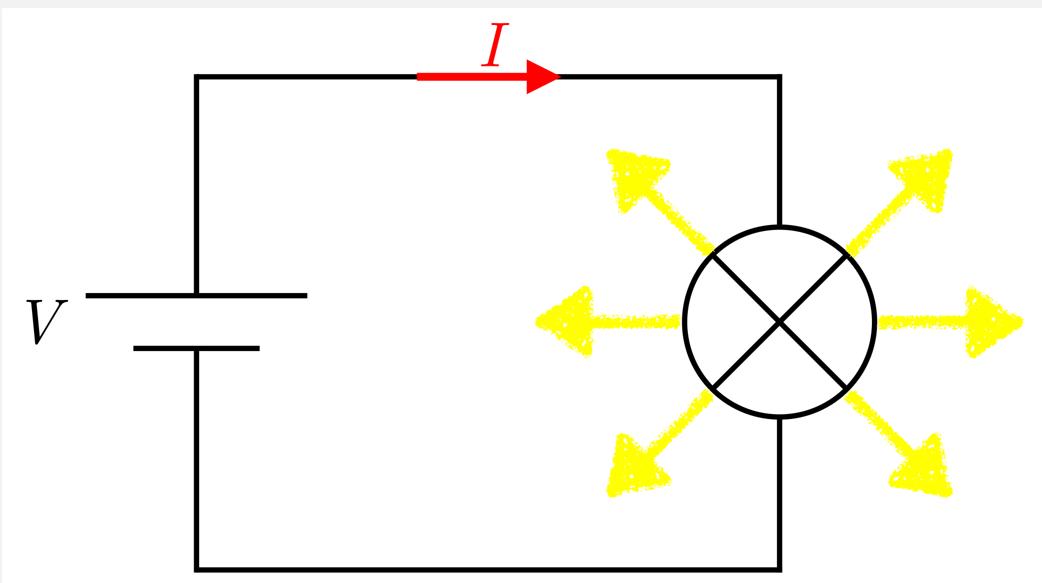
Investigation 1
Measuring Resistance of Various Devices

Electric circuits

We use electric circuits for so many things: lights, appliances, phones, *etc.* The list could go on forever. Ohm's law provides the relationship between the basic circuit properties of *voltage* (V), *current* (I), and *resistance* (R):

$$V = IR.$$

Often we model light bulbs as resistors because they convert electrical energy into heat and light. In this investigation we will study the electrical properties of a light bulb to test the *lightbulb as resistor* model.



The circuit diagram above contains a battery (different-length parallel lines, left) wired to a light bulb ($\otimes$, right). The yellow arrows represent the light emitted by the bulb.

Investigation 1 — Part 1

Background Information: Voltage, Current, and Resistance

1.1 Voltage, Current, and Resistance

Three important properties in an electric circuit are the voltage V, the current I, and the resistance R. The voltage, measured in volts (V), is the amount of electrical potential energy given to each coulomb of charge. A positive charge has higher electrical potential energy at a higher voltage and lower electrical potential energy at a lower voltage. Since the electric forces on negative charges are opposite the electric forces on positive charges, negative charges have more electrical potential energy at lower voltages than at higher voltages. Generally, a voltage difference causes positive charges to move (flow) from higher voltages to lower voltages (which means that negative charges move from lower voltages to higher voltages).

Current, measured in amperes (A), is the amount of charge passing through a cross section of the flow per unit time. The direction of the current is the direction of positive charge flow, meaning if the current is due to moving negative charges, the current is in the opposite direction of the actual motion of the negative charges. Note that this is what happens when electric currents flow through wires because electrons, which are negative charges, flow through the circuit.

Resistance, measured in ohms (Ω), is the ability of an object to oppose the motion of charges through it. Resistance depends on many properties including the makeup of the object (*i.e.*, how tightly the molecules hold on to electric charges), the cross-sectional area of the object, the length of the object (through which the charges must pass), and the temperature of the object. Specifically, the resistance is the voltage per unit current, or the voltage required to produce a current of 1 A. An object with a higher resistance requires more voltage to produce the same current as an object with a lower resistance.

1.2 Ohm's Law

The relationship between voltage, current, and resistance in an electric circuit is known as Ohm's law,

$$V = IR \tag{1.1}$$

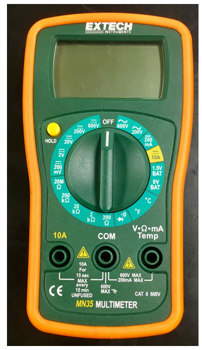


Figure 1.1: Digital multimeter used in PHYS 1261 laboratories. The selector can be set to measure DC voltage (V with straight lines), AC voltage (V with sine waves), low current (200 mA), high current (10 A), resistance (Ω), or other settings that you will not use. The three jacks near the bottom accept banana connectors. The left jack is labeled **10 A** for high current measurement and will not be used in this investigation. The middle jack is labeled **COM** for common (the reference measurement), and the right jack is labeled **V** for voltage measurement, **Ω** for resistance measurement, and **mA** for low current meaurement.

or, solving for current,

$$I = \frac{V}{R}. \tag{1.2}$$

You will use Eq. (1.2) in this investigation because you will adjust the voltage and measure the resulting current. The voltage will be the independent variable and the current the dependent variable. For many objects the resistance is independent of the current (*i.e.*, the resistance remains constant when the current changes), and the relationship between voltage and current is linear because Eq. (1.2) is a straight line with slope $1/R$. These materials are called ohmic materials. One example of an object made of ohmic materials is a resistor in an electric circuit. All objects are not ohmic, though. Some materials have electrical properties that change as the voltages across them or the current passing through them changes. These are called non-ohmic materials, and objects made of non-ohmic materials have resistances that are not constant.

1.3 Using a Multimeter

A multimeter is a device that can be used as a voltmeter to measure voltages or as an ammeter to measure currents. Most multimeters can also measure resistance as well as other properties. Multimeters have settings for different ranges, and they have jacks to insert probes for different measurements. (Note that for some multimeters you must insert the probes into different jacks to measure current and voltage. The multimeters that we will use do not require this.) Figure 1.1 shows a multimeter similar to those you will use for this experiment. In general, it is best to use the setting for which your measurement is closest to full scale. This gives a measurement with the highest precision. For example, if you are measuring a voltage of 10 V, you would use the DC 20 V scale and not the DC 200 V scale.

To measure a voltage, place the probes (in this lab, you will use wires with banana connectors for your probes) into the jacks labeled **COM** and **V** and set the selector to one of the voltage settings. The multimeter reads the voltage difference between the two points in the circuit that are connected to the two probes. The voltage difference is measured relative to the probe attached to the **COM** jack. If the voltage is positive, the probe connected to the **V** jack has a higher voltage than the probe connected to the **COM** jack, and if the voltage is negative, the probe connected to the **V** jack has a lower voltage than the probe connected to the **COM** jack.

To measure a low currents, place the probes into the jacks labeled **COM** and **mA** (same as the **V** jack for this multimeter model) and set the selector to the 200 mA setting. (You will not do high-current measurements in this investigation.) The multimeter reads the current passing through it. In order to measure the current in a circuit, you must connect the multimeter within the circuit. To do this, disconnect the wire from the part of the circuit where you want to measure the current and connect it to the **COM** jack on the multimeter. Then, connect the wire from the **mA** jack to the place you removed the wire you connected to **COM** jack. The number on the multimeter display is the current in mA. If the current measured by the multimeter is positive, the current is flowing from the **COM** jack to the **mA** jack, and if the current is negative, the current is flowing from the **mA** jack to the **COM** jack.

Investigation 1 — Part 2

Pre-lab: Determination of Resistance from a Current vs. Voltage Curve

The goal of this activity is to determine the resistance of an object from the current vs. voltage curve.

You will use a DC power supply, shown in Fig. 1.2(a), as a voltage source. The DC power supply acts as a battery with a voltage that is adjustable using using the Voltage knob on the right side. Note that the DC power supply has voltage and current indicators. Generally, it is better (and more precise) to measure the voltage and the current independently of the DC power supply display. In this investigation you will use one digital multimeter to measure voltages and a second digital multimeter to measure currents in circuits containing elements on a PASCO circuit board, shown in Fig. 1.2(b). The resistance is the reciprocal of the slope of the current vs. voltage curve, as given in Eq. (1.2).

2.1 Configuring the Equipment and Software

Configure the equipment to measure the current through the resistor at different voltages.

1. Connect the circuit as shown in Fig. 1.3 with the DC power supply replacing the battery and using the $100\,\Omega$ resistor. Note that the black connector is the negative side of the DC power supply and the red connector is the positive side.
2. Set the digital multimeter that you will use to measure current to the 200 mA scale and connect it in the circuit.
3. Set the digital multimeter that you will use to measure voltage to the DC 20 V scale and connect it to both sides of the resistor. Note that you may want to change the multimeter scale at low voltages because a lower scale reads voltages with greater precision.
4. Turn the voltage knob on the DC power supply all the way to the left. This turns the voltage to zero.
5. On the DC power supply turn the current knob, which sets the maximum current before the power supply shuts down, halfway to full scale.
6. Turn on the DC power supply.

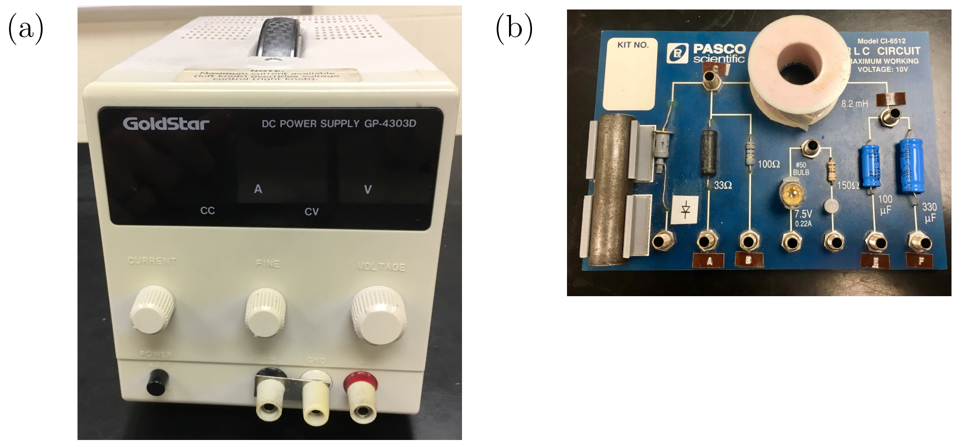


Figure 1.2: Equipment for resistance measurements. (a) DC power supply. (b) Pasco circuit board.

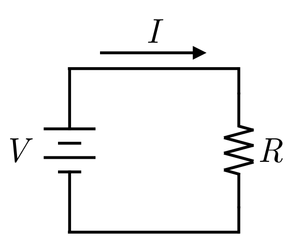


Figure 1.3: Simple circuit consisting of a battery (DC voltage source) with voltage V and a resistor R. The arrow represents the direction of the current I passing through the circuit.

7. Set the voltage on the DC power supply to 6.0 V, and vary the voltage from 6.0 V to 0.0 V, recording the voltage across the resistor and the current in the circuit.
8. When you get to 0.0 V switch the wires connected to the red and black connectors of the DC power supply. The voltages supplied to the circuit will be negative. Vary the voltage from 0.0 V to −6.0 V, recording the voltage and the current.

Note: The resistors in the PASCO circuit board can handle voltages well beyond ±6.0 V without damage, but the lightbulbs you will use in Part 3 could burn out at large (negative or positive) voltages. Please limit the voltages supplied to the light bulb to values from −6.0 V to 6.0 V.

2.2 Collecting Data

Record the current through the resistor at various voltages from 6.0 V to −6.0 V and plot current (y-axis) vs. voltage (x-axis) to determine the resistance from the slope of the curve. Be sure to convert your current measurements from mA to A (the SI unit of current) so your resistance will be in SI units (Ω) when you analyze your data.

2.3 Analyzing Data

Do the current vs. voltage plots look linear? If so, use a linear regression (see Appendix B.1) to determine the slope and intercept of the fit line and their uncertainties. If the plot is not linear, you must find a different type of regression to use for your data (see the other sections in Appendix B). For an ohmic resistor, the regression is linear because the resistance is constant (*i.e.* does not change with voltage), and the resistance is the reciprocal of the slope. We would expect the y-intercept of the regression line to be zero (within statistical uncertainty) because a zero voltage produces no current. Determine the statistical uncertainties of the resistances from the standard errors of the regression line slopes using uncertainty propagation (see Appendix A). Set the multimeter to measure resistance and measure the resistance of the resistor directly and compare the resistance you determined from your regression to the directly measured resistance. Which value is more accurate? Why? Repeat this for the 33 Ω resistor, and submit a group document with each of your graphs and measured resistances as well as a short synopsis of the measurements and analysis.

Before you leave

As a group:

1. Create a plot of current vs. voltage for each resistor.
2. Use a linear regression to determine the slope of each fit line and plot the fit line on the same graph as your data points.
3. Determine the resistances from the slopes of the fit lines, and report each value with both ***uncertainty*** and ***units***.
4. Compare the resistances determined from the linear regression to the resistances measured by the multimeter.

Type up your results and plots as a group and submit them on Blackboard. ***Before you submit, everyone must sign up for a group on Blackboard in order to get credit for the assignment.***

Investigation 1 — Part 3

Argumentation Question: Does a light bulb behave like a resistor?

This portion of the investigation is designed to last for two weeks. During the first week, your goals are to:

- Develop a proposal to answer the argumentation question.
- Get your proposal approved by the TA.
- Begin collecting and analyzing data. (Ideally, your data will be fully collected and analysis can happen during the week.)

During the second week of this investigation the main activity is the argumentation session. As such, you will need to:

- Finish data collection and analysis.
- Prepare your group's whiteboard for an argumentation session.
- Discuss the findings from the argumentation session.
- Finish your lab reports.

Based on your knowledge of physics, your task is to design and carry out a procedure to measure the resistance of a light bulb. However, before you begin taking measurements, you must create a proposal as a group. The proposal form is found on page 13. Be as specific as possible as you develop your proposal. In the "*How will you collect your data?*" box, you should pay attention to the following questions:

- What safeguards will you put in place to ensure that the measurements are reproducible?
- What will you do to ensure that your result holds for a wide range of parameters (*e.g.*, voltages and currents)?
- What are your potential sources of error, and how will you reduce them?

In the "*How will you analyze your data?*" box, you should pay attention to the following questions:

- How will you determine the relationship between the independent and dependent variables?

- How will you determine the resistance from this relationship?
- How will you determine whether the light bulb is ohmic or non-ohmic?

3.1 Lab Report

3.1.1 Guiding Question: Does a light bulb behave like a resistor?

And some follow ups:

- If yes, what is the light bulb's resistance?
- If no, under what circumstances does the light bulb behave like a resistor?

Once you have completed your work, you will prepare an investigation report that consists of three sections. Your report should answer these questions in 2 pages of text. This report must be typed (12 pt font and 1-inch margins) and any diagrams, figures, or tables should be embedded into the document.

Generally, you need one page for the first two sections and the second page for third section.

3.1.2 Section 1 (About $\frac{1}{2}$ page)

What concept were you investigating and how does it relate to the guiding question?

- Discuss the relationship between voltage and current for a simple circuit containing the device you are investigating and how resistance relates to the current vs. voltage relationship.
- Discuss ohmic and non-ohmic devices and the expected current vs. voltage relationship for each.

3.1.3 Section 2 (About $\frac{1}{2}$ page)

How did you go about your work and why? This is *not* the details of your procedure, but a discussion and justification of the process.

- Describe the methods for measuring the current vs. voltage data and any calculations that are made.
- Discuss what you did to reduce error/ensure consistent measurements.

3.1.4 Section 3 (About 1 page)

What is your argument? This third section is where you not only present your data, but also use the values you obtain as evidence in your reasoning. Statements like, "See data table for values," are *not* acceptable.

- State your claim.
- Use your measurements to support your claim.

- Include any figures that you created, along with the line of best fit to your data.
- Include a data table with the values that you measured for current and voltage.
- Discuss the limitations of your measurements and conclusions.
- Compare with other groups. Discuss reasons for differences.

3.1.5 Section 4 (about $\frac{1}{4}$ page, final report only)

In your final report include a short statement explaining your response to the peer reviews. If you changed something in your final report as a result of the peer reviews, describe what you changed. If you disagree with a suggestion given by a reviewer, state why. **Note**: Include this section in your final report only, not in your draft report you submit for peer review.

In addition to your lab report, also upload your Excel file with your data and analysis to Blackboard with your final report.

Name: ______________________ Date: ______________

Instructor: ______________________ Section/Group: ______________

3.2 Investigation 1 Proposal

The Guiding Question…

⇓

What data will you collect?

⇓

How will you collect your data?

⇓

How will you analyze your data?

I approve this investigation ______________ Date: ______________