered non-Ohmic devices based on your I-V curve measurements. Contrast their behavior with that of the Ohmic resistors studied in Measurement 1.

   (b) Quantify the non-Ohmic behavior by calculating the "resistance" of the Green LED at two different voltage points from your data: (a) at $0.5\,\mathrm{V}$ and (b) at $2.0\,\mathrm{V}$. Calculate resistance as $R = V/I$ at these points. How does the "resistance" of the LED change with voltage? Does this support your conclusion about non-Ohmic behavior?

Analysis 3 *Analysis of resistivity measurement (Measurement 3)* 12 points

In this analysis section, you will analyze the data from Measurement 3 to understand resistivity.

1. **Cable resistance correction:** (1 point)

   (a) Subtract the measured cable and connector resistance R_{cable} from all resistance measurements taken with the resistance wire board for all wire gauges and lengths. This gives you the corrected resistance values for the wires only. Explain why this correction is necessary.

2. **Resistance vs. length plots for wires:** (3 points)

   (a) For each wire gauge (Gauge 1, Gauge 2, Gauge 3), plot the corrected Resistance (R - R_{cable}) vs. Wire Length (L) data. Include all three plots in your report, with labeled axes and clear labels indicating wire gauge.

   (b) Describe the shape of the R vs. L curves. Are they linear, as expected from the relation $R = \rho \frac{L}{A}$?

3. **Resistivity calculation from graph slope:** (5 points)

   (a) For each R vs. L plot, determine the slope of the curve. According to theory, the slope is $\frac{\rho}{A}$.

   (b) Obtain the cross-sectional area A for each wire gauge. You may need to look up typical wire diameters for the given gauge numbers (you can use online wire gauge charts or tables, cite your source). Calculate the area $A = \pi(d/2)^2$, where d is the wire diameter. Report the diameter and calculated area for each gauge, with units and source of diameter values.

   (c) From the slope of each R vs. L plot and the calculated area A for that gauge, calculate the resistivity $\rho = \text{Slope} \times A$. Report the resistivity value ρ for each wire gauge, with units. Show your slope estimation and calculation in the report.

4. **Comparison with wire material resistivity:** (3 points)

   (a) For each wire gauge, compare your experimentally determined resistivity ρ with the typical resistivity values for the wire material indicated on the resistance wire board label (e.g., Nichrome, Copper, Kanthal A-1 alloy, etc.). You may need to look up typical resistivity values for these materials (cite your source).

   (b) Calculate the percentage difference between your measured ρ and the typical resistivity value for each wire gauge.

   (c) Do your measured resistivity values agree reasonably with the expected values for the wire material? Discuss possible reasons for any discrepancies. How does resistivity vary with wire gauge (if you observe a trend, even within uncertainties)? How does it compare across different wire materials if you used different materials for different gauges?

Learning outcomes

- Understand and experimentally verify Ohm's Law for Ohmic resistors.
- Measure voltage and current using Digital Multimeters (DMMs) in series and parallel configurations.
- Investigate the non-Ohmic behavior of Light Emitting Diodes (LEDs) and identify their turn-on voltage.
- Determine the resistivity of different wire gauges using resistance measurements and varying wire lengths.
- Analyze experimental data to calculate resistance, resistivity, and compare results with theoretical predictions and component specifications.
- Understand the relationship between resistance, resistivity, length, and cross-sectional area of a wire.

References

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