Resistors, LEDs, and More

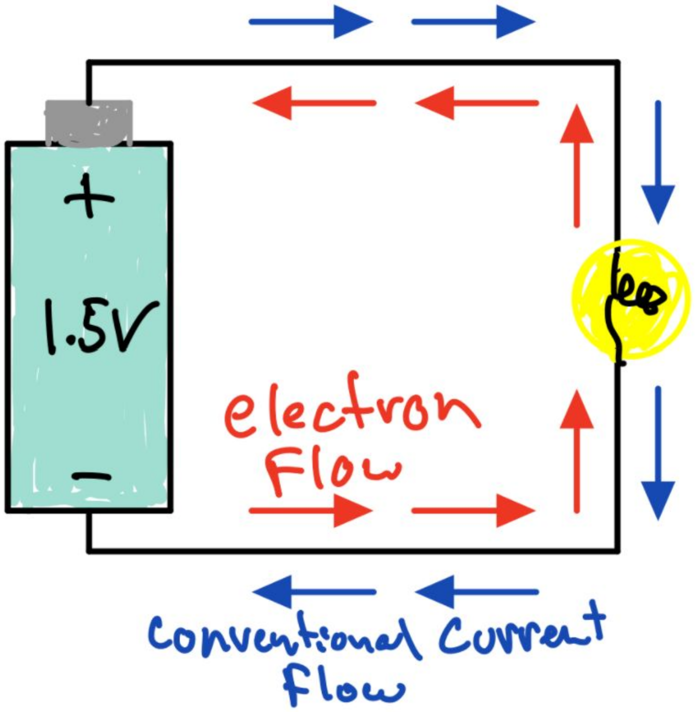
Circuit Setup and Basics

Two Conditions For Current to Flow

There are two primary requirements for current to flow within a circuit.

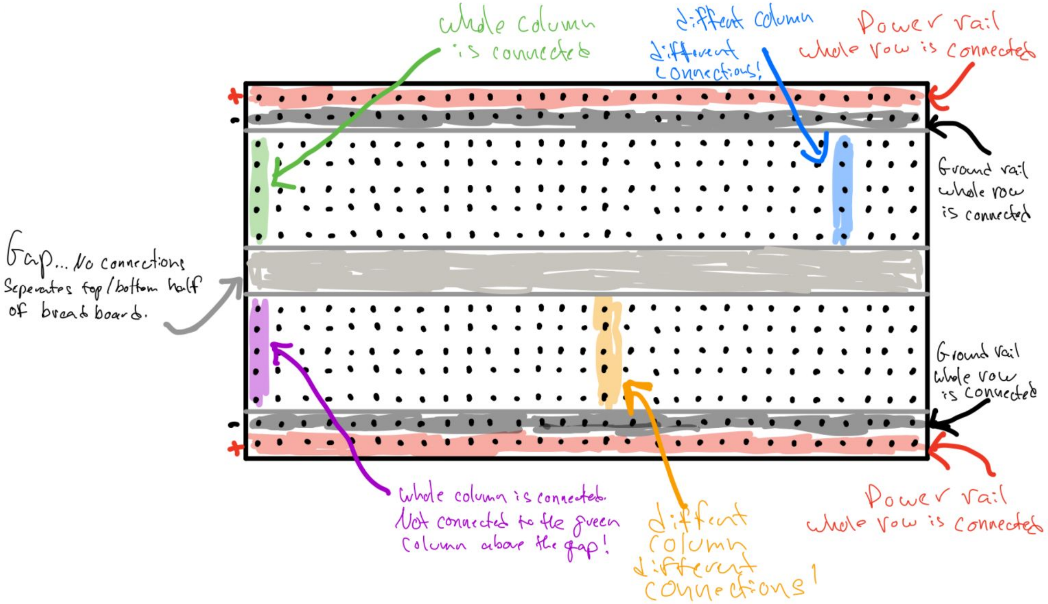
- There must be a voltage source.
  - We will be using either a **variable power supply** or a **9 volt battery** for our voltage source.
- There must be a closed circuit.
  - We will use a **breadboard with jumper wires** to create a closed circuit.

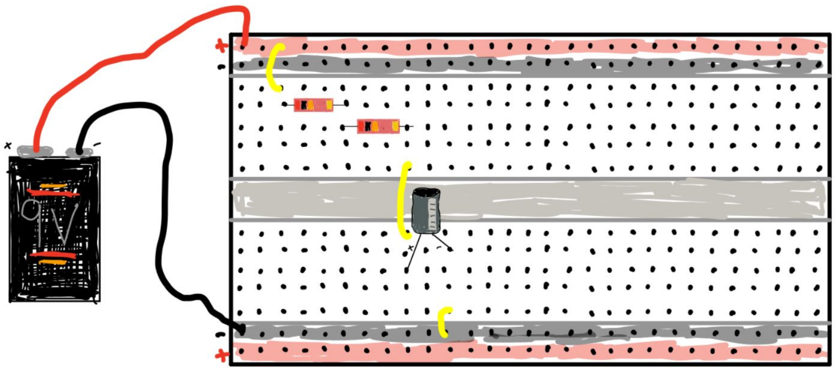
We will assume conventional current flow (positive charge) that flows out of the positive terminal of a battery and into the negative terminal.



Breadboard Overview

- We will connect our battery/power supply to the power rail, often called **Vcc** and to the **ground** rail.
- This means everything in red will be at 9 volts where we connect the battery and everything in dark grey will be at 0 volts where we connect the battery.
- Note, only the top red rail is at 9 volts and only the bottom grey rail is at 0 volts.
- We will then use the various rows/columns to build our circuit connecting various rows/columns together with jumper wire and components.



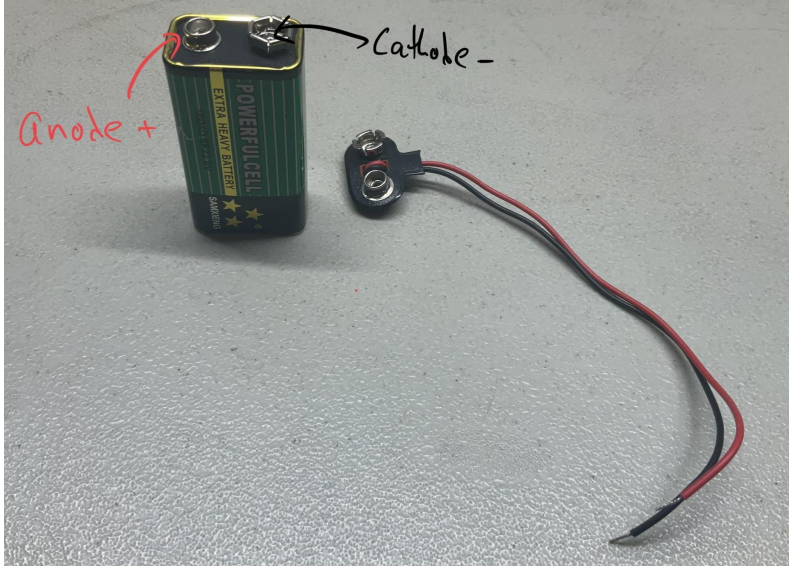


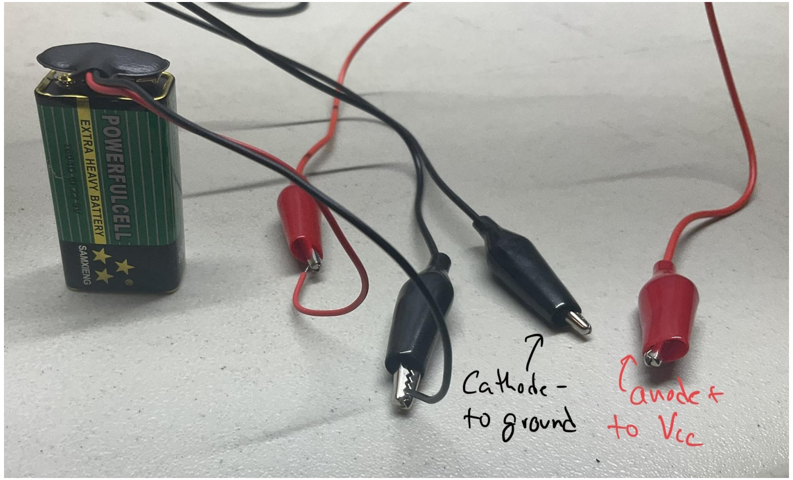
The Voltage Source: A Variable Power Supply

- A variable power supply can be adjusted to give a range of voltages and/or currents.
- The downside (for our purposes) is that a variable power supply requires us to have access to an outlet and not everyone might have a variable power supply.

The Voltage Source: A Battery

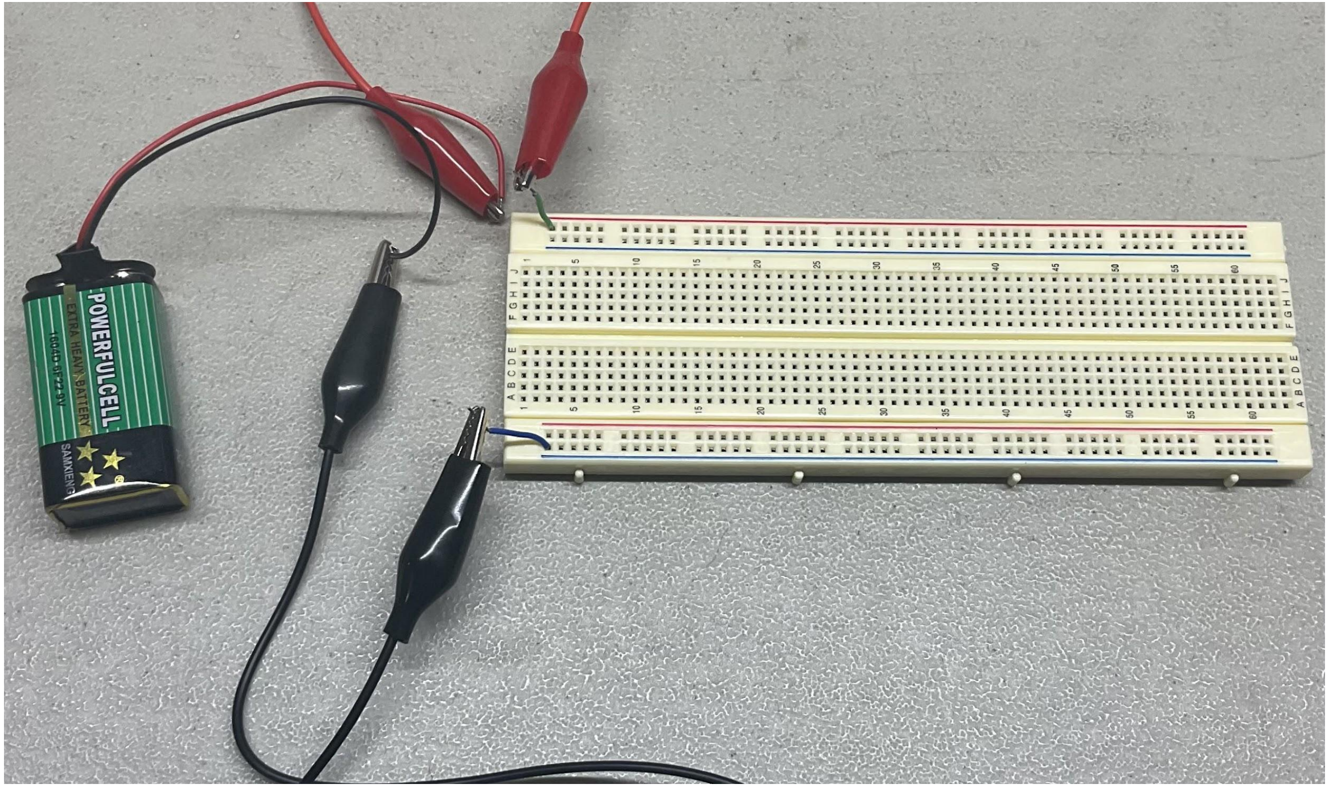
- A battery is a simple solution!
- Get a 9 volt battery, a battery pack, and 2 alligator clips.
- Note that the battery has a positive terminal (**the anode**) and a negative terminal (**the cathode**).
- We will use the battery pack and alligator clips to connect the anode (9 volts) to Vcc and the cathode (0 volts) to ground.
- I will switch between battery and power supply often but I will always be at 9 volts.





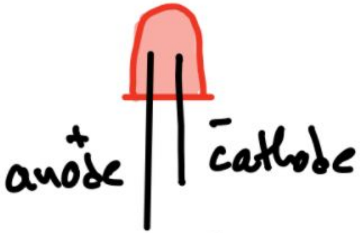
Hooking the Battery Up

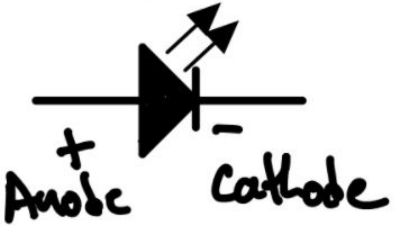
- We will use the top rail for our voltage of 9 volts; **Vcc**.
- We will use the bottom rail for our voltage of 0 volts; **ground**.

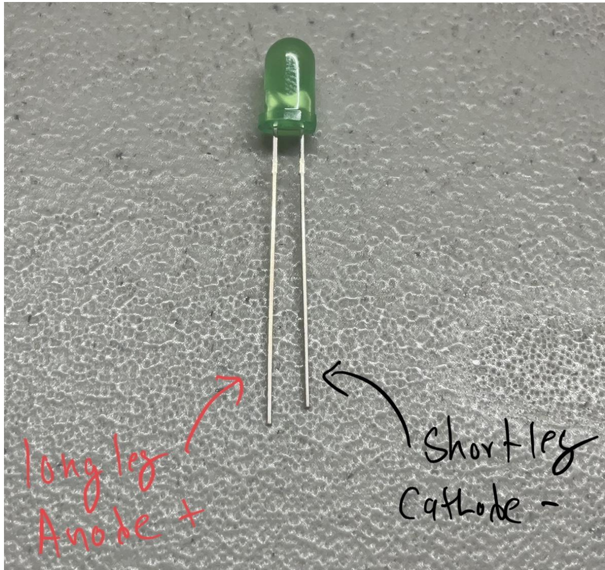


What is an LED

- An LED is a small clearish bulb which has a **light emitter** inside of it. That's what the LE stands for in LED.
- This light emitter creates light when a minimum voltage is applied across the two legs of the LED.
- LEDs are pretty simple, they only have two wires. One wire is the anode (positive, long leg) and one is the cathode (negative, short leg).
- The wires are important because LEDs only work in one direction. Current will only flow from the anode to the cathode.
- Components that only work in one direction like this are called **diodes**. That's what the D stands for in LED.



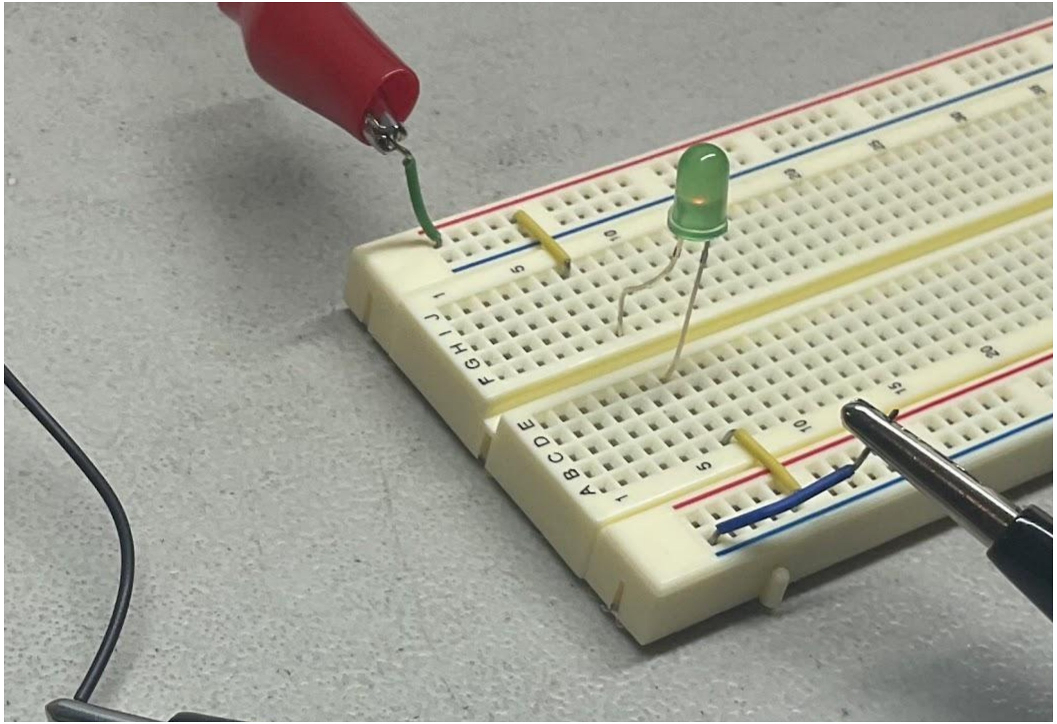




MURDER!!! Kill and LED! Once, and only once...

- Use a jumper wire to connect Vcc to one column on the breadboard.
- In that same column, place the anode (long leg) of an led and place the cathode (short leg) over the gap into a new column.
- Ground the cathode by connecting the column of the cathode to ground using a jumper wire.
- You have now made a closed loop!

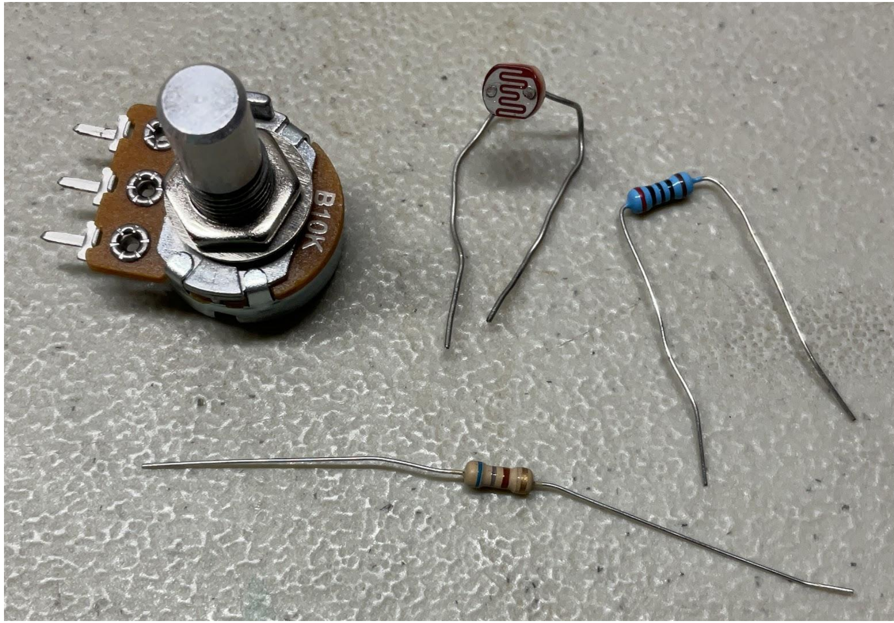
- Voltage source and closed loop...your LED should FRY! **Why do you think this is?**



What is a Resistor?

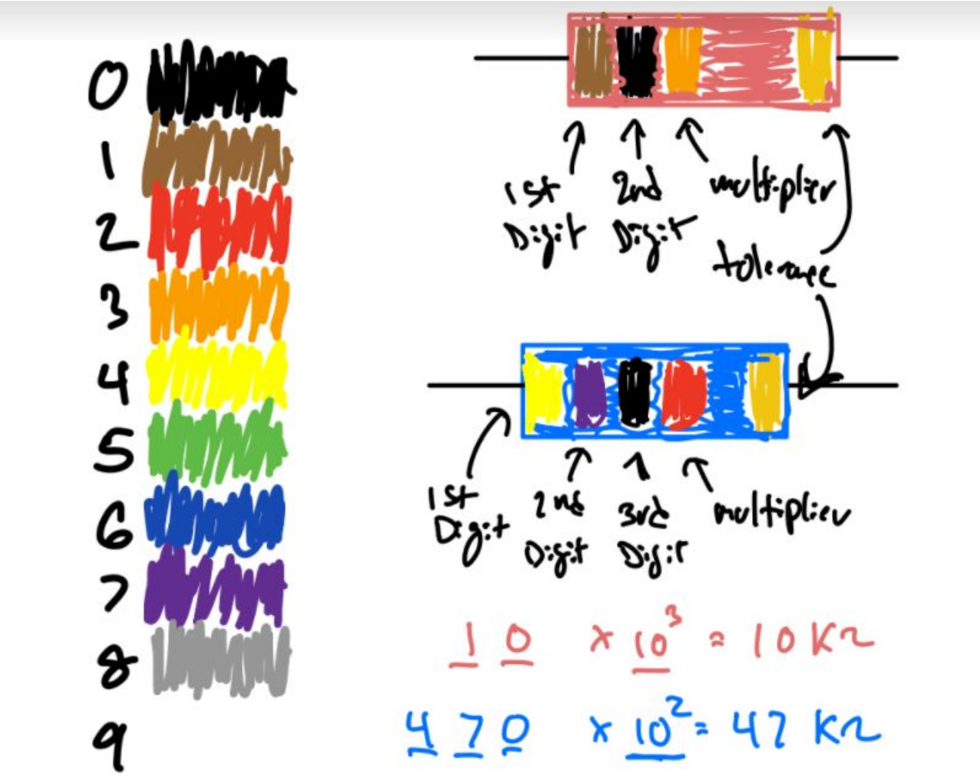
What is a Resistor

- A **resistor** is a passive two-terminal electrical component that limits the current flowing in a circuit.
- **Fixed resistors** are resistors whose resistance does not change.
- **Variable resistors** are resistors whose resistance can change. Examples include potentiometers and light dependent resistors.



Resistor Color Codes

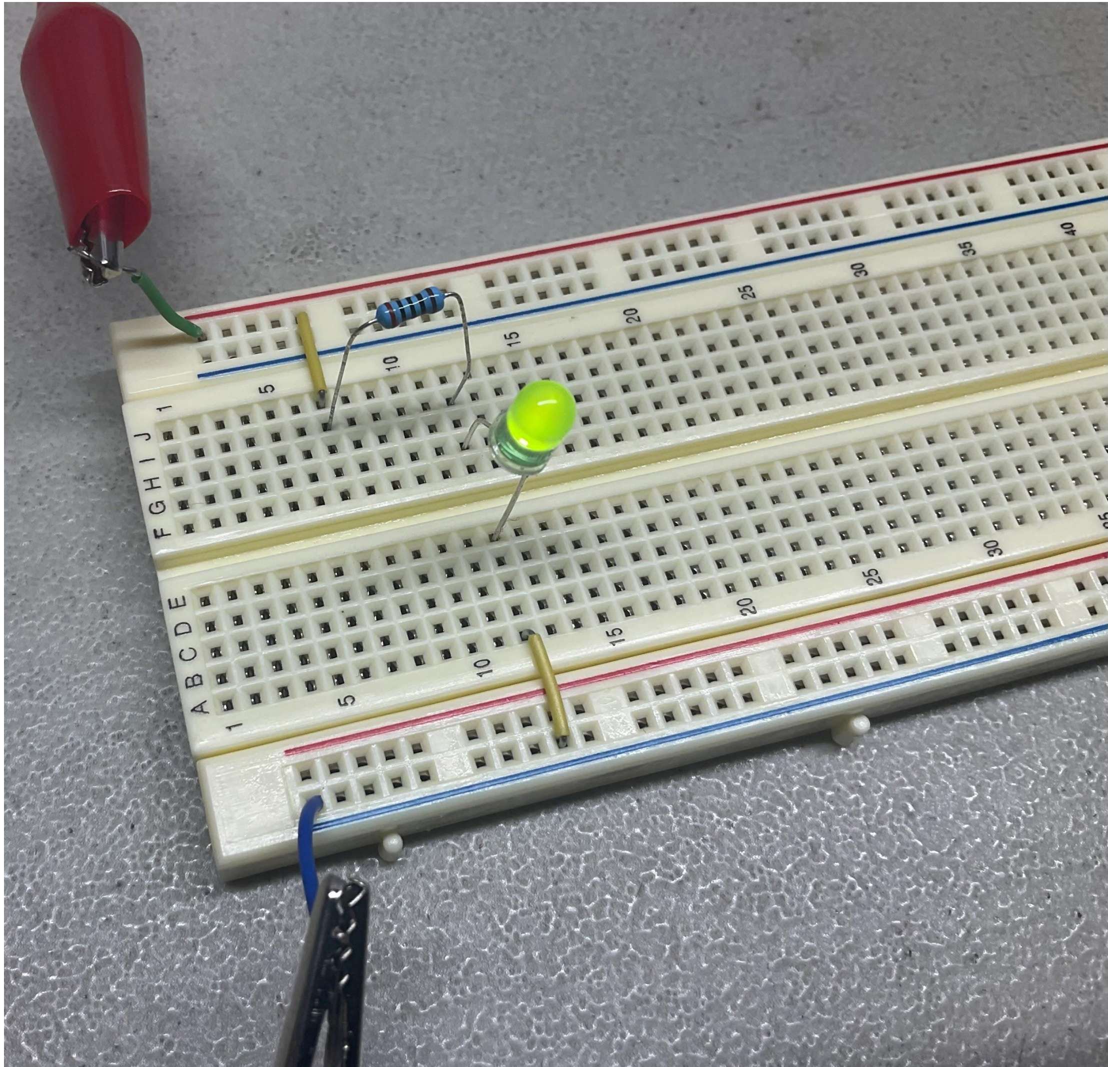
- The colored bands on a resistor indicate the resistance values.
- If there are 4 bands, they are the 1st digit, 2nd digit, multiplier, and tolerance.
- If there are 5 bands, they are 1st digit, 2nd digit, 3rd digit, multiplier, and tolerance.
- Tolerance is a measure of how accurate the resistor value might be. For example, +/- 5%.
- We will often not state the tolerance when describing the color of the bands.



Safely Light an LED

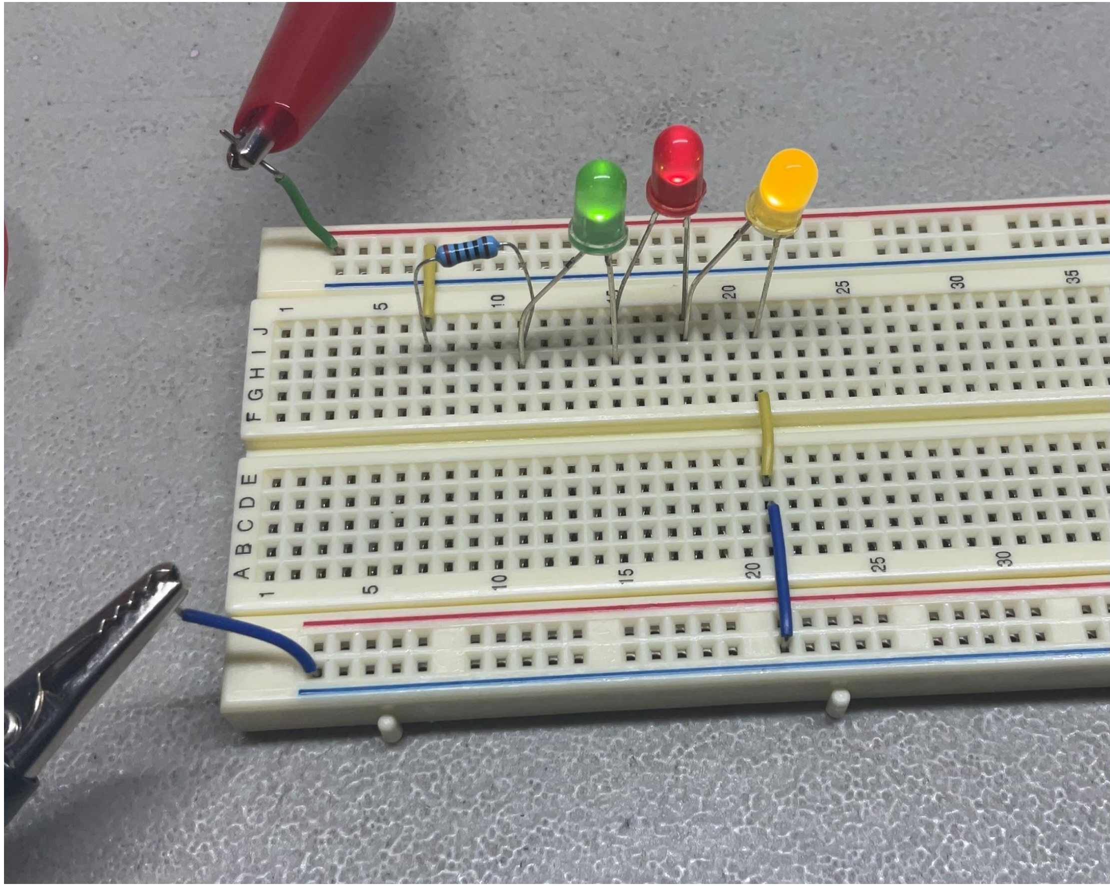
- Use a 200 ohm (red, black, black, black) resistor to limit the current flowing through the resistor.

- Red: 1st digit - 2
- Black: 2nd digit - 0
- Black: 3rd digit - 0
- Black: multiplier - x 10^0



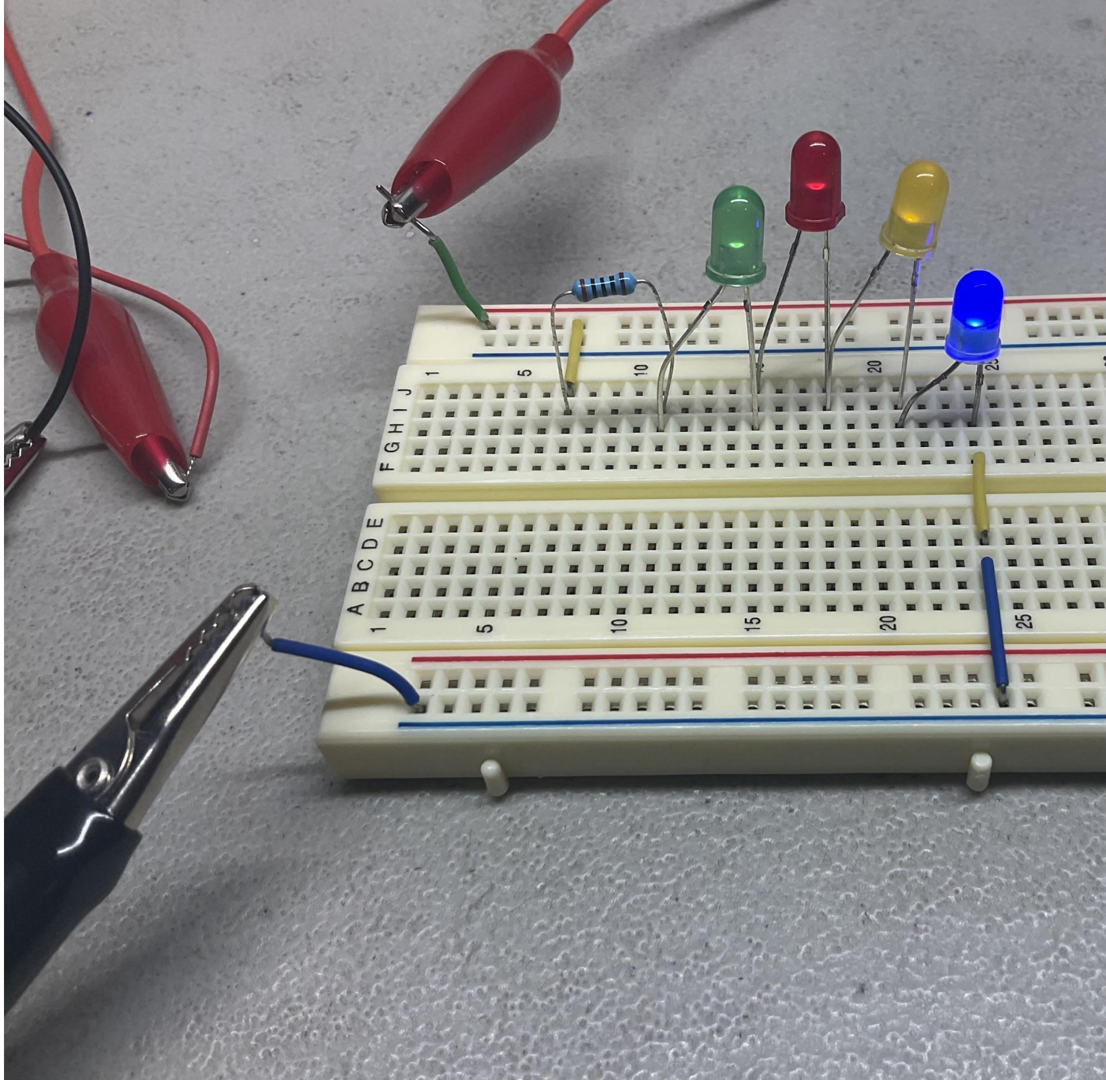
Safely Light More LEDs

- Light up three LEDs by placing them all in the same path.
- This is known as wiring **in series**.
- Use a 200 ohm (red, black, black, black) resistor to limit current.
- Make sure that the cathode (short leg) of one LED is connected to the anode (long leg) of the next and that you ground the last LED.



How Many LEDs Can You Light

- See how many LEDs you can light in this manner.
- What happens to the overall brightness of the LEDs as you add more and more this way?
- What happens if you remove just one LED or the resistor?
- Why do you think that is?



Circuit Challenge 1

Bright Bright Lights

Circuit Challenge 1: Bright Bright Lights

- In the last picture, the light from 4 LEDs was barely visible. Also, if you removed just one LED, all LEDs went out.
- This is because they were all wired in the same path; or **in series**.
- Can you wire up your circuit such that 4 LEDs shine at maximum brightness without blowing any of the LEDs and if you remove one LED the others remain lit?

- **HINT**: Maybe using 1 path is a bad idea here…for each path, you need a resistor!

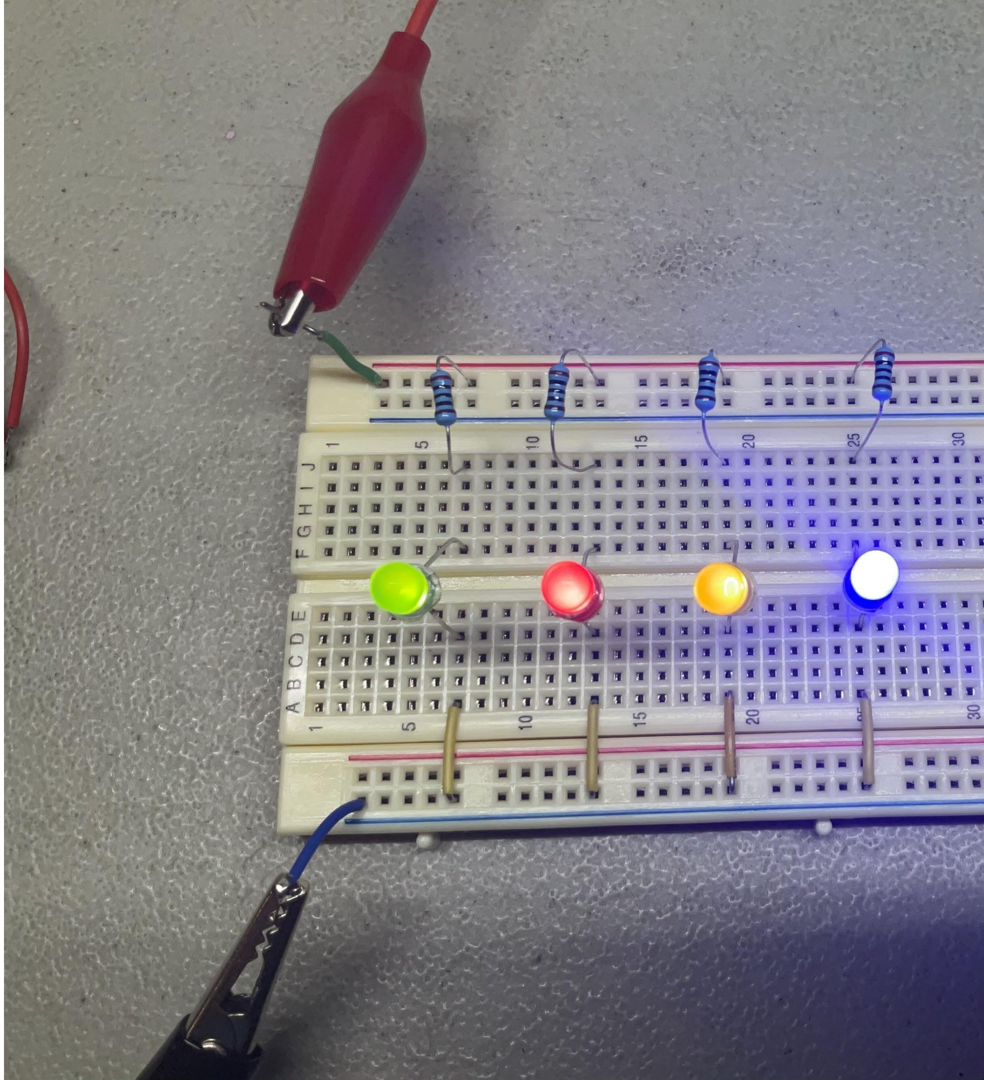
DO NOT ADVANCE to the next slide without trying to figure this out first!

Circuit Challenge 1: Solution

- Each LED is in it’s own path:

Vcc -> 200 ohm resistor -> LED -> ground

- Each path is being supplied with 9 volts which allows for a maximum (safe amount) of current to flow through the LED.
- This is known as wiring **in parallel**.



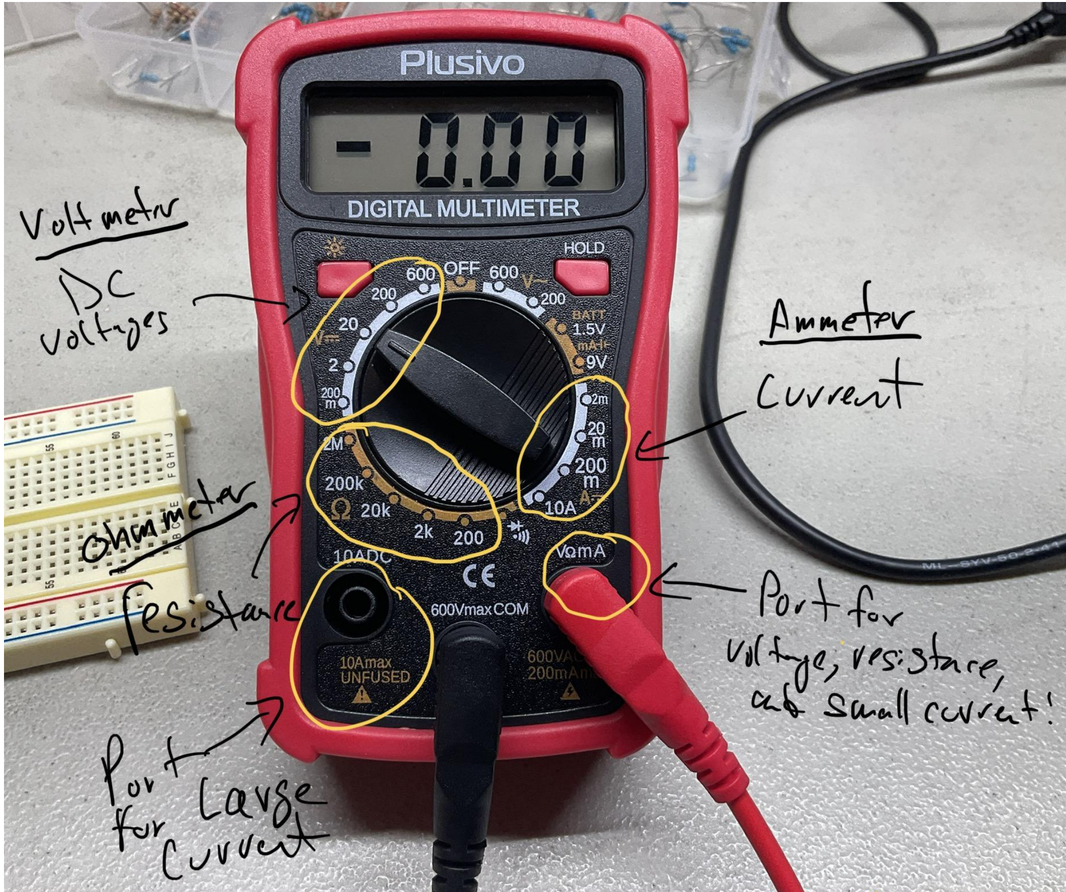
How to Use Multimeters

Meters of All Kinds

- Multimeters come in all sizes, shapes, and colors.
- They all basically function the same way.
- Learn how to use one, and you've learned how to use them all.

Using a Multimeter to Explore Series and Parallel

- The **voltmeter** measures DC voltages. This must be hooked up in **parallel**.
- The **ammeter** measures current. This must be hooked up in **series**.
- The **ohmmeter** measures resistance. This must be hooked up in **parallel** with no current flowing.
- For each meter, you have to turn your dial to the maximum potential reading. For example, right now I have a voltmeter selected that can read up to 20 volts.

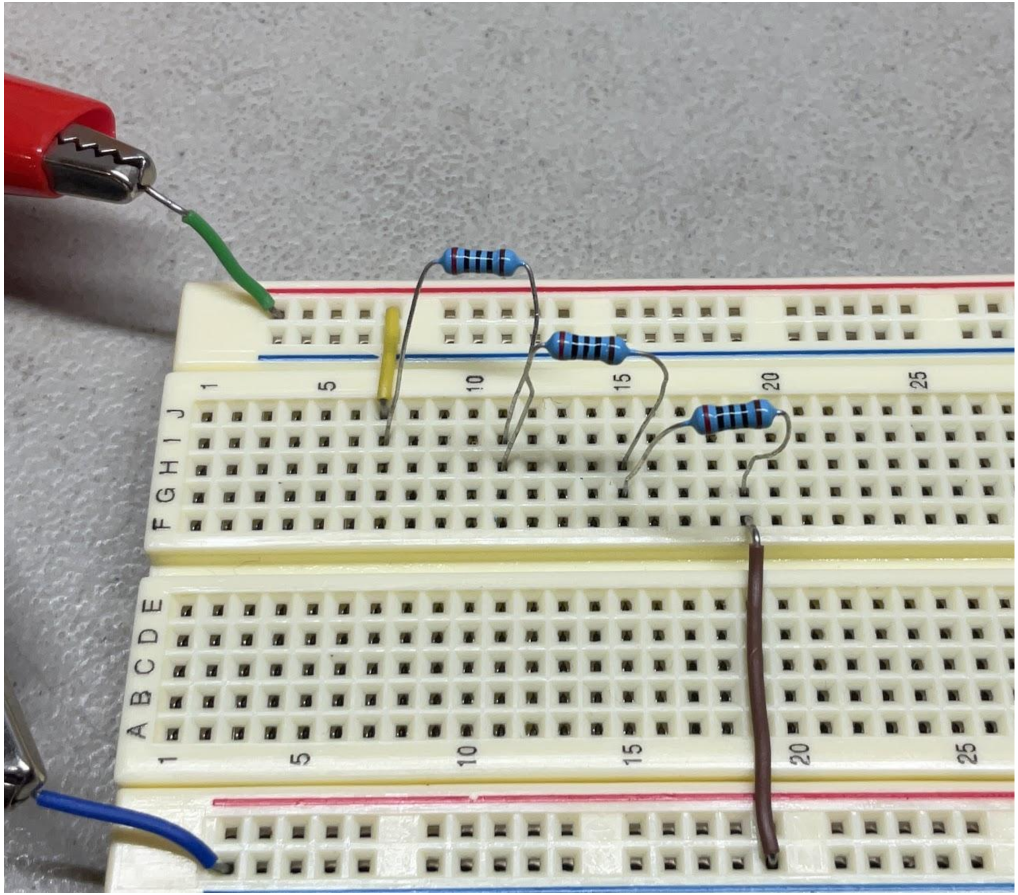


Resistors - In Series

- Place three 200 ohm (red, black, black, black) resistors in series, or all in the same path.
- When resistors are in series the total (or equivalent resistance) can be found as:

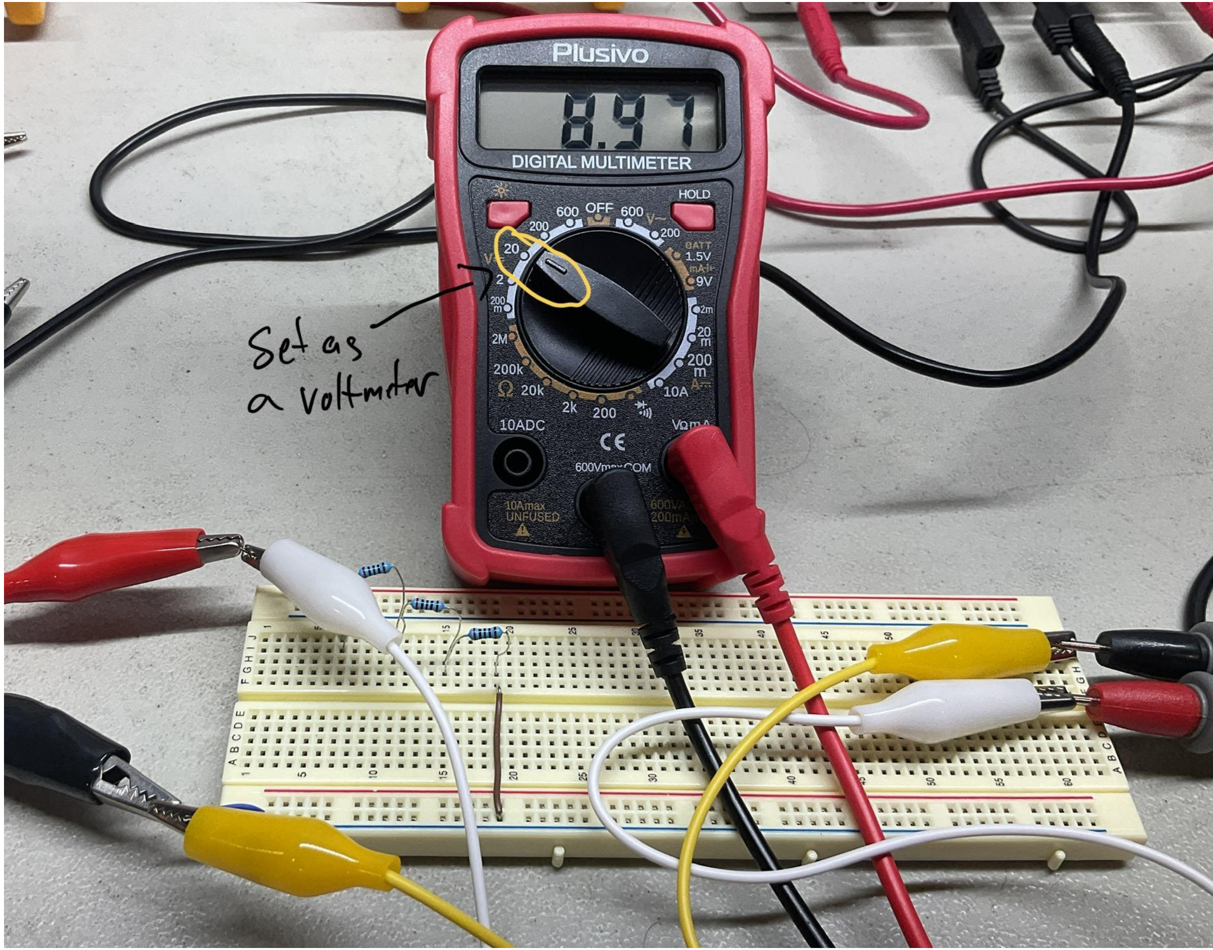
Rt = R1 + R2 + R3….

- In our case, the total resistance would be 200 ohms + 200 ohms + 200 ohms = 600 ohms.
- There is only one path for current to flow, so the current is the same through each resistor.
- Each time current meets a resistor, the battery must use some of its voltage to push charge through the resistor. So the total voltage (the voltage supplied by the battery) equals the sum of the voltage drops across each resistor.



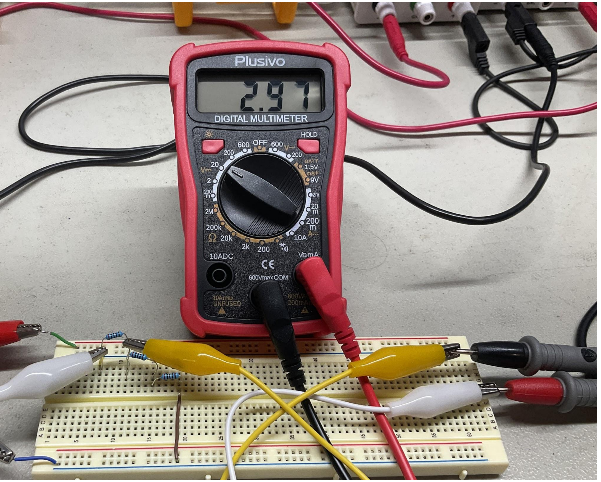
Resistors - In Series

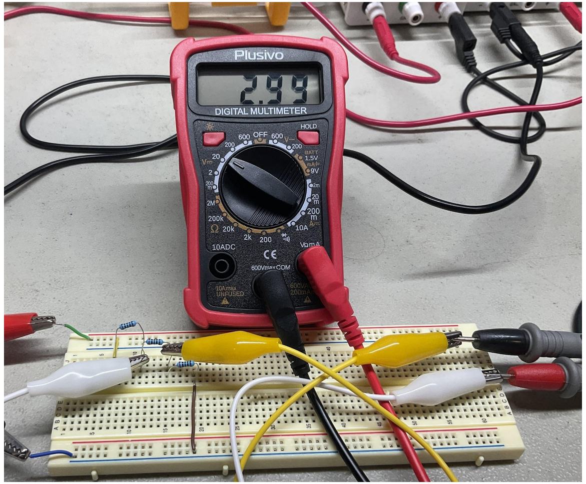
- Set the multimeter to a voltmeter to measure a maximum voltage of 20 V (or something similar to your meter).
- Place two alligator clips on the leads of the multimeter and connect the other ends to your jumper wires on Vcc and on ground.
- We have now placed the voltmeter in parallel to the battery. We are reading the total voltage of our circuit; supplied by the battery.

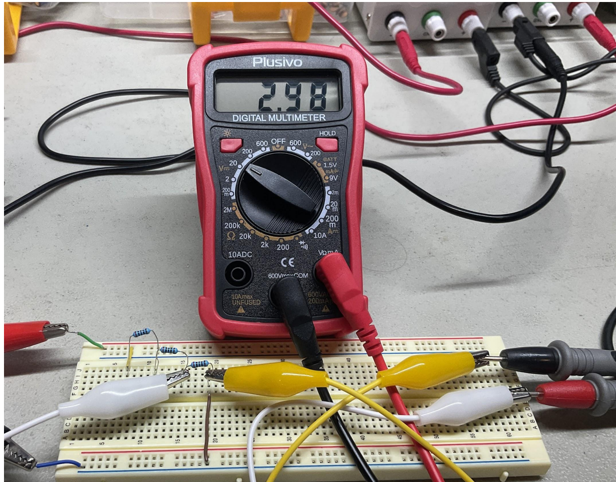


Resistors - In Series

- Use the voltmeter to measure the individual voltage drops across each resistor by placing the voltmeter in parallel to each resistor. Simply clip the leads of your alligator clips to each side of the resistor.
- The total voltage should equal the sum of the individual voltage drops.
- 2.97v + 2.99v + 2.98v = 8.94v
- Pretty spot on to 8.97!

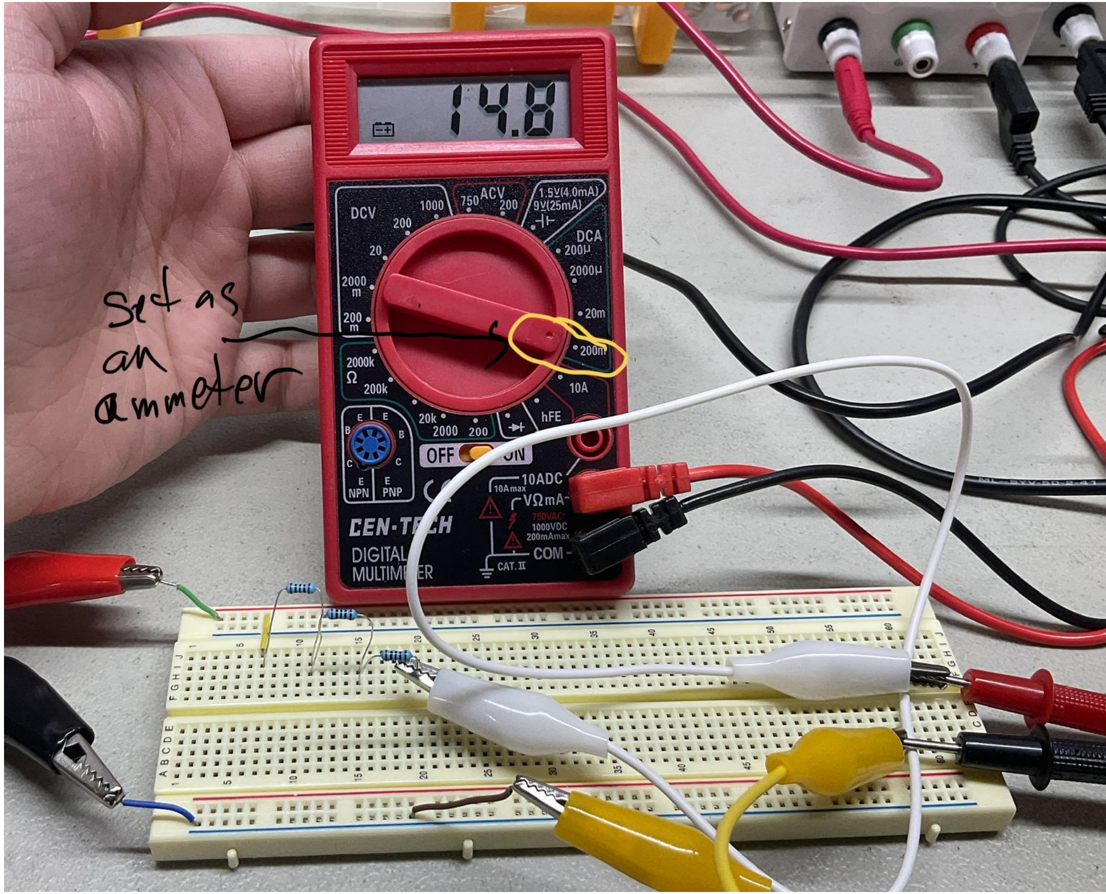






Resistors - In Series

- Set your multimeter as an ammeter that can read a maximum of 200 mA (or something similar to your meter).
- Ammeters have to be placed in series, or in the same path as the current you are trying to measure.
- We only have one path here. Remove your ground wire and connect it to the black lead of your multimeter. Connect the red lead of your multimeter the leg of your last resistor.
- Your ammeter is now in the same path as your resistors!



Resistors - In Series

- Our circuit has generated 14.8 milliamps of current; which is a small, safe amount!
- The reason why we have a small current is because our resistors (in series) have combined to give a total resistance of 600 ohms!
- Resistors are “ohmic” devices that follow ohm's law which states:

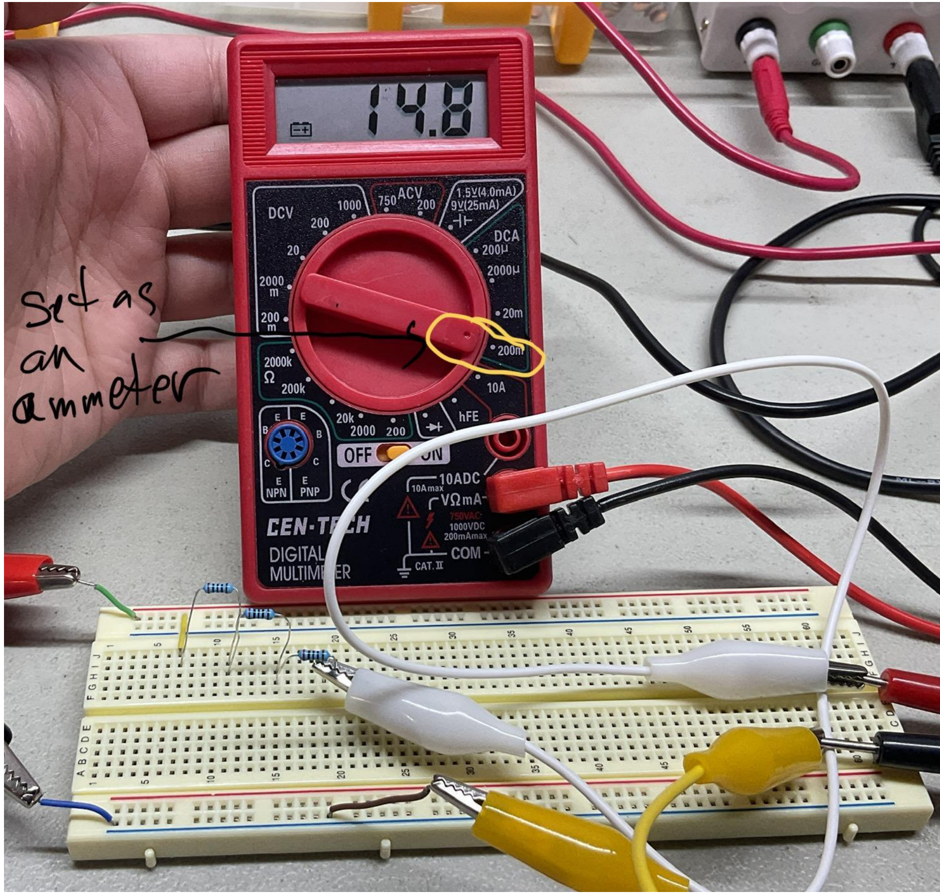
$$V = IR$$

- The current in our circuit (14.8 mA) is proportional to our total voltage (8.97 v) and our total resistance (600 ohms)!

8.97 v = (.0148 A)(600 ohms)

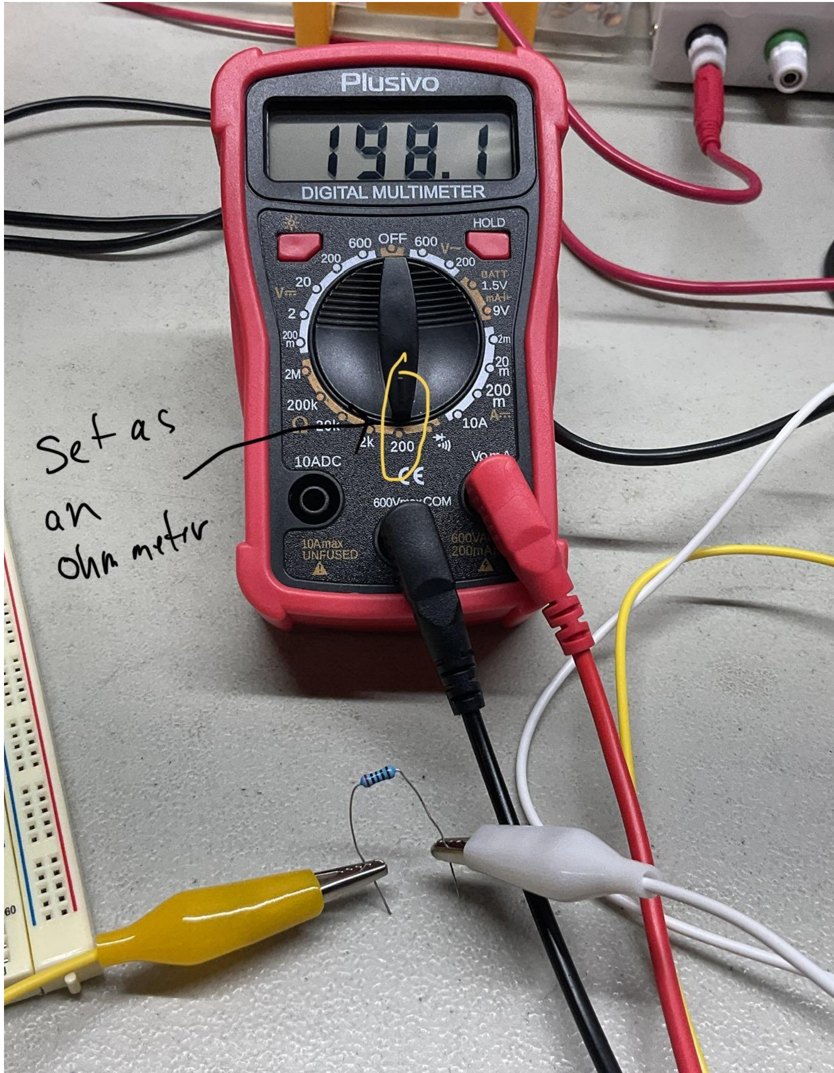
8.97 = 8.88

Pretty spot on!



Resistors - In Series

- Why are our values not exact?
- Well...nothing is exact in electronics :-(
- For example, pull your resistors out of the breadboard.
- Turn your multimeter to an Ohmmeter to measure a maximum resistance of 200 ohms (or something similar to your meter).
- Ohmmeters have to be placed in parallel with no current flowing (why we pulled it out of the board).
- Hook up your leads of your multimeter to each leg of the resistor and read the resistance of your resistors...They are not all 200 ohms!
- Remember, resistors have a tolerance...200 ohms +/- 5%, +/- 10%, etc….

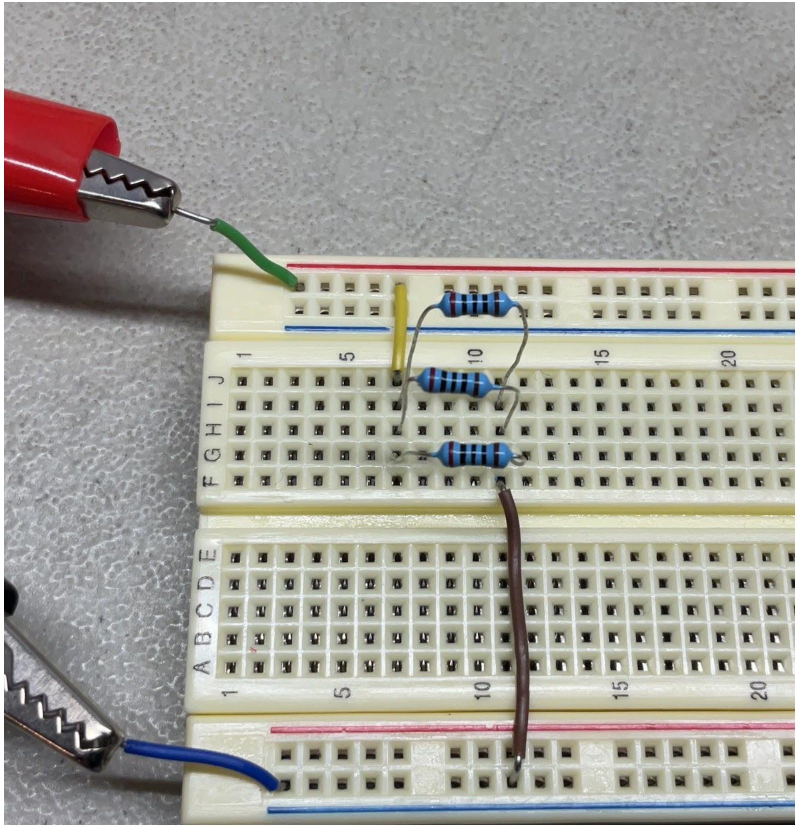


Resistors - In Parallel

- **Don't build this circuit...it generates a lot of heat and I don't want anyone to get hurt!**
- Here I have place three 200 ohm resistors in parallel...each in their own path from Vcc to ground.
- When resistors are in parallel the total (or equivalent resistance) can be found as:

1/Rt = 1/R1 + 1/R2 + 1/R3 …

- In our case, the 1/total resistance would be 1/200 + 1/200 + 1/200 = 3/200. So total resistance would be 200/3 or 66.7 ohms.
- There are three paths for current to flow in this circuit. So total current is the sum of each individual path's current.
- Each time current meets a resistor, the battery must use some of its voltage to push charge through the resistor. Here each resistor is connected to Vcc and ground. So the voltage drops across each resistor is the same; the voltage of our battery!

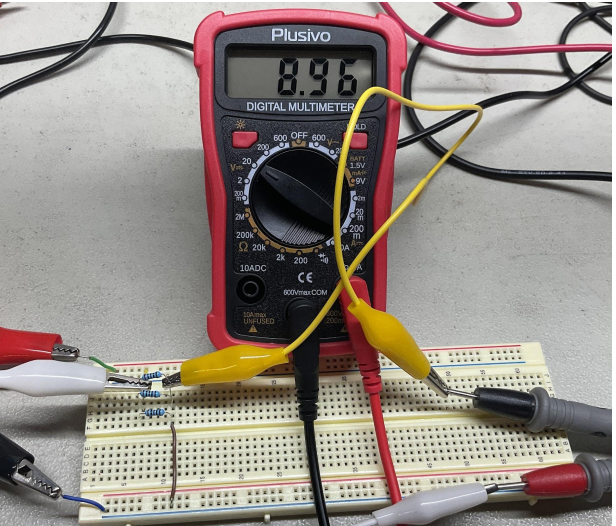


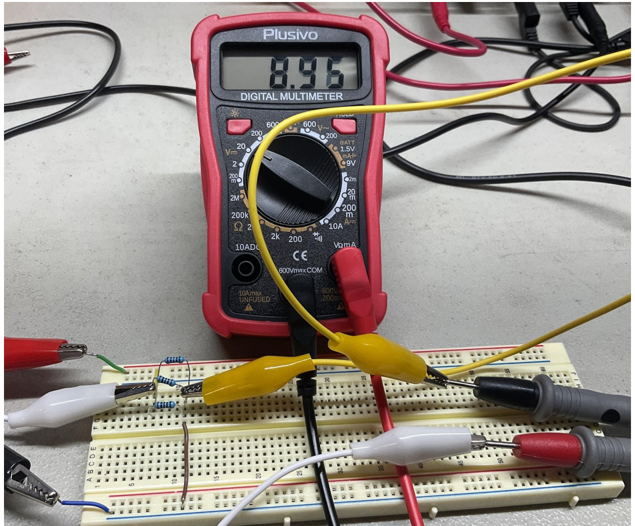
Resistors - In Parallel

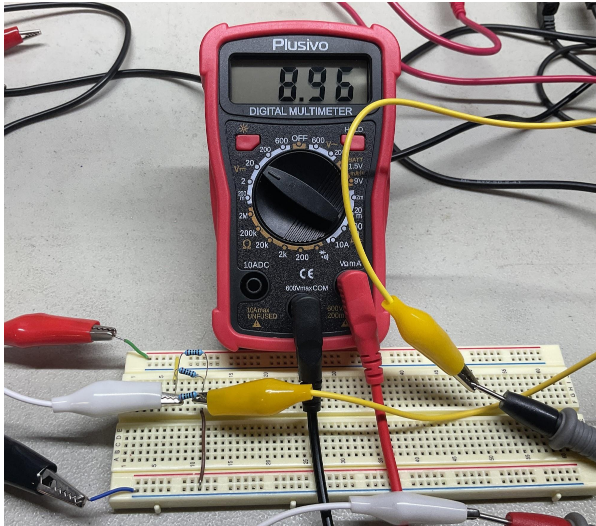
- Here you can see that the voltmeter is reading the same voltage across each resistor!
- This is the same as the voltage of our battery!
- When in parallel to the battery, each resistor gets all of the voltage of our battery; which means the battery can push more charge through each individual resistor following Ohm's Law.

$$V = IR \rightarrow 8.96\text{ V} = I(200\text{ ohms}) \rightarrow I = .0448\text{ A}$$

- Each resistor has .0448 A of current flowing through it.





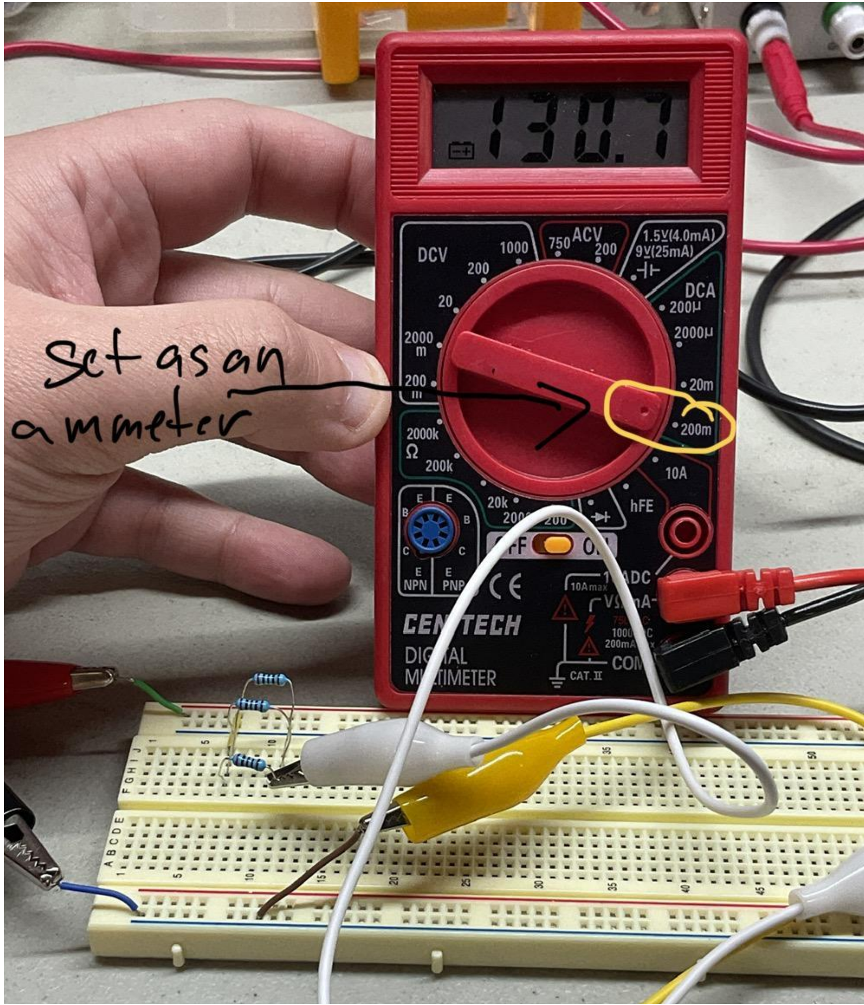


Resistors - In Parallel

- If each resistor has .0448 A of current flowing through it, then the total current in the circuit should be the sum of these individual currents.

.0448 A + .0448 A + .0448A = .1344 A

- Pretty close to what my ammeter is reading of 130.7 mA = .1307 A
- Our series circuit only had 14 mA of current, this has 130 mA! All that extra current generates **HEAT**!
- When working with large currents, **BE CAREFUL!**



Circuit Challenge 2

Meter Mystery

Circuit Challenge 2: Meter Mystery

- Can you build a circuit that generate 9.0 mA of current out of nothing but your 9 volt battery and 200 ohm resistors?
- If so, wire up your multimeter to measure the current in your circuit to prove that there is approximately 9.0 mA of current flowing through the circuit.

- **HINT**: Resistors are Ohmic devices and follow Ohm's law: $V = IR$. Also remember how resistors combine in series or in parallel.

DO NOT ADVANCE to the next slide without trying to figure this out first!

Circuit Challenge 2: Solution

- By Ohm's Law:

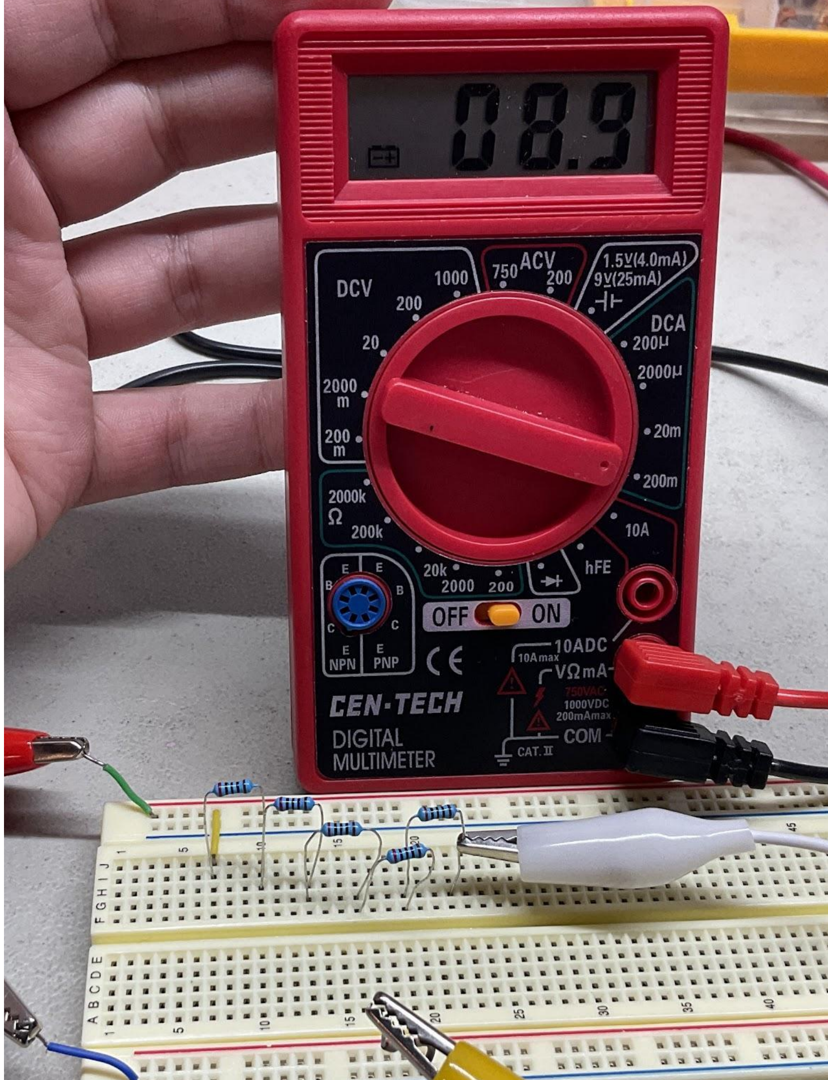
V = IR -> 9v = .009A(R) -> R = 1000 Ohms

- Using resistors in series…

Rt = R1 + R2 + R3 + ...

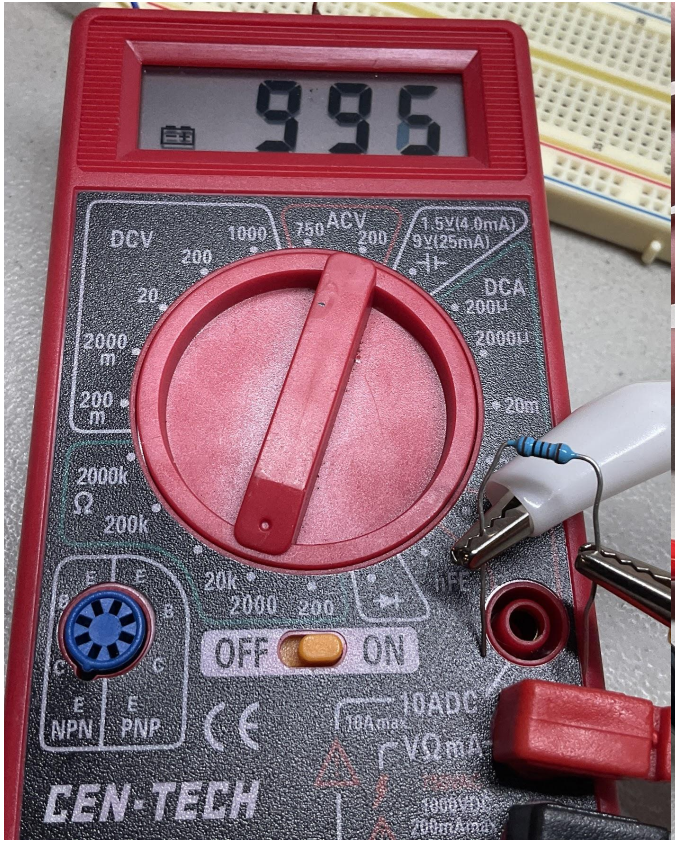
1000 = 200 + 200 + 200 + 200 + 200

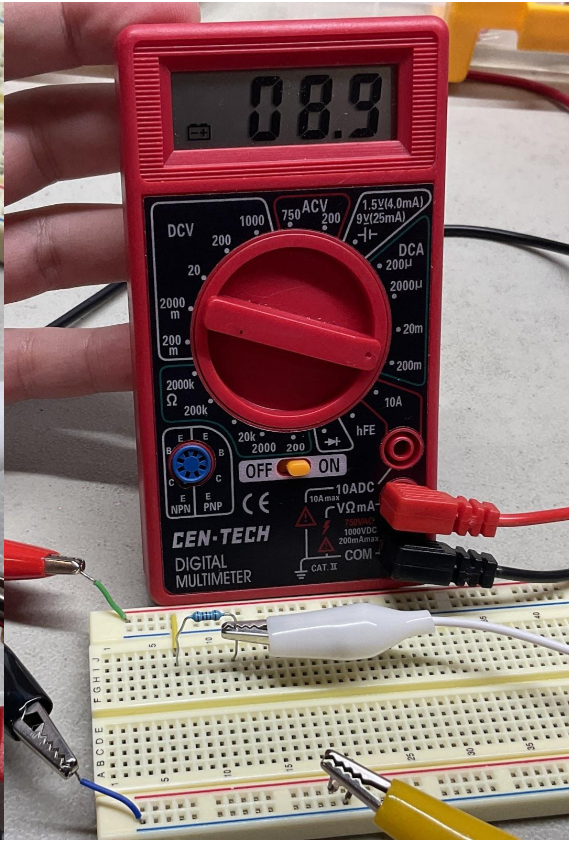
- Therefore, we need 5 200 ohm resistors wired in series and the ammeter wired in series proves this!



Circuit Challenge 2: Solution Another Way!

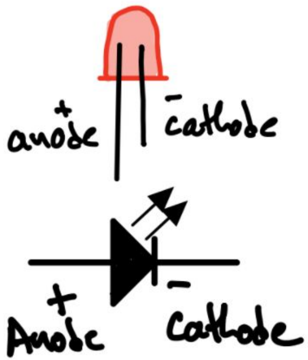
- We could accomplish the same goal by simply using a single 1000 ohm resistor!
- 1K ohm: Brown, Black, Black, Brown
- Brown: 1st digit - 1
- Black: 2nd digit - 0
- Black: 3rd digit - 0
- Brown: Multiplier - x 10^1





LEDs and Measuring Values

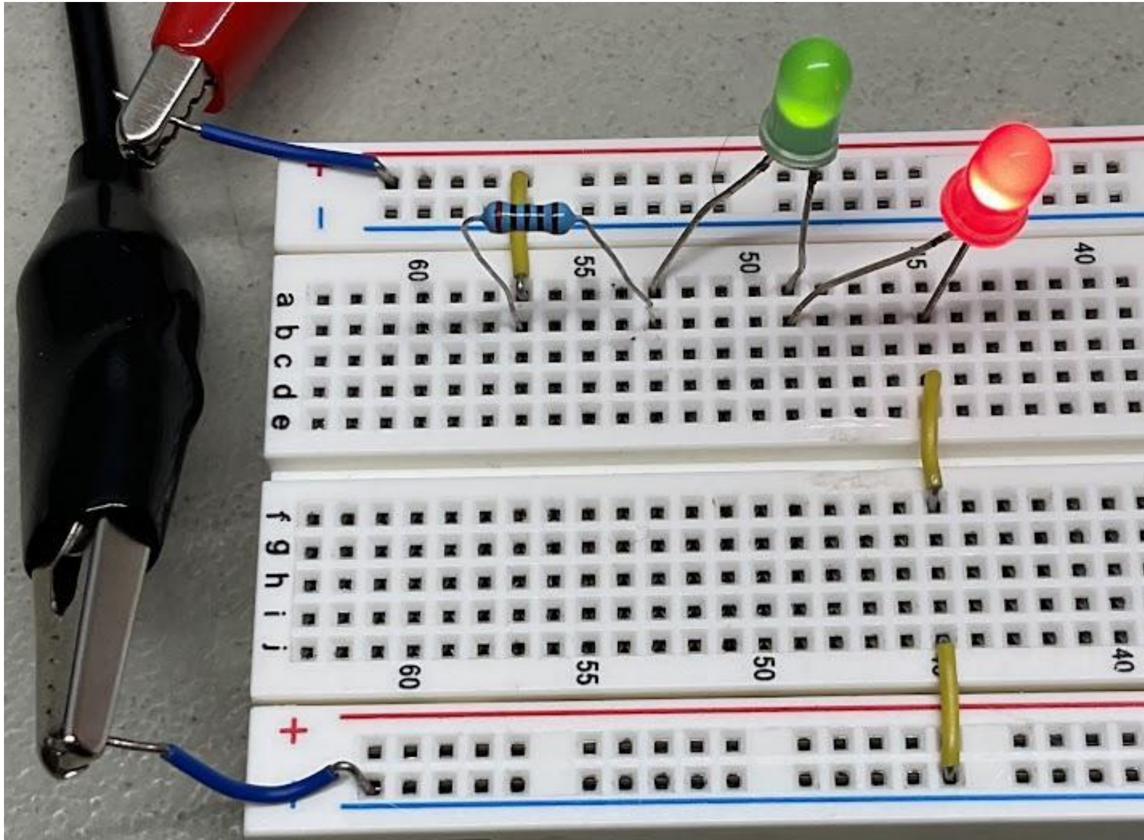
LEDs Are Not Ohmic



- LEDs are not ohmic devices.
- They do not follow Ohm's Law; V = IR
- Instead, LEDs follow a simple rule; they require a certain voltage to turn on and once they are on, they simply let A LOT of current flow through them.
- This is why when we hooked an LED directly up to our battery (9 volts), a TON of current was generated.
- Let's take a look at how we can use our multimeter to explore LEDs a little further and make sense of our previous series circuit.

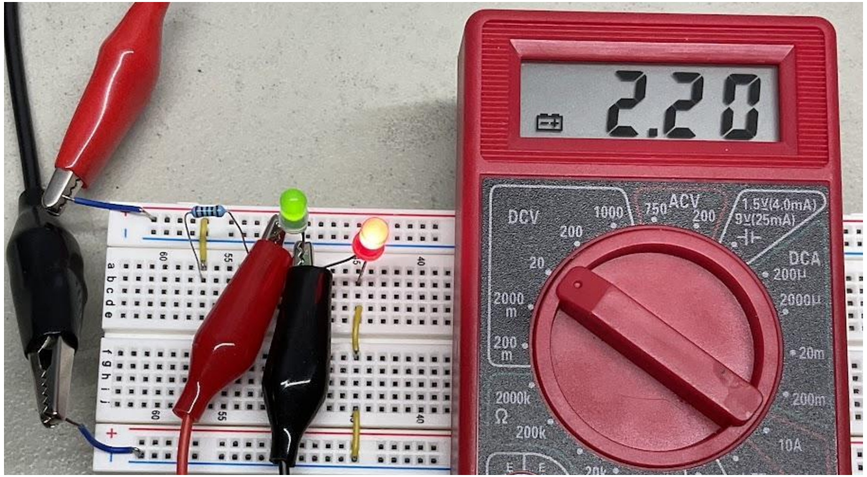
LEDs are Not Ohmic

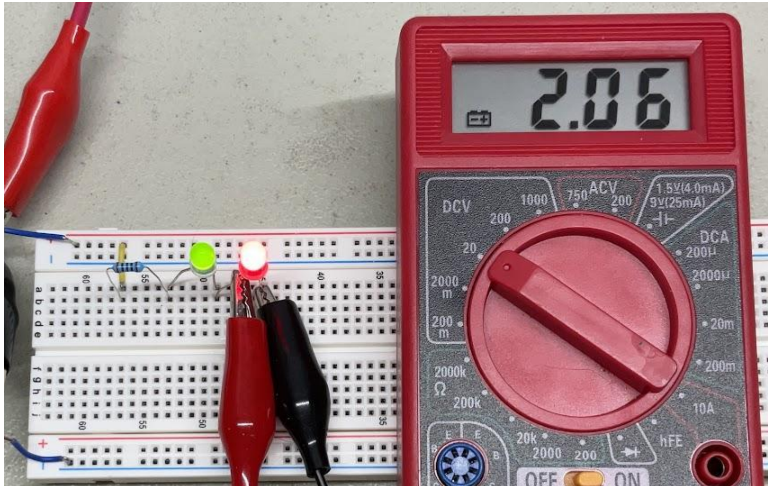
- Here I have created a series circuit using a 200 ohm (red, black, black, black) resistor, a green LED, and a red LED.



LEDs Are Not Ohmic

- Here I have my multimeter set as a voltmeter.
- I am reading a voltage drop of about 2.2 volts across the green LED to turn it on.
- I am reading a voltage drop of about 2.06 volts across the red LED to turn it on.
- Once these LEDs turn on, they allow current to flow; they do not provide resistance like a resistor.
- Using a 9 volt supply this leaves about 4.74 volts to be dropped across the resistor.



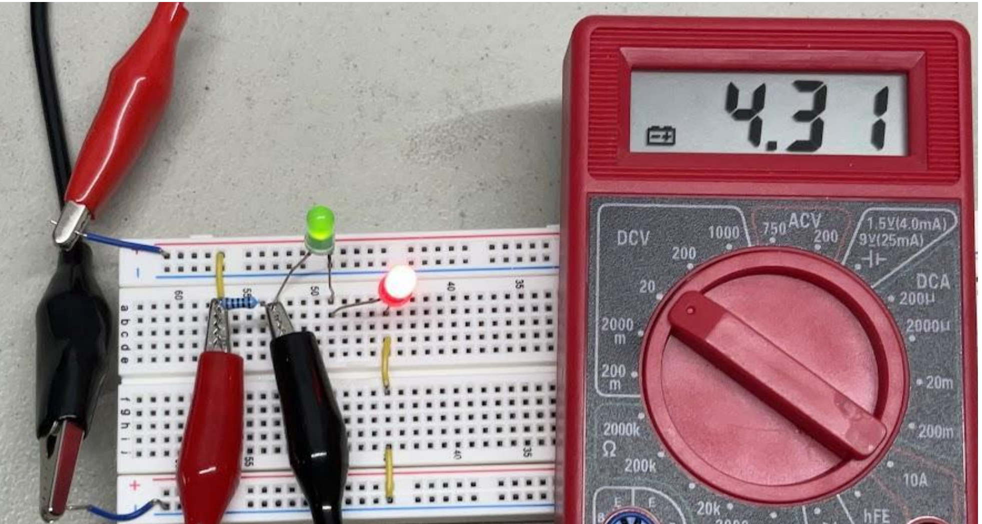


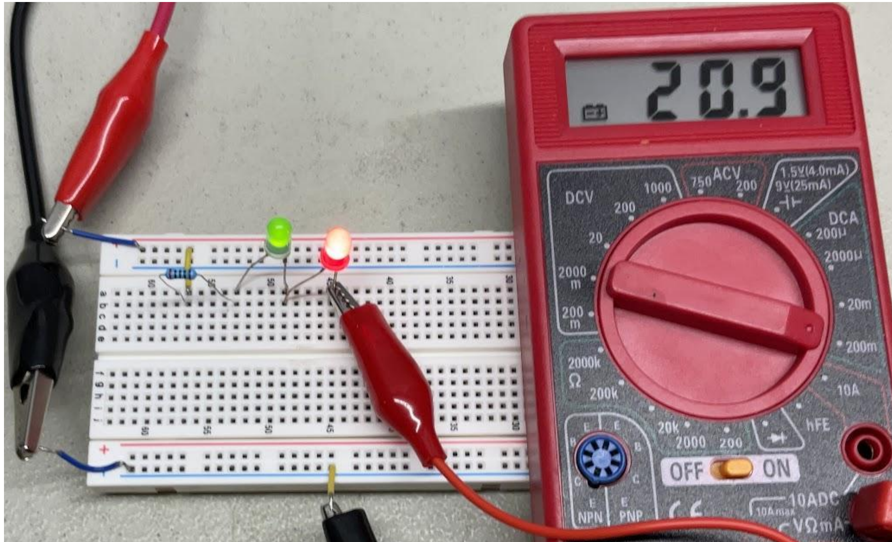
LEDs Are Not Ohmic

- The LEDs do nothing to limit the current; rather they just use up voltage to turn on.
- We can see that we are dropping 4.31 volts (close to 4.74) across the resistor.
- It's solely this resistor that is limiting the current in the circuit. We can use Ohm's law on the resistor to determine the current in the circuit!

V = IR -> 4.31 volts = I*200 ohms -> I = .021 amps

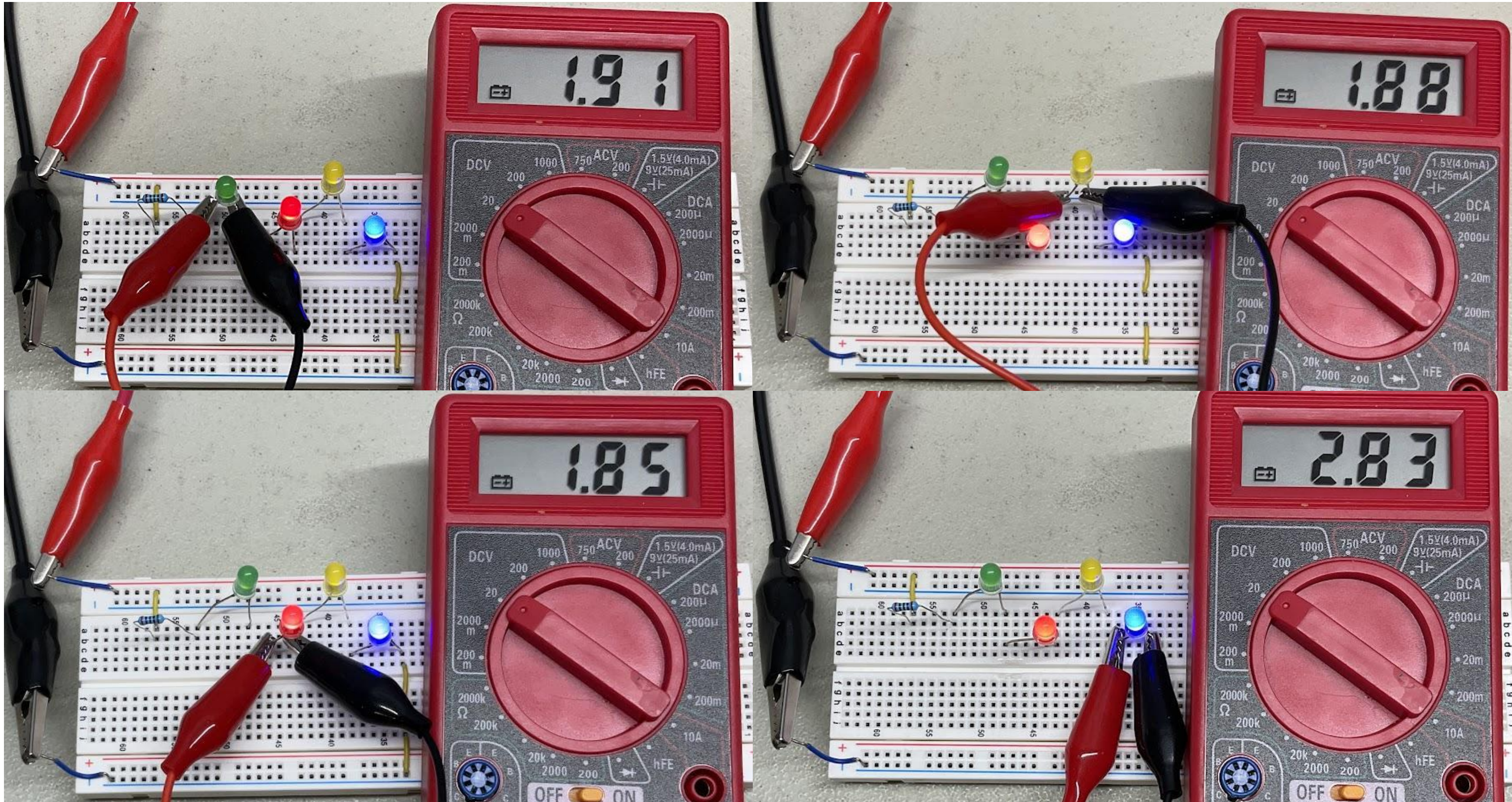
- Our ammeter is reading about 20.9 mA; pretty spot on!





LEDs Are Not Ohmic

- Adding more LEDs does not increase resistance.
- Rather, they just use up voltage in the circuit to turn on leaving less voltage to drop across the resistor.
- Here, we only have about .53 volts left to drop across the resistor.

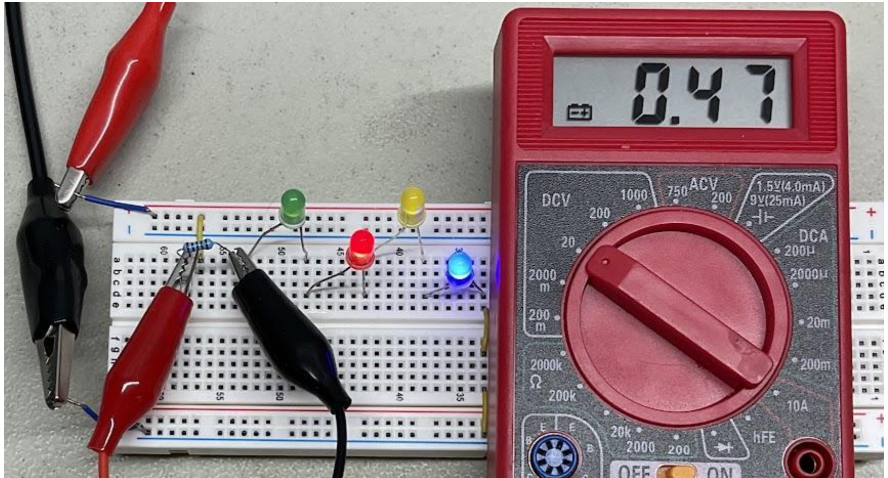


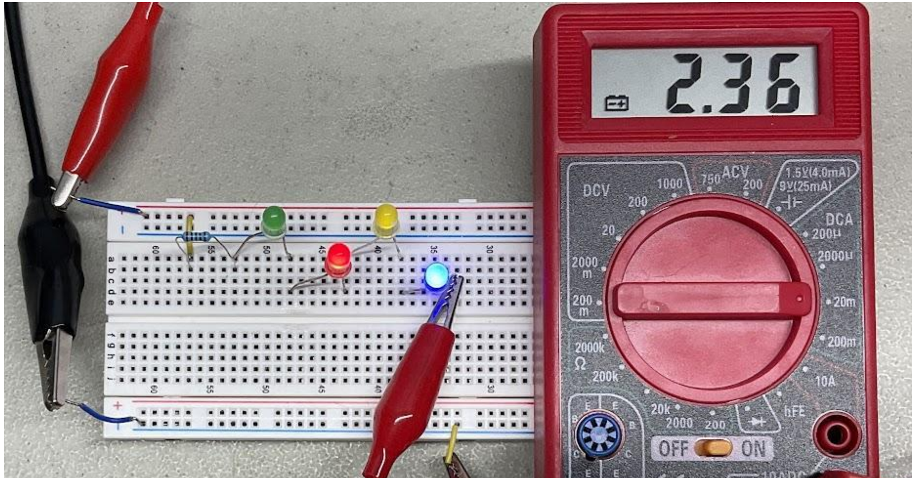
LEDs Are Not Ohmic

- The LEDs do nothing to limit the current; rather they just use up voltage to turn on.
- We can see that we are now only dropping .47 volts (close to .53) across the resistor.
- It’s solely this resistor that is limiting the current in the circuit. We can use Ohm’s law on the resistor to determine the current in the circuit!

V = IR -> .47 volts = I*200 ohms -> I = .00235 amps

- Our ammeter is reading about 2.36 mA; pretty spot on!
- The fact that the current is significantly smaller is why our LEDs are not as bright!

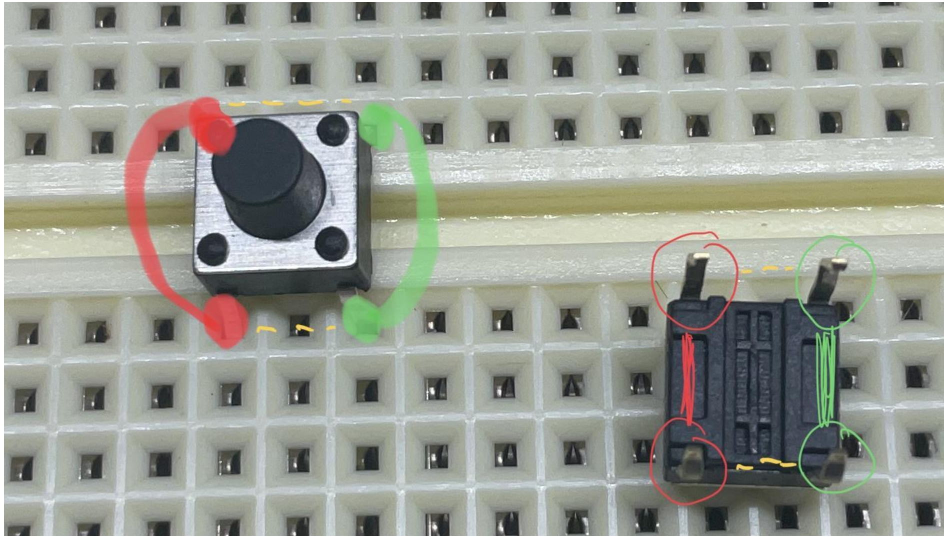




Understanding Push Buttons

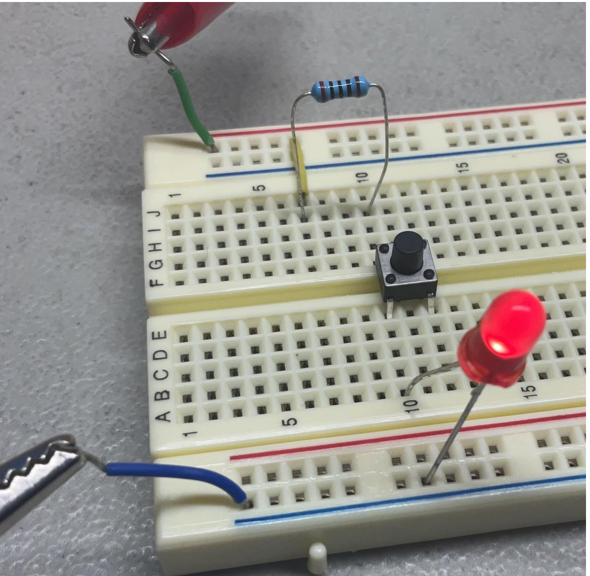
What is a Push Button

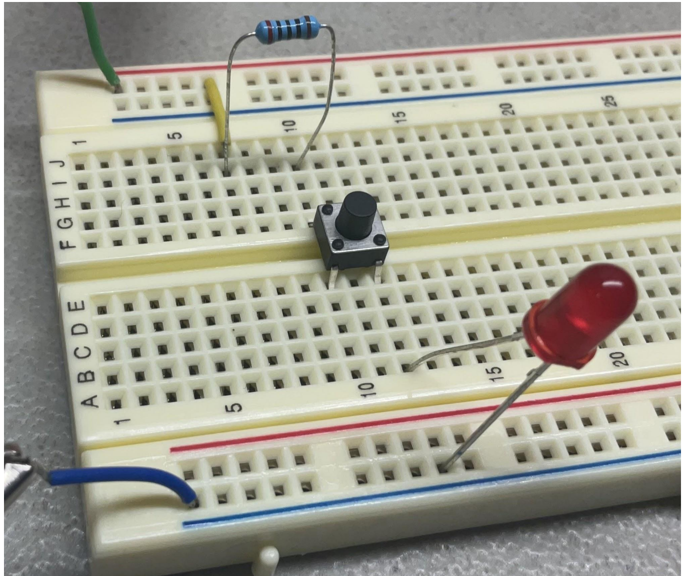
- A push button is a 4 terminal device that acts as a switch.
- When the button is not being pressed the two terminals in red are connected as are the two terminals in green.
- However, the red terminals and green terminals are not connected.
- When pressing the button, the red terminals and the green terminals get connected as if a switch was closed.

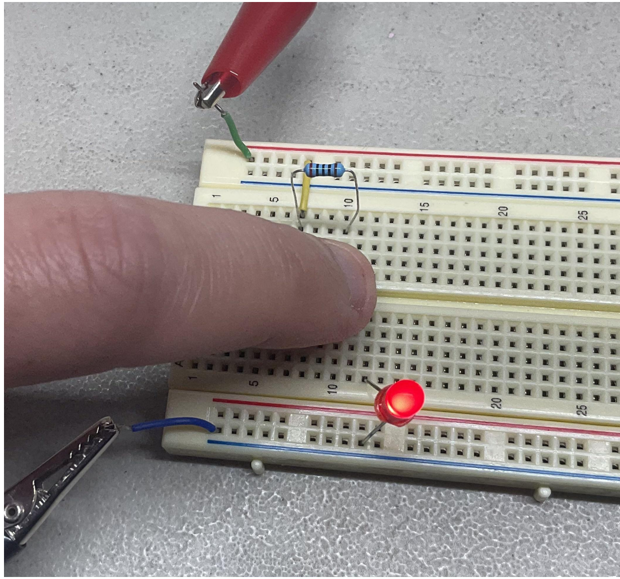


Light an LED with a Push Button

- Using a 200 ohm (red, black, black, black) resistor connected to Vcc to limit current, position the push button across the gap in the breadboard. Make sure the resistor is connected to the top left terminal of the button.
- When placing an LED to ground on the same side of the button as the connection to Vcc, the LED is always on.
- When placing an LED to ground on the opposite side of the button as the connection to Vcc, the LED only turns on when the button is pressed.

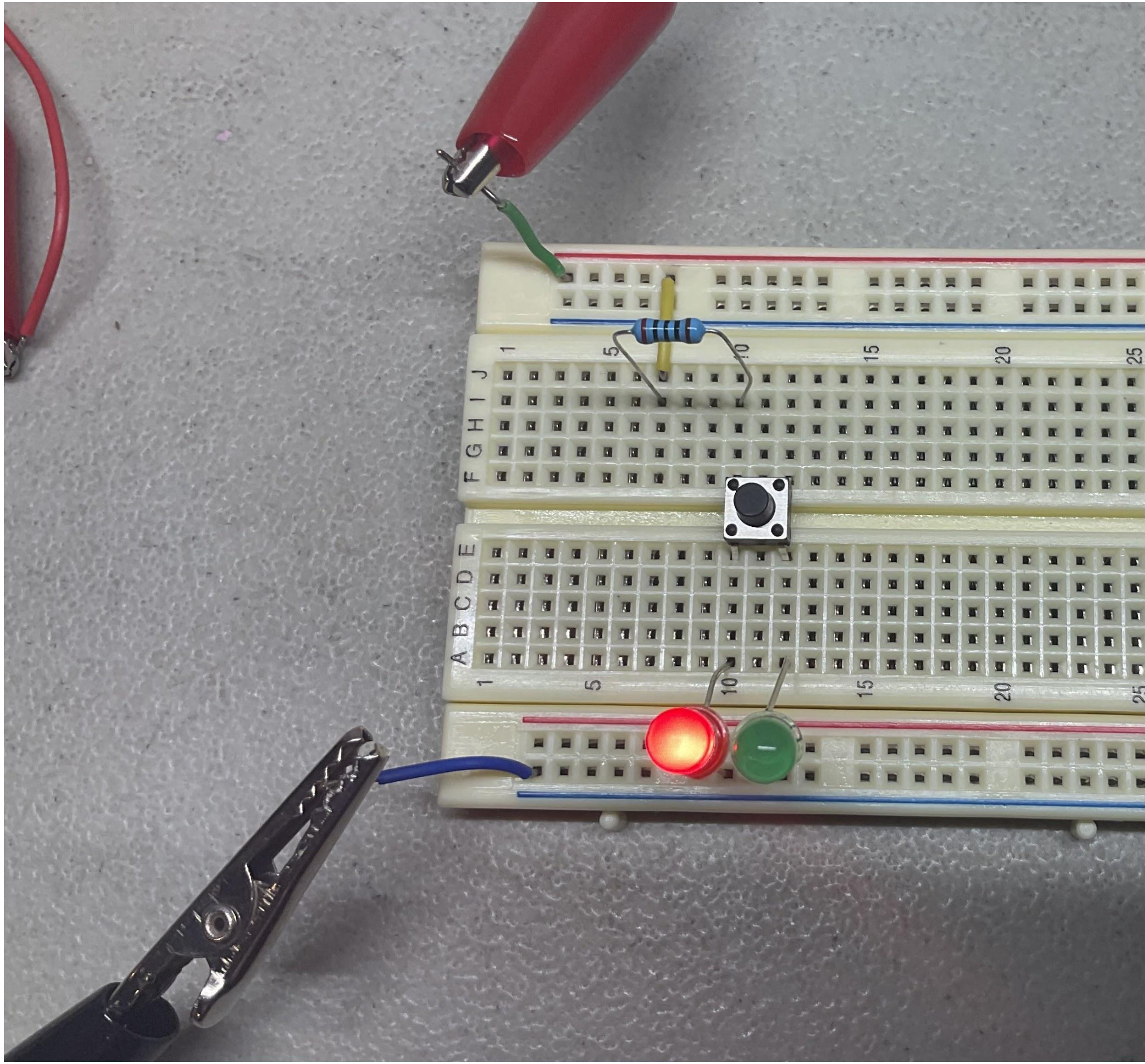






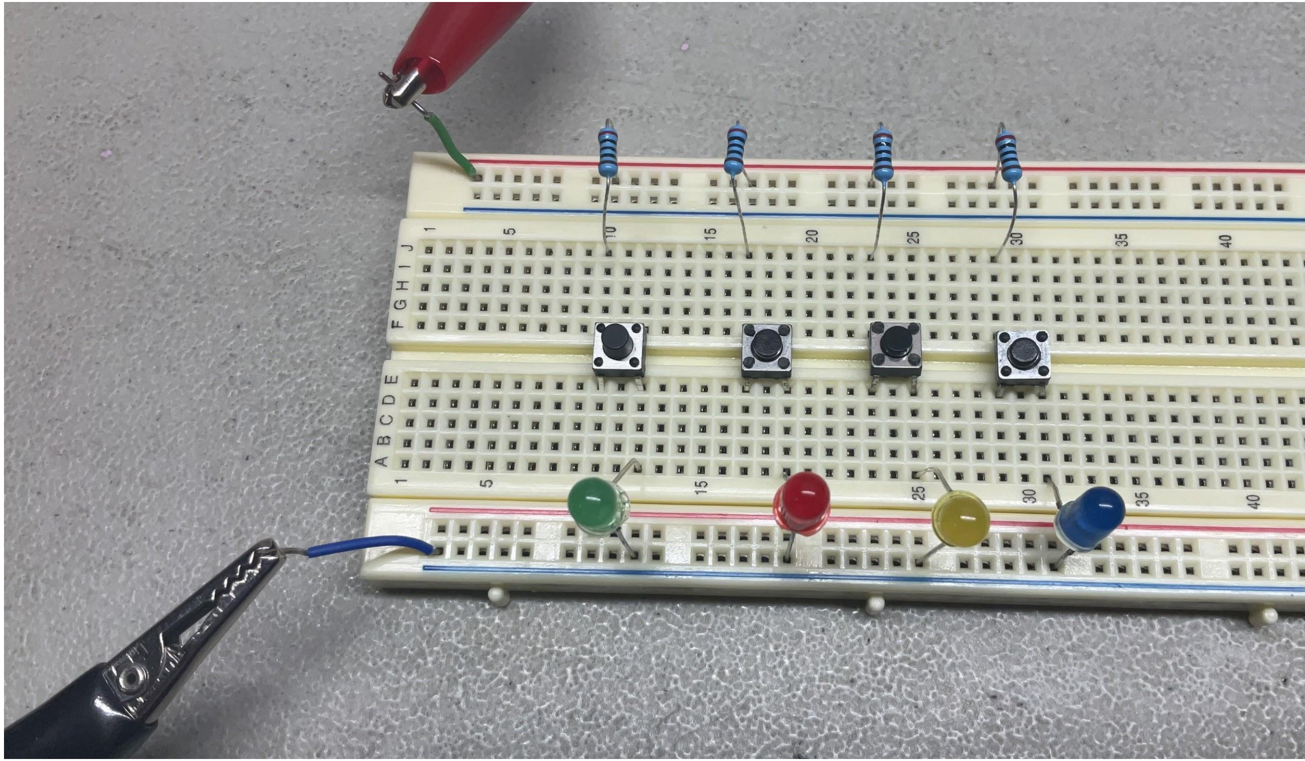
Light an LED with a Push Button

- You can have an LED on each side of the button.
- The red LED will always be on while the green LED only turns on when the button is pressed.



Light Multiple LEDs with Push Buttons

- Use four 200 ohm (red, black, black, black) resistors, each going into its own push button.
- On the opposite side of Vcc, place an LED to ground.
- When you press each button, the respective LED should light.



Circuit Challenge 3

Turn the Lights Off

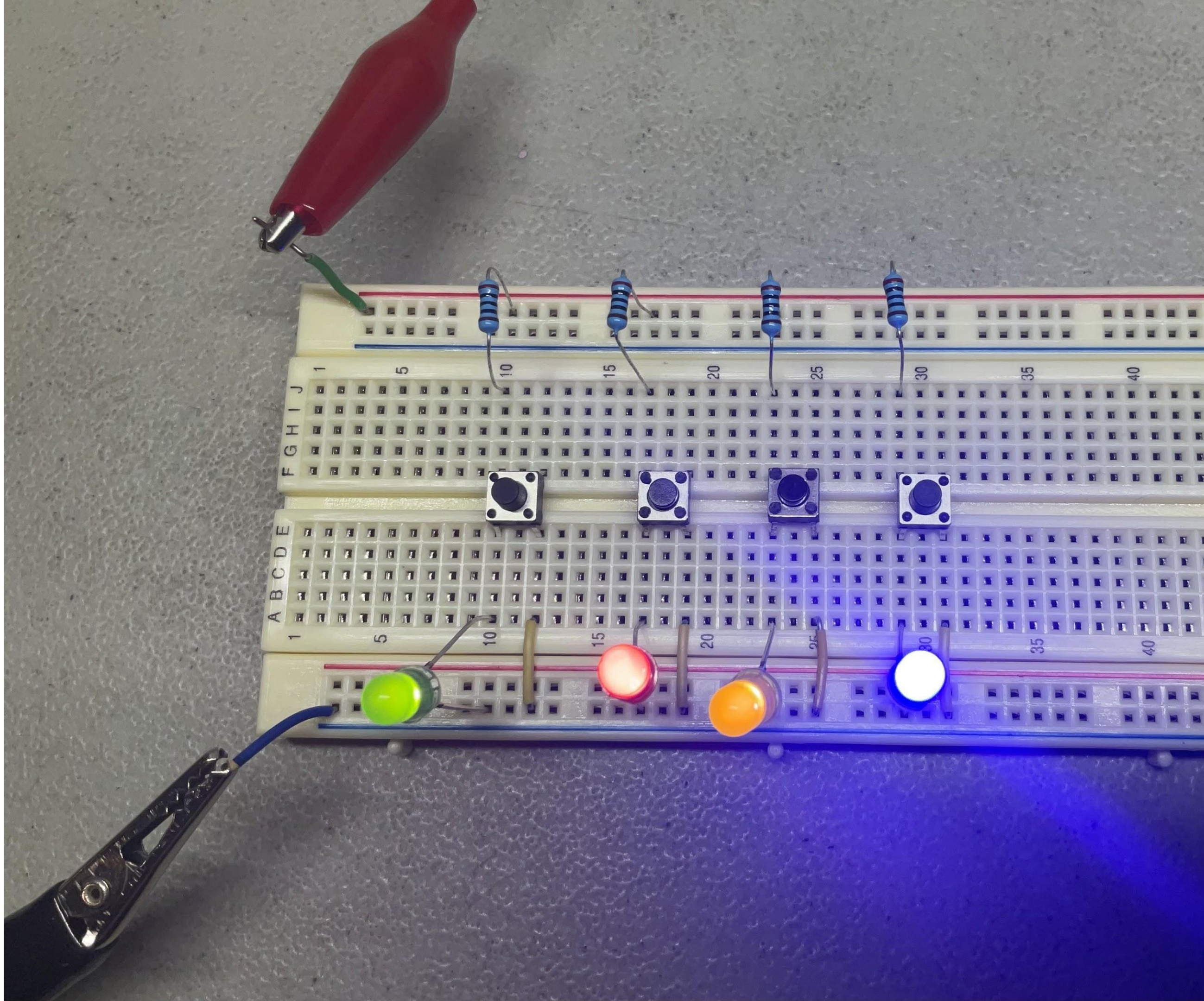
Circuit Challenge 3: Turn the Lights Off

- In the last circuit, we wired up our LEDs so they were off and turned on when we pressed the corresponding button.
- Can you wire a new circuit up such that each LED is on and turns off only when the corresponding button is pressed?

DO NOT ADVANCE to the next slide without trying to figure this out first!

Circuit Challenge 3: Solution

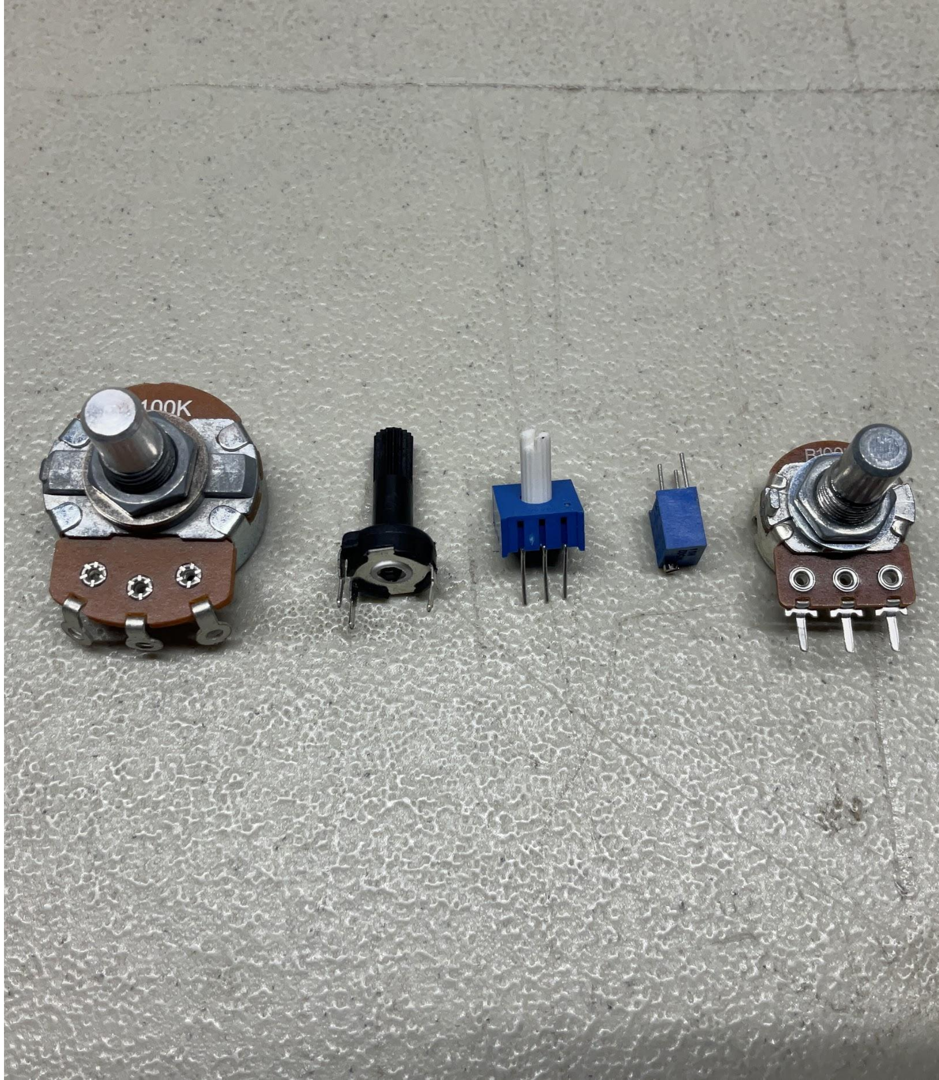
- When each button is pressed, the current flowing through the button is presented with two paths: LED to ground or a jumper wire to ground.
- The jumper acts as a short circuit and essentially “shorts” the LED so no current will flow through it.



How to Use Variable Resistors

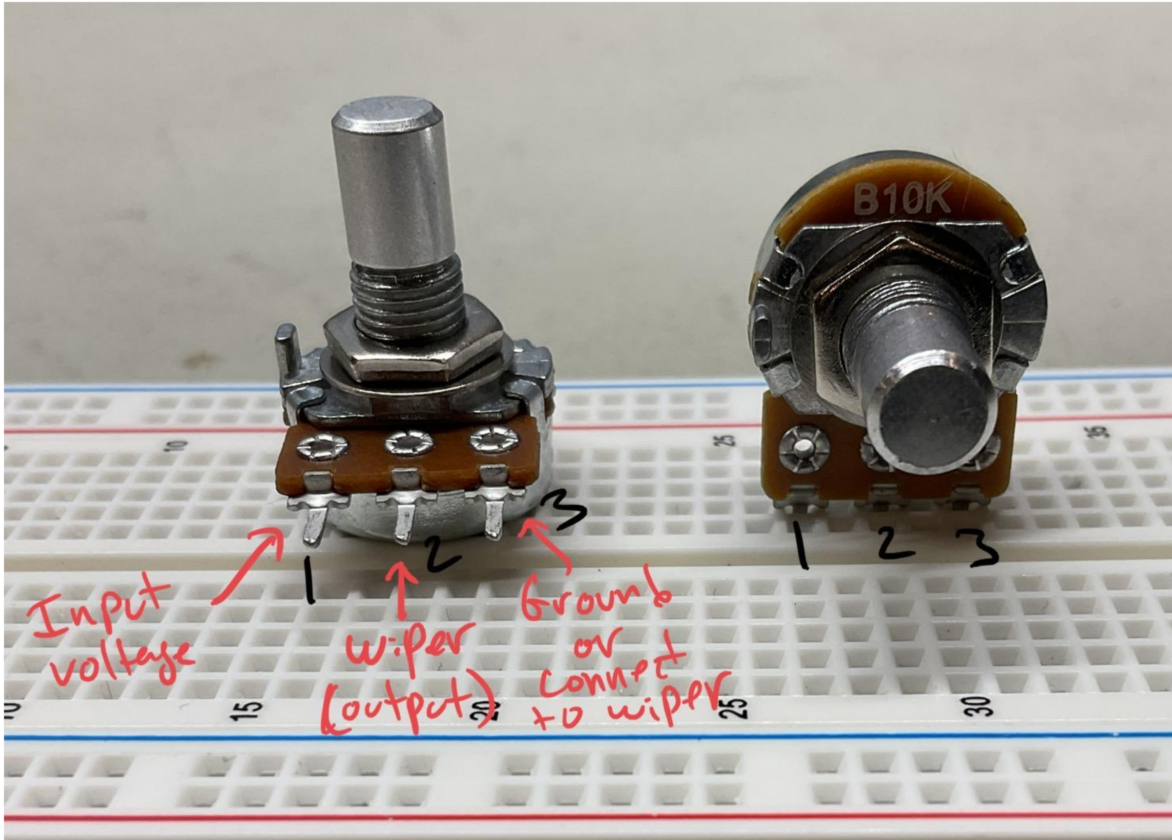
What is a Potentiometer (Pot)

- A potentiometer, or pot for short, is a three terminal resistor with a sliding contact that forms an adjustable voltage divider (more on voltage dividers in the future).
- The resistance of a potentiometer can be adjusted by turning the knob clockwise or counter clockwise depending on how the potentiometer is wired.
- Potentiometers come in all shapes, sizes, and colors.



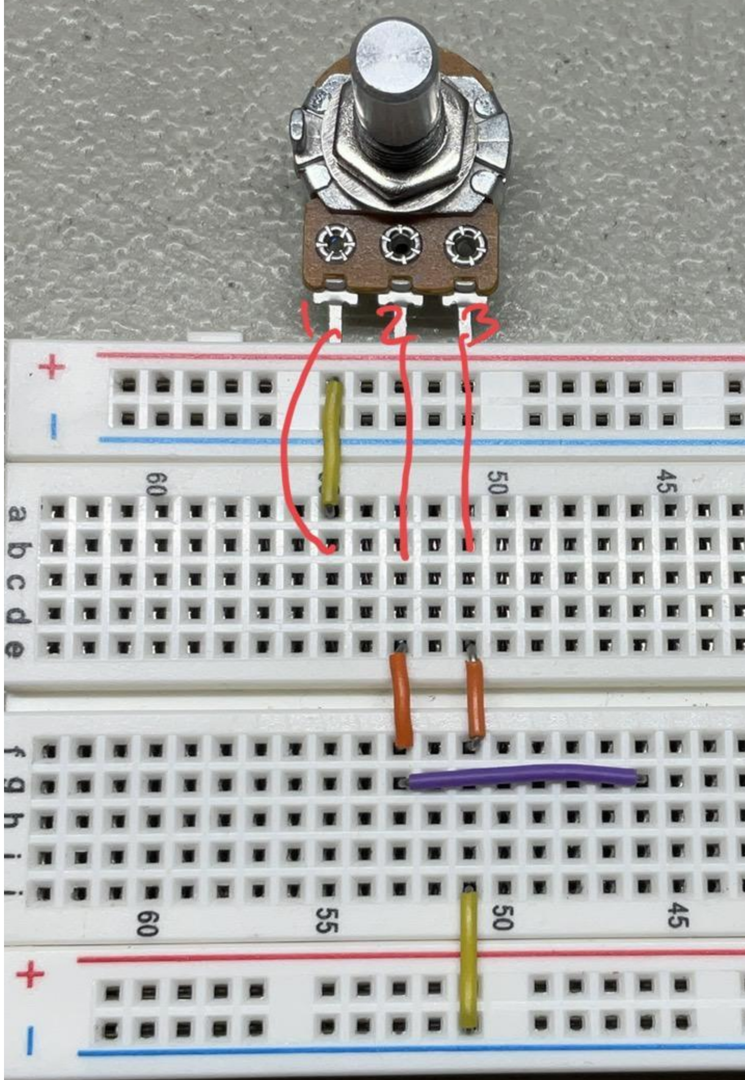
What is a Potentiometer (Pot)

- The first terminal of a potentiometer should be connected to your input voltage.
- The second terminal controls a wiper that varies the resistance inside the potentiometer. This connection is where you take your output voltage.
- The third terminal should either be connected to ground (potentiometer) or back to the wiper (variable resistor)



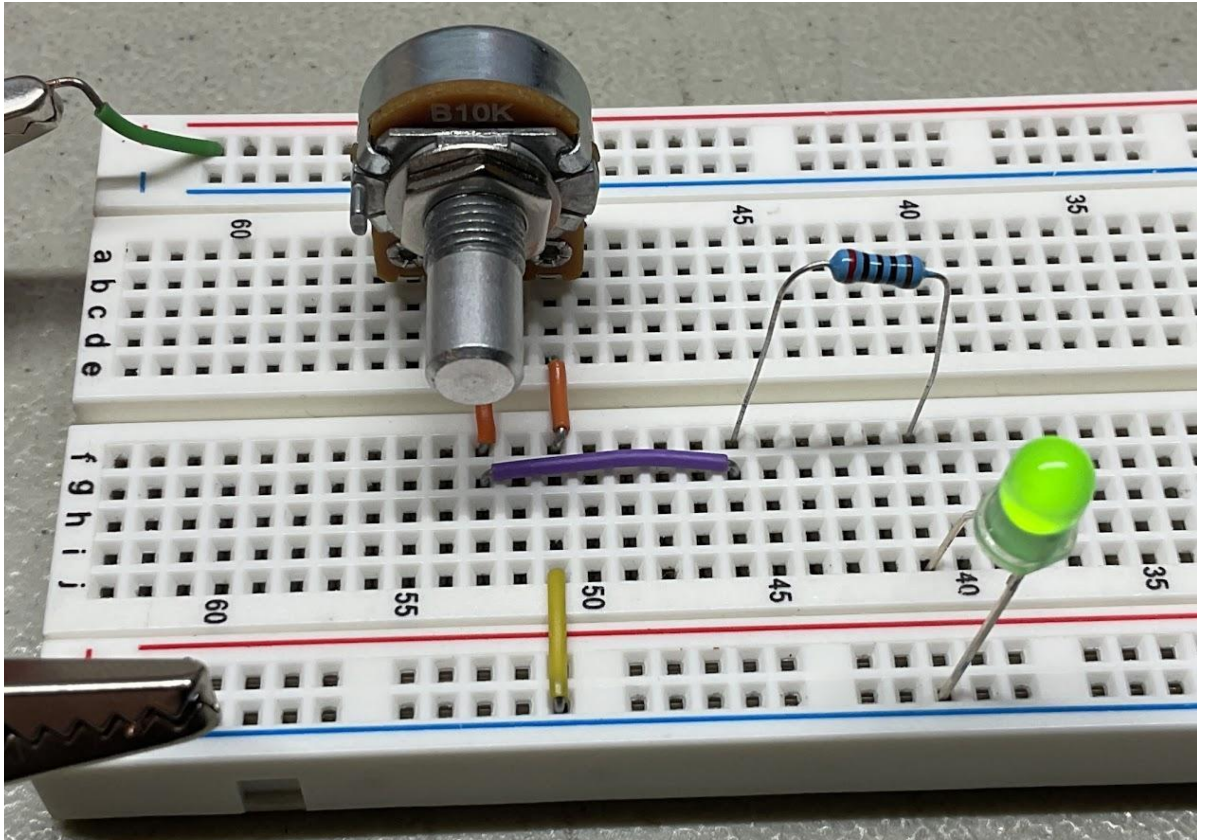
Potentiometer Wiring

- Here I've placed my jumper wires to show where the connections will be once I put the potentiometer in the breadboard.
- Right now, with the third terminal connected to ground I will have a potentiometer rather than a variable resistor.
- In this wiring, we are using all three terminals.
- Wiring a potentiometer like this allows us to create a variable voltage divider.



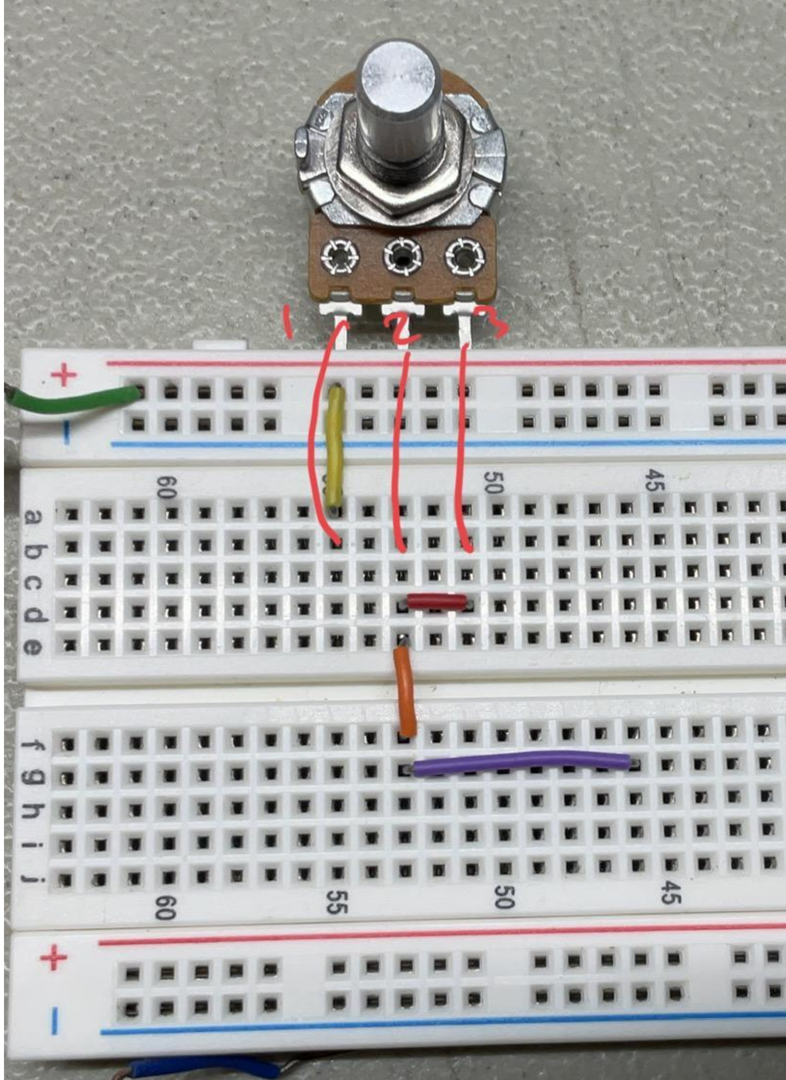
Potentiometer Wiring

- Place a 10K potentiometer in the breadboard at the correct location given your jumper wires.
- At the output, connect a 200 ohm (red, black, black, brown) resistor to an LED to ground.
- We should still use a 200 ohm resistor because if we turn the potentiometer too much, the resistance provided will be to low and our LED will burn.



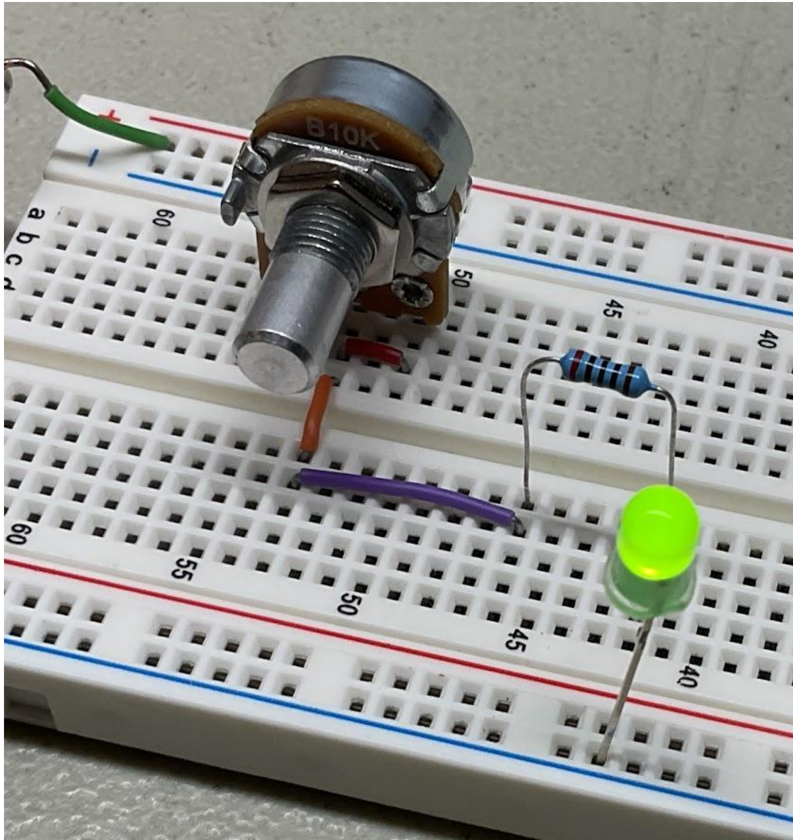
Variable Resistor Wiring

- Here I've placed my jumper wires to show where the connections will be once I put the potentiometer in the breadboard.
- Right now, with the third terminal connected back to the wiper via my red jumper wire, I will have a variable resistor rather than a potentiometer.
- In this wiring, we are using just two terminals.
- Wiring a potentiometer like this allows us to create a variable resistance.



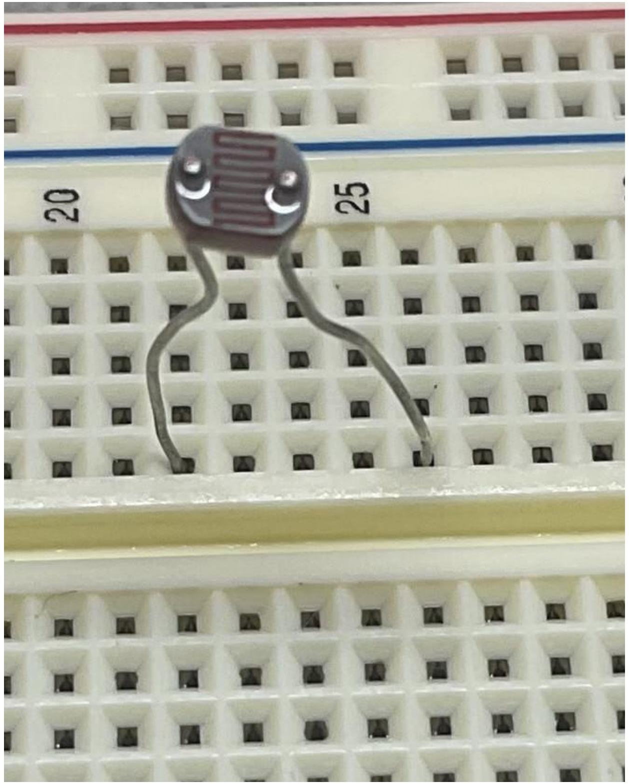
Variable Resistor Wiring

- Place a 10K potentiometer in the breadboard at the correct location given your jumper wires.
- At the output, connect a 200 ohm (red, black, black, brown) resistor to an LED to ground.
- We should still use a 200 ohm resistor because if we turn the potentiometer too much, the resistance provided will be to low and our LED will burn.



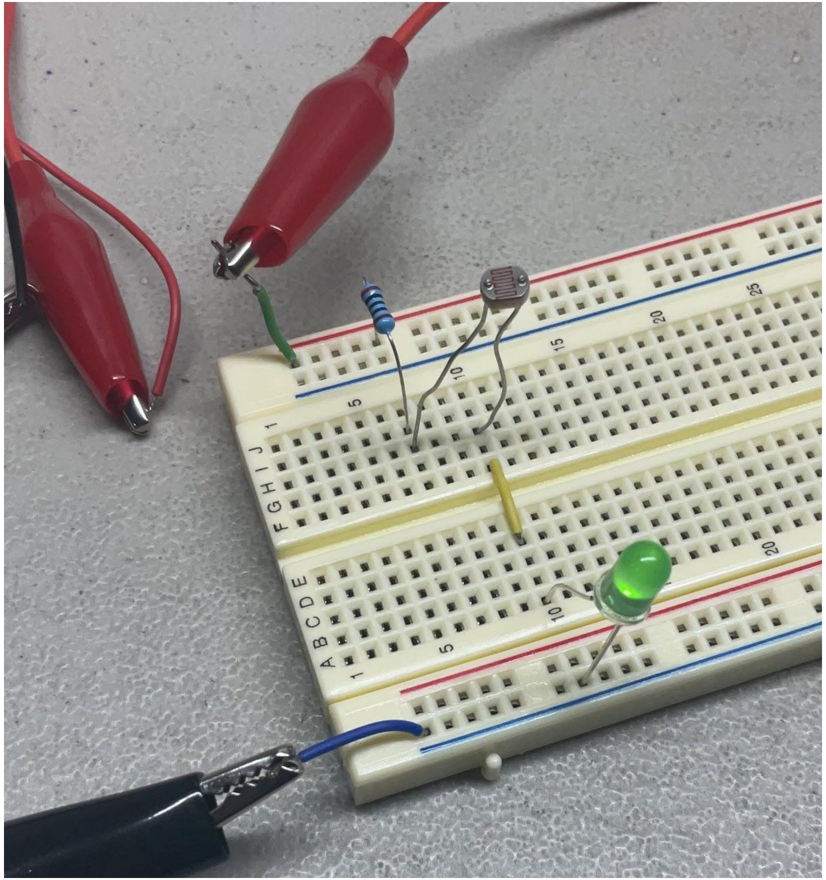
What is a Light Dependent Resistor (LDR)

- A light dependent resistor, or LDR for short, is a variable resistor whose resistance varies depending on the amount of light that hits it.
- The resistance range can vary depending on the LDR.
- The resistance is at a maximum in darkness and is at a minimum in bright light.



Dim an LED with a Light Dependent Resistor

- Use a 200 Ohm resistor from Vcc to one terminal of the light dependent resistor.
- Connect the anode (long leg) of an LED to the opposite end of the LDR.
- Connect the cathode (short leg) of the LED to ground.
- Wave your hand in front of the LDR or cover the LDR to create darkness.
- Note how resistance alters as more or less current flows through the LED.
- This would make a really bad night light…

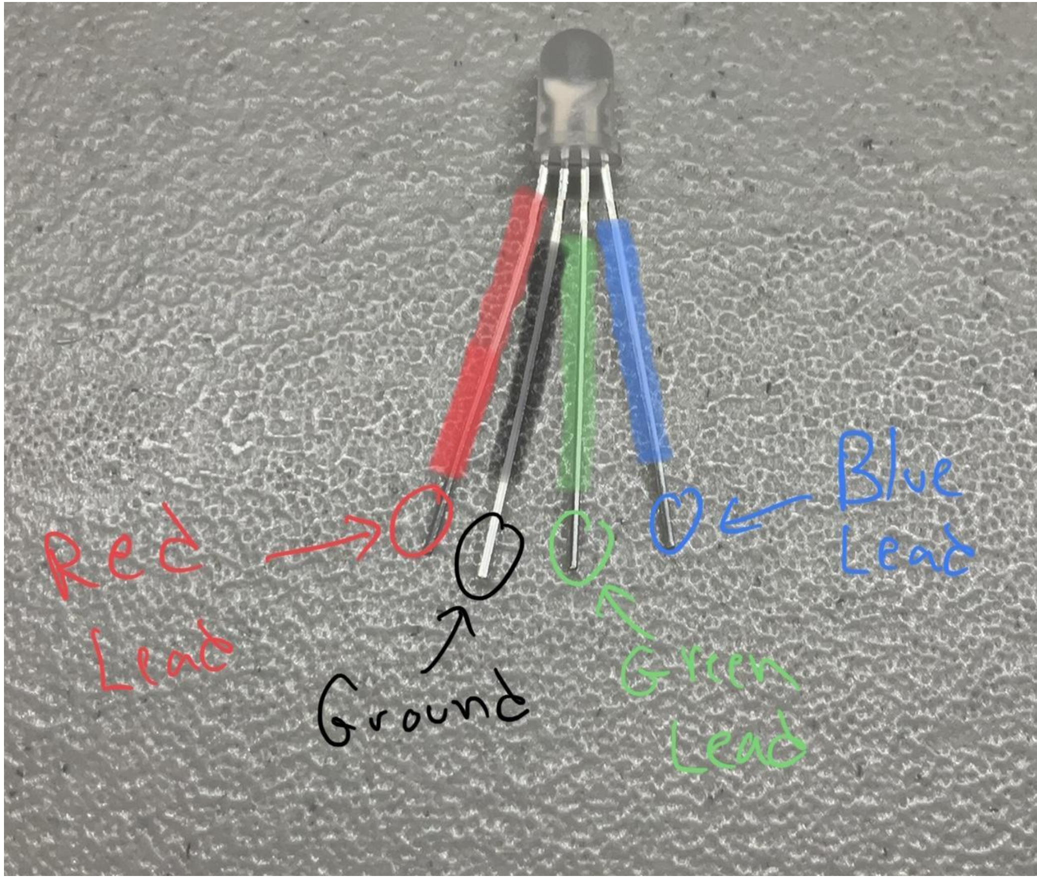


Circuit Challenge 4

Color the Rainbow

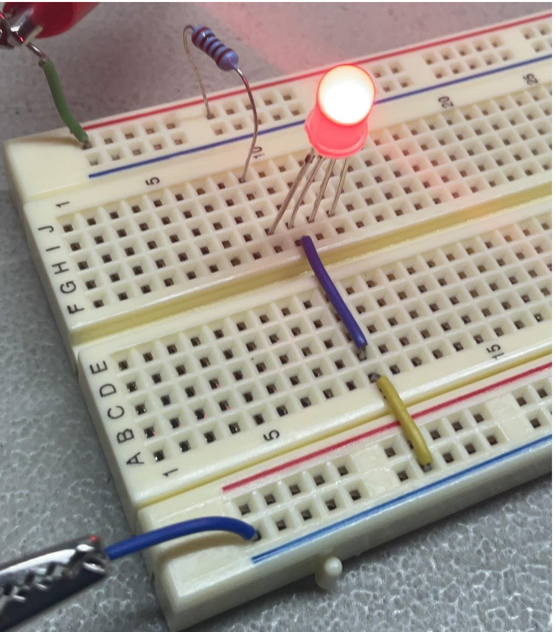
What is a Tri-Color LED?

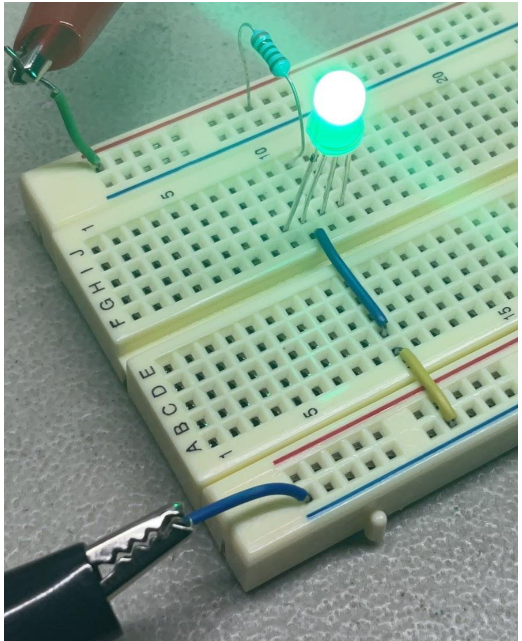
- A tri-color LED is a 4 terminal LED that consists of 3 individual LEDs sharing a common ground.
- The 1st terminal is the red LED.
- The 2nd terminal is the common ground.
- The 3rd terminal is the green LED.
- The 4th terminal is the blue LED.
- The three colors can be mixed to make a variety of colors by either applying/not applying a voltage to a given terminal or varying the resistance at a given terminal.

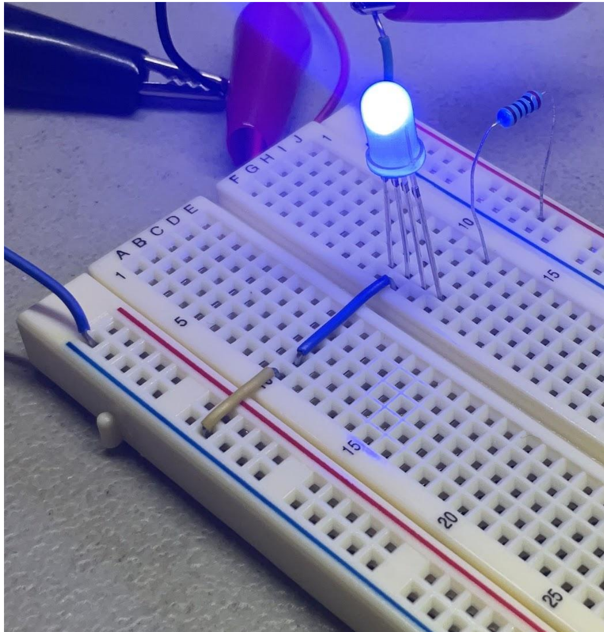


Working with a Tri-Color LED

- Ground the LED using the 2nd terminal (the longest leg).
- Use a 200 ohm (red, black, black, black) resistor from Vcc to each other terminal to see the red, green, and blue LED light.

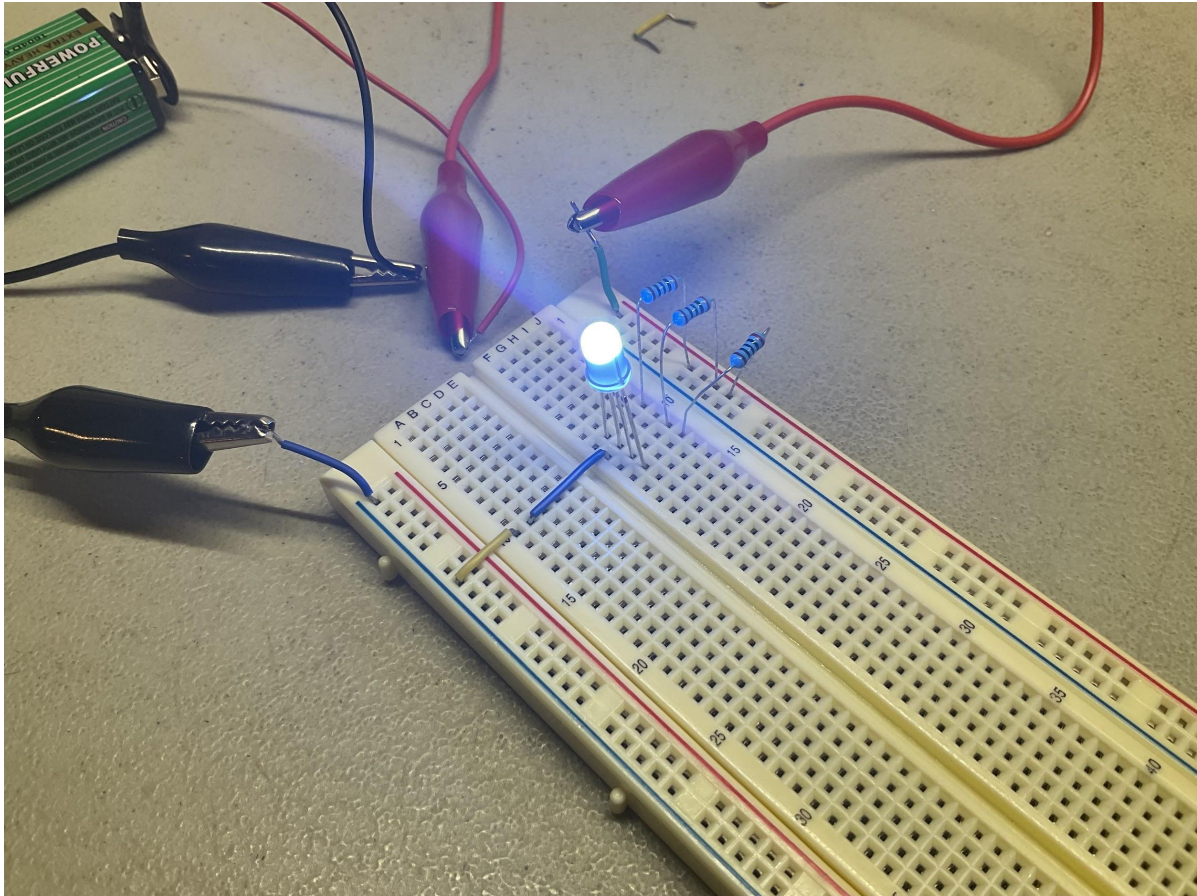






Working with a Tri-Color LED

- Keep all three LEDs on by putting a 200 ohm (red, black, black, black) resistor from Vcc to the respective terminal.
- By mixing the red, green, and blue light in equal proportions your LED should be glowing White.



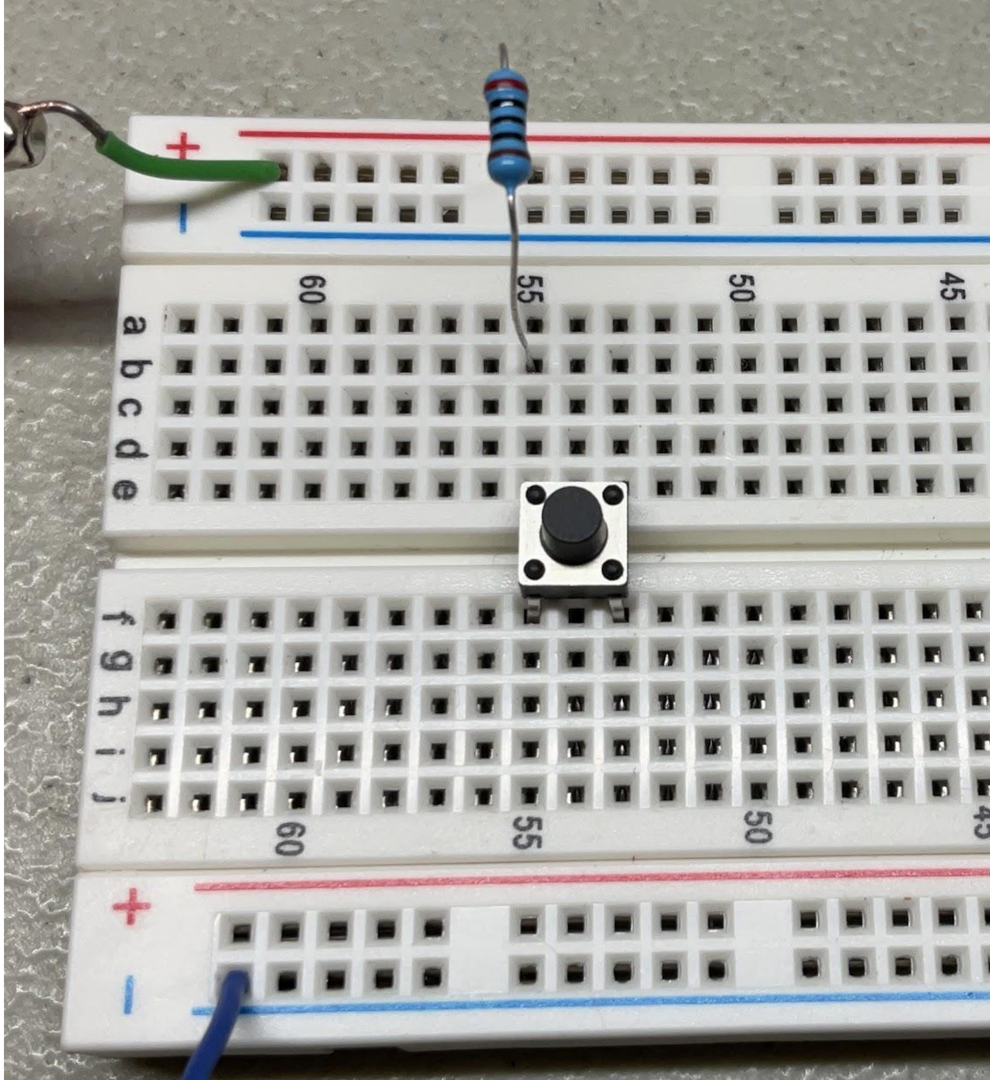
Circuit Challenge 4: Color the Rainbow

- Can you wire up a tri-color LED in the following manner such that we can experiment with color mixing?
    - The red channel should be connected to a push button to turn on the red LED when pressed.
    - The green channel should be connected to a push button to turn on the green LED when pressed and a light dependent resistor such that we can vary the amount of current flowing through the green LED.
    - The blue channel should be connected to a push button to turn on the blue LED when pressed and a 10K potentiometer such that we can vary the amount of current flowing through the blue LED.
- If done correctly, you should be able to create MANY different colors of light!
- **HINT**: Don’t forget your current limiting 200 Ohm resistors.

DO NOT ADVANCE to the next slide without trying to figure this out first!

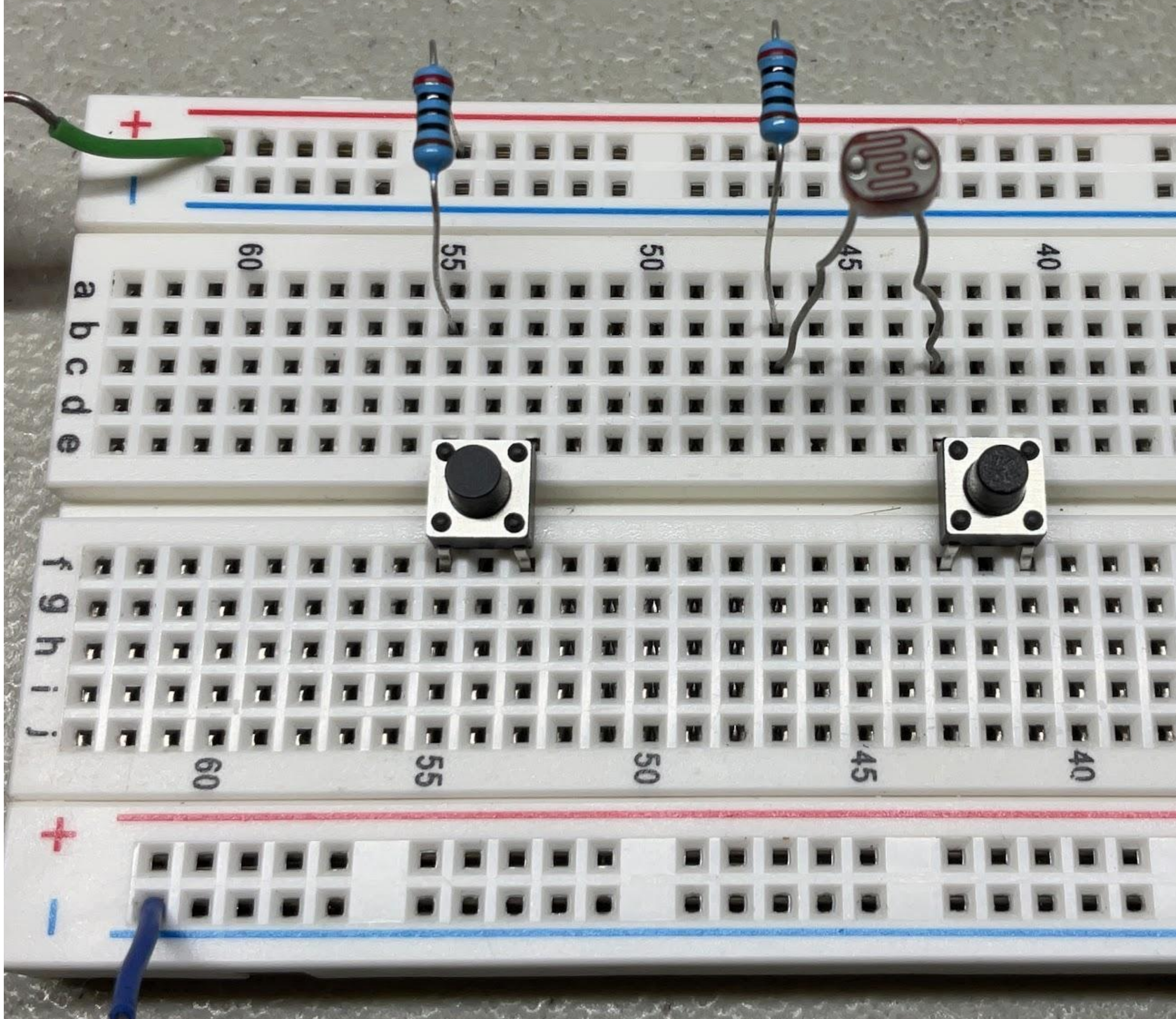
Color the Rainbow

- Set up a single push button with a 200 ohm (red, black, black, black) resistor connecting it to Vcc.
- This will control the red channel of our LED.



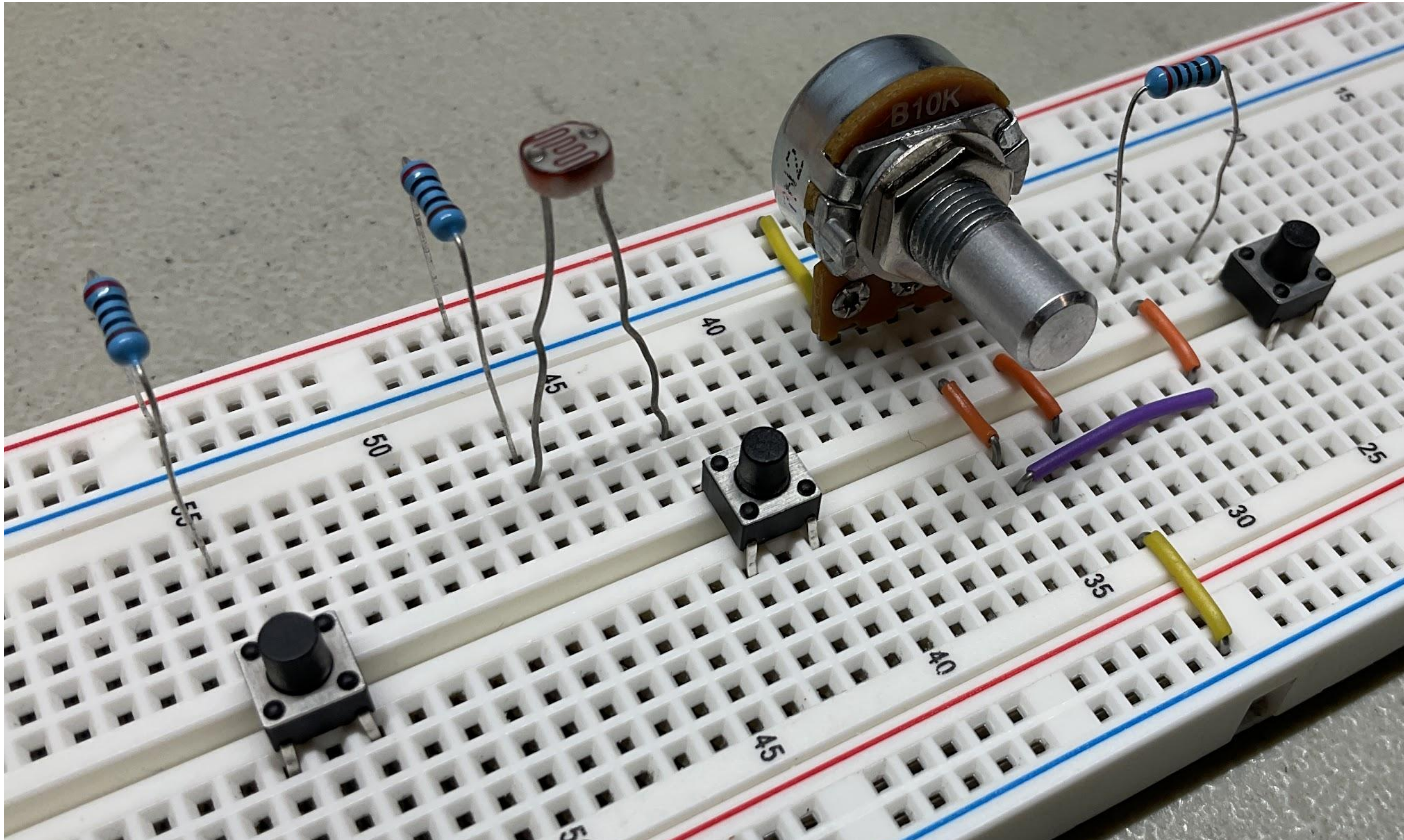
Color the Rainbow

- Add a second push button.
- Connect it to Vcc through a 200 ohm (red, black, black, black) resistor and a LDR.
- This will control and vary the green channel of our LED.



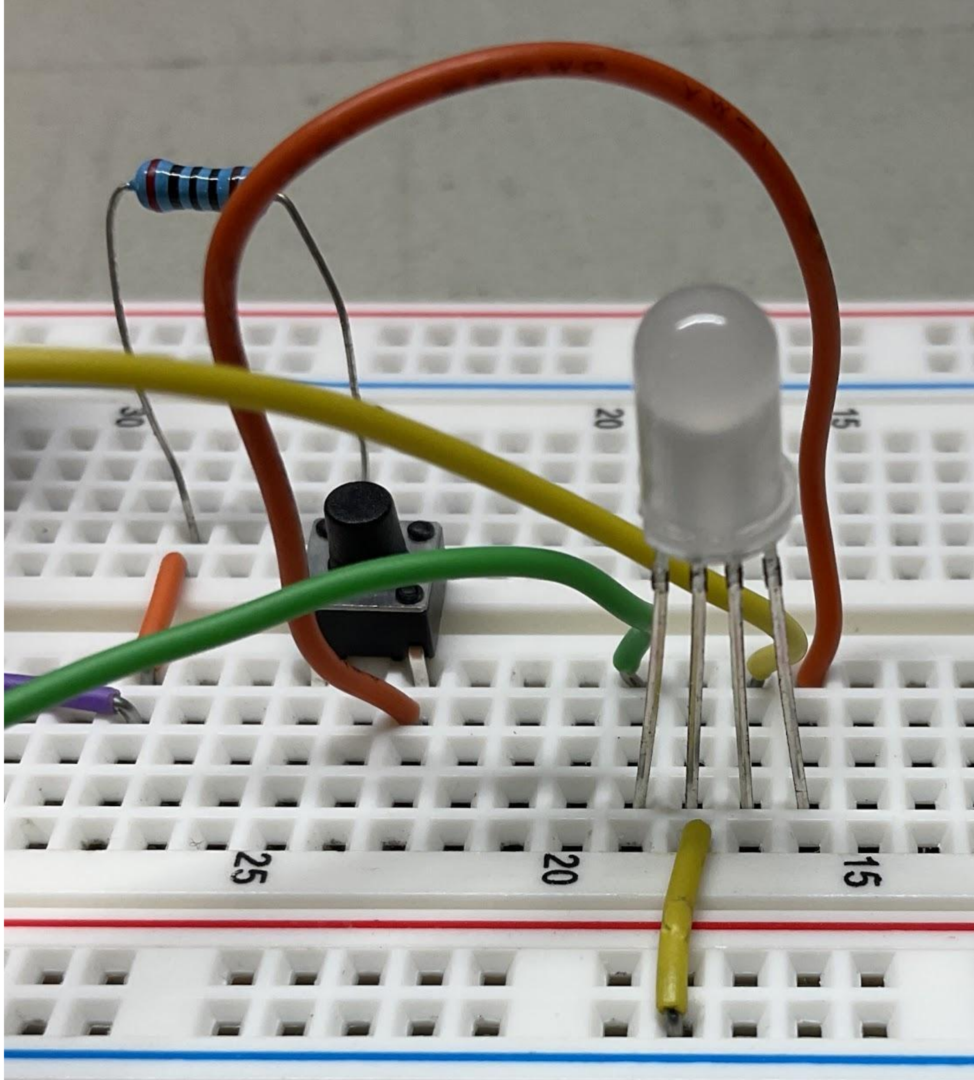
Color the Rainbow

- Add a 10K potentiometer.
- Make sure the first terminal is connected to Vcc, the second to our output, and the third to ground.
- At the output connect a 200 ohm (red, black, black, black) resistor into a third push button.
- This will control and vary the blue channel of our LED.



Color the Rainbow

- Add the tri color LED.
- Connect the 2 terminal (the longest lead) to ground.
- Connect a jumper to the red channel (green wire), green channel (yellow wire) and blue channel (orange wire).
- These jumpers will connect to their respective push buttons.



Circuit Challenge 4: Solution