

Lab 3. Ohm's Law

Goals

- To understand Ohm's law, used to describe the behavior of electrical conduction in many materials and circuits.
- To calculate the electrical power dissipated as heat.
- To understand and use a rheostat, or variable resistor, in an electrical circuit.
- To learn how to connect electrical components so that the current can flow around the circuit, and to learn how to use, connect, and read ammeters (current reading instruments) and voltmeters (voltage reading instruments).
- To measure and observe the behavior of the voltage across and the corresponding current through a simple resistor (electronic component) and a tungsten-filament light bulb.

Introduction

One of the most basic electrical circuits is a resistor connected to a voltage source, such as a battery or power supply. A heater is exactly this as the entire circuit. A quantity called the resistance, R , of a component is defined as the ratio of the potential difference, ΔV , across the component to the current, I , flowing through the component, or

$$R = \frac{\Delta V}{I} \quad (3.1)$$

When ΔV is expressed in volts and I is expressed in amperes (amps), then R is in the SI units of ohms (Ω). The power, P (in the SI unit of watts), dissipated by that component in the form of heat is given by

$$P = I(\Delta V) = I^2 R = \frac{(\Delta V)^2}{R} \quad (3.2)$$

The resistance of some materials is constant over a wide range of voltages and currents. When a material behaves in this way, it is called "ohmic." Electrical components made from ohmic materials are called resistors.

By measuring the current flowing through a component as a function of the voltage across the component, one can determine whether the ratio $\Delta V/I$ is a constant or not. If it is constant, then the

component is ohmic and the constant resistance in ohms can be determined. If the voltage to current ratio is not constant, the device is not ohmic and does not obey Ohm's law. A **voltmeter** is used to measure voltage and an **ammeter** is used to measure current. Ideal voltmeters and ammeters will not affect the currents or voltages in the circuit as the measurements are being made. Real meters only approximate this ideal.

An ammeter measures the electrical current that flows through it. To measure the current flowing through a particular device in a circuit, the ammeter must be connected in such a way that the same current flows through the ammeter as through the device. The ammeter is simply a flow meter for the electrical current, so the wire at one end of the device must be disconnected and the ammeter inserted. The disconnected wire end is now connected to one terminal of the ammeter and a new wire is connected between the second terminal of the ammeter and the device to restore the flow of current through the circuit. This type of connection is called a "series" connection. The ammeter in Figure 3.1 is represented by a box marked with the letter "A".

Caution: If current flows backwards through the ammeter, the ammeter tries to respond by registering a negative current. Since the meter needle can only show positive values, this can damage the meter. To check that the ammeter is connected with the correct polarity, quickly tap the knife switch (See Figure 3.1) before closing it completely. If the meter does try to deflect in the negative direction, exchange the connections of the two wires connected to the ammeter.

Current versus voltage for a $100\ \Omega$ (nominal) resistor

In this exercise the voltage across and the current through a known resistor are measured as the current through the circuit is varied. The power supply voltage is kept constant, but the current flowing in the circuit is controlled with a variable resistor, also called a rheostat. (See Figure 3.1.)

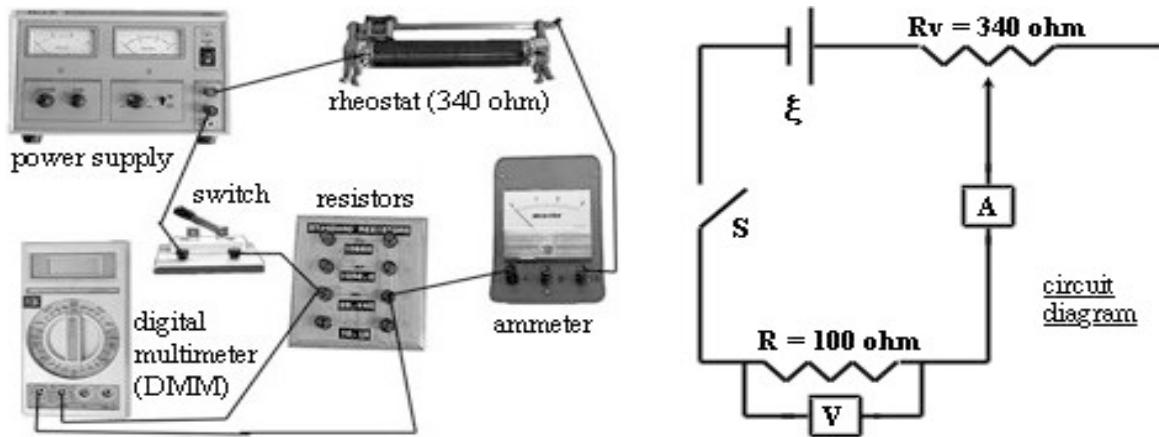


Figure 3.1. Circuit connections.

The rheostat has three terminals. Two terminals are on the ends of the device and are fixed, and the third is connected to a sliding contact that can be moved from one end of the device to the other. The resistance between the end terminals has a fixed value, but the resistance between the

one of the end terminals and the sliding contact can be varied from zero to the fixed value of whole device.

Preliminary calculations

Assuming that the power supply voltage is fixed at 5.0 V, calculate the following quantities to two significant digits:

1. The current through the nominally $100\ \Omega$ resistor when the resistance of the rheostat is a maximum (340 or $360\ \Omega$ —your rheostat is marked with the value to use here), and when the resistance of the rheostat is zero.
2. The maximum power dissipated as heat by the $100\ \Omega$ resistor. The rated maximum power for this resistor is 0.50 W. If the power you calculate exceeds 0.50 W, please ask your TA for help before proceeding!

Equipment set-up

Caution: If current flows backwards through the ammeter, the ammeter tries to respond by registering a negative current. Since the meter needle can show only positive values, this can damage the meter. The ammeter can also be damaged if the magnitude of the current is much larger than the current rating of the chosen scale. To check that the ammeter is connected with the correct polarity and to a safe current scale, quickly tap the knife switch (See Figure 3.1) without closing it completely. If the meter tries to deflect in the negative direction, exchange the connections of the two wires connected to the ammeter. If the meter tries to deflect off-scale in the correct direction, use a current scale with a higher current rating. If the meter passes these two tests, close the knife switch completely and proceed to make measurements.

1. Turn the current knob on the power supply to the straight-up or 12 o'clock position, and set the power supply voltage to 5.0 V.
2. Build the circuit shown in Figure 3.1, leaving the switch open, that is, not making electrical contact. Be sure to use an ammeter scale with a current rating large enough to measure the maximum current you calculated above. By convention ammeters read positive when electrical current flows into the positive terminal (red) of the meter and then flows out of the negative terminal (black) of the meter.
3. Set the rheostat for maximum resistance by moving the slide so that the current must travel through the entire coil.
4. Tap the knife switch to make sure that the ammeter connections are correct. If all is well (refer to bold section above), then close the switch. Both the ammeter and voltmeter should read non-zero values. If the measured current is below the current rating of a more sensitive scale, open the knife switch, move the connection to the more sensitive scale, and tap the knife switch closed to test the new scale. Use the most sensitive current scale that can handle the current safely (reading stays on-scale).

Data collection

1. Make at least ten different measurements of the voltage and corresponding current by adjusting the rheostat between its minimum and maximum resistance. To obtain data points at low currents, you can lower the voltage supplied to the circuit by the power supply to some value less than 5 V. Ask your TA for help as necessary.
2. How does the current measured by the ammeter change if the ammeter is connected between the power supply and the rheostat instead of between the rheostat and the resistor? What if it is connected between the power supply and the switch? Verify your answers experimentally.

Data analysis

1. Draw a graph of the voltage across the nominal $100\ \Omega$ resistor as a function of the corresponding current flowing through it.
2. Is the graph linear? Draw a best fit smooth line through your data points, and from your graph find an equation for ΔV as a function of I in SI units.
3. Does the resistor exhibit ohmic behavior? Explain your reasoning. If so, what is the “real” value of the resistance? How does your value compare to the nominal $100\ \Omega$ value indicated by the “color code” painted on it?

Current versus voltage for an incandescent light bulb

Equipment set up

Caution: Be sure to leave the switch open while you construct the new circuit. Before closing the switch, have your TA check your circuit.

1. Build a circuit analogous to the one in Figure 1, but use the $22\ \Omega$ rheostat instead of the 340 or $360\ \Omega$ one used above and replace the $100\ \Omega$ resistor with the small light bulb.
2. Use the highest current scale on the ammeter to begin with. You can always change to a more sensitive scale if the measured current is low enough.
3. Make sure that the power supply is still set to 5 volts.

Data collection

1. Make at least ten different measurements of the voltage and corresponding current by adjusting the rheostat between its minimum and maximum resistance.
2. Does current flow through the light bulb even when the bulb is not glowing? Be sure to take data over the full range of possible values, whether the bulb glows or not.

Data analysis

1. Make a graph of the voltage difference between the light bulb terminals as a function of current. What is the current flowing through the light bulb if the voltage across it is zero? Be sure to plot this point on your graph!

2. Is the light bulb ohmic? Explain your reasoning. If so, what is its resistance? If not, what are the minimum and maximum values of its resistance?
3. What is the maximum power dissipated by the light bulb? (This power is dissipated primarily in the form of heat, but some also appears in the form of visible light.) What is the power dissipated by the bulb when it first begins to glow?

Summary

Compare and contrast the electrical behavior of the resistor and the light bulb. Consult a textbook and try learn why the light bulb exhibits a more complicated behavior than the resistor. Explain this in your notes.

	No Effort	Progressing	Expectation	Scientific
SL.A.a Is able to analyze the experiment and recommend improvements <small>Labs: 1-3, 5, 7, 8, 10-12</small>	No deliberately identified reflection on the efficacy of the experiment can be found in the report	Description of experimental procedure leaves it unclear what could be improved upon.	Some aspects of the experiment may not have been considered in terms of shortcomings or improvements, but some are identified and discussed.	All major shortcomings of the experiment are identified and reasonable suggestions for improvement are made. Justification is provided for certainty of no shortcomings in the rare case there are none.
SL.B.b Is able to explain patterns in data with physics principles <small>Labs: 1-3, 5, 7-9, 12</small>	No attempt is made to explain the patterns in data	An explanation for a pattern is vague, OR the explanation cannot be verified through testing, OR the explanation contradicts the actual pattern in the data.	An explanation is made which aligns with the pattern observed in the data, but the link to physics principles is flawed through reasoning or failure to understand the physics principles.	A reasonable explanation is made for the pattern in the data. The explanation is testable, and accounts for any significant deviations or poor fit.
CT.A.a Is able to compare recorded information and sketches with reality of experiment <small>Labs: 3, 4, 6, 7</small>	No sketches present and no descriptive text to explain what was observed in experiment	Sketch or descriptive text is present to inform reader what was observed in the experiment, but there is no attempt to explain what details of the experiment are not accurately delivered through either representation.	Sketch and descriptive text are both present. The sketch and description supplement one another to attempt to make up for the failures of each to convey all observations from the experiment. There are minor inconsistencies between the two representations and the known reality of the experiment from the week, but no major details are absent.	Sketch and description address the shortcomings of one another to convey an accurate and detailed record of experimental observations adequate to permit a reader to place all data in context.

	No Effort	Progressing	Expectation	Scientific
CT.B.a Is able to describe physics concepts underlying experiment Labs: 1-3, 5, 7, 8-12	No explicitly identified attempt to describe the physics concepts involved in the experiment using student's own words.	The description of the physics concepts underlying the experiment is confusing, or the physics concepts described are not pertinent to the experiment for this week.	The description of the physics concepts in play for the week is vague or incomplete, but can be understood in the broader context of the lab.	The physics concepts underlying the experiment are clearly stated.
QR.A Is able to perform algebraic steps in mathematical work. Labs: 3, 6, 8, 10-12	No equations are presented in algebraic form with known values isolated on the right and unknown values on the left.	Some equations are recorded in algebraic form, but not all equations needed for the experiment.	All the required equations for the experiment are written in algebraic form with unknown values on the left and known values on the right. Some algebraic manipulation is not recorded, but most is.	All equations required for the experiment are presented in standard form and full steps are shown to derive final form with unknown values on the left and known values on the right. Substitutions are made to place all unknown values in terms of measured values and constants.
QR.B Is able to identify a pattern in the data graphically and mathematically Labs: 1-3, 5, 7-9, 12	No attempt is made to search for a pattern, graphs may be present but lack fit lines	The pattern described is irrelevant or inconsistent with the data. Graphs are present, but fit lines are inappropriate for the data presented.	The pattern has minor errors or omissions. OR Terms labelled as proportional lack clarity - is the proportionality linear, quadratic, etc. Graphs shown have appropriate fit lines, but no equations or analysis of fit quality	The patterns represent the relevant trend in the data. When possible, the trend is described in words. Graphs have appropriate fit lines with equations and discussion of any data significantly off fit.
QR.C Is able to analyze data appropriately Labs: 1-4, 6-12	No attempt is made to analyze the data.	An attempt is made to analyze the data, but it is either seriously flawed, or inappropriate.	The analysis is appropriate for the data gathered, but contains minor errors or omissions	The analysis is appropriate, complete, and correct.
IL.A Is able to record data and observations from the experiment Labs: 1-12	"Some data required for the lab is not present at all, or cannot be found easily due to poor organization of notes. "	"Data recorded contains errors such as labeling quantities incorrectly, mixing up initial and final states, units are not mentioned, etc. "	Most of the data is recorded, but not all of it. For example measurements are recorded as numbers without units. Or data is not assigned an identifying variable for ease of reference.	All necessary data has been recorded throughout the the lab and recorded in a comprehensible way. Initial and final states are identified correctly. Units are indicated throughout the recording of data. All quantities are identified with standard variable identification and identifying subscripts where needed.

	No Effort	Progressing	Expectation	Scientific
WC.B Is able to draw a graph Labs: 3, 6, 8, 12	No graph is present.	A graph is present, but the axes are not labeled. OR there is no scale on the axes. OR the data points are connected.	"A graph is present and the axes are labeled, but the axes do not correspond to the independent (X-axis) and dependent (Y-axis) variables or the scale is not accurate. The data points are not connected, but there is no trend-line." "	The graph has correctly labeled axes, independent variable is along the horizontal axis and the scale is accurate. The trend-line is correct, with formula clearly indicated.
WC.D Is able to draw a circuit diagram Labs: 3, 4	No circuit diagram is drawn.	Components of the circuit are missing, or connected incorrectly. Components are not clearly labelled.	"Circuit diagram is missing key features, but contains no errors. It may be difficult to follow electrical pathways, but it can be determined which components are connected with sufficient scrutiny."	Circuit diagram contains minimal connecting lines, components are neatly arranged to ensure labels are readily identified to appropriate components.

Print this page. Tear in half. Each lab partner should submit their half along with the lab report and then retain until the end of semester when returned with evaluations indicated by TA.

Lab 3 Ohm's Law:

Name: _____

Lab Partner: _____

EXIT TICKET:

- Turn off the power to all the equipment. ESPECIALLY the multimeter.
- Disassemble the circuit and place the make sure wires are not tangled.
- Quit any software you have been using.
- Straighten up your lab station. Put all equipment where it was at start of lab.
- Required Level of Effort.
 - Complete the pre-lab assignment Arrive on time
 - Work well with your partner Complete the lab or run out of time

SL.A.a	
SL.B.b	
CT.A.a	

CT.B.a	
QR.A	
QR.B	
QR.C	

IL.A	
WC.B	
WC.D	

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QR.C	

IL.A	
WC.B	
WC.D	