Simple Circuits – Series & Parallel

Pre-lab questions:

1. What is the goal of this experiment? What physics and general science concepts does this activity demonstrate?
2. Given three resistors, will their equivalent resistance be higher if they are wired in series or in parallel?
3. If resistors are wired in parallel, can the equivalent resistance ever be higher than the resistance of a single resistor in the circuit? Can you support your answer with the equations given in the lab?
4. If resistors are wired in series, can the equivalent resistance ever be lower than the resistance of a single resistor in the circuit? Can you support your answer with the equations given in the lab?
5. Given the same power supply voltage, do you expect the current to increase or decrease when you have multiple resistors wired in series (as compared to the single resistor)? What about when they are wired in parallel?
6. For resistors wired in series, what is constant: current through the resistors, or voltage across the resistors?
7. For resistors wired in parallel, what is constant: current through the resistors, or voltage across the resistors?

Equipment:

[Instructor note: PASCO equipment may be used. See PASCO lab manual #75 for details]

- 3 lightbulbs or resistors
- Board with lightbulb sockets
- Patch cords with alligator clips
- "Switch" (unplug from board)
- PASCO voltage sensor
- High current sensor
- PASCO 850 power supply

- **An ammeter** is a device used to measure **current** through an object, and it **is wired in series** with the object. The positive terminal of the ammeter (marked with a + sign or colored red) is connected so that it leads directly back to the positive terminal of the voltage source (the battery). On some ammeters two different ranges of current can be measured and this is indicated by having two different negative terminals. Use the lower range scale unless the ammeter reads too much current. If the ammeter goes "off-scale" then use the higher range scale. The PASCO high current sensor, connected to the 850 interface and monitored via Capstone, serves as the ammeter.

- **A voltmeter** measures **voltage across a resistor**. That means it must be wired so that it stretches across the device. The positive terminal of the voltmeter (indicated by a positive sign or colored red) is connected to the end of the device being measured that is nearest to the positive terminal of the battery. On some voltmeters, three different ranges of voltage can be measured and this is indicated by having three different negative terminals. The PASCO voltage sensor, monitored with Capstone, serves as the voltmeter.

The goal of Experiment A is to find the resistance of each resistor using a voltmeter, an ammeter, and Ohm's Law calculations. This data will be used in experiments B and C, so it is important that you consistently use the same resistors throughout. If you burn out a lightbulb or resistor by passing too much current through it, you will need to restart the laboratory exercise with Experiment A.

The goal of Experiment B is to find the equivalent resistance of elements (lightbulbs or resistors) connected in series. The goal of Experiment C is to find the equivalent resistance of elements connected in parallel. You will compare these experimental values to those values predicted by the theory outlined in the introduction. You will use the ammeter to measure the current through the bulbs or resistors, the voltmeter to read the voltage drop across the bulbs or resistors and then using Ohm's law, you can calculate the resistance of each bulb and equivalent resistance of the circuit.

Introduction:

Any electrical device has an inner resistance ***R***. When current ***I*** flows, the resistance dissipates electrical energy converting it into heat. This causes a **drop in voltage** across the resistance in the amount of ***V = I R*** – known as Ohm's Law. **Power** dissipation on a resistor is given by $\boldsymbol{P = I\,V}$. In the simplest circuits, we can connect resistors in either series or parallel connections.

In electrical circuits with **series** connection, all electrical devices (such as light bulbs) are attached in a line (see figure 2). Therefore, the **current through one is the same as the current through all the others.**

The **voltage drop** across each element **add up** to give the total voltage dropped across the series circuit:

$$\boldsymbol{V = V_1 + V_2 + V_3} \qquad (1)$$

According to Ohm's law, a voltage drop on a resistor is equal to the product of current and resistance:

$$\boldsymbol{V = I * R} \qquad (2)$$

Rewriting the equation (1):

$$\boldsymbol{I\,R_{eq} = I\,R_1 + I\,R_2 + IR_3} \qquad (3)$$

Current through all the resistors in series is the same, so it can be eliminated by factoring and dividing by *I*:

$$\boldsymbol{R_{eq} = R_1 + R_2 + R_3} \qquad (4)$$

Resistors wired in series have the same effect as one **"equivalent" resistance**, which is simply the sum of all the resistors in series. **Series resistors add up** to a resistance higher than any single resistor.

Another way of wiring devices together is called "parallel". Devices, which have all the same beginning and all the same end point, are wired in parallel (see figure 4). Since they start at the same point and end at the same point, they have the same voltage drop across them. These shared points are called junctions. The current can divide at these junctions and follow different paths through the circuit, so the current through each device may be different. The total current entering a junction point is the sum of the currents leaving that point:

$$I_{total} = I_1 + I_2 + I_3 \tag{5}$$

According to Ohm's law, current is voltage divided by resistance: $I = \frac{V}{R}$
Rewriting the equation (5):

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \tag{6}$$

Because the voltage drop is equal across devices wired in parallel, we can eliminate that term from equation (6), giving:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \tag{7}$$

For devices wired in parallel, the reciprocal of the equivalent resistance is equal to the sum of the reciprocal of each individual resistor. Resistors wired in parallel have a lower resistance than any single resistor in the circuit simply because there are more paths the current can follow and so current can flow more easily.

Experiment A – Individual resistor value:

- ☐ Set your power supply to about 5 V.
- ☐ Connect the + terminal of the power supply to the positive terminal of the ammeter.
- ☐ Connect the negative terminal of the ammeter to one side of the first resistor (it does not matter which one, but you will refer to this as R#1 throughout the lab).
- ☐ Connect the other side of the resistor to the negative terminal of the power supply – "close" the switch. (Remember, "open" switch means disconnect from the power supply.) This is a series circuit because there is only one path the current can follow.

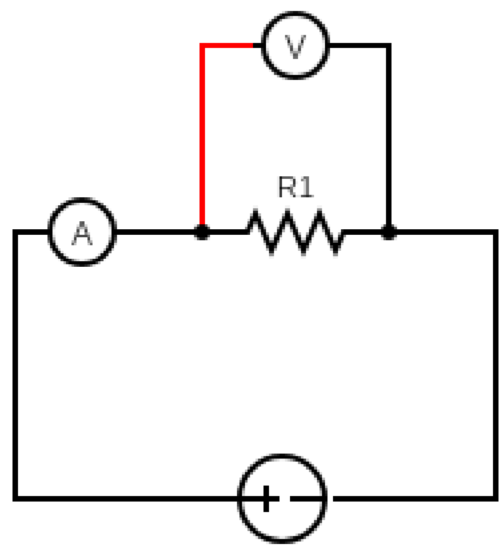

Figure 1: Circuit diagram for Experiment A - finding individual resistance values using Ohm's law.

- ☐ Read the current flowing through the ammeter (and since it is in series, this is the current through the resistor). The ammeter is supposed to have very little effect on the circuit, so you can treat it as if it were not there.
- ☐ Now we can measure the **voltage drop** across the resistor. Put the voltmeter in parallel with the resistor as shown in the circuit diagram above.
- ☐ Open the switch after making your observation.
- ☐ Record I and V values in Table 1. Calculate R from these.
- ☐ Repeat these measurements for R#2 and R#3.

Experiment B – Series Circuit:

Set up:

Now, using your extra gator-clip cords, connect all three resistors in series. Notice that there is only one possible path for the current to take; this is what makes it a purely series circuit. Adjust your power supply up to about 10 V. We will measure their total resistance and compare this with the expected

$$\boldsymbol{R_{eq} = R_1 + R_2 + R_3} \quad (4)$$

The setup, we measure the total voltage V_T across all three resistors:

Procedure:

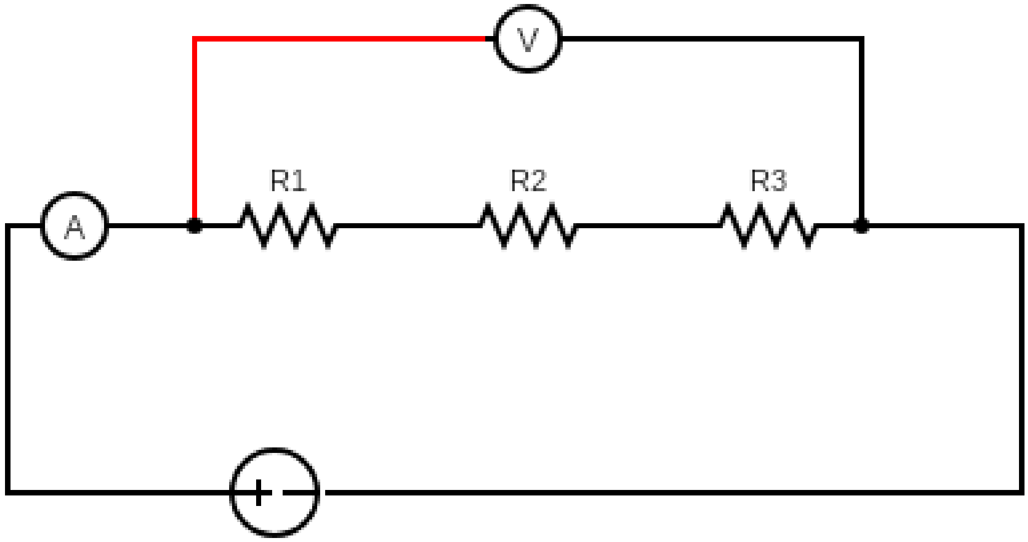

Figure 2: Series circuit with three resistive elements. Notice that the voltmeter is measuring the total voltage drop across all three circuit elements.

- [ ] Using the set up shown in Figure 2, measure current (I) and total voltage drop (V_T) across the three resistors. Record this in Table 2.

Note: This is a different circuit than Experiment A. We can expect the resistance (R_i) for individual resistors to remain constant, but we should not expect V or I to remain constant from one circuit set up to the next.

- [ ] Calculate the experimental equivalent resistance of the circuit using the total voltage, total current and Ohm's Law: $R_{eq} = V_T/I$ Record this in the data table.
- [ ] Calculate the predicted equivalent resistance using equation (4) from the introduction and the resistance values found in Experiment A. Record this in the data table. Make note of the difference between the experimental value and the resistance expect from the theoretical calculation.
- [ ] Now we want to predict (calculate) from the known current the voltage drops across each resistor. We use the resistances measured in part 1 and calculate $V_i = I * R_i$ for the i^{th} resistor. Record this calculated value for each resistor in Table 3.
- [ ] Now measure the voltage drop across each resistor. Figure 3 is an example of how you would measure voltage across resistor 1:

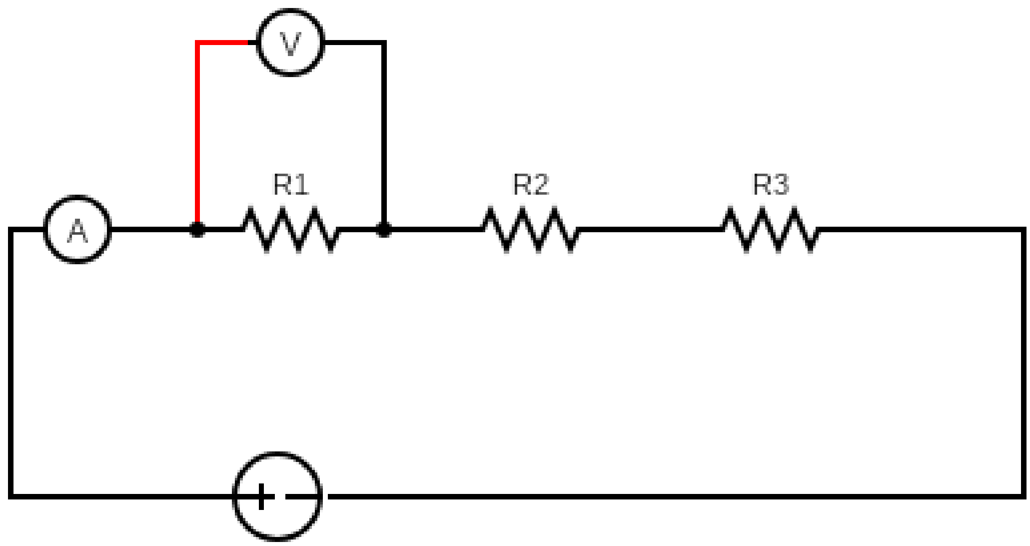

Figure 3: Series circuit with three resistive elements. Notice that the voltmeter is measuring the voltage drop across only the first circuit element.

Experiment C – Parallel Circuit:

Set up:

☐ Reduce the power supply to about 2.5 V.

☐ Connect the + terminal of the power supply to the ammeter + terminal.

☐ Connect the – terminal of the ammeter to three wires to create a junction point.

☐ Attach the other end of the three wires to one side of each of the resistors.

☐ Connect three more wires to the other side of each of the resistors.

☐ Connect the other side of these three wires to one side of the switch.

☐ Leave the switch open.

☐ Connect the – terminal of the power supply to the other side of the switch.

☐ Have the professor check your circuit before proceeding. It should look similar to the diagram below:

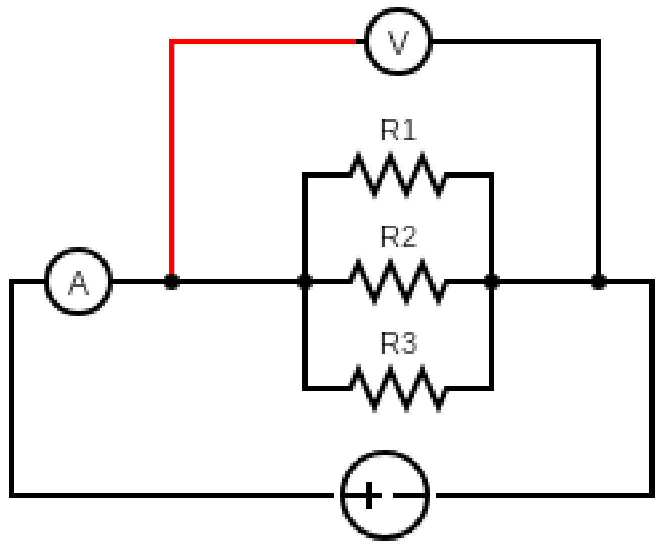

Figure 4: Schematic of parallel circuit with voltmeter in parallel measuring the (same) voltage drop across all resistors and ammeter in series measuring the total current into the parallel circuit.

Procedure:

☐ Using the set up shown in Figure 4, measure total current (I_{tot}) and total voltage drop (V_T) across the three resistors. Record this in Table 4.

Note: This is a different circuit than Experiment A. We can expect the resistance (R_i) for individual resistors to remain constant, but we should not expect V or I to remain constant from one circuit set up to the next.

☐ Calculate the experimental equivalent resistance of the circuit using the total voltage, total current and Ohm's Law: $R_{eq} = V_T/I_{tot}$ Record this in the data table.

☐ Calculate the predicted equivalent resistance using equation (7) from the introduction and the resistance values found in Experiment A. Record this in the data table. Make note of the difference between the experimental value and the resistance expect from the theoretical calculation.

☐ Now we want to predict (calculate) the current through each resistor. We use the resistances measured in part 1 and calculate $I_i = V/R_i$ for the i^{th} resistor. Record this calculated value for each resistor in Table 5.

☐ *Remember that the voltage drop across parallel devices is the same, but the current divides at the junction point.* Because of conservation of charge, your individual currents should sum to the total current: $I_{tot} = I_1 + I_2 + I_3$. Check this.

☐ Now measure the current through each resistor. Record these values and compare to your calculated current. Figure 5 is an example of how you would measure current through resistor 2:

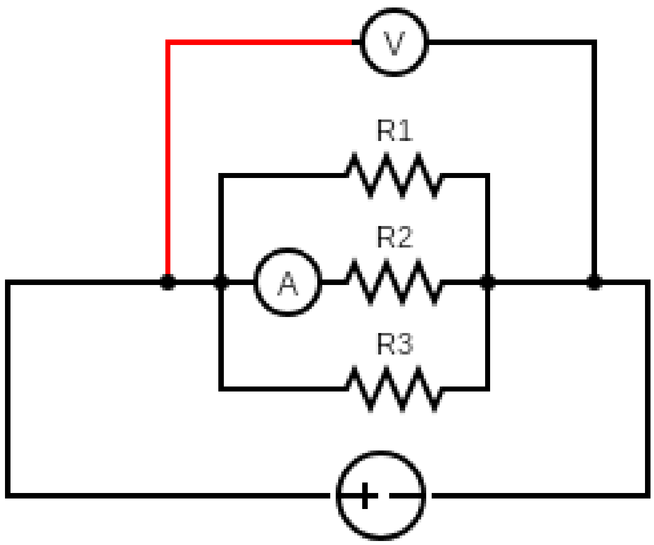

Figure 5: Schematic of parallel circuit with voltmeter in parallel measuring the (same) voltage drop across all resistors and ammeter in series measuring only the current into the middle resistor.

Data, Computations, and Analysis:

Table 1: Experiment A - individual resistor values.

i	*color code if using resistors*	I (A)	V (V)	R (Ω) = V/I	***leave blank***
1					
2					
3					

Table 2: Experiment B - Series circuit equivalent resistance.

Total voltage (measured)	
Current (measured)	
Equivalent resistance (from measured values)	
Equivalent resistance (theoretical, from R values in experiment A)	

Table 3: Experiment B - Series circuit individual voltage drops.

Resistor	Resistance (from table 1)	Measured Current [A]	Measured Voltage [V]	Calculated Voltage [V]	Percentage Difference
#1					
#2					
#3					

Compare measured V_T to measured $V_1 + V_2 + V_3$:

Table 4: Experiment C - Parallel circuit equivalent resistance.

Total voltage (measured)	
Current (measured)	
Equivalent resistance (from measured values)	
Equivalent resistance (theoretical, from R values in experiment A)	

Table 5: Experiment C - Parallel circuit individual currents.

Resistor	Resistance (from table 1)	Measured Voltage [V]	Measured Current [A]	Calculated Current [A]	Percentage Difference
#1					
#2					
#3					

Compare measured I_{tot} to measured $I_1 + I_2 + I_3$:

Conclusions:

How do your measured values compare to the expected values for equivalent resistance, potential difference (voltage) or current? Address this for both the series and parallel circuit.

Does your experimental data agree with theory? Is the equivalent resistance of the series circuit larger than any individual resistor value? Is the equivalent resistance of the parallel circuit smaller than any individual resistor value?

If you left your power supply at 10 V for the parallel circuit, what effect would this have on the total current flowing into the parallel circuit? Why might this be a bad thing?

Sources of errors:

What assumptions were made that caused error? What is the uncertainty in your final calculation due to measurement limitations?

Questions

Four resistors of 3 Ω, 4 Ω, 2 Ω and 6 Ω are connected in series. Draw this circuit somewhere to help you answer the questions below.

a) What is their equivalent resistance?

b) If a 30 V battery is connected to these resistances, what would be the current through the circuit?

c) What would be the current through the 2 Ω resistor? Through the 6 Ω resistor? [Remembering that things are connected in *series*]

d) What would be the voltage drop across each resistor?

e) What power does each resistor dissipate?

f) What power is delivered by the battery? Should it be equal to *e*)?