

## Series & Parallel Circuits ([20 min of useful training vids](#))

**Prior to lab:** [The pre-lab for this lab starts just after the conclusion questions.](#) This assignment is actually good practice for both exams and the real world. If you fully understand the pre-lab algebra and make the Excel sheet in advance you can expect the lab to take 2-2.5 hours instead of 3!

**Apparatus:** batteries, battery holders, resistors (one 22  $\Omega$ , 33  $\Omega$ , and 47  $\Omega$  for each group), breadboards, banana cables, alligator clips, DMMs (handheld and benchtop), DMM red leads, DMM black leads, jumper wires

### Goals:

- 1) Know how to build a series circuit, parallel circuit, and the two different mixed circuits
- 2) Know how to measure  $\Delta V$ ,  $I$ , and  $R$  in those simple circuits (and compute  $\mathcal{P}$ )
- 3) Verify relationships between  $\Delta V$ 's and  $I$ 's amongst the branches of various circuits

**Theory:** Four circuits are drawn on the pages following the conclusion questions. The circuits show the various stages of combining series and parallel circuits as well as two mixed circuits. This basic process of combining resistors to draw equivalent circuits can be done using the following rules:

$$\text{For Series Resistors: } R_{eq} = R_1 + R_2 + R_3 + \dots$$

$$\text{For Parallel Resistors: } \frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$$

$$\text{Shortcut for Two Parallel Resistors: } R_{12} = \frac{R_1 R_2}{R_1 + R_2}$$

In today's lab you first calculate the equivalent resistance for each circuit. You then assume the voltage across the battery ( $\Delta V_{batt}$ ) is equal to the voltage across the equivalent resistance. This ignores internal resistance and implies that terminal voltage is the same as the ideal maximum or open-circuit voltage of the battery (also called the electromotive force or EMF). Read the first two pages of the chapter on Direct Current Circuits in your textbook to help you answer conclusion questions on this.

Once you know  $R_{eq}$  and  $\Delta V_{eq}$ , determine current in the equivalent resistor  $I_{eq}$  and power delivered to it  $\mathcal{P}_{eq}$ . Since the equivalent circuit is a single resistor and a single battery this current must match that of the battery. Assuming the battery's internal resistance is negligible, power delivered to the resistor should match the power output of the battery.

To determine voltage across, current through, and power delivered to each resistor use two simple rules.

- 1) **Resistors in series have the same current.**
- 2) **Resistors in parallel have the same voltage.**

### For the lab assignment, you are to do the following:

- Measure actual values of each  $R$  & open circuit  $\Delta V_{batt}$  with a DMM (prior to connecting the circuit).
- [Excel spreadsheet similar to page 8](#) as your theoretical work (using DMM measured values for  $R$ 's &  $\Delta V$ ).
- Measure voltage across the battery and each resistor while the circuit is operating.
- Measure current through the battery and each resistor while the circuit is operating.
- Use your *measured* values of  $I$ 's and  $\Delta V$ 's to calculate the *actual* power delivered to each resistor and power delivered by the battery. Note: to get the power delivered to an item simply use  $\mathcal{P}_x = I_x \Delta V_x$ .
- Make a 1/2 -page sketch of each circuit showing all components with the following:
  - Measured values of all  $R$ 's,  $I$ 's, &  $\Delta V$ 's as well as calculated values of  $\mathcal{P}$ 's
  - Percent differences (*might* help to make a 2<sup>nd</sup> copy of spreadsheet with *measured* values?)
- Answer all conclusion questions in full sentences which make clear what question was asked. Conclusion questions should be answered in a numbered list (intro & procedure no bulleted lists)
- **Exceptions today: Do NOT show any calculations/work for the lab (do show them on the pre-lab).**

**Building Circuit 1:**

Build a series circuit (Circuit 1) with two resistors in series. Connect the battery to the breadboard using banana cables and alligator clips (see Figure 1). Connect the wires and the resistors in the breadboard as shown in Figure 2. Do not go on until every member of the group can build the circuit AND measure all currents and voltages. Compute each power. Don't forget to record the value of each resistance. When measuring resistance, be sure to isolate each resistor prior to making the measurement. If you try to measure resistance of a resistor while it is in a circuit (operating or not) you may get overloads or unintentionally record the measurement of some equivalent resistance.



Figure 1: A top view of the circuit in its entirety.

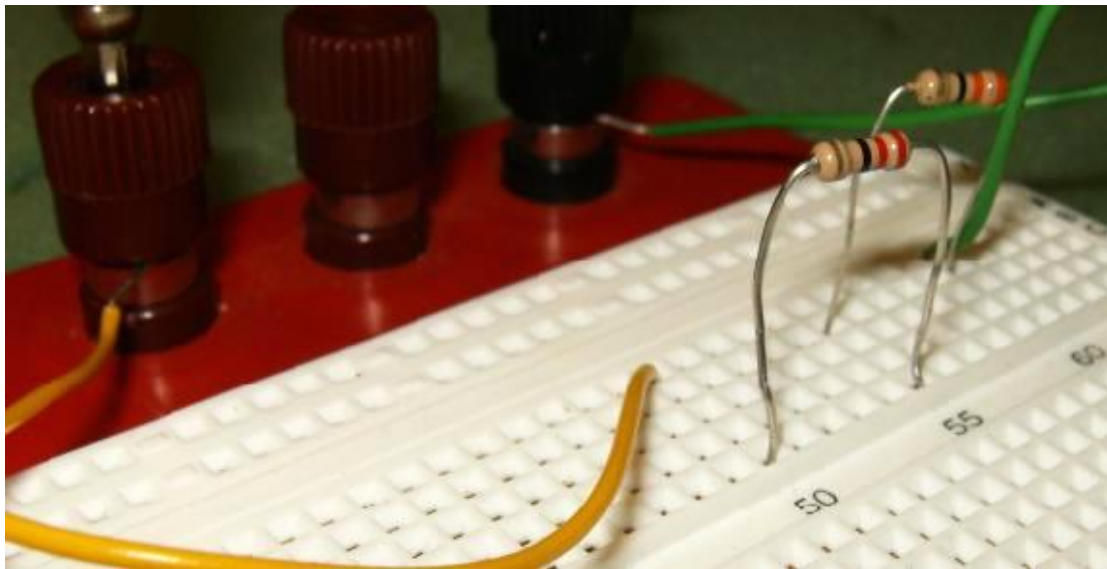


Figure 2: Close-up of the breadboard. Notice that the yellow wire is securely fastened to the red terminal by tightening the knob and compressing the metal part of the wire to the metal part under the red knob. Row 50 connects the yellow wire to one end of the resistor. Row 55 connects the two the resistors. Row 60 connects the green wire to the other end of the 2<sup>nd</sup> resistor. Lastly the green wire connects securely to the black terminal. Going back to figure 1 you can see that the banana cables and battery complete the circuit by connecting the red terminal to the black terminal.

**Continue with Circuits 2-4:** Build Circuits 2, 3, and 4. For each circuit measure all currents and voltages. Compute each power. Don't forget to record the value of each resistance. When measuring resistance, be sure to isolate each resistor prior to making the measurement. If you try to measure resistance of a resistor while it is in a circuit you may unintentionally record the measurement of some equivalent resistance.

There is a tip for measuring current below these figures.

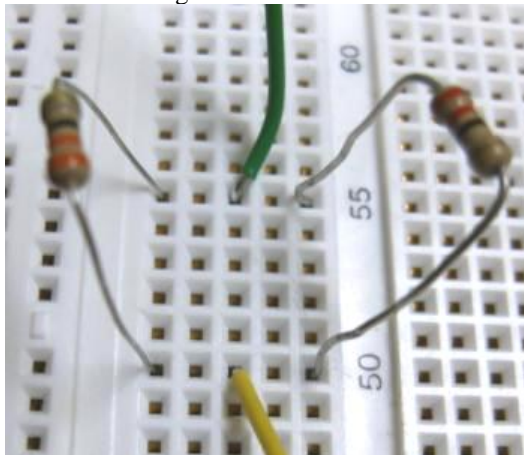


Figure 3: Notice both resistors now connect row 50 to 55. This means any current that comes into row 50 has two channels to flow to row 55.

It gets tricky when you try to measure currents in a parallel circuit. A technique I call “break & replace” seems to help some students make fewer errors. This technique is shown in the Figures 4a and 4b below.

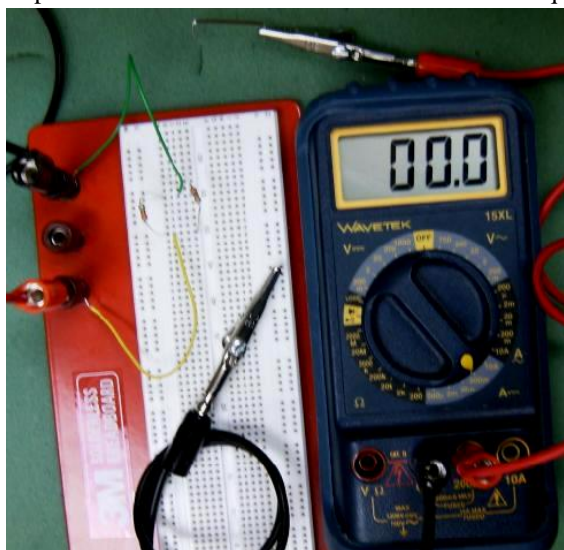


Figure 4a: Just before the break and replace method. Notice that the DMM is using the 200 mA setting & the cables are in the proper place for measuring current with the 200 mA setting. The banana cables from the DMM both have alligator clips. One of the alligator clips has a small wire gripped in its teeth.

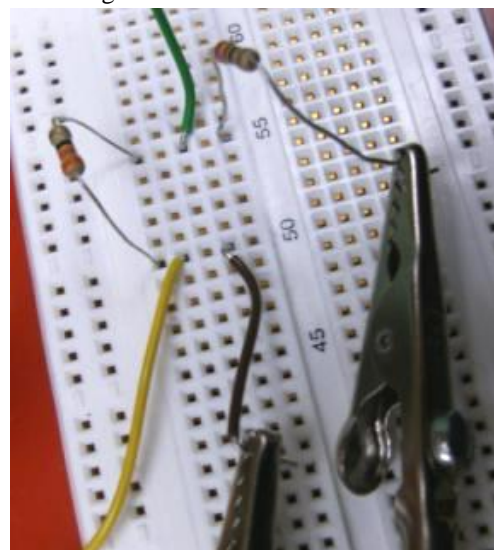


Figure 4b: To measure the current through the left resistor I “break” the circuit by removing one leg of the resistor and connecting it to one side of the DMM measuring current. I then “replace” the removed resistor wire with the alligator clip wire from the other terminal in the DMM. This causes current through the DMM which can be measured.

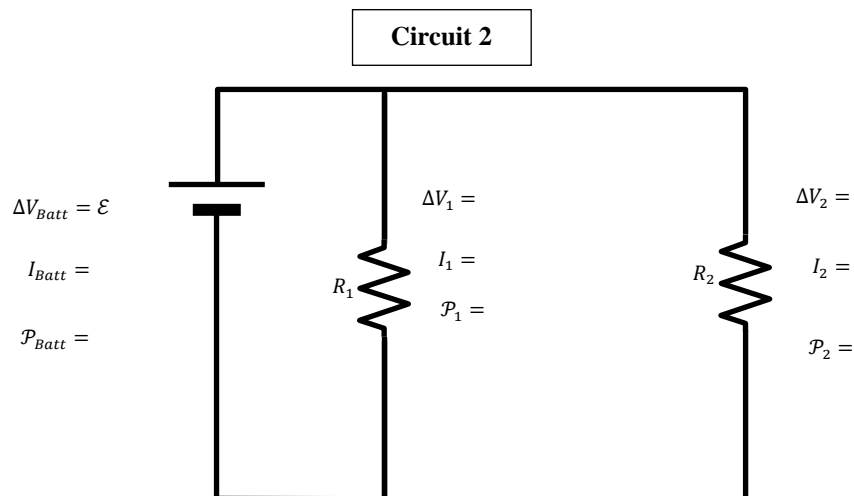
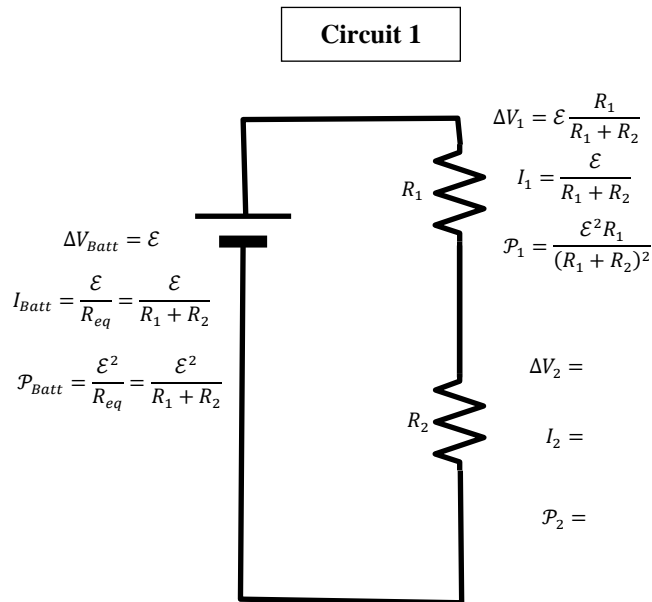
**Conclusions:** (correctly use the phrases **current through**, **power delivered**, and **voltage across** (or **potential difference**) as appropriate:

- 1) For the simple series circuit (**Circuit 1**): Compare the VOLTAGES ACROSS each resistor. Which should have more  $\Delta V$ : the larger or the smaller resistor...or do they have the same  $\Delta V$ ? Are your measurements in good agreement (less than 5% different)? Support your answer by providing the % difference between theoretical and experimental *voltages* for each resistor.
- 2) For the simple parallel circuit (**Circuit 2**): Compare the CURRENTS THROUGH each resistor. Which should carry more current: the larger or the smaller resistor...or do they carry the same current? Are your measurements in good agreement (less than 5% different)? Support your answer by providing the % difference between theoretical and experimental *currents* for each resistor.
- 3) For **Circuit 3**:
  - a. Consider currents  $I_{batt}$ ,  $I_1$ ,  $I_2$ , and  $I_3$ . Which two should be equal?
  - b. In theory, we expect  $I_{batt} = I_1 + I_2$ . Determine an experimental summed value using the equation  $I_{batt\ exp} = I_{1\ exp} + I_{2\ exp}$ . Compare the experimental summed current  $I_{batt\ exp}$  to the theoretically predicted value with a % difference.
  - c. Consider potential differences  $\Delta V_{batt}$ ,  $\Delta V_1$ ,  $\Delta V_2$ , and  $\Delta V_3$ . Which two should be equal?
  - d. In theory, we expect  $\Delta V_{batt} = \Delta V_2 + \Delta V_3$ . Determine an experimental summed value using the equation  $\Delta V_{batt\ exp} = \Delta V_{2\ exp} + \Delta V_{3\ exp}$ . Compare the experimental summed value to the theoretical value with a % difference.
- 4) For **Circuit 4**:
  - a. Consider currents  $I_{batt}$ ,  $I_1$ ,  $I_2$ , and  $I_3$ . Which two should be equal?
  - b. In theory, we expect  $I_{batt} = I_1 + I_2$ . Determine an experimental summed value using the equation  $I_{batt\ exp} = I_{1\ exp} + I_{2\ exp}$ . Compare the experimental summed *current* to the theoretical value with a % difference.
  - c. Consider potential differences  $\Delta V_{batt}$ ,  $\Delta V_1$ ,  $\Delta V_2$ , and  $\Delta V_3$ . Which two should be equal?
  - d. In theory, we expect  $\Delta V_{batt} = \Delta V_1 + \Delta V_3$ . Determine an experimental summed value using the equation  $\Delta V_{batt\ exp} = \Delta V_{1\ exp} + \Delta V_{3\ exp}$ . Compare the experimental summed value to the theoretical value with a % difference.
- 5) For each circuit compare the sum of power delivered to all resistors to battery power with a % difference.
- 6) Consider two  $10\ \Omega$ 's in parallel with an ideal 12 V battery versus five  $10\ \Omega$ 's in parallel with an ideal 12 V battery. Assume wire resistance is negligible. Draw each circuit and determine the equivalent resistance, current through each resistor, the voltage across each resistor, the power delivered to each resistor, the total current and the total power delivered by the battery in each case.
  - a. Which circuit has more equivalent resistance in total?
  - b. Which battery drives more total current?
  - c. Which battery will run out faster?
- 7) A household circuit is analogous to the scenario described in the previous problem. As one turns on more lights/appliances, one is effectively adding additional resistance in parallel to the household circuit.
  - a. What happens to current drawn from the power company as one turns on additional appliances?
  - b. Does turning on a 2<sup>nd</sup> appliance decrease the potential difference across an already operating appliance?
- 8) The utility company charges you by the  $\text{kW} \cdot \text{hr}$ . Is this a unit of voltage, current, resistance, power, or something else? Support your work by converting  $1.00\ \text{kW} \cdot \text{hr}$  to a more common unit used in class.
- 9) Batteries often include a rating in units of  $\text{A} \cdot \text{hr}$ . Is this a unit of voltage, current, resistance, power, or something else? Support your work by converting  $1.00\ \text{A} \cdot \text{hr}$  to a more common unit. Side note: Amps are technically an SI unit while Coulombs are not. Side note: SI stands for "systeme internationale".

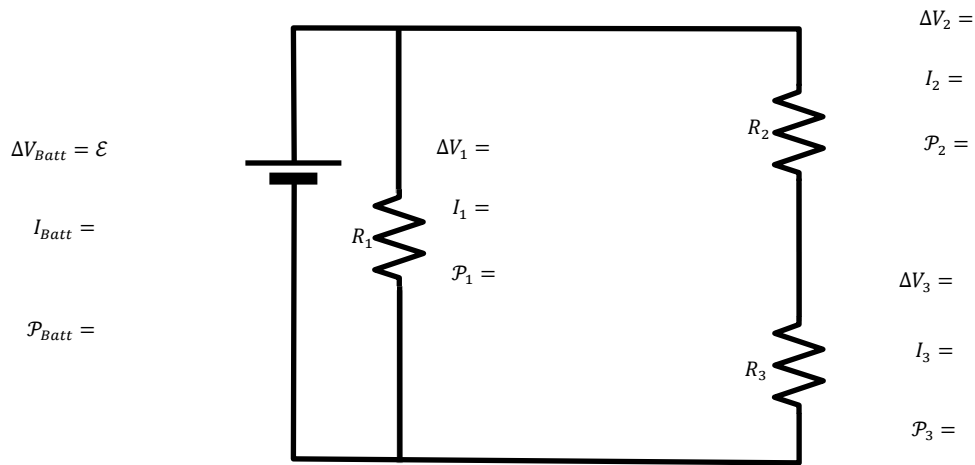
	Version A	Version B	Version C	Version D	Version E	Version F
$R_1$	33 $\Omega$	47 $\Omega$	22 $\Omega$	33 $\Omega$	47 $\Omega$	22 $\Omega$
$R_2$	22 $\Omega$	33 $\Omega$	33 $\Omega$	47 $\Omega$	22 $\Omega$	47 $\Omega$
$R_3$	47 $\Omega$	22 $\Omega$	47 $\Omega$	22 $\Omega$	33 $\Omega$	33 $\Omega$
$\Delta V_{Batt}$	1.5 V	1.5 V	1.5 V	1.5 V	1.5 V	1.5 V

As a pre-lab assignment, determine algebraic theoretical values for each potential difference, current, and power listed in the first four circuit diagrams shown below (two on the next page). I expect you to show equivalent circuits and a bit of work for Circuits 3 & 4. I have already started the first one for you to give you an idea of how the answers should look. Watch out: Circuit 4 gets pretty ugly...

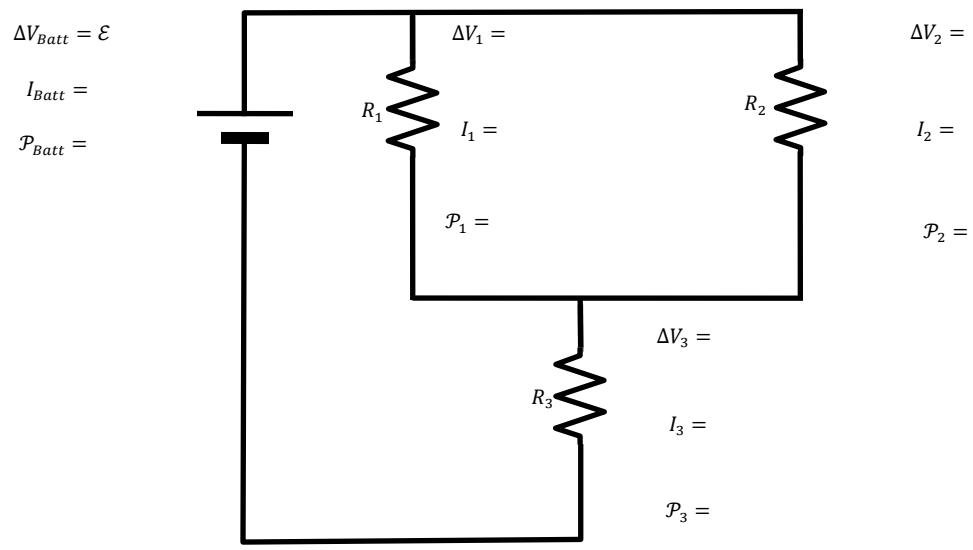
Ideally you should create an Excel spreadsheet for computing the theoretical values for any of the above versions prior to coming to lab. I made a [screen shot](#) of the one I made on the page after Circuit 5. When you arrive in class, your instructor will give each group a different version. You should be able to input the DMM measured values of resistance and DMM measured open circuit battery voltage into your spreadsheet to have it predict theoretical currents, powers, etc.



**Circuit 3**



**Circuit 4**



**Circuit 5:** This circuit (shown below) is *optional* unless your instructor suggests otherwise. I'll give up to 2 extra lab points for completion of this activity (discuss with instructor prior to attempting).

Let  $R_1 = R_3 = 10 \Omega$ ,  $R_2 = R_4 = 22 \Omega$  &  $R_5 = 33 \Omega$ . Compute theoretical currents using these nominal resistance values and KVL/KCL. Assume we are using an ideal battery with terminal voltage approximately equal to 1.2 V.

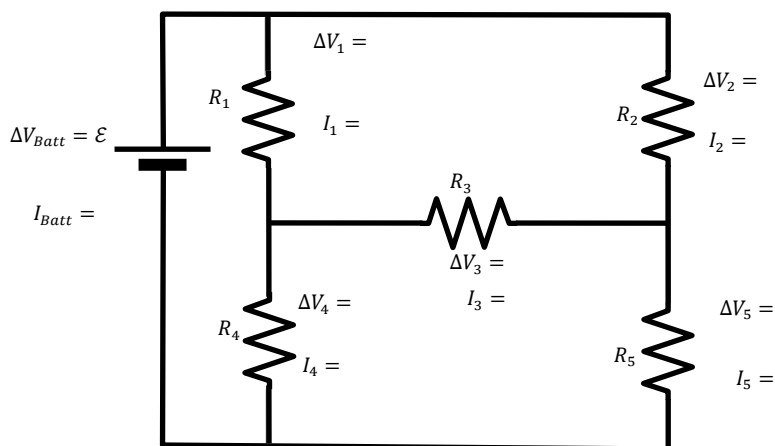
Create a simulation in TinkerCAD to produce theoretical values of current & voltage ([TinkerCad instructions](#)).

In lab, build the circuit actually measure each current & voltage.

Finally, compute the % differences between theoretical and experimental values.

If you do this, be prepared to show me your simulation during lab to receive the extra credit.

I'll ask you to make some modifications to the circuit live right in front of me to ensure you didn't just copy someone else's simulation.



Below is a screen shot of an Excel Workbook I made. I change the constants in cells b1 through b4 and all of the voltages, currents and powers will auto update. If you make such a table, you can check your work against this screen shot by using the same values. If you want, you can check your algebraic work against this screen shot as well. Simply plug in the resistance values shown in the screen shot into your algebraic formulas and verify you get the same results as my screen shot!

Watch out: notice I used mA for currents (and mW for power). By doing this the current values are much easier to read and match the units the DMM will produce when you do the experiment in class. You'll want to think carefully about either multiplying or dividing by 1000 as appropriate.

**Note:** after doing the lab, you'll update the sig figs to reflect our normal standards (unlike my table).

**Also note:** units were included here (since those are always important) but it is ok to ignore italics and subscripts for today.

	A	B	C	D	E	F	G	H
1	<b>R1</b>	55.5		<b>All resistances in Ohms</b>				
2	<b>R2</b>	44.4		<b>All voltages in Volts</b>				
3	<b>R3</b>	33.3		<b>All currents in mA</b>				
4	<b>Vb</b>	1.5		<b>All powers in mW</b>				
5								
6	<b>Circuit 1</b>							
7	<b>Vb</b>	1.50	<b>V1</b>	0.833	<b>V2</b>	0.667		
8	<b>Ib</b>	15.0	<b>I1</b>	15.0	<b>I2</b>	15.0		
9	<b>Pb</b>	22.5	<b>P1</b>	12.5	<b>P2</b>	10.0		
10								
11	<b>Circuit 2</b>							
12	<b>Vb</b>	1.50	<b>V1</b>	1.50	<b>V2</b>	1.50		
13	<b>Ib</b>	60.8	<b>I1</b>	27.0	<b>I2</b>	33.8		
14	<b>Pb</b>	91.2	<b>P1</b>	40.5	<b>P2</b>	50.7		
15								
16	<b>Circuit 3</b>							
17	<b>Vb</b>	1.50	<b>V1</b>	1.50	<b>V2</b>	0.857	<b>V3</b>	0.64
18	<b>Ib</b>	46.3	<b>I1</b>	27.0	<b>I2</b>	19.3	<b>I3</b>	19.3
19	<b>Pb</b>	69.5	<b>P1</b>	40.5	<b>P2</b>	16.5	<b>P3</b>	12.4
20								
21	<b>Circuit 4</b>							
22	<b>Vb</b>	1.50	<b>V1</b>	0.64	<b>V2</b>	0.64	<b>V3</b>	0.86
23	<b>Ib</b>	25.9	<b>I1</b>	11.5	<b>I2</b>	14.4	<b>I3</b>	25.9
24	<b>Pb</b>	38.8	<b>P1</b>	7.3	<b>P2</b>	9.2	<b>P3</b>	22.3

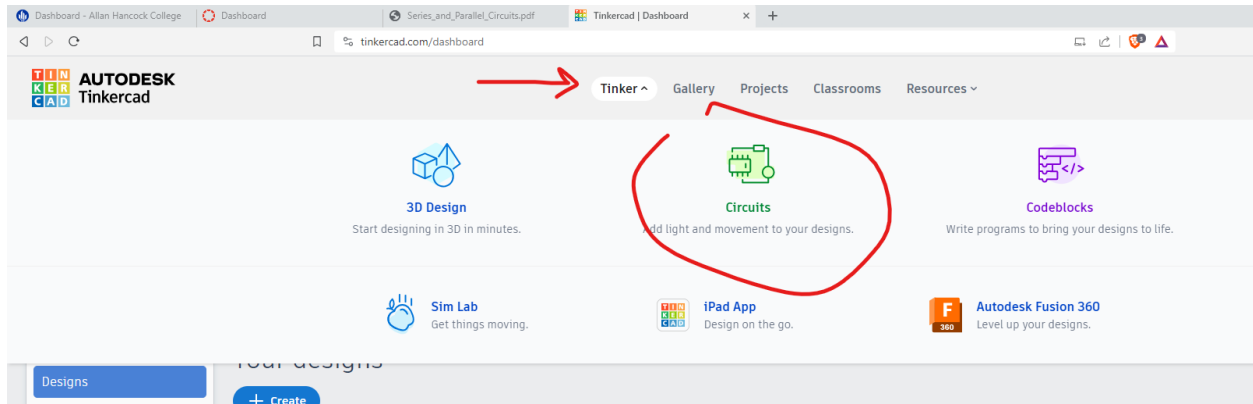


## Tinkercad info

I logged in using a google account at this website: <https://www.tinkercad.com/>.

Then I clicked on the dropdown entitled “Tinker”.

Then I clicked on “Circuits”.

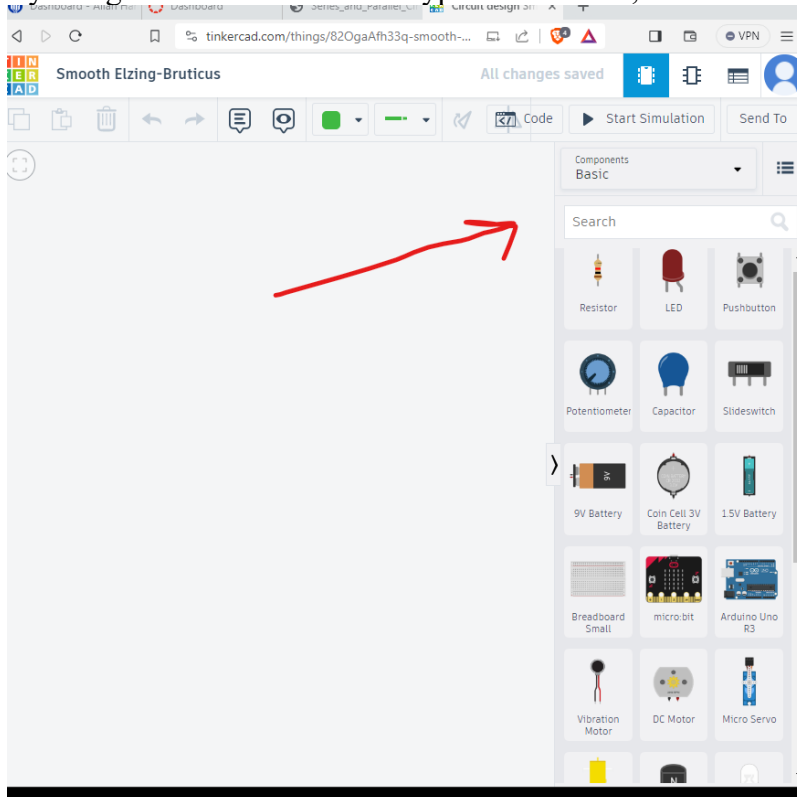


On the next page I clicked on “Start Tinkering” at the bottom of the page.

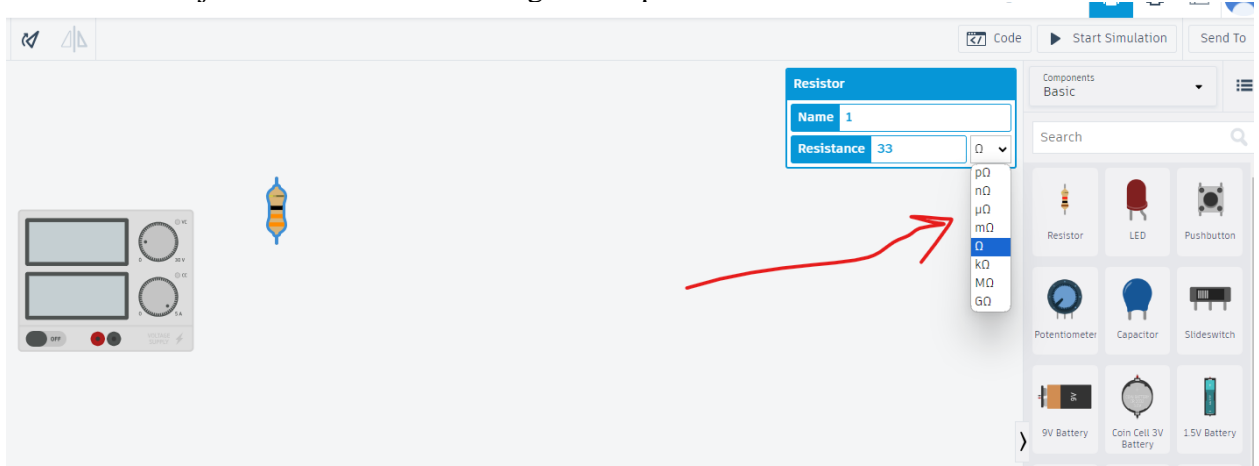
Finally I clicked on “Create” to start a circuit design.

Upon doing all that I saw this screen.

By using the search bar I could type in “resistor”, “multimeter”, “power supply”, etc.



Here is me starting to put some pieces out.  
Notice I can adjust the resistor units using the drop down box.



After about five minutes I had the following simulation running.  
Notice I used the drop-down menu on the meter to change it to an ammeter.  
Upon clicking on a meter I, rotated it using the button near the top middle of the screen.  
In the top right corner there is a button to change the Start/Stop state of the simulation.  
Notice I also gave the circuit elements names names (like "i\_2" & R\_2").

