Lab 5: Series & Parallel Circuits

1. Introduction

Nearly all electronics contain more than one circuit element, so we need to know how to begin to analyze networks of devices. How can we predict the current in a more complicated circuit if we supply a voltage? Does it matter how we connect circuit elements together, and are there any advantages for a particular way of connecting them? How are our homes wired for electricity? Your body has already solved these problems with its advanced vascular network, for example. For devices in our homes, we often find that multiple batteries are required, but what does this accomplish? Are there any rules we can follow for analyzing more complex circuits? In this lab, you will perform several experiments where you will analyze examples of both series and parallel circuits. For additional definitions and references, see **Chapter 23.1-23.6** in the Knight textbook.

2. Experiment

Activity 1a - Introduction to Series & Parallel Circuits

We will consider two ways of connecting circuit elements: *series* and *parallel*. For both series and parallel circuits, one can change the order of sub-circuit components without changing what the circuit does. Consider the circuit shown in Figure 1a. It contains two battery packs B1, a switch S1 and two lamps (L1 & L2). With S1 closed (ON), how

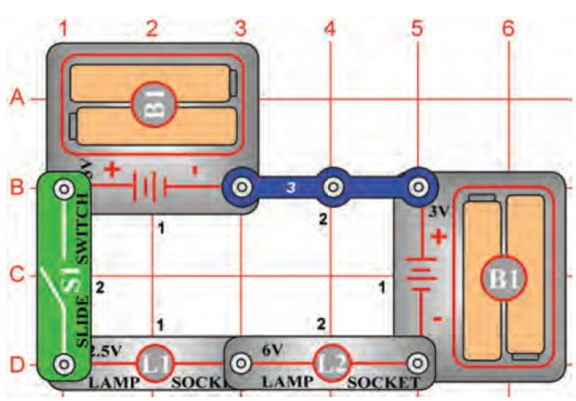


Figure 1a: *simple series lamp circuit*

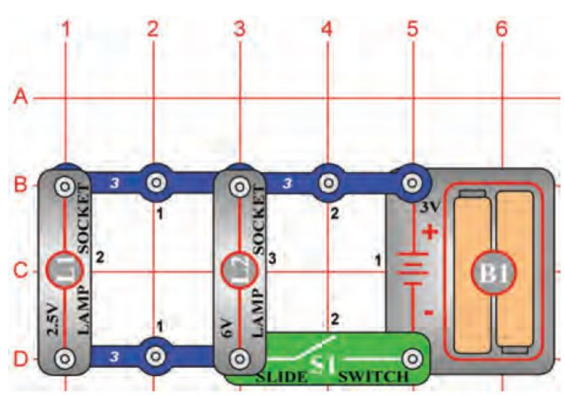


Figure 2a: *simple parallel lamp circuit*

many possible uninterrupted paths are there between the ‘+’ side of B1 and the ‘-’ side of the same B1? Can you predict what will happen if you assemble the circuit leaving out L1 (or L2 or one B1)? Assemble the circuit and test your predictions. Next, consider what might change if you switch the positions of L1 and L2 and/or the B1s, implement one of your changes, and activate your circuit again. Did anything change? This is an example of a *series* circuit because each circuit element is connected sequentially along a single path from the ‘+’ side of one B1 to the ‘-’ side of the same B1. In other words, all of the current must pass through all of your circuit elements. If charges can bypass any circuit elements, then they are not all connected in series. Using these same components (add any blue connectors as necessary), construct two of your own equivalent series circuits and check to see if they work as you expect. For **deliverable 1**, take pictures of both your circuits with the lamps on. Include a circuit diagram corresponding to each of your circuits using the symbols in Figure 23.2 of your textbook. Why do you think this circuit contains two battery packs connected in series?

Next, consider the basic parallel circuit in Figure 2a, which contains similar elements (only a single B1 this time), but the lamps are arranged differently. Before assembling and testing the circuit, predict what will happen if you leave lamp L1 out of the circuit. L2? How about S1? Assemble your circuit and test your various predictions. Does anything change if you swap the positions for L1 and L2? This is an example of a *parallel* circuit because both L1 and L2 are independently connected to B1, so the total current carried by the circuit is divided between each lamp along its branch of the circuit. In other words, this circuit has two independent paths between the terminals of B1: one passing through L1 and another passing through L2. You should have also noticed that removing S1 made it impossible for either L1 or L2 to light up. For **deliverable 2**, include a picture of your working parallel circuit and a circuit diagram for this circuit. Also state whether S1 is connected in series or parallel with the L1 + L2 sub-circuit and explain your reasoning.

For your series circuit, you observed that with either L1 or L2 missing or burned out, neither bulb will light. Any one bulb along a broken section of holiday lights may be burned out, preventing the others from working, so you have to check each one to find the culprit. In our homes, a non-working lamp or turning off a light switch in one room usually doesn’t affect the circuits in another room, which implies that the electricity within our homes is not wired in series but in parallel. Similarly, in your parallel circuit you should find that removing one lamp still permitted the other to light up with S1 ON. Note that in the parallel circuit, the lamps have the same brightness as in the series circuit, even though only one battery pack is used. This is because in the parallel circuit, both L1 and L2 can see the full battery voltage ($\cong$ 3 V), and this might even appear more efficient than the series circuit with two B1s working together. However, the current to light the lamps is the same, so this means that the parallel circuit is draining the batteries twice as fast as the series circuit. The battery-powered devices in our homes use batteries connected in parallel when the voltage from one battery alone is all we need, but the required current is more than one battery can provide.

Activity 2a - Voltmeters and Ammeters

You already have some experience with *voltmeters*, which are devices that measure potential difference (often relative to 0 V), from Lab 3 where you took readings of the voltage V of your battery pack. *Ammeters* are devices that measure current I. Our goal here is to understand how these measurement tools should be connected in a circuit to characterize devices correctly. Recall your connections for the battery pack measurement in Lab 3, in which you connected your multimeter directly to the '+' and the '-' sides. Regardless of what other components were connected in your circuit, your voltmeter had its own independent connections to B1, meaning it was connected in parallel. Therefore, whenever you want to measure V (i.e., potential difference) for a particular circuit element, you will always connect the voltmeter in parallel with that element. To put it another way, you want the voltmeter to see the same V that the circuit element sees.

An ideal voltmeter does not affect the behavior of the circuit element it is measuring, which means that it should draw no current (i.e., resistance $R = \infty$). In practice, voltmeters are designed with very large (10^6 - 10^8 Ohms) resistance so that $I = \Delta V/R$ drawn along its branch of the circuit is negligibly small (but still non-zero, since a small I is still required for the voltmeter to measure ΔV). Consider a simple single lightbulb circuit similar to Figure 3a, which shows the multimeter setup to read ΔV for the lamp L1 and you can convince yourself that the voltmeter is in parallel with L1.

Warning: to avoid blowing the low-current fuse on your multimeter, adjust your multimeter settings before connecting it to your circuit. Passing through any of the ammeter settings with S1 closed and your multimeter connected could create a short circuit and the low-current side of your multimeter will be useless. Also review safety precautions on p. 4 of your circuits manual before continuing.

Figures 3a & 4a show the same circuit with a voltmeter reading ΔV for the lightbulb OFF & ON, respectively. The voltmeter reads $\Delta V = 0$ V when S1 is open because no current is flowing, while $\Delta V = 2.96$ V when S1 is closed and current is allowed to flow. For

deliverable 3, include a picture of your own circuit with your voltmeter readings of your lightbulb visible, and draw a circuit diagram that includes the voltmeter. Also see Figures 23.24 and 23.25 in your textbook for help with notation.

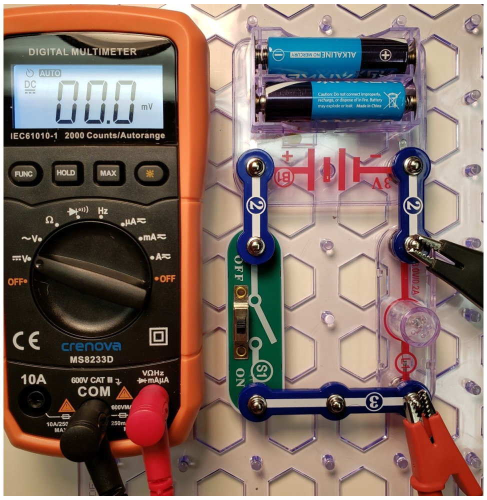


Figure 3a: *voltmeter measurement with S1 open*

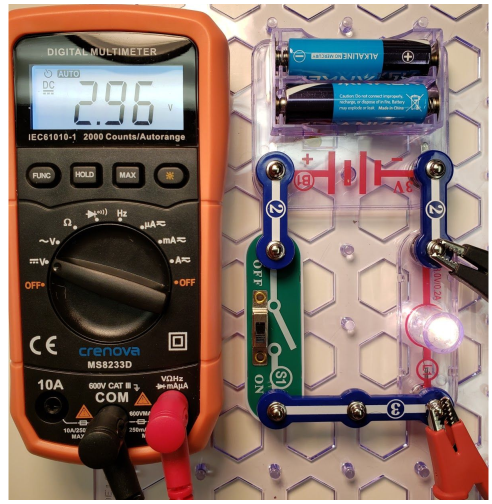


Figure 4a: *voltmeter measurement with S1 closed*

Next, return to the parallel lamp circuit you built (Figure 2a) in Activity 1a, and measure ΔV_1 and ΔV_2 for lamps L1 and L2, respectively. You should find that they are nearly the same value. This is expected, since both L1 and L2 see the full ΔV_{B1} supplied by the battery pack. Therefore, another way to think about circuit elements connected in parallel is that those elements must see the same ΔV.

If you want to measure I for a particular circuit element (or the branch of the circuit that contains that element), you will always connect the ammeter in series with that element. To put it another way, you want the ammeter to be able to 'count' all of the charges passing by that also pass through the circuit element. Any internal resistance in the ammeter will result in $\Delta V \neq 0$ across it, which means the presence of the ammeter has an undesirable effect on the rest of the circuit. For this reason, an ideal (i.e. perfect) ammeter would have R = 0. Set your multimeter to read DC current in Amps (A), and add your ammeter to your lightbulb circuit similar to Figure 5a, where we measure I = 0.197 A. Does your lightbulb turn on? Does it matter where in the circuit you place the ammeter? Why or why not? For **deliverable 4**, include images and circuit diagrams of your circuit with your ammeter properly connected at two different positions in the circuit. Compare your two I values, and interpret your results.

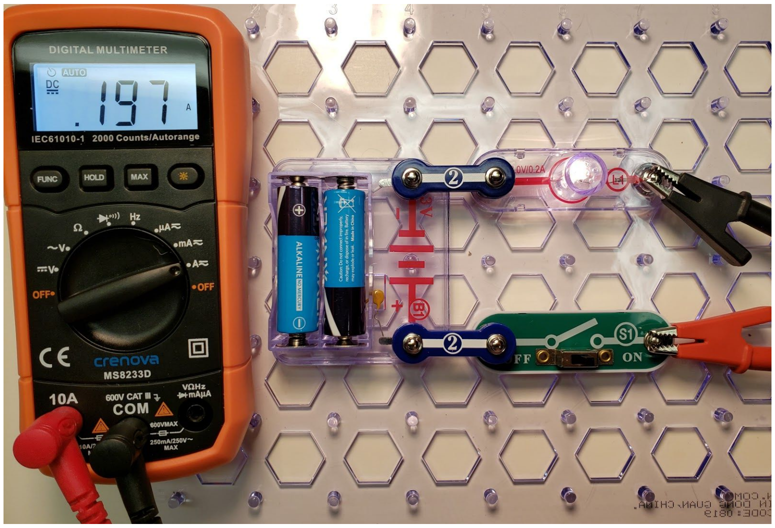


Figure 5a: *ammeter measurement with S1 closed*

Activity 1b - Introduction to Series & Parallel Circuits

In this lab, we will consider two ways of connecting circuit elements: *series* and *parallel*. For both series and parallel circuits, one can change the order of sub-circuit components (e.g., a lightbulb or a resistor) without changing what the circuit does. Consider the circuit shown in Figure 1b. It contains a single battery, a switch, and two lightbulbs. If we close the switch to complete the circuit, how many possible uninterrupted paths are there between the battery terminals? Can you predict what will happen if you assemble the circuit leaving out one of the light bulbs and close the switch? Why do you think the simulation labels an open switch as having infinite resistance? Navigate to the circuit construction kit simulation. Keep ‘Labels’ and ‘Values’ checked in the upper right set of options for now.

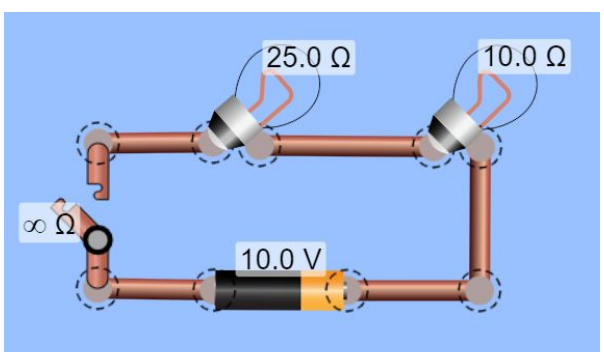


Figure 1b: *simple series lamp circuit*

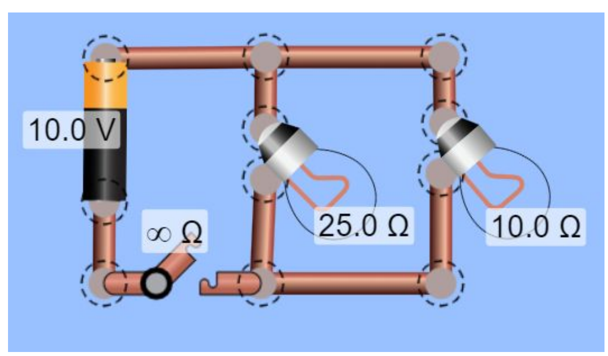


Figure 2b: *simple parallel lamp circuit*

Assemble the circuit in Figure 1b consisting of two lightbulbs L1 and L2 with resistances R_1 = 25 Ω and R_2 = 10 Ω respectively, a switch, and a single 10 V battery (adjust the resistances and the battery voltage by clicking on each component and adjusting the sliders at the bottom of your workspace). Test your earlier predictions by switching the positions of L1 and L2 and then by removing either L1 or L2 from the circuit. This is an example of a *series* circuit because each circuit element is connected sequentially along a single path from the '+' side of the battery (gold) to the '-' side (black). In other words, all of the current must pass through all of these circuit elements. If charges can bypass any circuit elements, then they are not all connected in series. Using these same components, (add any wires as necessary), rearrange the circuit to construct two of your own equivalent series circuits and check to see if they work as you expect. For **deliverable 1**, take screenshots of both of your circuit variations showing the lamps on. Draw a circuit diagram corresponding to each of your circuits using the symbols in Figure 23.2 of your textbook. Are L1 and L2 the same brightness? Can you explain why or why not? What happens if you decrease the battery voltage to 5 V?

Next, consider the basic parallel circuit in Figure 2b, which contains similar elements, but the lightbulbs are arranged differently. Before assembling and testing the circuit, predict what will happen if you leave lamp L1 out of the circuit. L2? How about the switch? Assemble your circuit and test your predictions. Does anything change if you swap the positions for L1 and L2? This is an example of a *parallel* circuit because both L1 and L2 are independently connected to your battery, so the total current carried by the circuit is divided between each lightbulb along its branch of the circuit. In other words, this circuit has two independent paths between the battery terminals: one passing through L1 and another passing through L2. You should have also noticed that removing the switch (or equivalently, leaving it open) made it impossible for either L1 or L2 to light up. For **deliverable 2**, include a picture of your activated parallel circuit and a circuit diagram for this circuit. Also state whether your switch is connected in series or in parallel with the L1 + L2 sub-circuit and explain your reasoning.

For your series circuit, you should have observed that with either L1 or L2 missing or not connected properly, neither bulb will light. Any one bulb along a broken section of holiday lights may be burned out, preventing the others from working, so you have to check each one in that section to find the culprit. In our homes, a burned out lamp or turning off a light switch in one room usually doesn't affect the circuits in another room, which implies that the electricity within our homes is not wired in series but in parallel. Similarly, in your parallel circuit you should find that removing one lamp still permitted the other to light up when the switch was closed (i.e., ON). Note that in the parallel circuit, the simulation showed both lamps 'brighter' than they were in the series circuit. This is because in the parallel circuit, both L1 and L2 can see the full battery voltage ($\cong$ 10 V), and this might even appear more efficient than the series circuit where we didn't achieve the same brightness with the same battery. However, the current to light the bulbs in the parallel circuit is higher since each bulb sees 10 V, so this means that the parallel circuit is draining the batteries faster than the series circuit. The battery-powered devices in our homes use batteries connected in parallel when the voltage is sufficiently high from one battery alone, but the required current is more than one battery can provide.

Activity 2b - Voltmeters and Ammeters

You already have some experience with *voltmeters*, which are devices used to measure potential difference (often relative to 0 V) from Lab 4 where you took readings of ΔV for a resistor. *Ammeters* are devices that measure current I. Our goal here is to understand how these measurement tools should be connected in a circuit to characterize the circuit correctly. Recall your connections for the single resistor measurement in Lab 4, in which you connected your voltmeter leads to either end of your resistor to measure ΔV only across that element. In other words, regardless of what other components were connected in your circuit, your voltmeter had its own independent (parallel) connection to your circuit element. Therefore, whenever you want to measure V (i.e., potential difference) for a particular circuit element, you will always connect the voltmeter in parallel with that element. To put it another way, you want the voltmeter to see the same V that the circuit element sees.

An ideal voltmeter does not affect the behavior of the circuit element it is measuring, which means that it should draw no current (i.e., resistance $R = \infty$). In practice, voltmeters are designed with very large (10^6 - 10^8 Ohms) resistance so that $I = \Delta V/R$ drawn along its branch of the circuit is negligibly small (but still non-zero, since a small I is still required for the voltmeter to measure ΔV). Your circuit simulation voltmeter is programmed to have $R = \infty$. Consider a simple single lightbulb circuit similar to Figure 3b, which shows the multimeter setup to read ΔV for the lightbulb L1 and you can convince yourself that the voltmeter is in parallel with L1.

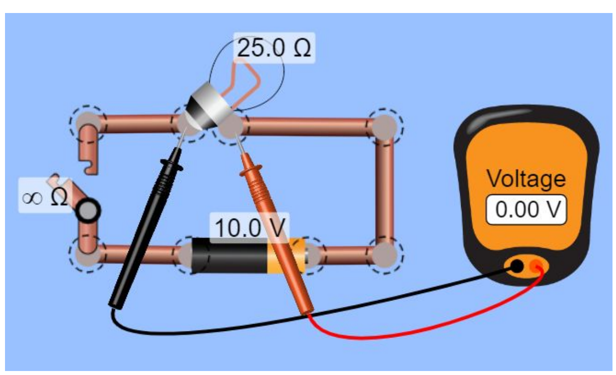


Figure 3b: *voltmeter measurement with switch open*

The voltmeter reads ΔV = 0 V when the switch is open because no current is flowing. What should it read when the switch is closed and current is allowed to flow? For **deliverable 3**, include screenshots of your series lightbulb circuit similar to Figure 1b in Activity 1b that shows your voltmeter properly connected for voltage readings ΔV_1 and ΔV_2 for L1 and L2 respectively. Draw circuit diagrams that include the voltmeter for each one, and explain why $\Delta V_1 \neq \Delta V_2$. You can reference Figures 23.24 and 23.25 in your textbook for help with notation.

Next, return to the parallel lightbulb circuit you built (Figure 2b) in Activity 1b, and measure ΔV_1 and ΔV_2 for this circuit. You should find that $\Delta V_1 = \Delta V_2$. This is expected, since both L1 and L2 see the full ΔV supplied by the battery. Another way to think about circuit elements connected in parallel is that those elements must see the same ΔV.

If you want to measure I for a particular circuit element (or the branch of the circuit that contains that element), you will always connect the ammeter in series with that element. To put it another way, you want the ammeter to be able to 'count' all of the charges passing by that also pass through the circuit element. Any internal resistance in the ammeter will result in $\Delta V \neq 0$ across it (because $IR \neq 0$ if $R \neq 0$), meaning that the presence of the ammeter has unintentionally affected the rest of the circuit. For this reason, ideal ammeters have R = 0. Drag your ammeter onto your workspace, which will provide a current reading in Amps (A), and add your ammeter somewhere in your series lightbulb circuit (e.g., Figure 4b), where we measure I = 0.29 A. Do your lightbulbs still turn on? Does it matter where in the circuit you place the ammeter? Why or why not? For **deliverable 4**, include screenshots and circuit diagrams of your circuit with your ammeter properly connected at two different positions in the circuit. If your simulation could represent an ammeter that is not ideal (i.e., R > 0), explain how adding this more realistic ammeter would have affected your readings for I in your circuit.

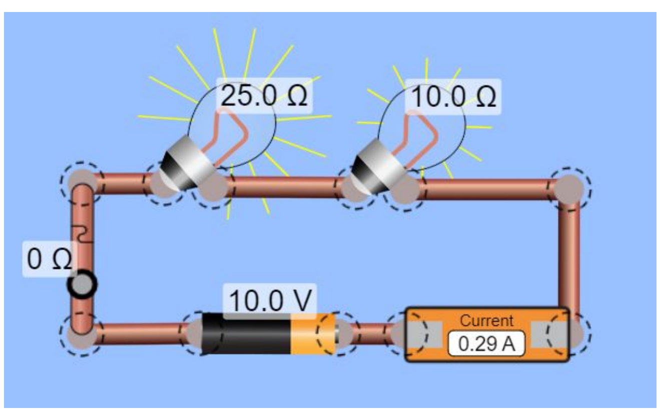
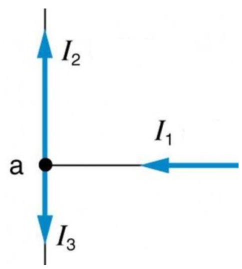


Figure 4b: *ex. ammeter measurement for the series circuit*

Activity 3 - Apply Kirchhoff's Rules in Circuits

A location in a circuit that is an intersection where three or more circuit paths meet is called a *junction*. Due to conservation of charge, all of the current entering a junction must also be leaving that junction. In other words, the junction itself can neither be a source or sink for current, and this is sometimes referred to as the 'Junction Rule':

$$\sum_j I_{j,in} = \sum_j I_{j,out} \qquad (1)$$



For example, consider point 'a' in the left diagram. All terms on the left side of Equation 1 are those currents going into the junction, while all terms on the ride side are those currents leaving the junction. Therefore, in this example, $I_1 = I_2 + I_3$. Return to your parallel lightbulb circuit from (e.g., Figure 2a/2b) in Activity 1a/1b and identify the junctions. Choose one junction to evaluate Equation 1 by adding your ammeter at each appropriate location for measuring your currents I_1, I_2, and I_3. Hint: remember that current flows from high to low V through your circuit, so one convention is to consider I_1 entering your junction with I_2 and I_3 leaving, as in the diagram above. For **deliverable 5**, include images of each of your circuits with your ammeter connected, along with the corresponding circuit diagrams for each measurement. Also clearly indicate your definitions for I_1, I_2, and I_3 in your diagrams. Does your circuit obey Equation 1? Explain your reasoning.

As charge moves around any closed loop in a circuit, it sees a different value of V as it passes through any circuit elements. Back at its starting point on that same loop, the value of V must be the same as its starting value due to energy conservation. Another way of stating this in terms of electric potential is that the sum of all changes in potential ΔV for that loop must be zero, sometimes referred to as 'Loop Rule':

$$\Delta V_{loop} = \sum_j \Delta V_j = 0 \qquad (2)$$

Here, ΔV_j is the potential difference moving across the jth element in the loop. For the analysis in this lab, we will choose a direction of positive loop current I so that for sources of potential difference like batteries $\Delta V_j > 0$ as we evaluate Equation 2 passing through the battery from the '-' side to the '+' side. If we encounter a resistive element like a lightbulb with resistance R_B, then we get $\Delta V_j = -(IR_B) < 0$. For further details and graphical illustrations, see Chapter 23.2 in your textbook.

Next, let's experimentally evaluate Equation 2 for your series lightbulb circuit (e.g., Figure 1a/1b) from Activity 1a/1b using your voltmeter. Reconstruct this circuit and measure the voltages for your battery B, L1, and L2 when your switch is ON. How many loops are in this circuit? Do your values of ΔV_B, ΔV_{L1}, and ΔV_{L2} obey Equation 2? For **deliverable 6**, include images of each of your circuits with your voltmeter properly connected and give your values of ΔV_B, ΔV_{L1}, and ΔV_{L2} with the correct sign. Your circuit diagrams for each should include the position of your voltmeter. If your values do not obey Equation 2 exactly, then offer a possible explanation.

Activity 4a - Series & Parallel Resistors

When multiple resistors are in a circuit, our experiments have explored how resistors for that loop of the circuit share the same current I. The total resistance R_S is the sum of individual resistances R:

$$R_s = \sum_j R_j = R_1 + R_2 + R_3 + \ldots \qquad (3a)$$

Resistors in parallel see the same potential difference ΔV, and the total resistance R_P is

$$\frac{1}{R_P} = \sum_j \frac{1}{R_j} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \qquad (4a)$$

Consider the circuits in Figures 6 & 7. In which circuit are the resistors R_1 = 100 Ω and R_2 = 1 kΩ (1 kΩ = 10^3 Ω) in series and in which are they in parallel? How can you tell? Before constructing both circuits, use Ohm's Law and Equations 3a & 4a to compute the equivalent resistance for each circuit and make a prediction about which circuit will make the red LED D1 brighter. (Hint: D1 will be brighter in the circuit that carries the largest I.) Once you have determined which circuit has R_1 and R_2 in series, (carefully) insert your ammeter at various points to convince yourself that both resistors pass the same I. Once you have determined which circuit has R_1 and R_2 in parallel, use your voltmeter to convince yourself that both resistors see the same ΔV.

For **deliverable 7**, take pictures of both of your working circuits and include your circuit diagrams for each. Also identify which circuit made the LED the brightest and explain your findings. For **deliverable 8**, draw the equivalent circuit diagram for each circuit containing only a single resistor, S1, D1, and B1, and show your work using Equations 3a & 4a to calculate the total resistance values for your series circuit R_S and your parallel circuit R_P.

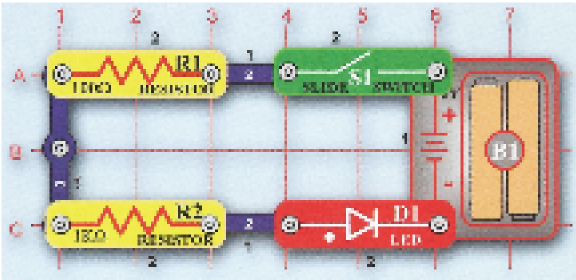


Figure 6: *simple resistor + diode circuit 1*

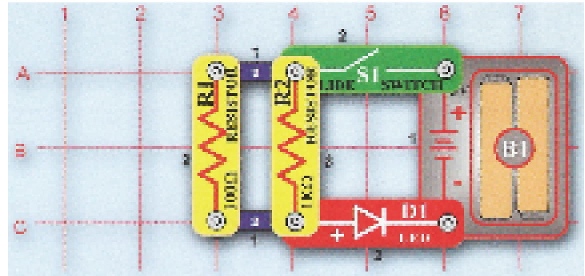


Figure 7: *simple resistor + diode circuit 2*

From this set of experiments, you should find that placing resistors in series increased the total resistance of the circuit, decreasing the current to the LED. When placed in series, the total resistance is greater than the value of the largest resistor value. Placing resistors in parallel decreases the total resistance to a value smaller than the smallest resistor, which increased the current to the LED.

Using these same two circuits, predict what would happen to the brightness of the LED in each circuit if you add one of your other component resistors R_3 = 5.1 kΩ (while leaving S1, B1, and D1 in their original positions). Will your new values for R_S and R_P increase, decrease, or stay the same? For **deliverable 9**, include pictures and a circuit diagram for each of your modified circuits with R_3 added, and explain any differences between the LED brightnesses in your new circuits vs. your original circuits that you built in Figures 6 & 7 in terms of series/parallel circuits. Does the LED indicate that the total current *I* carried by your new circuits increased, decreased, or stayed the same?

Activity 4b - Series & Parallel Resistors

When multiple resistors are in a circuit, our experiments have explored how resistors for that loop of the circuit share the same current *I*. The total resistance R_S is the sum of individual resistances *R*:

$$R_s = \sum_j R_j = R_1 + R_2 + R_3 + \ldots \qquad (3b)$$

Resistors in parallel see the same potential difference Δ*V*, and the total resistance R_P is

$$\frac{1}{R_P} = \sum_j \frac{1}{R_j} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots \qquad (4b)$$

Consider the circuits in Figures 5b & 6b below. In which circuit are the resistors R_1 = 10 Ω and R_2 = 30 Ω in series and in which are they in parallel? How can you tell? Before constructing both circuits using the circuits simulation, use Ohm's Law and Equations

3b & 4b to compute the equivalent resistance for the R_1 & R_2 sub-circuits (i.e., excluding the battery and the lightbulb with R_L = 25 Ω) for each circuit and make a prediction about which circuit will make the lightbulb brighter. (Hint: the simulation is programmed to display brightness in proportion to power dissipated in the bulb, i.e., brighter in the circuit that carries the largest I.) Once you have determined which circuit has R_1 and R_2 in series, add your ammeter at various points to convince yourself that both resistors pass the same current I. Once you have determined which circuit has R_1 and R_2 in parallel, use your voltmeter to convince yourself that both resistors see the same ΔV.

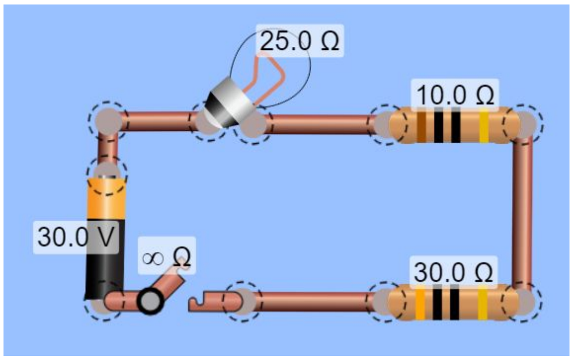


Figure 5b: *resistor + bulb circuit 1*

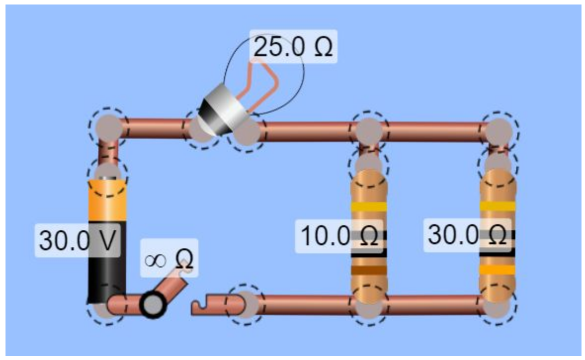


Figure 6b: *resistor + bulb circuit 2*

For **deliverable 7**, take screenshots of both of your working circuits and include your circuit diagrams for each. Also identify which circuit made the lightbulb the brightest and explain your findings. For **deliverable 8**, draw the equivalent circuit diagram for each circuit containing only a single resistor, your switch, the lightbulb, and battery, and show your work using Equations 3b & 4b to calculate the total resistance values for your series circuit R_S and your parallel circuit R_P. How would you use the simulation to verify whether your R_S and R_P values were correct?

From this set of experiments, you should find that placing resistors in series increased the total resistance of the circuit, decreasing the current to the lightbulb. When placed in series, the total resistance is greater than the value of the largest contributing resistor. Placing resistors in parallel decreases the total resistance to a value smaller than the smallest resistor, which increased the current to the lightbulb and increased its brightness due to the increase in power $P = I^2R_B$.

Using these same two circuits, predict what will happen to the brightness of this same lightbulb in both the parallel and the series circuit if you add another resistor R_3 = 40 Ω (while leaving all other circuit components unchanged). Will your new values for R_S and R_P increase, decrease, or stay the same? For **deliverable 9**, include screenshots and a circuit diagram for each of your modified circuits with R_3 added. Explain any differences between the lightbulb brightnesses in your new circuits vs. your original circuits that you built in Figures 5b & 6b in terms of series/parallel circuits. Does your lightbulb indicate that the total current I carried by your new circuits increased, decreased, or stayed the same?

3. Deliverables

For full credit please include the following in your lab report. Follow the template provided on the Weebly Lab 5 page and include one deliverable per Google Slide in the order that they are presented for your set of activities below. Always label your images.

1. Images of the simple series/parallel circuits with lamps on; a circuit diagram for each circuit using symbols in textbook Figure 23.2. Explain the presence of two battery packs in the series circuit.
2. Image & circuit diagram of working parallel circuit. Is S1 is connected in series/parallel with the L1 + L2 sub-circuit and explain your reasoning.
3. Image of your own simple lightbulb circuit with voltmeter readings, and draw a circuit diagram including the voltmeter.
4. Images & circuit diagrams of your simple lightbulb circuit with ammeter properly connected at two different positions. Compare & interpret your I values.
5. Images of circuits with ammeter connected & corresponding circuit diagrams for each measurement. Definitions for I_1, I_2, and I_3 in your diagrams. Does your circuit obey Equation 1? Explain your reasoning.
6. iImages of each of your circuits with your voltmeter properly connected & your ΔV_B, ΔV_{L1}, and ΔV_{L2} values with the correct sign. Circuit diagrams that include voltmeter. If values do not obey Equation 2, then offer a possible explanation.
7. Pictures & circuit diagrams of both of your working resistors + LED circuits. Identify which circuit made the LED the brightest and explain your findings.
8. Equivalent circuit diagrams for circuit above containing only a single resistor, S1, D1, and B1. Show work using Equations 3a & 4a to get R_S, R_P.
9. Pictures & circuit diagrams for modified circuits with R_3 added; explain any differences in LED brightnesses in new vs. original circuits from Figures 6 & 7 in terms of series/parallel circuits. Does the LED indicate that the total current I carried by your new circuits increased, decreased, or stayed the same?

1. Screenshots & circuit diagram of both circuit variations showing the lamps on. using the symbols in Figure 23.2 of your textbook. Are L1 and L2 the same brightness? Can you explain why or why not?
2. Screenshot & circuit diagram of activated parallel circuit; is switch connected in series or parallel with L1 + L2 sub-circuit and explain your reasoning.
3. Screenshots of your series lightbulb circuit similar to Figure 1b in Activity 1b with voltmeter setup to measure ΔV_1, ΔV_2 for L1 and L2. Draw circuit diagrams that include voltmeter, and explain why $\Delta V_1 \neq \Delta V_2$.
4. Screenshots & circuit diagrams with ammeter properly connected at two different positions. Explain how a realistic ammeter would affect your I values.
5. Images of circuits with ammeter connected & corresponding circuit diagrams for each measurement. Definitions for I_1, I_2, and I_3 in your diagrams. Does your circuit obey Equation 1? Explain your reasoning.
6. iImages of each of your circuits with your voltmeter properly connected & your ΔV_B, ΔV_{L1}, and ΔV_{L2} values with the correct sign. Circuit diagrams that include voltmeter. If values do not obey Equation 2, then offer a possible explanation.
7. Screenshots & circuit diagrams for series/parallel resistor + bulb circuits; identify which circuit made the lightbulb the brightest and explain your findings.
8. Equivalent circuit diagrams for circuits above containing only a single resistor, your switch, the lightbulb, and battery, and show your work using Equations 3b & 4b to calculate R_S, R_P. How can the simulation verify your R_S and R_P values?
9. Screenshots & circuit diagrams for each modified circuit with R_3 added. Explain any differences in lightbulb brightnesses in your new vs. original circuits based on Figures 5b & 6b in terms of series/parallel circuits. Does the lightbulb indicate total current I in your new circuits increased, decreased, or stayed the same?