PHY222 – Lab 4 Ohm's Law and Electric Circuits

Ohm's Law; Series Resistors; Circuits Inside Three- and Four-Terminal Black Boxes

February 8, 2017

Print *Your Name*

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Print *Your Partners' Names*

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Instructions

Before the lab, read all sections of the *Introduction to Ohm's Law and electric circuits*, and answer the Pre-Lab questions on the last page of this handout. Hand in your answers as you enter the general physics lab.

You will return this handout to the instructor at the end of the lab period.

Table of Contents

0. Introduction to Ohm's Law and electric circuits

Abstract Concepts that are part of the lab activities

0.1 *Current*

0.1.1 Current is the amount of charge per second, measured in Coulombs/s, flowing out of a power source, past a point on a wire, or through something (light bulb, motor, radio, etc).

0.1.2 Current is usually represented by the letter ***I*** in equations.

0.1.3 The unit of current is the *ampere*, defined to be *one coulomb per second*.

0.2 *Ohm's Law*

0.2.1 Ohm's Law is $V = IR$.

- ***V*** is the difference in electric potential (in volts) between two points in a circuit.
- ***I*** is the current flowing along the path between those two points.

0.2.2 The meaning of Ohm's Law is that voltage *V* is proportional to current *I*.

- ***R*** is the proportionality constant between the voltage ***V*** and the current ***I***. ***R*** is called the *resistance*.

0.2.3 The unit of resistance is the *Ohm*, represented by a Greek uppercase omega: Ω.

0.2.4 Ohm's Law, the proportionality between voltage and current, is true for many things that conduct current but not for everything. Light bulbs are an example of something that conducts current but does not obey Ohm's Law. If you apply different voltages to a light bulb and measure the light bulb currents, you get different values of the ratio V/I. This makes it impossible to assign a fixed resistance R to a light bulb. Things which do have a fixed resistance always yield the same V/I ratio no matter what voltage you apply to it. ***Then*** it is possible to say that $V/I = R$ is the resistance, because the ratio is always the same.

0.3 *The graphic symbols for things without and with resistance*

Wires or things that have little or no resistance are represented by straight lines. The idea behind resistance is that it resists the flow of electrical current, so resistance is represented by a jagged line (which should make you think of a difficult path).

- Wire, or something with little or no resistance: ______________
- Something with significant resistance: 

0.4 *Two resistances connected in series*

You can connect two things having resistance by joining one of the ends of the first to one of the ends of the second. The result is a new single thing with resistance. This is called a *series* connection, and the resistances of the two separate things combine to make the resistance of the new single thing. This is represented using the graphic symbol for a resistor as shown immediately below.

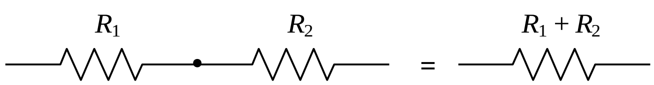
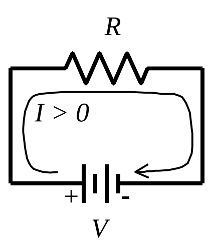


Figure 1 Combining resistors in series

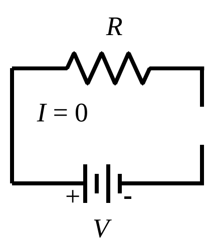
0.5 *Current always flows in a closed loop*

Electric current flowing out of a power supply or battery must always return to where it started. More precisely, current flowing out of the positive terminal of a power supply or battery must flow back in the negative terminal of the same power supply or battery.

This forces electric current always to flow in closed loops. If the circuit does not contain a continuous closed loop, no electric current can flow.



Current flowing in a closed loop



Current cannot flow

Figure 2 With no closed loop conductive path, as in the circuit on the right, current cannot flow.

0.6 *Ammeters*

0.6.1 An ammeter is an instrument that measures the rate at which electric charge flows through a wire in amperes, which are the same as coulombs per second. An ammeter also tells the direction the current flows by the sign of the reading or the direction of the needle swing (see 0.6.4).

0.6.2 The only way the ammeters used in our labs can know how much current flows through a wire is if the wire's current actually flows through the ammeter. If you had a single wire and wanted to know the current flowing through it, you would have to cut the wire and connect the two cut ends of the wire to the ammeter so that the current passes through the ammeter.

0.6.3 Measurements in electric circuits do not require you to cut wires, but you do have to arrange the circuit connections so that the current you want to measure is diverted to flow through your ammeter. In a circuit diagram, the connection looks as shown in Figure 3.

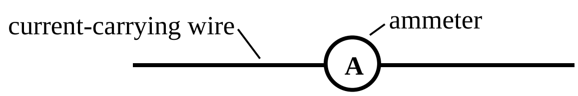


Figure 3 An ammeter connected to measure the electric current flowing through a wire

0.6.4 Of the two places on the ammeter where you connect a wire (to measure the current flowing through it), one will be named ***ground*** (sometimes abbreviated to **GND** or indicated with a ground symbol: ⏚). If the current flows out of the ammeter's ground terminal after flowing in the other terminal, the ammeter identifies the current as positive. If the current flows into the ground terminal and out of the other terminal, the ammeter identifies the current as negative. That is how you can tell which direction the current is flowing. (If the current is positive, then electrons are moving in the opposite direction.)

0.7 *Voltmeters*

0.7.1 In a circuit with resistors and batteries, an electron in the wire sees some places as higher in energy than others – and harder to get to – while an electron will see other places as lower than others – and getting to those low places is easy, like rolling down a hill. However, there is no way a human can look at a circuit and immediately see which points in the circuit look high and which points in the circuit look low from an electron's perspective. Those high and low places (to an electron) are there even if the circuit is completely flat on the table.

0.7.2 One thing is usually easy for a human to see. To electrons, batteries and power supplies look like escalators, moving electrons uphill, from the low places to the high places. You can look at a battery and see which terminal is + and which is –. To an electron, the + terminal is low (because negative electrons are attracted to positive) and the – terminal is high. Since batteries pull electrons in at the + terminal (the low end) and push them out the – terminal (the high end), batteries act like electron escalators.

0.7.3 Elsewhere in circuits, which places are high and which places are low is not immediately obvious to human eyes, and this is why humans use voltmeters. To use a voltmeter, you touch its two terminals to two different points in a circuit. The voltmeter compares the two points, determines which is high and which is low, and tells you what the height difference is in *volts*, that being the measure of height that the electrons respond to. (Height in volts has to do with electric forces and has nothing to do with height in meters from which things fall due to the gravity force. Different forces have different measures of height, but it is the same idea in both cases.)

0.7.4 Using a voltmeter to measure the voltage difference between different parts of a circuit requires you to touch the two voltmeter terminals to the two different parts of the circuit. Figure 4 shows how a voltage measurement looks in a circuit diagram.

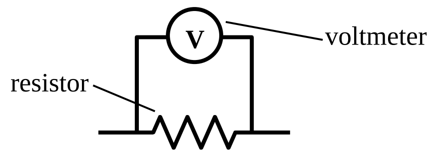


Figure 4 Using a voltmeter to determine the voltage ("height") difference between two ends of a resistor

0.7.5 The voltmeter reads out the difference in height between the two points it touches in volts. If the voltage is positive, the ground terminal of the voltmeter touches the circuit point that is – from an electron's point of view – higher than the other point. If the voltage is negative, the ground terminal touches the high point. This is confusing because it means a circuit point with a positive voltage is *lower* than the comparison point. The confusion is due to the fact that everyone talks about electricity as if it were a flow of positive particles moving from + to –, in spite of the fact that it really is a flow of negative particles moving from – to +.

0.7.6 **To make this less confusing, pretend – along with everyone else – that electricity is a flow of positive particles. Then a positive voltage reading means the ground terminal of the voltmeter is touching the lower point and the other terminal is touching the higher point, from the positive particle's point of view. Conversely, a negative voltage means it is the ground terminal that is touching the high point.**

0.8 *DC and AC*

0.8.1 Electric current that always flows in one direction is called *DC*, for *direct current*. Current that keeps changing directions is called *AC*, for *alternating current*. Ammeters and voltmeters can measure current and voltage for both kinds of current, but you have to tell the meter which kind of current it is measuring before you do the measurement.

0.8.2 On the big rotary switch that determines what the meter will measure, you will see either A–, A~, V–, V~ or $\overline{\text{A}}$, $\tilde{\text{A}}$, $\overline{\text{V}}$, $\tilde{\text{V}}$. The symbols with wiggle lines indicate AC, and the symbols with straight lines indicate DC. Thus, either A~ or $\tilde{\text{A}}$ might be used to indicate the AC ammeter function, and similarly either V– or $\overline{\text{V}}$ might be used to indicate DC voltmeter function.

0.8.3 In this lab, all currents are DC, so you will never use the meters to measure AC current or voltage.

0.9 Setting the maximum current that a power supply will allow

0.9.1 This feature is quite important and will prevent you from at the least, burning a fuse on your ammeter and causing you to lose time because of 'broken' equipment, or worse, burning up a resistor and actually damaging equipment.

0.9.2 Recall the procedure from the lab activites last week.

0.9.3 Turn all four knobs fully counterclockwise (CCW). This sets both the current and the voltage to 0.

0.9.4 Connect an ammeter directly to the red (+) and black (-) outputs of the power supply.

0.9.5 Set the ammeter scale to the smallest setting that will still allow you to read the maximum value of the current you want to output. For example, if you know that you only need 25 mA, you should use the 200 mA setting. While setting the ammeter to the 2 mA will not cause damage, you will not see a reading because you exceeded the range.

0.9.6 Check again, make sure all knobs are fully CCW. Turn up a voltage knob. Gradually adjust the CURRENT knobs to reach the maximum allowable current that you want.

0.9.7 Once you see the current you want, do not touch the CURRENT knobs.

0.9.8 Turn the VOLTAGE knobs fully CCW to return the output to 0.

1. Activity #1: Instructor demonstrates circuit building for Activity #2

Equipment: Computer with Logger Pro or Excel
DC ammeter set for 2.0 or 3.0 amperes DC
DC voltmeter set for 20 or 30 volts DC
DC power supply (0.12 amperes)
Unknown resistors *A*, *B*, and *C* mounted for banana plug connection
See the picture of the three resistors mounted on a small box, below.
Banana plug wires (each group gets their own from the common supply)

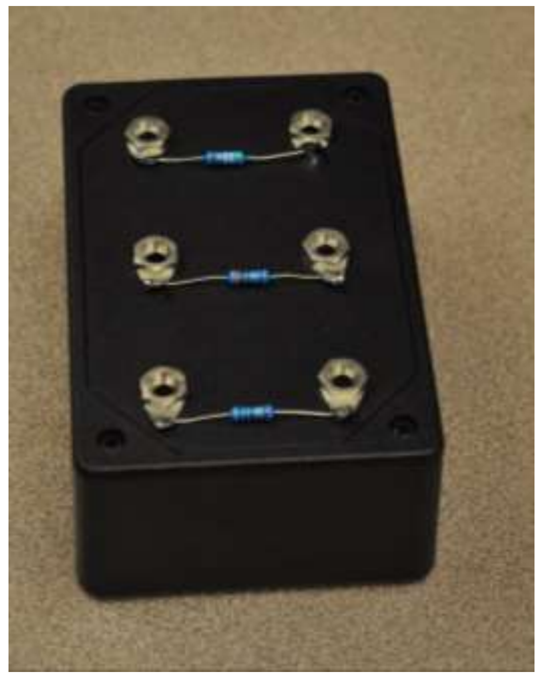
1.1 The instructor does the following as a demonstration.

1.1.1 Ignoring the voltmeter, build the main current loop in Figure 5 (power supply, resistor, ammeter).

1.1.2 Add the voltmeter.

1.1.3 Set the voltmeter scale to 20 V DC or 30 V DC, whichever the voltmeter has, and turn the meter on.

1.1.4 Set the ammeter scale to 2 A DC or 3 A DC, whichever the ammeter has, and turn the meter on.



1.2 After verifying that everyone understands building the circuit, the instructor disassembles the circuit and turns off the meters.

1.3 The Lab instructor mentions the importance of not exceeding 0.12 A from the power supply.
This is so the resistors do not overheat.

2. Activity #2: Ohm's Law

Abstract An experimental demonstration of Ohm's Law

2.1 Verify that the power supply, the voltmeter, and the ammeter are turned off.

2.2 Obtain banana plug wires as needed from the rack mounted on the wall.

2.3 Using resistor *A* on the resistor board, construct the circuit shown in Figure 5. The following steps will help.

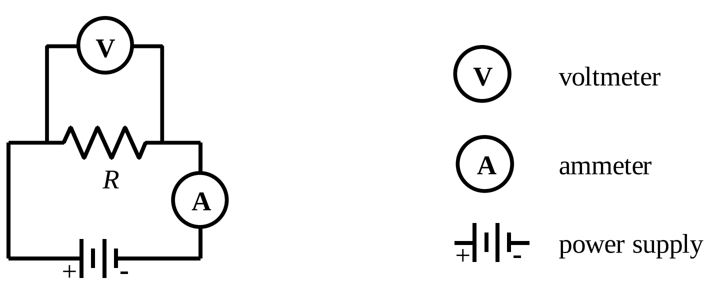


Figure 5 The circuit to build for Activity #2

2.3.1 Ignoring, for the moment, the voltmeter, connect the power supply, resistor, and ammeter in series, with the black lead from the ammeter connected to the – terminal (which is black) of the power supply. When done, these three components and their connecting leads should form a closed loop. As a check, see if you can start with the + terminal of the power supply and trace a path around the loop that passes first through the resistor and then through the ammeter and back to the – terminal of the power supply.

Datasheet for Ohm's Law Activities –

Activity #2 Resistor A

	I (amps) (x)	V (volts) (y)
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		
9.		
10.		

__________ Ω
Resistance of A (from linear fit)

Ω stands for "ohms," the unit of resistance

$$\%\,discrepancy = \frac{(Value1) - (Value2)}{(Average\,Value)} \times 100\%$$

where

$$Average\ Value = \tfrac{1}{2}\,(Value\,1 + Value\,2)$$

Activity #3

R_A	__________ volts V_A	__________ amps I_A	__________ Ω R_A (= V_A/I_A)
R_B	__________ volts V_B	__________ amps I_B	__________ Ω R_B (= V_B/I_B)
R_C	__________ volts V_C	__________ amps I_C	__________ Ω R_C (= V_C/I_C)

Activity #4

__________ volts V_{TOTAL} (from meter)	__________ volts V'_A (from meter)
__________ amps I_{TOTAL} (from meter)	__________ volts V'_B (from meter)
__________ Ω R_{TOTAL} (= V_{TOTAL}/I_{TOTAL})	__________ volts V'_C (from meter)
__________ Ω $R_A+R_B+R_C$ (= R_{TOTAL}?)	__________ volts $V'_A+V'_B+V'_C$ (= V_{TOTAL}?)
__________ % discrepancy (total R's)	__________ % discrepancy (total V's)

2.3.2 Now connect the voltmeter leads, one lead to each end of the resistor, with the black lead from the voltmeter connected to the resistor at the same place as the red lead of the ammeter.

2.3.3 Set the voltmeter scale to: ____________

2.3.4 Set the ammeter scale to: ____________

2.3.5 Have your instructor check your circuit **BEFORE YOU TURN ANYTHING ON**. S/he will initial here when the circuit is correct. ______________

Instructor's Initials

2.4 Turn on the voltmeter and the ammeter.

2.5 Turn the VOLTAGE control knobs of the power supply down to zero, and then turn on the power supply.

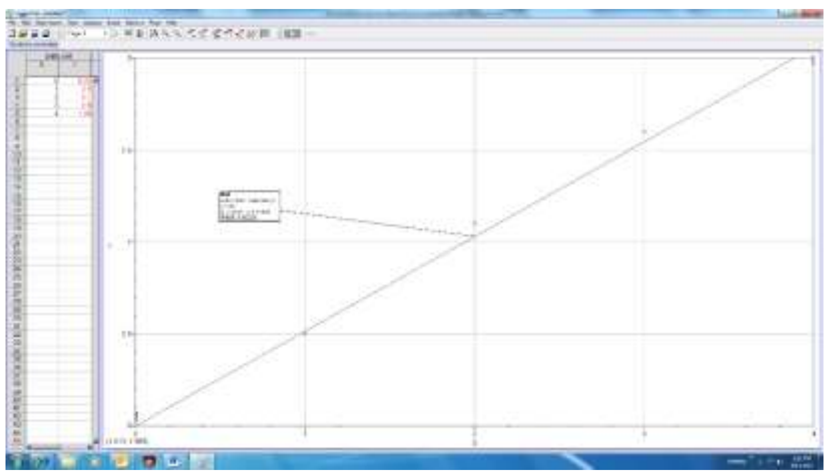
2.6 Turn the voltage up to about 0.5 volts, as displayed on the voltmeter. **Never read voltage or current from the meters on the power supply**, because those meters are only approximately correct. **Always use the voltmeter and the ammeter**.

2.7 If the voltmeter and the ammeter both show positive readings, they are connected properly. If not, turn the power off and reverse the connections to whichever meter is reading negative.

2.8 Record, in the datasheet on page 7 of this handout, values of current and voltage for values of voltage 0.1 V, 0.2 V, 0.3 V, ...,. Certainly, collect 10 data points spanning the entire current range from 0 A to 0.12 A. The voltage values for which you record the measurements need not be exactly those in this list, but they should be near. Record the exact values given by the meters – not the nominal values from the list – in the datasheet.

Do not exceed 0.12 A

2.9 Make a spreadsheet in LoggerPro, or Excel and graph your data.



2.9.1 Double click the X column heading and enter I (Name) and Amps (units). Similarly, modify the Y column for the voltage.

2.9.2 *I* (current in amperes) is on the *x*-axis; *V* (voltage in volts) is on the *y*-axis

2.9.3 If any of the data do not fall on a straight line through the origin, re-do the measurement.

2.9.4 Add a straight line fit to the plot.

- Analyze → Curve Fit… Select Ax (Proportional). This sets the y-intercept to zero.
- Try fit…

2.10 Print a copy of the spreadsheet and graph for everyone in your group.

2.11 Write the slope of the straight line fit in the box labeled "Resistance of *A* (from linear fit)" in the Datasheet where you recorded your current and voltage data.

Q 1 Have you verified Ohm's Law for resistor A? If you think you have, do you think it was a good, convincing verification? How well does your data fit the theory compared to your experiments in PHY221 (first semester physics lab)?

3. Activity #3: The resistance of three individual resistors (I_{max} = 0.07 A)

3.1 Without changing the circuit (so that resistor *A* is still connected to the power supply), set the power supply to some intermediate current not to exceed 0.07 A, enter the voltage and current values into the appropriate place under Activity #3 in the Datasheet on page 7, and use a hand calculator to calculate the resistance of resistor *A*.

3.2 Repeat these measurements and the resistance calculation for resistors *B* and *C* on the resistance board.

3.3 The values you just obtained for the resistances of the three resistors will be used in Activity #4.

4. Activity #4: Resistance and voltage in a series combination of resistances

4.1 Turn off the power supply.

4.2 Construct the circuit in Figure 6.

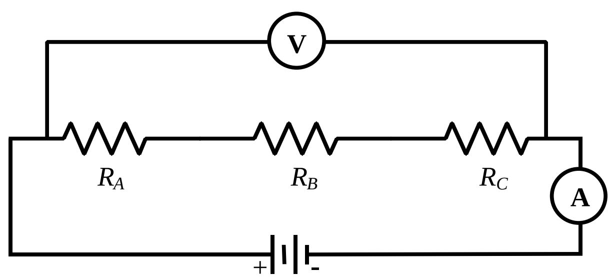


Figure 6 The circuit to build for Activity #4

4.3 Turn on the power supply, and set its current to .07 A.

4.4 Record the actual voltage and current meter readings in the spaces for V_{TOTAL} and I_{TOTAL} in the appropriate part of the Datasheet for Activity #4.

4.5 Use a calculator to calculate R_{TOTAL}, and enter its value in the appropriate place in the Datasheet.

4.6 Leaving the power supply turned on at the same voltage as above, and without disconnecting the resistors or the ammeter, do the following.

4.6.1 Disconnect the voltmeter from the circuit.

4.6.2 Connect the voltmeter so that it reads the voltage across resistor *A*.

4.6.3 Record the voltage across *A* in the place for V'_A in the Datasheet for Activity #4.

4.6.4 Repeat the voltage measurement for resistors *B* and *C*, and record those values in the Datasheet as V'_B and V'_C.

4.7 Complete the remaining entries in the part of the Datasheet for Activity #4.

Percent discrepancies are calculated as follows.

$$\%\ discrepancy = \frac{(Value\,1) - (Value\,2)}{(Average\,Value)} \times 100\%$$

The result may be either positive or negative.

where *Average Value* = ½ (*Value* 1 + *Value* 2).

4.8 At this point, please return your banana plug wires to their rack. *Thanks!*

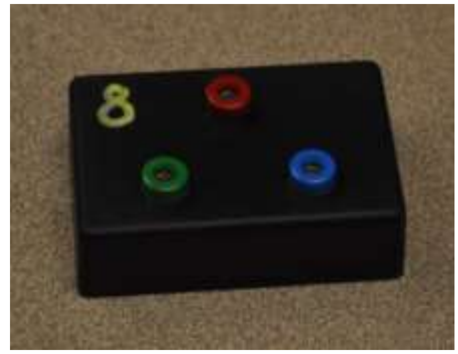
4.9 **Assume you are given three resistors having resistances of 15 Ω, 23 Ω, and 42 Ω. The resistors are connected in series, and the series circuit is connected to a power supply. The current flowing through the circuit is *I* = 0.225 A. Work with your lab partners to answer the following questions.**

Q 2 Draw the circuit. Have your lab instructor check your drawing.

Q 3 The current I flows through all three resistors. Use Ohm's Law, V = IR, to find the voltage across each resistor.

Q 4 What is the voltage of the power supply? Show your calculation.

5. Activity #5: Electric circuits with the three-terminal black box



Activity #5 is practice for Activity #6. Your instructor will help you if necessary with Activity #5, but when doing Activity #6 you are on your own.

Equipment: DMM to measure resistance
(Use the DMM's 200 Ω or 300 Ω scale)
Three terminal black box (see picture)
Paper
Pencil or pen

5.1 Preliminary: Everybody does the following

5.1.1 Get out a pen or pencil and a sheet of notebook paper, to be used as scratch paper for this lab.

5.1.2 Have your lab instructor explain how to use the Digital MultiMeter (DMM, for short) to measure resistance and to check continuity.

5.2 Locate your three terminal box. See the diagram to the right. The three-terminal box has three terminals colored red, green, and blue. There is also an identification number written on the box.

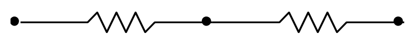


Figure 7 The circuit inside the three-terminal black box. The problem is to determine the values of the resistors and the color to assign to each connection point (indicated above by a dot).

5.2.1 Inside the three-terminal box, two resistors are connected as shown in Figure 7.

5.2.2 The values of the two resistors are unknown, but they are all near even multiples of 10 Ω.

5.2.3 The dots at the ends of the resistors represent the terminals on the box. Which dot is red is unknown. Similarly for the other terminals.

5.3 *Your task* is to deduce the values of the resistors and how they are connected to the terminals. Merely having the right answer is insufficient; you *must conclusively prove you are right*.

5.3.1 Your only tools are the DMM (to measure resistance) and the fact that if resistors with resistance R_1 and R_2 are connected in series, the series connection has a resistance of $R_1 + R_2$ ohms. See Figure 8.

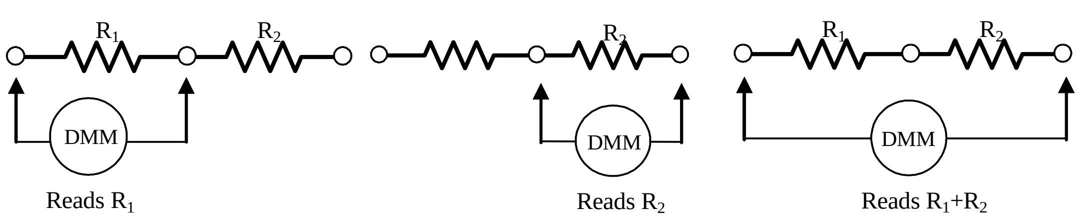
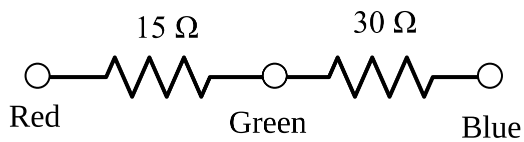


Figure 8 The resistance of a series connection is the sum of the individual resistances

5.3.2 You are done when you can draw the circuit inside the box with the correct resistor values and with the terminals correctly labeled by their colors. Here is an example of what a complete answer would look like.



This is what a typical complete answer looks like.

5.3.3 You must make all possible measurements and verify that they agree with the circuit you think is in the box. Otherwise you have not conclusively proved your circuit is actually the one inside the box.

5.4 In the empty space below ...

5.4.1 Write the identification number of your four-terminal black box in the space provided.

5.4.2 Draw the circuit inside your three terminal box, identifying the terminals by their colors, red, green, blue, and labeling all resistors by their resistances, rounded to the nearest 10 Ω.

5.4.3 List all measurements you made and their results. *Example* red to green = 120 Ω.

Box Number =

6. Activity #6: Electric circuits with the four-terminal black box

You and your lab partners are on your own while you do this activity.

Equipment:
- Ohmmeter (200 or 300 Ω scale)
- *Optional* Continuity checker (beeps to indicate continuity)
- Four terminal black box with a break in the circuit (see picture)
- Paper
- Pencil or pen

6.1 Locate your four terminal box. See the photo to the right.

6.1.1 The four-terminal box has four terminals colored gray, green, orange, and white arranged in a square pattern.

6.1.2 In addition, there are three terminals colored red, black, and yellow in a straight line under a silver terminal.

6.1.3 Inside the four-terminal box is one of the two circuits shown in Figure 9.

6.1.4 The break in the circuit (see the caption to Figure 9) can be fixed by connecting the silver terminal to one of the red, black, or yellow terminals under the silver terminal. Only one of the three possible connections will actually fix the break.

6.1.5 Once the break in the circuit is fixed, the box is just like the box of *Activity #5* but with three resistors in series instead of two resistors in series.

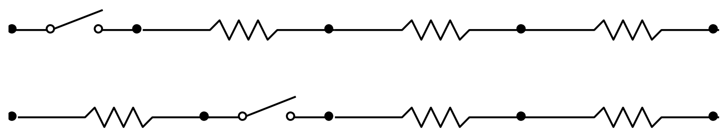


Figure 9 Inside the four-terminal black box is one of these two circuits. The switch symbol, , represents a break in the circuit, through which electric current cannot flow.

6.2 *Your task* is to determine (1) which color terminal connected to the silver terminal fixes the break in the circuit, (2) the values of the resistors, (3) how the resistors are connected to the terminals, and (4) where in the circuit the break is located. Merely having the right answer is insufficient; you *must conclusively prove you are right*.

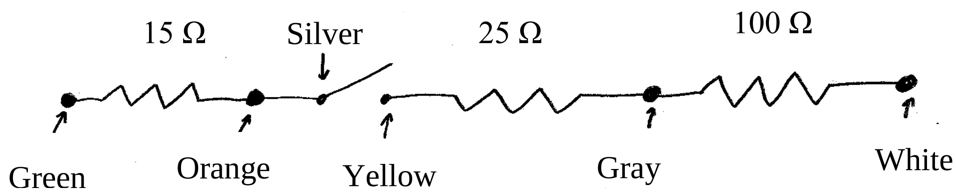
6.3 Your tools are the following.

6.3.1 A DMM, optionally with an audible continuity check, so that the DMM beeps when current can flow through the circuit

6.3.2 The facts that a broken circuit ( ) blocks the flow of current and prevents the DMM continuity checker from beeping, but an unbroken circuit ( ) permits the flow of current and causes the DMM continuity checker to beep.

6.3.3 The fact that if resistors with resistance R_1 and R_2 are connected in series, the series connection has a resistance of $R_1 + R_2$ ohms (recall Figure 8 in *Activity #5*).

6.4 You are done when you can fix the break in the circuit and when you can draw the circuit inside the box showing where the break in the circuit is, with resistors correctly labeled with their resistance values and with the box terminals correctly labeled. Here is an example of what a complete answer would look like.



To fix the break, connect silver to yellow.

This is what a typical complete answer looks like.

6.5 Rather than trying to determine the entire box circuit right from the beginning, break the task into the following sub-tasks, and do each in the order given here.

6.5.1 Determine how to fix the break in the circuit. You can do this using only the DMM's audible continuity checker (if it has one – otherwise just check resistances).

6.5.2 After the break is fixed, determine the arrangement and value of each of the three resistors and the colors of the terminals connected to each resistor. This is like *Activity #5*.

6.5.3 Determine the location of the switch in the circuit.

For full credit you must have both the correct circuit and also a complete proof — based on measurements — that the circuit is correct. A correct circuit which is not conclusively proved to be correct does not get full credit.

6.6 In the empty space below ...

6.6.1 Write the identification number of your four-terminal black box in the space provided.

6.6.2 Draw the circuit inside your four terminal box, showing the break in the circuit, identifying all terminals by their colors; labeling all resistors by their resistances, rounded to the nearest 10 Ω; and showing the color that the silver terminal connects to in order to fix the break in the circuit.

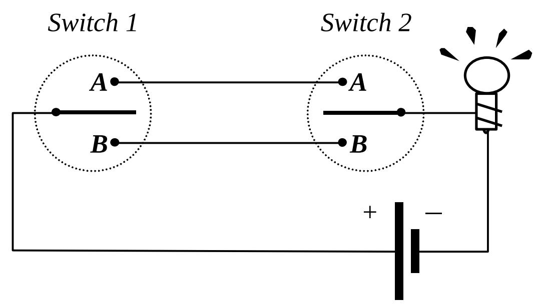
6.6.3 List all measurements you made and their results. The first example below is from fixing the break in the circuit. The second example is from determining the resistors and the way they are connected in the circuit.

Example Connect silver to red: DMM says green and black are unconnected
Example Measured resistance of black to blue: DMM says 90 Ω

Box Number =

7. Activity #7: Questions

The questions in this activity can be answered by using the fact that electric current will flow only when there is an unbroken conductive loop for it to follow.

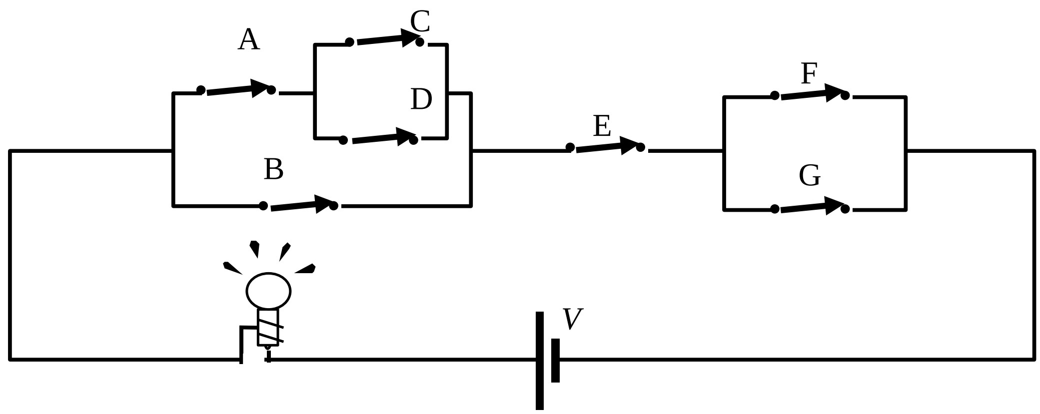


7.1 The drawing to the right shows a circuit in which a light bulb is connected to the household AC voltage via two switches *Switch 1* and *Switch 2*. The horizontal bar inside each switch can be swung either upward, to touch terminal ***A***, or downward, to touch terminal ***B***.

Q 5 When Switch 1 is touching terminal A, which position of Switch 2 , A or B, turns the light on?

Q 6 When Switch 1 is touching terminal B, which position of Switch 2 , A or B, turns the light on?

7.2 The figure below shows an electric circuit in which a light bulb is connected to a voltage source *V* through a network of switches. The switches are labeled A, B, C, D, E, F, and G. For the bulb to light up, electric current must flow in one of the wires connected to the bulb and out the other wire. The circuit is shown with all switches closed and the light bulb shining brightly.



Q 7 Which switches, if opened while leaving all other switches closed, will immediately make the light go off?

Q 8 Which* pairs *of switches, if opened together while leaving all other switches closed, will make the light go off?

Q 9 What is the largest number of switches which can be opened while still leaving the bulb turned on, and which switches are these?

8. When you are finished ...

8.1 Make sure

- 8.1.1 The Datasheet on page 7 is completely filled in.
- 8.1.2 All questions are answered.
- 8.1.3 All banana plug wires have been put away.

8.2 Attach the following to this handout:

- 8.2.1 The spreadsheet and graph from Activity #2 (printed in paragraph 2.10)

8.3 Hand them in.

Pre-Lab Questions

Print *Your Name*

____

Read the *Introduction* to this handout, and answer the following questions before you come to General Physics Lab. Write your answers directly on this page. When you enter the lab, tear off this page and hand it in.

1. What is the definition of electric current?

2. If something that obeys Ohm's Law allows a current of 2.4 amperes to pass through it when a voltage of 52 volts is applied to it, what is its resistance? Show your calculation, and append the correct units to your answer.

3. How, in a circuit diagram, does one indicate wires and things that have no resistance?

4. How, in a circuit diagram, does one indicate something that has resistance to the flow of electricity.

5. Which way does current always flow?

6. A 5 Ω resistor and a 12 Ω resistor are connected in series. Draw the circuit.

7. What is the total resistance of the 5 Ω and 12 Ω resistors when they are connected in series?

8. What is the largest power supply voltage you can use with resistors *A*, *B*, and *C*? (See paragraph 2.8 on page 8.)

Continued on the next page ...

9. In all the circuits in this lab handout, the ammeter is connected to be part of the closed loop around which current flows. Why? [See section 0.6.]

10. In all the circuits in this lab handout, the voltmeter is never part of the closed loop around which current flows. Instead, the voltmeter is always connected to the two ends of something else (usually a resistor) that *is* part of the closed loop. Why? [See section 0.7.]

11. Write the symbols found on meters that indicate AC and DC current and voltage.

12. What is the difference between a resistor and a light bulb that makes it impossible to assign a resistance to a light bulb?

13. When a current flows in a circuit, is there an electric field inside the conductor? If yes, what is the source of that electric field? If no, how can you explain the current?

14. Sketch the circuit required to adjust the maximum current output of a power supply. Make sure to label all connections on the power supply and ammeter. Please explain the procedure. (This question will be graded.)